應用於寬頻分碼多工擷取上鏈路之信道估測
On the Uplink Channel Estimation in WCDMA

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摘要

由於數位信號處理技術的進步以及有限的頻寬資源，第三代移動通訊採用同調偵測來提昇系統效能。信道估測的目的在於量測信道的相位和振幅響應。本文中我們比較了適用於寬頻分碼多工擷取的信道估測技術，並提出我們模擬的結果。

關鍵字：寬頻分碼多工擷取，信道估測，同調偵測

Abstract

Due to the improvements of DSP technology and restricted bandwidth resources, coherent detection is applied in 3G systems to improve system performance. The goal of channel estimation is to estimate the amplitude and phase of the channel response. In this paper we compare different approaches for WCDMA uplink channel estimation. We also show some simulation results of our design.

Keywords: WCDMA, Channel Estimation, Coherent Detection

1. Introduction

The WCDMA has been selected as part of IMT-2000 radio technology. The demands on high data rates and vehicular velocities from 3km/h to 250km/h[1] require efficient and accurate channel estimation. In traditional CDMA systems, non-coherent detection is applied to demodulate the received signals. Due to the improvements of DSP technology and restricted bandwidth resources, coherent detection is applied in 3G systems to improve system performance. The phase information is the key to coherently demodulate the signal. For coherent CDMA systems with the rake receiver, the amplitude information is also required to combine different output of rake fingers. The goal of the channel estimation is to estimate the amplitude and phase of the channel response.

Fig. 1 shows the constellation diagram of a typical QPSK modulated signal. Fig. 1(a) shows the transmitted constellation. As the signal propagates through the channel, the amplitude and phase are changed which is shown in Fig. 1(b). We can compensate the phase error if we can accurately estimate the phase response. The resulting constellation is shown in Fig. 1(c). Note that the amplitude is not compensated directly. In a direct-sequence spread-spectrum system, the multipath is thought of as the transmission diversity. At the receiver end, the multipath signal is recombined before the decisions are made. We need the information to optimally combine the different paths. The *maximum ratio combining* (MRC) was proved to be the optimum multipath combining method in rake receiver. Therefore we have to estimate the signal gain in the channel that is used as the weighting of each path.

1.1. Frame structure

Fig. 2 shows the frame structure of the uplink dedicated physical channels [2]. Each radio frame of length 10 ms is split into 15 slots, each of length T_{slot} = 2560 chips, corresponding to one power-control period. The DPDCH and the DPCCH are I/Q multiplexed within each radio frame. The uplink DPDCH is used to carry the DCH transport channel. The uplink DPCCH is used to carry control information generated at Layer 1. The Layer 1 control information consists of known pilot bits to support channel estimation for coherent detection, transmit power-control (TPC) commands, feedback information (FBI), and an optional transport-format combination indicator (TFCI). The exact number of bits in the uplink DPDCH and the different uplink DPCCH fields (N_{pilot},

N_{TFCI}, N_{FBI}, and N_{TPC}) are configured and can also be reconfigured by higher layers. The spreading factor of DPCCH is always equal to 256.

1.2. Context

The dual channel QPSK modulation is applied in the uplink direction. In the transmitter part, the Q-channel and I-Channel convey the data bits of DPCCH and DPDCH respectively. After up-converted to radio-frequency band, the signal is transmitted through the multipath-fading channel. The receiver down converts the signal and passes it to the baseband.

The rake architecture is commonly used in CDMA systems. After the DPCCH and DPDCH are separated using different spreading code, they are sent to the channel estimator which extracts the channel gain information. In general both of the physical channels are available to estimate the channel gain. However the pilot field exists only in DPCCH. Decision-feedback or some hybrid techniques are applied to make DPDCH useful. If DPDCH is not applied to simplify the design, the resulting rake finger structure is shown in Fig. 3. There is a 2 phase difference between the I- and Q-channel.

The transmitted symbols of dual channel QPSK are complex values,

$$D(n) = d_d(n) + jd_c(n)$$

where $d_d(n)$ and $d_c(n)$ are the data bits in DPDCH and DPCCH respectively. The received symbol for one path can be expressed as, in the baseband equivalent point of view,

$$b\,(d_d(n)s_d(n) + jd_c(n)s_c(n)) + N''$$

where N'' is the noise and the complex channel gain is equal to $A_{ch}e^{jqch}$, in which A_{ch} is the magnitude response and q_{ch} is the phase response. The spreading code $s_c(n)$ and $s_d(n)$ are the product of scrambling and channelization codes of each channel respectively. Assume the local scrambling and channelization code are ideally synchronized with the ones in transmitter. We also lump the front-end gain into the channel gain. Therefore the despreaded symbol of DPCCH feeding into the channel estimator can be approximated as

$$\begin{aligned} R_C(n) &= b\,(n)\left(\frac{d_d(n)}{SF} + jd_c(n)\right) + N'(n) \\ &= A_{ch}(n)e^{j(q_{ch}(n)+p\ /\ 2)}d_c(n) + N(n) \end{aligned} \tag{1}$$

where N is the noise including the signal coupled from DPDCH, and SF is the spreading factor of DPCCH.

2. Channel Estimation Techniques

There are many channel estimation techniques ranging from simple average to adaptive filtering. Different methods are suitable for different channel environment and require different computing power. We summarize the characteristics of some of the techniques in the following.

Multipath diversity is maintained by combining different path components in the rake receiver. This requires one channel estimator for each path. Therefore the channel estimator must be simple enough and be able to operate in low-SIR environment.

2.1. Simple Average

This is a simple but effective method to estimate the channel complex gain. Many other channel estimation techniques exploit it to reduce the sampling rate from symbol rate to slot rate before the algorithms are applied to reduce the complexity.

For a simple average method, the pilot fields in DPCCH are correlated with the local pilot bits generated in the receiver. Refer to Eq.(1), the correlator output $b_a(n)$ is down-sampled to produce the estimation output.

$$\begin{aligned} \overline{R}_C(n) &= \frac{1}{N_p}\sum_{i=1}^{N_p} R_C(i)p(i) \\ &= \frac{1}{N_p}\sum_{i=1}^{N_p}\left(A_{ch}(i)e^{j(q(i)+p\ /\ 2)} + N(i)\right) \end{aligned} \tag{2}$$

where N_p is the number of pilot bits in each pilot field and $R_c(n)$ is the channel estimator input in Eq.(1). The averaging suppresses the noise term $N(i)$. The channel gain can be figured out as

$$\begin{aligned} b_a(n) &= \overline{R}_C(n)e^{-jp\ /2} \\ &= \frac{1}{N_p}\sum_{i=1}^{N_p}\left(A_{ch}(i)e^{jq(i)} + N_{sa}(i)\right) \end{aligned} \tag{3}$$

The product of the received signal and the conjugate of $b_a(n)$ is the compensating factor feeding into MRC.

2.2. WMSA

Weighted-multislot averaging method

(WMSA)[4] is a special case of FIR filters. It smoothes the outputs of the simple averaging method. The structure is shown in Fig. 4. The output values of the WMSA are equal to

$$b_{WMSA}(n) = \sum_{i=-K+1}^{K} a_i b_a(n+i)$$

where K controls the bandwidth of the FIR filter.

2.3. Wiener Filter

The Wiener filter approach[3][6] requires the knowledge of the Doppler spread and the signal-to-noise ratio (SIR). For low velocities, the Wiener filter approach is quite robust against model errors. However for high velocities, the performance of Wiener filter degrades. In the interpolation perspective, linear interpolation performs well compared with Wiener filter for high velocity environment. Power Control also worsens the model error.

2.4. Forward Linear Prediction

Forward prediction[5][6] reduces the memory requirement to store outputs of rake fingers. However it degrades if non-AWGN exists which do exist in practical environment.

3. Simulation Results

In the simulations we employ slot format #0[2] which is suitable for 12.2Kb voice service. There are 6 pilot bits in each slot. The chip rate is 3.84MHz, and the DPCCH symbol rate is 15KHz. We follow the multipath fading propagation condition in [1] including the speeds and number of paths. Fig. 5, Fig. 6, and Fig. 7 show the block error rate of ideal channel estimation, simple average, and our system with ideal delay estimation and 1/3 Viterbi decoder which meet the 3GPP requirements [1].

4. Summary

Pilot field-aided coherent detection is adopted in 3GPP WCDMA uplink. To make the receiver cost effective, a simple and robust channel estimation structure is required. The simple average approach reduces the data rate. Therefore many advanced techniques employ it as a front-end stage. After the estimation process is completed, the linear interpolation is usually adopted to match the data rate for DPCCH and DPDCH. Adaptive filtering is effective for low vehicular velocity environment without fast power control. As the environment changes, different channel estimation technique should be applied. Therefore velocity estimation is required. There are also many other algorithms rely on velocity estimation, eg. multipath tracking and SIR measurement for handover.

Channel estimation affects the baseband performance severely. According to our design experience, there are 2dB or more E_b/N_0 gap between simple and properly designed channel estimation mechanisms to achieve the same block error rate.

5. Reference

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[3] Bengt Lindoff, Christer Ostberg, and Hakan Eriksson, “Channel Estimation For The W-CDMA System, Performance and Robustness Analysis From A Terminal Perspective”, IEEE 49th Vehicular Technology Conference, Vol. 2, 1999.

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[6] Simon Haykin, *Adaptive Filter Theory*, 3rd edition, Prentice Hall, 1996

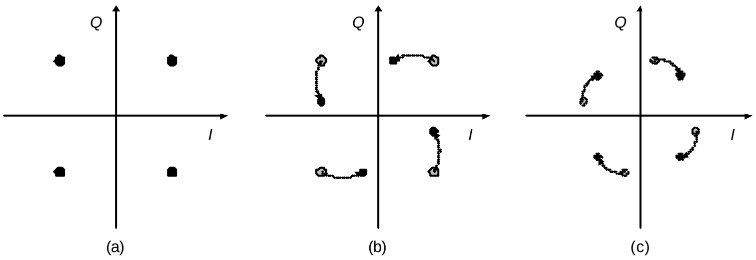

Fig. 1, Constellation diagram for QPSK. a) transmitted, b) received, and c) compensated signal

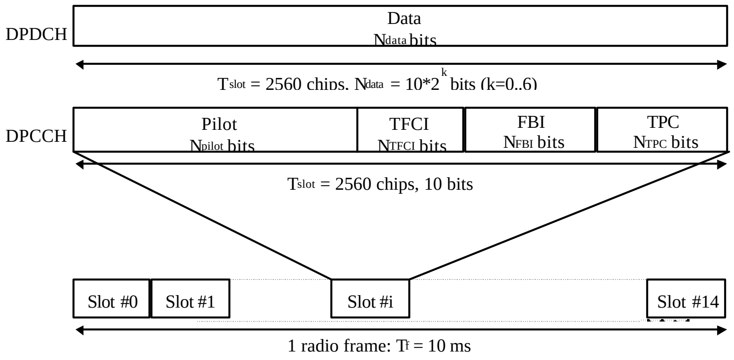

Fig. 2, Frame structure for uplink DPDCH/DPCCH

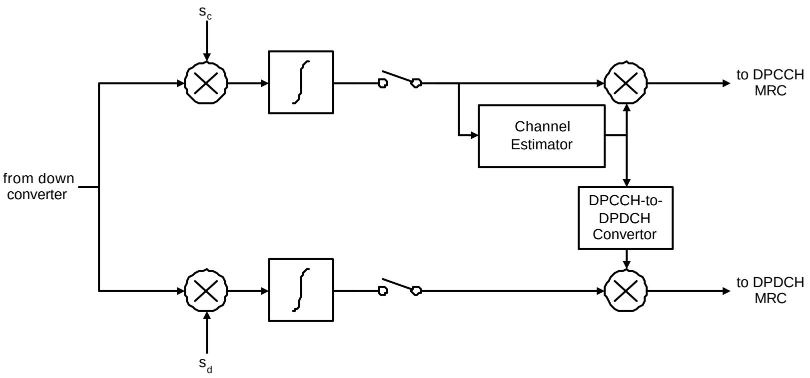

Fig. 3, Simplified rake finger with channel estimator

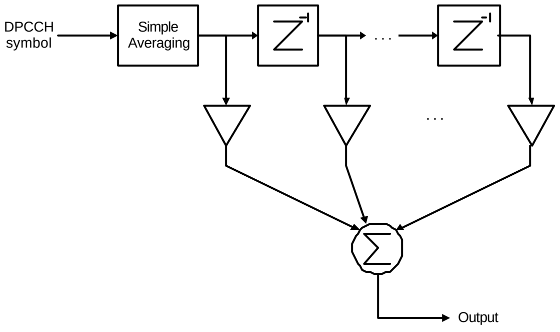

Fig. 4, Block diagram of WMSA

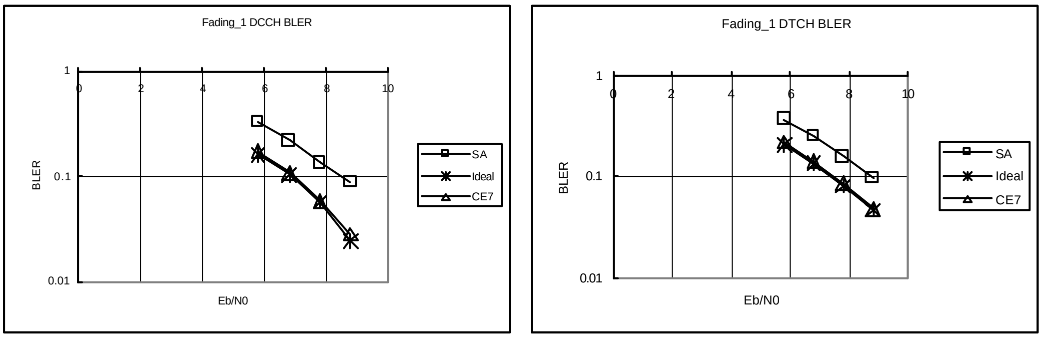

Fig. 5, Block error rate of FADING_1

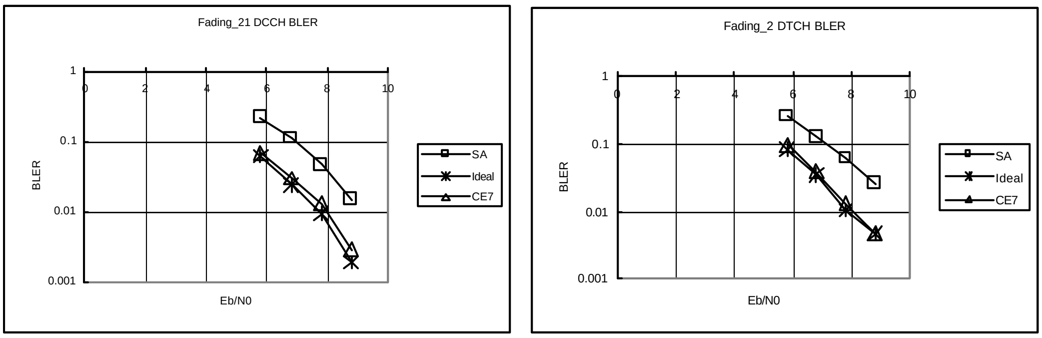

Fig. 6, Block error rate of FADING_2

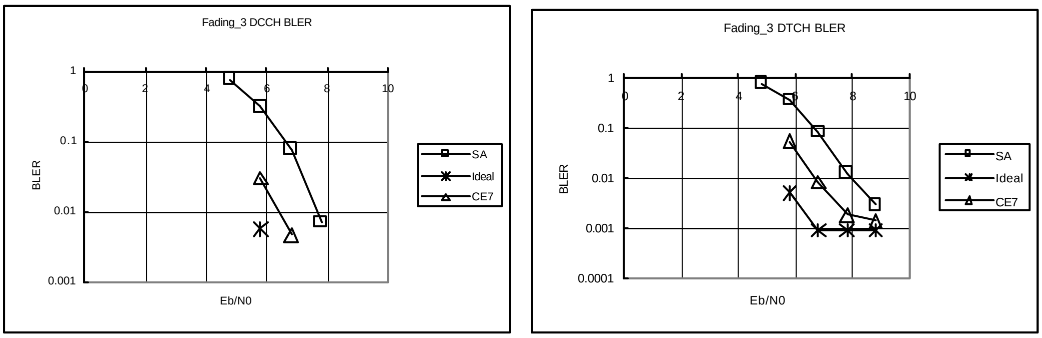

Fig. 7, Block error rate of FADING_3