MMSE-BASED RECEIVER BEHAVIOUR IN HANDOVER SITUATIONS
Study of Intercell Interference

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Abstract: This paper focuses on the use of an equalization-based receiver for WCDMA (Wideband Code-Division Multiple Access) in an inter-cellular environment, for handover studies. The receiver is based on the MMSE (Minimum Mean Square Error) algorithm and uses the UMTS (Universal Mobile Telecommunications System) HSDPA (High Speed Downlink Packet Access) standard as a basis, alongside the reference UMTS environments

1. INTRODUCTION

In order to cover great areas with coverage for high data-rate transmissions, several Base Stations (BSs) need to be employed, with overlapping coverage areas in order to ensure mobility without dropped calls. These joint coverage areas are the most troublesome areas of a cellular system, since it is where the power levels are lower and where significant interference from the neighboring cells is present.

There are many occasions in which the UE (User Equipment; e.g., mobile phone) is receiving signals from more than one BS; when in a dense environment it usually receives signals from a multitude of BS, though only one or two "interfering" BSs (Base Stations) usually present a significant power level. In this study, two setups were considered, one with two BSs (Figure 1), and the other with three BSs (Figure 2).

considered to have two transmit antennas, operating simultaneously, in order to increase the data rate (spatial multiplexing mode).

Figure 1 – Schematic for a 2 BS setup.

In both setups, two positions were taken as reference. One where the UE is receiving the same amount of power from both BSs, and dealing with one BS. Thus, all other Base Stations constitute interference. For the case where the UE is at point B, it's considered that the signal from the closest BS arrives 3dB higher than the other Base Stations, whose receive power level is considered to be equal.

In each setup, two cases were considered; one where the UE knows nothing about the messages from the interfering BS (Single BS decoding), and the other were the UE knows the interfering BSs codes, so it can decode their messages in order to cancel out their interference (Joint BS decoding). Each BS was
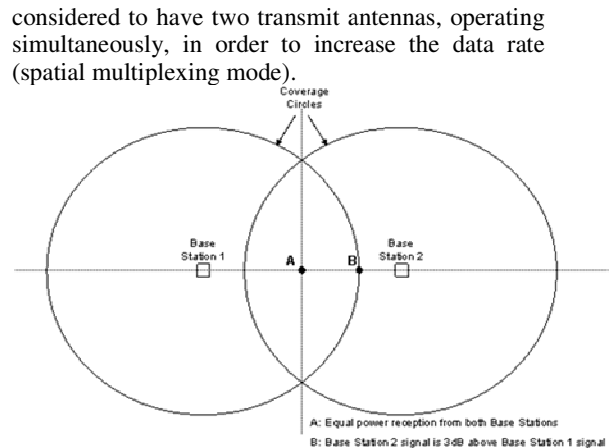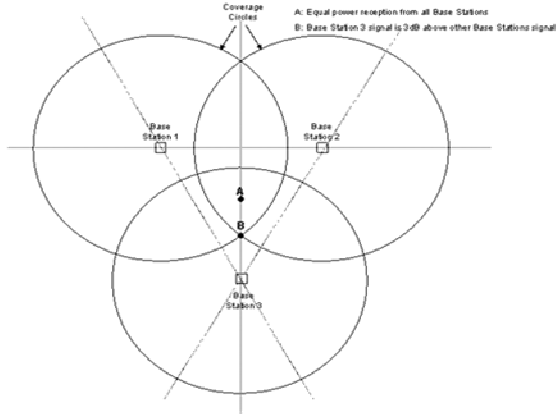
Figure 2 – Schematic for a 3 BS setup.

Another variable to be considered has to do with the number of antennas available at the UE. This is an important issue, since most common UEs usually have only one antenna (case of normal cellular phones nowadays), while others may have either two or more (case of some laptops). The number of considered receive antennas were one, two and the total number of transmit antennas (twice the number of BSs).

As a reference for the current study, the enhanced HSDPA mode of the UMTS using QPSK modulation and a *SF*=16 (Spreading Factor) was chosen as a reference; a system designed for high data rates. In order to study the worst case scenario for QPSK, it was assumed that 6 physical channels (including the control channel) were transmitting simultaneously.

In order to solve for all messages in an efficient manner, an equalization based receiver adapted for multipath MIMO (Multiple Input, Multiple Output) (Foschini, 1998) is considered for this work, based on the MMSE algorithm (Latva-aho, 2000).

The structure of the paper is as follows. In section II, the MMSE receiver for MIMO with multipath is introduced, and the main results of the inter-cellular simulations are discussed in section III. The conclusions are drawn in section IV.

2. LMMSE RECEIVER

A standard model for a DS-CDMA system with K users (assuming 1 user per physical channel) and L propagation paths is considered. The modulated symbols are spread by a Walsh-Hadamard code with length equal to the Spreading Factor (*SF*).

Assuming that the transmitted signal on a given antenna is of the form

$$e(t)_{tx=1} = \sum_{n=1}^{N} \sum_{k=1}^{K} A_{k,tx} b_{k,tx}^{(n)} s_k(t - nT), \quad (1)$$

where N is the number of received symbols, $A_{k,tx} = \sqrt{E_k}$, E_k is the energy per symbol, $b_{k,tx}^{(n)}$ is the n-th transmitted data symbol of user k and transmit antenna tx, $s_k(t)$ is the k-th user's signature signal (equal for all antennas) and T denotes the symbol interval.

The received signals of a MIMO system with N_{TX} transmit and N_{RX} receive antennas, on one of the receiver's antennas can be expressed as:

$$r_{v_{rx=1}}(t) = \sum_{tx=1}^{N_{TX}} e_{tx}(t) * c_{tx,rx}(t) + n(t) \quad (2)$$

where $n(t)$ is a complex zero-mean AWGN (Additive White Gaussian Noise) with variance σ^2,

$$c_{tx,rx}(t) = \sum_{l=1}^{L} c_{tx,rx,l}^{(n)} \delta(t - \tau_l) \quad \text{is the impulse}$$

response of the radio link between the antenna tx and rx (assumed equal for all users using this link), $c_{tx,rx,l}$ is the complex attenuation factor of the l-th path of the link, τ_l is the propagation delay (assumed equal for all antennas) and * denotes convolution. The received signal on can also be expressed as:

$$r_{v_{rx=l}}(t) = \sum_{n=1}^{N} \sum_{tx=1}^{N_{TX}} \sum_{k=1}^{K} \sum_{l=1}^{L} A_{k,tx} b_{k,tx}^{(n)} c_{tx,rx}(t) s_k(t - nT - \tau_l) + n(t) \quad (3)$$

Using matrix algebra, the received signal can be represented as

$$r_v = SCAb + n, \quad (4)$$

where S, C and A are the spreading, channel and amplitude matrices respectively. The structure of the matrices is explained in detail in (Silva, 2005).

Vector b represents the information symbols. It has length $(K \cdot N_{TX} \cdot N)$, and has the following structure

$$b = \left[b_{1,1,1}, \ldots, b_{N_{TX},1,1}, \ldots, b_{1,K,1}, \ldots, b_{N_{TX},K,1}, \ldots, b_{N_{TX},K,N} \right]^T. \quad (5)$$

Note that the bits of each transmit antenna are grouped together in the first level, and the bits of other interferers in the second level. This is to guarantee that the resulting matrix to be inverted has all its non-zeros values as close to the diagonal as possible. Also note that there is usually a higher correlation between bits from different antennas using the same spreading code, than between bits with different spreading codes.

The n vector is a $(N \cdot SF \cdot N_{RX} + N_{RX} \cdot \psi_{MAX})$ vector with noise components to be added to the received vector r_v, which is partitioned by N_{RX} antennas,

$$r_v = \left[r_{1,1,1}, \ldots, r_{1,SF,1}, \ldots, r_{N,1,1}, \ldots, r_{N,SF+\psi_{MAX},1}, \ldots, r_{N,1,N_{RX}}, \ldots, r_{N,SF+\psi_{MAX},N_{RX}} \right]^T \quad (6)$$

Equalization-based receivers compensate for all effects that the symbols are subject to in the transmission chain, namely the MAI (Multiple Access Interference), ISI (Inter-Symbolic Interference) and the channel effect. Thus being, only the thermal noise cannot be compensated for, since only its power level can be effectively estimated.

The equalization receiver used as basis in this works makes use of the MMSE algorithm, as is based on the Matched Filter output,

$$y_{MF} = \left(SCA \right)^H r_v \tag{7}$$

The MMSE estimate aims to minimize $E\left(\left| b - \hat{b} \right|^2 \right)$, where

$$\hat{b} = L^H r_v \tag{8}$$

is the MMSE estimate. From (Kay, 1993), the EM (Equalization Matrix) includes the estimated noise power σ^2, and is represented by

$$E_{M,MMSE} = R + \sigma^2 I . \tag{9}$$

$$R = A \cdot C^H \cdot S^H \cdot S \cdot C \cdot A \tag{10}$$

The MMSE estimate is thus

$$y_{MMSE} = \left(E_{M,MMSE} \right)^{-1} y_{MF} , \tag{11}$$

with

$$L = SCA \cdot \left(R + \sigma^2 I \right)^{-1} . \tag{12}$$

3. RESULTS

All results are portrayed in BER versus received E_b/N_0. In the case of simulations for point B, results are portrayed against the received E_b/N_0 value of the closest BS. Four different channels were simulated; one with 6 equal fingers/taps, the flat fading channel (1 finger), the Vehicular A and the Pedestrian A channel models referenced for the UMTS (3GPP, 2003). For the simulations performed in position A, the BER of the "Best" BS was also shown. This BER is indicative of the system's performance if a scheme similar to STD was to be employed. What was considered in the simulation was simply to account the errors of the BS with the least amount of errors for each simulated block – this provides an important performance bound.

For the simulations using position B, the BER of the high power (closest) BS was analyzed, alongside the BER of the low power (one of the farthest) BS. Therefore, it's possible to obtain some precious conclusions from both cases of position B, especially for handover situations.

Results - UE in point A – Single BS Decoding

For Position A with single BS detection, only for the case where the UE has 2 or more receive antennas (Figure 4 and Figure 5), there are some good results for the case of only one interfering BS, contrary to the case in Figure 3. When using 2xBS receive antennas, all results are satisfactory (close to 10^{-2}). Note also that the channels with the largest spread (6 finger and Vehicular A channels) yield the worse results when a small numbers of antennas is used at the receiver, and yield the best results when the full number of antennas are employed (2xBS), due to the added capability of the antennas sorting out the different multipath components, and exploiting them for added diversity gains.
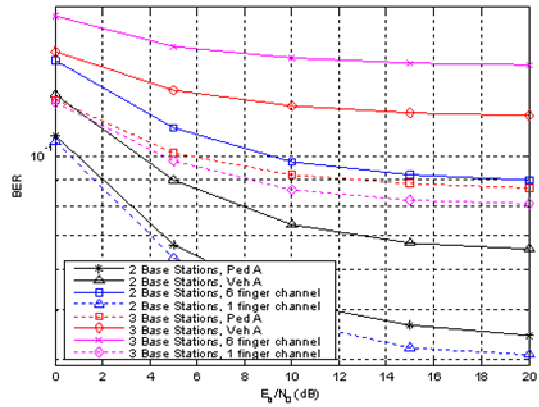

Figure 3 – BER performance for the best BS in position A using a single BS decoding philosophy and 1 receive antenna.
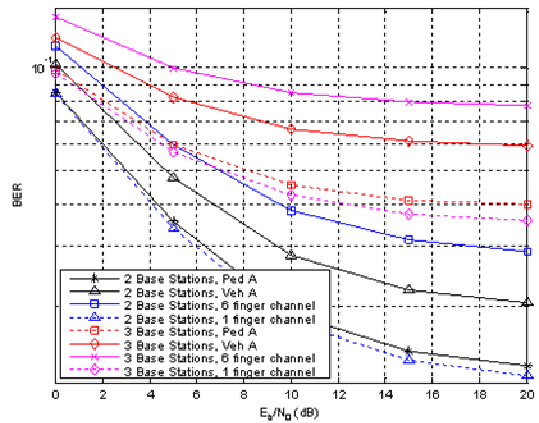

Figure 4 – BER performance for the best BS in position A using a single BS decoding philosophy and 2 receive antennas.
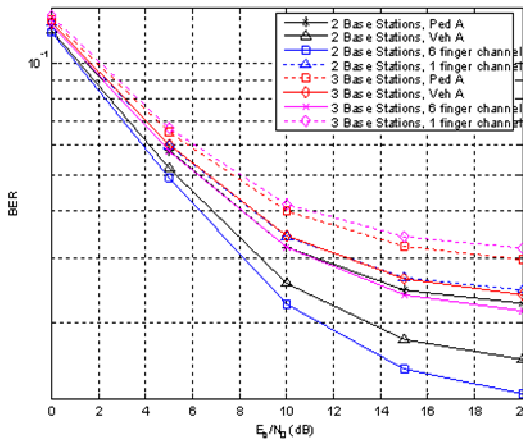
Figure 5 – BER performance for a fixed BS in position A using a single BS decoding philosophy and 2xBS receive antennas.
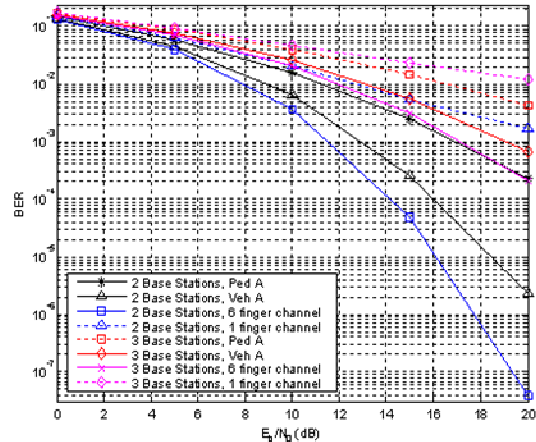

Figure 7 – BER performance for position A using a joint BS decoding philosophy and 2 receive antennas.

Results - UE in point A – Joint BS Decoding

When using joint decoding (Figure 6 and Figure 7), the UEs with one receive antenna only present satisfactory results (in this case, a BER value lower than 10^{-1} for an Eb/N0 of 20dB) when there is only one interfering BS. UEs with a higher number of receive antennas perform well under all scenarios. Note also that when using joint-decoding of the BSs, the dispersive channels present the best results, due to the exploitation of multipaths.
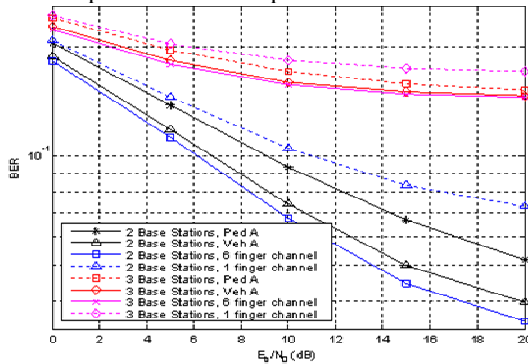

Figure 6 – BER performance for position A using a joint BS decoding philosophy and 1 receive antenna.

Results - UE in point B – Single BS Decoding

For position *B* with single BS detection, using one receive antenna (Figure 8) is only somewhat acceptable (BER of 10^{-1}) in the presence of 2 BS, and when the UE is using the closer BS. For the case of using the farthest BS, BER levels of 10^{-1} and lower are only possible with 2xBS antennas (Figure 9).
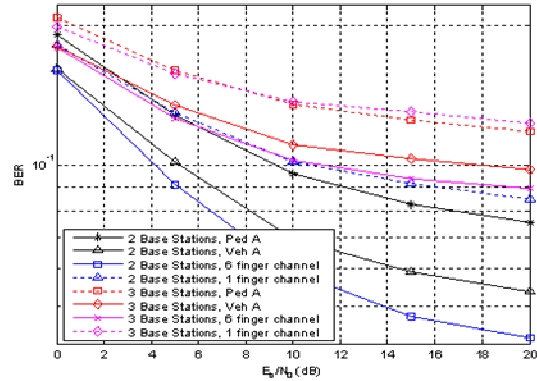

Figure 8 – BER performance for position B using a single BS decoding philosophy and 1 receive antenna; results for decoding the high power BS.
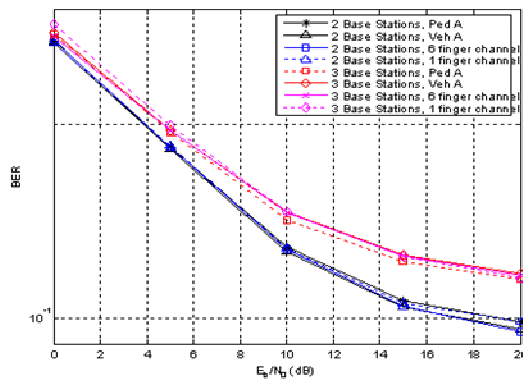
Figure 9 – BER performance for position B using a single BS decoding philosophy and 2xBS receive antennas; results for decoding the low power BS.

Results - UE in point B – Joint BS Decoding

When using joint detection, the UE with 1 receive antenna (Figure 10) performs acceptably when there is only one interfering BS (2 Base Stations), and the UE is farther from this interferer (high power BS); however, when another interferer is introduced (3 Base Stations), the performance degradation is very significant.
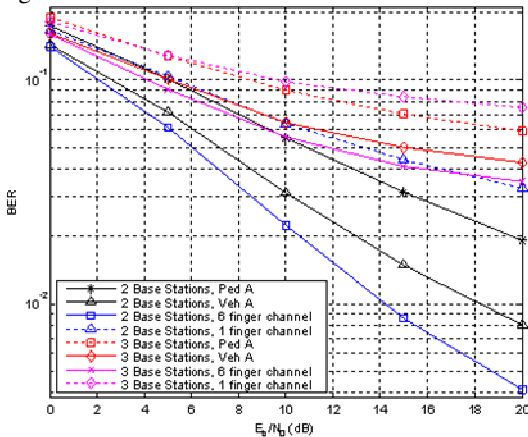

Figure 10 – BER performance for position B using a joint BS decoding philosophy and 1 receive antenna; results for decoding the high power BS.

With a higher number of receive antennas (2 and 2xBS antennas for Figure 11 and Figure 12 respectively), all cases provide good results (BER of 10^{-2} and lower).
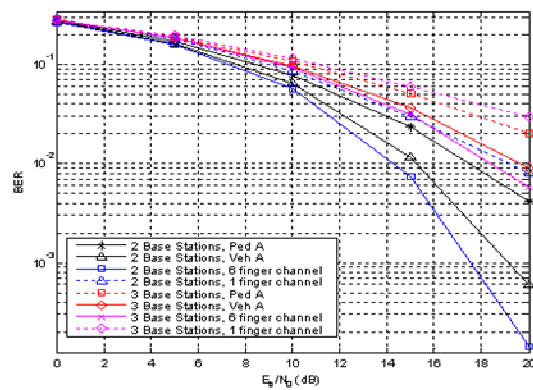

Figure 11 – BER performance for position B using a joint BS decoding philosophy and 2 receive antennas; results for decoding the low power BS.
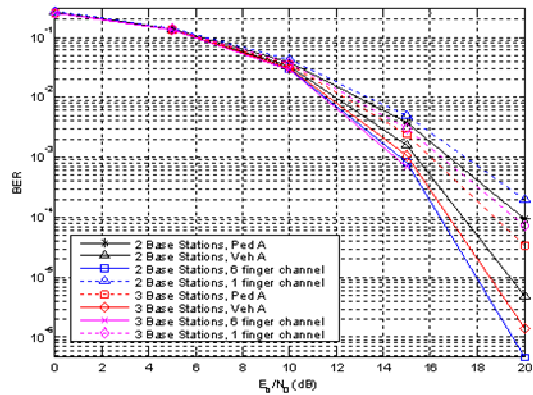

Figure 12 – BER performance for position B using a joint BS decoding philosophy and 2xBS receive antennas; results for decoding the low power BS.

4. CONCLUSIONS

In summary, when using single BS decoding and when there is a significant amount of interference from other BSs, 1 receive antenna at the UE simply does not work. However, with the use of 2 or more receive antennas, and ultimately with the aid of the codes from the other BSs in order to cancel their interference effect as much as possible, best results can be obtained in the presence of significant interference. What this means, in terms of handover, is that a soft handover is required between cells, especially for the case of UEs with a small number of receive antennas, using the HSDPA protocol. Hard handovers should only be allowed when the receiver is able to cope with the adverse conditions of the interfering cells when at the transitional zone.

5. REFERENCES

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