International Journal of Research
International Journal of Research (IJR)
e-ISSN: 2348-6848, p- ISSN: 2348-795X Volume 2, Issue 12, December 2015
Available at http://internationaljournalofresearch.org

Performance Analysis of Macro diversity MIMO Systems in Wimax Networks Using MMSE and ZF Receivers

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Abstract—
We considered a multiuser system where number of users communicate with a distributed receive array over Rayleigh fading paths which are independent. The receive array computes minimum mean squared error (MMSE) and perfect channel state information is assumed at the receiver. This is done when the receiving antennas are located in a single array .But when the antennas are distributed, they have different average SNRs and this is a more challenging issue. In this paper, we provide approximate distributions for the output SNR of a ZF receiver and the output signal to interference plus noise ratio (SINR) of an MMSE receiver. In addition, simple high SNR approximations are provided for the symbol error rate (SER) of both receivers a considering M-PSK or M-QAM modulations. These high SNR results provide array gain and diversity gain information as well as a remarkable simple functional link between performance and the link powers. By adding the WIMAX layer instead of MIMO, to get the better Symbol error Rate performance than MIMO.

Index Terms—Macro diversity; MMSE; ZF; outage probability; optimum combining; zero-forcing; Network MIMO; COMP

I.INTRODUCTION

The arise of space diversity systems, decoupling users through channel aware signal processing techniques in the presence of multiple access interference (MAI) and noise has become an integral part of the system design. There are various processing techniques now widely adopted in research and standards [1]. Among them, linear combining methods are popular for their simplicity. Two key linear combiners are zero forcing (ZF) and minimum mean squared-error (MMSE). Although they are not optimal, the MMSE receiver satisfies an alternative criteria, i.e., it minimizes the mean squared error (MSE) and ZF is known to eliminate MAI completely. The performance analysis of such linear receivers is of great interest in wireless communication [2] because it provides a link level performance metric for the system. Macro diversity combining both has recently become important in wireless communication. Any system where both transmit and receive antennas are separated can be interpreted as a macro diversity multiple input multiple output (MIMO) system. The performance of macro diversity systems can be investigated via simulation

In this paper, we extend the results to more general user and antenna configurations. In particular, the contributions made are as follows:

1. We derive the approximate probability distribution function (PDF) and cumulative distribution function (CDF) of the output SINR/SNR of MMSE/ZF receivers...
2. High SNR approximations for the SER of MMSE/ZF receivers are derived for a range of modulations and these results are used to derive diversity order and array gain results.

III. PROPOSED METHOD

In this section, we present the system model which is considered throughout this paper. The multiuser MIMO system investigated in this paper consists of N distributed single antenna users communicating with nR distributed receive antennas in an independent flat Rayleigh fading environment. The $CnR\times1$ receive vector is given by

$$\boldsymbol{r} = \boldsymbol{Hs}+\boldsymbol{n}, \quad (3)$$

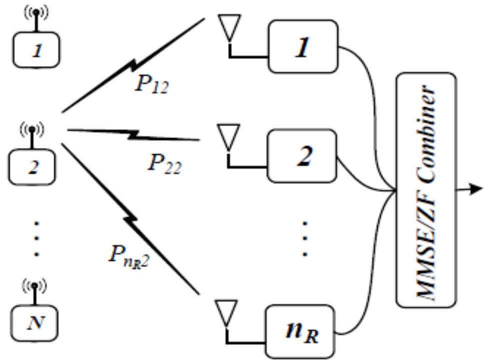

Fig. 2. System diagram. To reduce clutter, only paths from a single source are shown.

International Journal of Research

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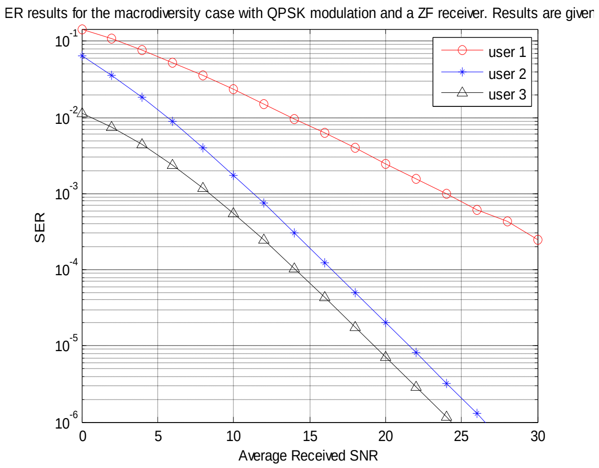
where the $CN\times1$ data vector, $s = (s1, s2, . . . , sN)T$, contains the transmitted symbols from the N users and it is normalized, so that $E\_|si|2\_= 1$ for $i = 1, 2, . . .,N$. n is the $CnR\times1$ additive-white-Gaussian-noise (AWGN) vector, $n \sim CN\ \_\ 0, \sigma 2I$, which has independent entries with $E\_|ni|2\_= \sigma 2$, for $i = 1, 2, . . ., nR$. The channel matrix contains independent elements, $Hik \sim CN\ (0, Pik)$, where $E\ \_|Hik|2\_= Pik$. A typical macrodiversity MU-MIMO multiple access channel (MAC) is shown in Fig. 2, where it is clear that the geographical spread of users and antennas creates a channel matrix H, which has independent entries with different Pik values. We define the $CnR\times N$ matrix, $P = \{Pik\}$, which holds the average link powers due to shadowing, path fading, etc.



By assuming that perfect channel state information is available at the receiver side, we consider a system where channel adaptive linear combining is performed at the receiver to suppress multiple access interference [1]. Therefore, the $CN\times1$ combiner output vector is $\tilde{r} = V\ Hr$, where V is a $CnR\times N$ weight matrix. In this work, we consider two well-known linear combining schemes: MMSE and ZF. The structure of V and the resulting output SINR/SNR for MMSE/ZF schemes are well-known and are given below. Without loss Of generality, we assume that the index of the desired user is $i = 1$. The combining vector and output SINR of the MMSE receiver for user 1 are given by [3], [20] as

$$\boldsymbol{v}_1 = \left(\boldsymbol{H}\boldsymbol{H}^H + \sigma^2\boldsymbol{I}\right)^{-1}\boldsymbol{h}_1, \qquad (4)$$

$$\mathrm{SINR} = \boldsymbol{h}_1^H\boldsymbol{R}^{-1}\boldsymbol{h}_1, \qquad (5)$$

where

$$\boldsymbol{R} = \sum_{k\neq i}^{N}\boldsymbol{h}_k\boldsymbol{h}_k^H + \sigma^2\boldsymbol{I}, \qquad (6)$$

And $H = (h1, h2, hN)$. Defining $v2, . . . , vN$ similarly gives $V = (v1, v2, . . . ,vN)$. The vectors, hk, clearly play An important role in MMSE combining and it is useful to define the covariance matrix of hk by $Pk = E\ hkhH\ k\_=\mathrm{diag}(P1k,\ P2k,\ . . . ,\ PnRk)$. From [4], [7], the combining matrix, V, and output SNR of the ZF receiver for $nR \geq N$ are given by

$$\boldsymbol{V} = \boldsymbol{H}\left(\boldsymbol{H}^H\boldsymbol{H}\right)^{-1} \qquad (7)$$

$$\mathrm{SNR} = \frac{1}{\sigma^2\left[\left(\boldsymbol{H}^H\boldsymbol{H}\right)^{-1}\right]_{11}}. \qquad (8)$$

V. ZF ANALYSIS

In this section, we derive an approximate CDF for the output SNR of a ZF receiver, a high SNR approximation to SER and also consider some special cases. The following PDFs for the columns of the channel matrix are used throughout the analysis.

$$f(\boldsymbol{h}_k) = \frac{1}{\pi^{n_R}|\boldsymbol{P}_k|}e^{-\boldsymbol{h}_k^H\boldsymbol{P}_k^{-1}\boldsymbol{h}_k}, \qquad (9)$$

For $k = 1, 2, N$.

5.1. CDF Approximations:

The output SNR of a ZF receiver in (8) can be written as

$$\tilde{Z} = \frac{1}{\sigma^2}\boldsymbol{h}_1^H\left(\boldsymbol{I} - \boldsymbol{H}_2\left(\boldsymbol{H}_2^H\boldsymbol{H}_2\right)^{-1}\boldsymbol{H}_2^H\right)\boldsymbol{h}_1 \qquad (10)$$

$$= \frac{1}{\sigma^2}\boldsymbol{h}_1^H\boldsymbol{M}\boldsymbol{h}_1, \qquad (11)$$

$\boldsymbol{M} = \boldsymbol{I} - \boldsymbol{H}_2\left(\boldsymbol{H}_2^H\boldsymbol{H}_2\right)^{-1}\boldsymbol{H}_2^H$ $h1$ removed.

The full CF can then be obtained by averaging the conditional CF in (23), to give

$$\phi_{\tilde{Z}}(t) = \frac{1}{|\boldsymbol{D}|}E\left\{\frac{|\boldsymbol{H}_2^H\boldsymbol{H}_2|}{|\boldsymbol{H}_2^H\boldsymbol{D}^{-1}\boldsymbol{H}_2|}\right\}, \qquad (12)$$

5.2. High SNR Approximations:

The CF in (24) is a ratio of determinants, where $D = I - 1\ \sigma 2\ jtP1$. As the SNR grows, $\sigma 2 \rightarrow 0$ and keeping only the dominant power of $\sigma 2$ in (24) gives

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$$\phi_{\tilde{Z}}(t) = \tilde{K}_0 \left(\frac{\sigma^2}{-jt}\right)^{n_R - N + 1}, \qquad (13)$$

Where

$$\tilde{K}_0 = \frac{1}{|\boldsymbol{P}_1|} E\left\{ \frac{\left|\boldsymbol{H}_2^H \boldsymbol{H}_2\right|}{\left|\boldsymbol{H}_2^H \boldsymbol{P}_1^{-1} \boldsymbol{H}_2\right|} \right\}. \qquad (14)$$

VI. MMSE ANALYSIS

6.1. CDF Approximations:

In this section, we derive the approximate CDF of the output SINR of an MMSE receiver and a high SNR approximation to the SER. Let Z be the output SINR of an MMSE receiver given by (5). Following the same procedure as in the ZF analysis, the CF of Z is

$$\phi_Z(t) = E\left\{e^{jtZ}\right\} = E\left\{e^{jt\boldsymbol{h}_1^H \boldsymbol{R}^{-1} \boldsymbol{h}_1}\right\}. \qquad (15)$$

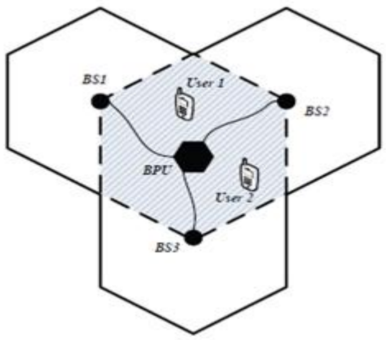
Next, the CF conditioned on *H*2 becomes [14]

$$\phi_Z(t|\boldsymbol{H}_2) = \frac{1}{\left|\boldsymbol{I} - jt\boldsymbol{R}^{-1}\boldsymbol{P}_1\right|}. \qquad (16)$$

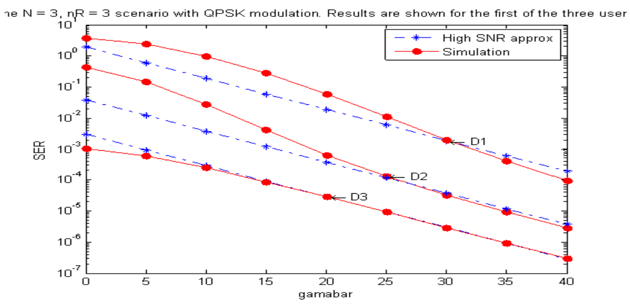
The conditional CF in (53) becomes

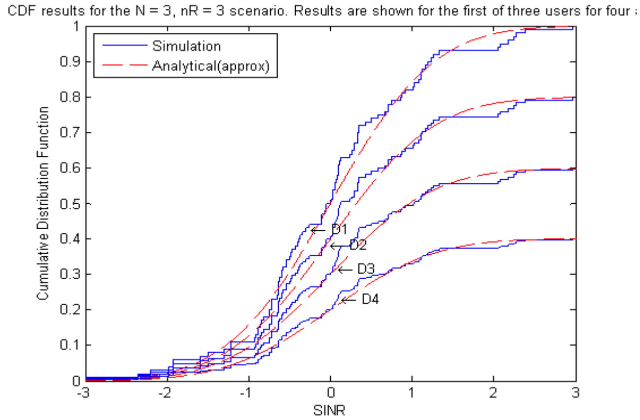
$$\phi_Z(t|\boldsymbol{H}_2) = \frac{1}{\left|\boldsymbol{I} - jt\left(\sigma^2\boldsymbol{I} + \boldsymbol{H}_2\boldsymbol{H}_2^H\right)^{-1}\boldsymbol{P}_1\right|} \qquad (17)$$

$$= \frac{\left|\sigma^2\boldsymbol{I} + \boldsymbol{H}_2\boldsymbol{H}_2^H\right|}{\left|\sigma^2\boldsymbol{I} - jt\boldsymbol{P}_1 + \boldsymbol{H}_2\boldsymbol{H}_2^H\right|}. \qquad (18)$$



Network MIMO/edge-excited cell scenario where three base stations serve users in a three-sector cluster. To reduce clutter, only two users are shown.





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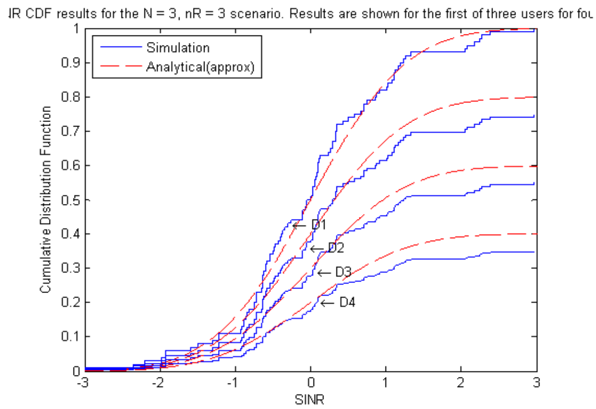
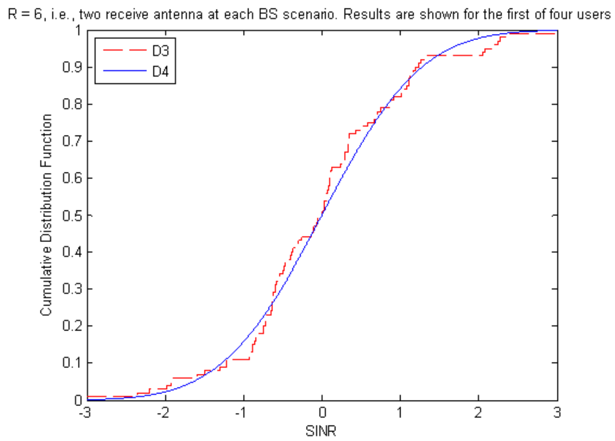
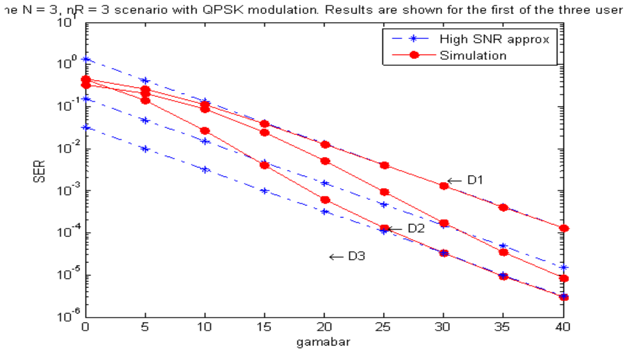
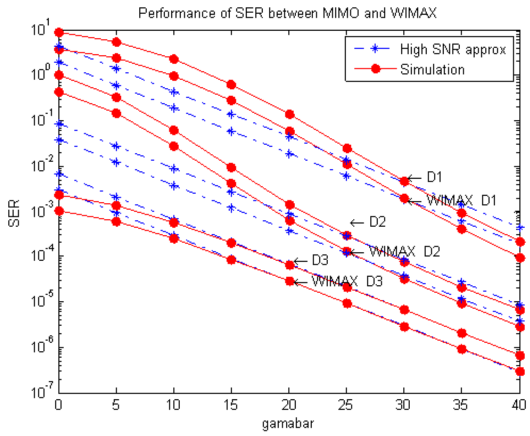
Here, we investigate both the approximate SINR distributions and the approximate SER results for an MMSE receiver.



SER is plotted against the transmit SNR, $\bar{\gamma}$. Results are shown for the case of four single antenna users and six distributed receive antennas is considered. High SNR, SER curves are plotted Results are shown for both MMSE and ZF with QPSK modulation. The results are very useful concerning macro diversity combining ZF and MMSE







Simple SIR metric give the same performance ranking with D3 the best and D1 the worst. The fourth drop, D4, is the interesting case. Here, the SIR is -10dB, which is lower than both D2 and D3. Hence, from Fig. D4 has a better SER performance than D2 and D3 despite having a worse SIR.

VIII. CONCLUSION

The performance of MMSE and ZF receivers is mostly well-known in micro diversity systems where receive antennas are co-located. However, in the macro diversity case, closed form performance analysis is a long-standing, unsolved research problem. In this paper, we make the progress towards solving this problem by considering an arbitrary number of transmit and receive antennas. The analysis is based on a derivation which targets the characteristic function of the output SINR. This leads to an expected value which is highly complex in its exact form, but can be simplified by the use of an extended Laplace type approximation. The SINR distribution is shown to have a remarkably simple form as a generalized mixture of exponentials. Results obtained by simulation are very useful combining ZF and MMSE

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