Adaptive Receiver Structure for UMTS FDD in Multipath Channels Characterised by Long Delay Spreads

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Abstract: This paper investigates the effects of long delay spreads on the performance of the WCDMA system and then proposes an adaptive receiver structure to improve performance in such environments. The motivation for this work is when considering a WCDMA system operating in areas with very low user and traffic densities such as the non-urban areas of Africa. In such areas, the coverage areas are likely to be very big, creating susceptibility to effects of long delay spreads of 60 microseconds or more. One of the main challenges for this radio environment is excessive multiple access interference (MAI) induced by long multipath delay spreads. In this paper, we first present literature on the performance results of using typical receiver structures and then propose a special receiver structure that combines the capabilities of a RAKE receiver and a MAI Canceller to mitigate the effects of long delay spreads. We show that the proposed receiver structure is better suited for dealing with the MAI and multipath delay spread problem for this type of operating environment.

Key words: wideband CDMA (WCDMA), bit error rate (BER), Frequency Division Duplexing (FDD), Universal Mobile Telecommunications Services (UMTS), delay spread, multiple access interference (MAI).

I. INTRODUCTION

Wideband CDMA is the adopted scheme for the UMTS terrestrial air interface for FDD frequency bands. The choice of such a multiple access technique is attractive because of its potential capacity and coverage range increases and inherent technical features such as privacy and multipath rejection capabilities. However, for practical systems, the performance of CDMA can be significantly degraded not only due to multiple access interference (MAI) and the near-far effects, but also by the wideband channel fading characteristics [10].

This paper compares the performance of the various receiver structures that have been proposed for UMTS, and investigates the relative performance improvement achieved by adopting a hybrid RAKE / MAI Canceller receiver structure.

II. THE DELAY SPREAD EFFECT ON A WIDEBAND CHANNEL

Wideband channel models are heavily dependent on the operating environment and on the radio system’s architecture. Xia [8] gives reference wideband channel models and guidelines for the evaluation of radio transmission technologies for UMTS. These channel models are obtained by means of a statistical scatter distribution; and every environment is characterised in terms of a number of scatterers (N < 20) and some parameters relative to each of the scatterers, like their relative amplitudes, time delays, Doppler variations and wavefront’s incidence angles. Of the various parameters that are involved in radio characterisation, we confine the paper to the effects of long delay spreads on the wideband radio channel.

In wideband channel propagation, delay spreading introduces the multipath fading to mobile stations and degrades system performance. The increasing number of users in each cell will increase the total interference to the system and, caused by this reason, the Eb/No for each user will decrease [1]. Users located at the cell boundary will receive the signal less than the required Eb/No and will be dropped out or handed off. In this case, it will seem like the cell’s coverage area is reduced. This situation can be alleviated by means of the use of a suitable receiver structure.

III. DETECTION TECHNIQUES

In mobile communication systems, high performance receivers are critical to maximise coverage. An important challenge is for uplink receivers in 3G systems such as UMTS. Such an uplink receiver is required to offer high coverage, despite the effects of MAI and excessive multipath delay spread, coupled with a low computational complexity and corresponding low power consumption. Generally when multi-user detection is employed, the complexity of an optimum detector is exponential to the number of users, and is thus complicated for practical implementation [9]. There has been great interest in finding sub-optimum detectors with acceptable complexity and marginal performance degradation as compared to the optimum detector. Various sub-optimum detectors have been proposed, most of which are discussed in the following subsections.

A. The Conventional, Single User Receiver

There is a major limitation for conventional wireless transmitters in multipath channels, and this is due to a large fading margin. In its simplest form, the single user detector for direct sequence spread spectrum systems (DS-CDMA) is a
matched filter of the desired signal, which considers other users’ signals as noise. The conventional receiver uses a bank of optimum single-user detectors operating independently. Since in general the input to every threshold has an additive component of MAI, the conventional receiver is not optimum in terms of error-probability. Thus for DS-CDMA systems, the signal constellation has a large bandwidth. Therefore, the cross-correlations between the signals can be kept to a low level for some relative delays, and acceptable performance can be achieved [9]. Nevertheless, if data demodulation is restricted to single-user detection systems, the cross-correlation properties of the signal constellation carry the entire burden of complexity required to achieve a given performance level. However; performance degradation can eventuate when the power of some of the interfering users is dominant.

B. Multi-user Receivers

In multi-user detection (MUD), a joint detection and interference cancellation is performed. 3G WCDMA uses fast closed loop power control both in the uplink and downlink. Since all multi-user detectors are in practice near-far limited, power control is required even if MUD is used. In the uplink, fast power control improves the performance in three ways: (i) by equalising the user powers, the detrimental near-far effect is mitigated, (ii) by compensating the channel fading, Eb/No performance is improved; and (iii) by minimisation of the transmit power, the battery life of the mobile stations is increased and MAI reduced [1]. In the downlink, power control also improves performance against fading but contrary to the uplink, it increases power differences between the received signals at the mobile station [1]. MUD can facilitate larger differences in power levels and thus offers better compensation of deep fades.

In linear multi-user detectors, a linear transformation is performed to the soft outputs of the conventional detector to produce a new set of decision variables with MAI greatly (or completely in the case of the decorrelating detector) decoupled. Two of the most cited linear multi-user detectors are the decorrelating detector, which chooses the linear filter to have zero output MAI [2]; and the Minimum Mean Squared Error detector (MMSE), which chooses the linear filter to have minimum output energy within the constraints that the response of the filter is fixed [3, 4].

Some of the many desirable features of the decorrelating detector are that: (i) it yields the optimal value of near-far resistance performance metric, (ii) it does not need to estimate the amplitude of the received signal and (iii) it corresponds to the maximum likelihood sequence detector when the energies of all users are unknown at the receiver. However, there is a need to compute the inverse of a cross-correlation matrix, which brings in a computational complexity and as a result, it is unacceptable for practical implementation.

C. Interference Cancellers

In receiver structures such as Interference Cancellers (IC), estimates of the interference are generated and subtracted out before detection. The cancellation can be carried out either successively - successive interference canceller (SIC) [3] or in a parallel manner - parallel interference canceller (PIC) [5].

Subtractive interference cancellers are much easier to implement compared with linear multi-user detectors, but the performance gap between them is quite obvious. Another disadvantage of subtractive interference cancellation is that they usually need to estimate the amplitude and carrier phase of all active users. SIC has less computational complexity and is thus less hardware intensive. Since cancelling is done serially, the delay bits are added as the number of users increases, which could result in large delays. On the other hand, PIC causes less delay, but is more hardware-intensive to process users in parallel. Comparisons of these are done in [7] and with perfect power control, PIC performs better than the SIC. Without power control the opposite is true, according to results from [7]. However, in single-path Rayleigh fading and 2-path frequency selective Rayleigh fading [6], the PIC and SIC performances are close.

D. RAKE Receivers

A diversity scheme is a method that is used to develop information from several signals transmitted over independently fading paths [1]. The objective is to combine the multiple signals and to reduce the effects of excessively deep fades. Diversity schemes can minimise the effects of fading, since deep fades seldom occur simultaneously during the same time intervals on two or more paths. The RAKE structure can be considered as a diversity scheme.

The RAKE receiver has the ability to resolve multipath components because there is a high degree of path diversity inherent in the wideband channel (the wide bandwidth gives resolvable multipath). With downlink macro-diversity, the RAKE receiver’s capability to gain from the extra diversity depends also on the number of available RAKE fingers. If, for example, a RAKE receiver cannot collect enough energy from transmissions from two or three base stations due to a limited number of RAKE fingers, the extra transmissions to the mobile station can have a negative effect on total system capacity due to increased interference. In addition to providing gain against multipath fading, macro diversity also gives gain against shadowing [1]. Macro diversity can thus be used to increase the cellular range.

Conventional single-user RAKE receivers, on the one hand, are considered to be the main candidates for implementation in mobile terminals, but their performance is limited with a high number of active users due to a strong multiple access interference (MAI). Optimal multi-user receivers, on the other hand, are complex for implementation and require knowledge of spreading sequences of all active users, whereas in UMTS each mobile user knows only its own spreading sequence. None-the-less, the fact that the RAKE receiver has diversity reception makes it prohibitively computation intensive.
IV. A CASE FOR COMBINED RAKE/MAI CANCELLER RECEIVER

The CDMA system consists of an uplink case and a downlink case, hence the simulations need to be done separately. In this paper we consider only the uplink receiver structure. Figure 1 below shows the approach adopted towards modelling the system.

From the evaluation of *WCDMASim™* it was found that the uplink simulation of the software can be adapted so as to mimic the behaviour of the proposed receiver structure under specular multipath fading channel conditions. Moreover, we are able to add as many interfering mobiles as required. These interfering mobiles are assumed to be intra-cellular (i.e MAI) interferers, because they arrive at the base station receiver with the same average power, although they fade independently. There is no limit on the number of multipath components and each of the components’ associated delay. However, the more the added multipath components and the larger the delays, the more the computation intensity. This is the case because a fading signal is generated for each multipath component, and the largest relative delay determines the length of each fading signal. For error calculations, the simulator output provides a vector wherein every odd element is the number of consecutive correct decisions and every even element is the number of consecutive errors. Thus the BER is simply the sum of all the even elements in the vector divided by the sum of all the elements in the vector.

For better BER performance, the hybrid MAI/RAKE receiver is an attractive prospect because RAKE receivers cannot deal adequately with multiple access interference and a MAI Canceller receiver performs poorly in multipath channels [10]. The channel impulse response that we adopt for simulation purposes is the Wide-Sense Stationary Uncorrelated Scattering (WSSUS) channel - as given in Table 1 - which is one of those that have been proposed for UMTS [11].

<table>
<thead>
<tr>
<th>Path</th>
<th>Relative delay (ns)</th>
<th>Average Power (dB)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>310</td>
<td>-1.0</td>
</tr>
<tr>
<td>3</td>
<td>710</td>
<td>-9.0</td>
</tr>
<tr>
<td>4</td>
<td>1090</td>
<td>-10.0</td>
</tr>
<tr>
<td>5</td>
<td>1730</td>
<td>-15.0</td>
</tr>
<tr>
<td>6</td>
<td>2510</td>
<td>-20.0</td>
</tr>
</tbody>
</table>

Table 1: WSSUS channel impulse response

Figure 2 depicts the necessary combination of system-level and circuit-level modelling for multiple users. Both levels of abstraction are necessary to effect an adequate evaluation of certain critical performance aspects. The model parameters are

adjusted so that all orthogonal channels are active and transmit continuously. The model is based on the European UMTS W-CDMA proposal and incorporates models for the Synchronization CHannel (SCH), the Common Control Physical CHannels (CCPCH) and the dedicated channels (DPCH) [1].

V. PERFORMANCE EVALUATION

In this section we present the evaluation of the proposed receiver structure. The structure performs both MAI cancellation and diversity reception; hence it is highly computation intensive. BER curves are illustrated are in Figure 3. A calibration run for the linear case (no amplifier in the signal path) is shown in diamonds, superimposed on the theoretical result for antipodal signaling in AWGN. The performance with the non-linear amplifier with only the desired signal active is shown in squares. Note that the presence of the SCH channel does not significantly affect the BER results, since the SCH signal is randomised (but not orthogonalised) at the receiver.

The BER curve representing the performance with only the proposed receiver structure is shown in crosses. As expected, the performance of the system is essentially destroyed due to the distortion in the amplifier. This result indicates that a highly linear amplifier may be needed to
maintain signal fidelity. Exact BER results will depend on the amplifier characteristics and the statistics of the user traffic in a complex way. Simulation provides the only means of realistically assessing the system performance under these varying conditions. Figure 4 presents the results obtained from the simulation of five users at different mobile speeds.

<table>
<thead>
<tr>
<th>Eb/No (dB)</th>
<th>BER</th>
</tr>
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<tbody>
<tr>
<td>5 km/hr</td>
<td>1.00E-04</td>
</tr>
<tr>
<td>50 km/hr</td>
<td>1.00E-03</td>
</tr>
<tr>
<td>100 km/hr</td>
<td>1.00E-02</td>
</tr>
<tr>
<td>200 km/hr</td>
<td>1.00E-01</td>
</tr>
<tr>
<td>400 km/hr</td>
<td>1.00E+00</td>
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</table>

Figure 2: BER vs. Eb/No for various simulated speeds (in km/h) for the WSSUS multipath channel

As can be seen, BER performance improves with increasing Eb/No. These results indicate that reasonable performance can be obtained for Eb/No greater than 10 dB across the entire range of simulated speeds. This result is to be expected when compared with simulation results presented in [6], [12] and [13] for other receiver structures, where significant speed dependence is not observed for Eb/No less than 15 dB.

VI. CONCLUSION

We have presented literature on multipath delay spread, its effect on the wideband channel, and on common detection techniques applicable to CDMA systems. The comparison on receiver structures was based on the performance and complexity, since there is very limited literature on the robustness of these structures. At the advent of advanced detection techniques such as those used in the MUD receiver, this paper has proposed a sub-optimum but adequate receiver structure comprising the conventional RAKE receiver with the added capabilities of the MAI Canceller. This structure has the advantage of simplicity whilst combining the powerful features of the RAKE receiver in using multipath diversity and reducing the effect of co-channel interference by using the inherent MAI Canceller capability.

Results indicate that the proposed receiver structure has better BER performance than the sub-optimum receiver structures that have been discussed in this paper. However, it is evident that more work needs to be done into receiver structures with regard to performance optimisation. Hence there will always be a need to explore more advanced detection techniques such as the MUD receiver.

REFERENCES


Biography:

P. Motsoasele received his BSc (Eng) degree in Electrical Engineering from the University of Cape Town, South Africa, in 2001. He is currently a full-time MSc (Eng) student at the University of the Witwatersrand, Johannesburg, in South Africa.

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