Transmit diversity antenna system for CDMA frequency selective channels

Khalida Ghanem, and Tayeb. A. Denidni *
INRS-EMT, University of Quebec
800, de la Gauchetière West, suite 6900, Montreal, Canada
kghanem@emt.inrs.ca

Introduction

To solve the spectral resource scarceness problem and support voice and data communication services, CDMA systems have been developed and use the RAKE receiver architecture to exploit multipath diversity. However, with the RAKE structure, the increase of multipath signals results in additional required signal processing and power consumption. This induces an increase of the cost and the size of the mobile unit, and affects battery life duration. One possible solution is the pre-RAKE processing, in which the diversity gain is maintained but the structure of the RAKE is removed from the portable unit to the base station. This allows to pre-amplify the signal before transmission and to use a simple matched filter for the detection.

Nowadays, the objective is to design high-data rate transmission systems. In such case, it is likely that the channel becomes frequency selective, causing severe intersymbol interference (ISI). One solution is reached through multicarrier modulation by partitioning the channel into parallel flat subchannels [1].

In this paper, a new transmit antenna diversity system for multicarrier CDMA communications is proposed. This system uses an antenna array at the base station to ensure transmit diversity, a pre-Rake processing to reduce the hardware complexity at the portable unit and a multicarrier modulation to mitigate ISI. To show the efficiency of the proposed design, its performance in terms of bit error rate (BER) is compared to the conventional DS-CDMA-RAKE-based and the multiple-antenna-prerake system with single carrier systems.

System and channel models

The system under consideration is constituted of M transmit antennas at the base station and one receive antenna at the mobile as depicted in Fig. 1. N orthogonal frequency signals $s^{(n,k)}$, $n = 1 \ldots N$, are generated for each bit of the k^{th} user by a serial-to-parallel conversion (S/P) of the incoming stream, followed by a code spreading of the resultant signal, an application of the IFFT, and a parallel-to-serial (P/S) conversion with a prefix insertion. The incorporated cyclic prefix is assumed to successfully removing ISI. Each of the N-OFDM signals $s^{k,n}$, $n = 1 \ldots N$, can be formulated as follows

$$s^{k,n}(t) = d_k(i)\pi\left(\frac{t}{T_b}\right)c_{k,n} \exp\left\{j2\pi\left(f_c + \frac{n-1}{T_b}\right)t\right\} \qquad (1)$$

where $\pi\left(\frac{t}{T_b}\right)$ is the shaping impulsion, and d_k is the i.i.d of k^{th}-user BPSK data sequence. $c_{k,n}$ refers to the n^{th} chip selected from the k^{th} user signature code sequence $\boldsymbol{C}_k$ of length $N = T_b/T_c$, where T_c and T_b are the chip and the bit durations.

Then the pre-RAKE processing consists in passing the n^{th} carrier signal of the k^{th} user emitted by the m^{th} antenna by the transmit weight vector

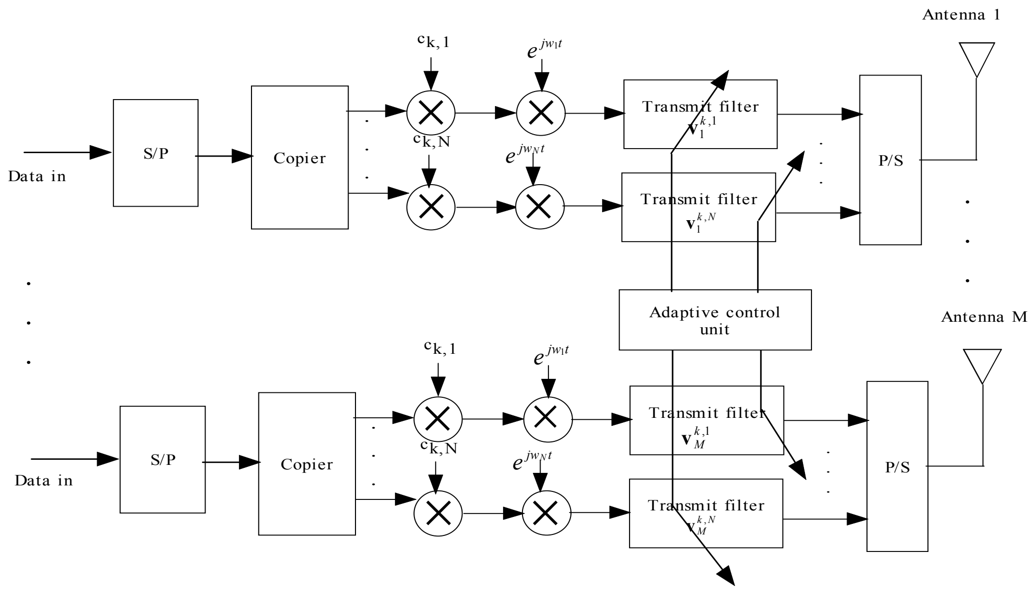

Fig. 1 Structure of the proposed MC-CDMA scheme with transmit diversity.

$$\boldsymbol{V}_{\mathrm{m}}^{(\mathrm{k,n})} = [v_{m,0}^{(k,n)}\; v_{m,1}^{(k,n)}\; \ldots\; v_{m,Lt-1}^{(k,n)}]^{\mathrm{T}}, \quad m = 1 \ldots M,$$

where L_t is the transmit filter length. After the FFT application at the receiver, the k^{th} user signal is analogously passed in a L_r transversal filter defined as

$$\boldsymbol{U}^{(\mathrm{k,n})} = [u_0^{(k,n)}\; u_1^{(k,n)}\; \ldots\; u_{Lr-1}^{(k,n)}]^{\mathrm{T}}.$$

Herein, the FFT processing is first performed to recover the transmitted signals, then receive filtering is applied on each subcarrier separately. After that, the subcarrier signal is detected and the despreading operation is applied.

If we assume that a maximum of L chip-separated multipath components exist between the m^{th} transmit antenna and the k^{th} mobile, then the channel is

$$h_m^{k,n}(t) = \sum_{l=0}^{L-1} h_{m,l}^{(k,n)} \delta(t - lT_c) \exp\{j\theta_{n,k}\} \tag{2}$$

where $h_m^{k,n}$ is the complex low-pass impulse response of the n^{th} subcarrier whose components $h_{m,l}^{(k,n)}$ are the complex gain corresponding to the l^{th} multipath component. The parameter l is the path index, while k and n refer to the user and the carrier indices.

By convolving the impulse responses of the channel and the transmit transversal filter, the resultant channel transfer matrix from the m^{th} transmit antenna to the k^{th} user receiver is noted $\mathbf{H}_m^{(k,n)}$. Therefore, the received signal within one bit duration at the $k'^{\,th}$ user receiver can be formulated as

$$s^{(k')}(t) = \sum_{k=1}^{K} \sum_{n=1}^{N} \mathbf{P}^{(k,n)}(t) \mathbf{H}^{k',n} \mathbf{V} + n^{k'} \tag{3}$$

where $\boldsymbol{H}^{k',n}$ is the $(L+L_t-1) \times L_t M$ channel transfer matrix whose components are $\boldsymbol{H}_m^{k',n}$, $m = 1 \ldots M$. $\boldsymbol{V}^{k,n}$ is the $L_t.M \times 1$ transmit filter vector whose elements are $V_m^{k,n}$, $m = 1 \ldots M$. $n^{(k')}$ is the zero mean white Gaussian noise with variance σ^2, and K is the number of users. For a bit duration, $\boldsymbol{P}^{\mathrm{k,n}}$ is the $1\times (L+L_t-1)$ vector containing the temporal terms of the received signal.

Detection of the signal at subcarrier n' is performed by the correlation with the n'^{th} subcarrier. If we note $\boldsymbol{S}^{(\mathrm{k',n'})}$ the output of the n'^{th} detector of the FFT, then

$$S'^{(k',n')} = \sum_{n=1}^{N}\sum_{k=1}^{K}\sum_{m=1}^{M} P'^{(k,k',n,n')} H_m V_m + n'^{(k')} \quad (4)$$

where $\boldsymbol{P}^{'k,k',n,n'}$ is the $1\times(L+L_t\ -1)$ correlation vector with the n'^{th} carrier whose components are noted $r^{(k,k',n,n')}(l)$, $l = 0 \ldots L+L_t\ -2$. Assuming that perfect phase compensation is reached then the contribution of all ($n \neq n'$) terms leading to ICI is demonstrated to be null.

The term $n'^{(k')}$ in Eq. (4) is the k'^{th} user receiver noise sampled at the n'^{th} subcarrier. After applying FFT, receive filtering is performed on each subcarrier. Let us define $\boldsymbol{Q}^{(k,k',n')}$ the modified $L_r\times(L+L_t\ -1)$ subcarrier-correlation matrix as

$$Q^{(k,k',n')} = \begin{bmatrix} r^{(k,k',n')}(0) & r^{(k,k',n')}(1) & \cdots & r^{(k,k',n')}(L+L_t-2) \\ r^{(k,k',n')}(-1) & r^{(k,k',n')}(0) & \cdots & r^{(k,k',n')}(L+L_t-3) \\ \vdots & \ddots & & \\ r^{(k,k',n')}(-L_r+1) & r^{(k,k',n')}(-L_r+2) & \cdots & r^{(k,k',n')}(L+L_t-L_r-1) \end{bmatrix} \quad (5)$$

Then combining the transmit and receive filtering, the decision statistic of the n'^{th} detector for the k'^{th} user can be formulated as

$$Z^{k',n'} = \mathrm{Re}\left(\sum_{k=1}^{K} U^{k',n'H} Q^{(k,k',n')} H^{k',n'} V^{k,n'} + \eta'^{(k',n')}\right) \quad (6)$$

where Re (.) represents the real part.

Proposed transmit diversity multicarrier system

The optimum transmit vector $V^{k',n'}$ and receive vector $U^{k',n'}$ $\forall$ n', et $\forall$ k', that maximize the signal-to-interference-plus noise ratio (SINR) at the detector n' of user k', are investigated. A further development of Eq.(6) allows to write the decision variable as:

$$Z^{k',n'} = D^{k',n'} + \alpha^{k',n'} + \beta^{k',n'} + \eta^{k',n'} \quad (7)$$

The pair of transmit and receive transversal filters are chosen such that the SINR for each user at each subcarrier is maximized. Since the self-interference component is weighted by the channel attenuation $\exp\left\{-j2\pi\left(f_c + \frac{n'-1}{T_b}\right)lT_c\right\}$ and is further mitigated in the despreading process, its contribution will be ignored in this analysis. It follows that the received SINR at the n'^{th} detector of the k'^{th} user can be written as

$$SINR^{k',n'} = \frac{E\left(D^{k',n'}\right)^2}{\mathrm{var}\left(\beta^{k',n'}\right) + N_o T_b / 2} \quad (8)$$

As Eq. 8 is function of all user-transmit vectors, the optimal solution can not be derived. To simplify the analysis, the receive filter is constrained to be $U^{k',n'}=1$ and the optimal transmit weight vector maximizing (8) is accordingly found to be

$$\left(V^{k',n'}\right)_{opt} = \arg\max\left(P_i H^{(k',n')} V^{k',n'}\right)^2 \qquad k = 1 \ldots K,\ n = 1 \ldots N \quad (9)$$

Finally, the despreading process is applied by multiplying each n'^{th} detector output of the k'^{th} user by the corresponding chip and summing over the length N of the code, such that the resultant signal for the k'^{th} user at the i^{th} bit can be formulated as

$$X^{k'}(i) = \sum_{n'=1}^{N} Z^{k',n'} c^{k'}(n') \quad (10)$$

Simulation results

To investigate the bit error rate (BER) performance of the proposed scheme, the number of multipath is fixed to two, the transmit power of all users is kept the same and a 2-tap transmit filter is also used. In addition, a BPSK modulation is used, 100 data packet are sent, and each packet contains 1000 data symbols, the number of users is 10, and random sequences are used for the code generation. To support the scheme presented in Fig. 1, a processing gain of 8 and 16 are used for a 8-subcarrier case, and 16-subcarrier case, respectively.

The BER performance enhancement with the increase of the number of subcarriers is investigated in Fig. 2. From these results, it is observed that adding more subcarriers ensures power saving as for a target BER less SNR value is required. In addition, for a given number of subcarriers, the increase of transmit diversity order results in a BER performance improvement. It follows that the multicarrier design necessitates less transmit antennas to achieve a given BER performance compared to the single carrier scheme.

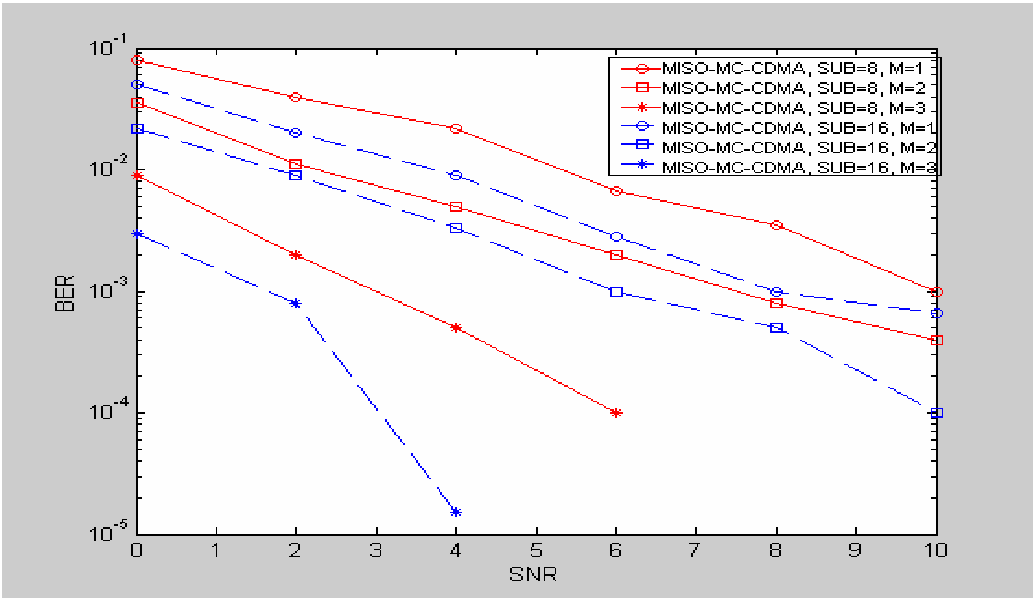

Fig. 2 Performance of the proposed transmit antenna array with multicarrier and pre-RAKE processings.

Conclusion

In this paper, the performance of a multiple-antenna transmit diversity system at the frequency selective downlink channels incorporating MC-CDMA modulation has been studied. The proposed system provides significant improvements with increase of the number of transmit antennas and subcarriers components. Thus, a notable hardware complexity reduction is achieved with the multicarrier architecture compared with the single carrier one.

References:

[1]L. Hanzo and al. , ``OFDM and MC-CDMA for Broadcasting Multi-User Communications, WLANS and Broadcasting", Wiley, 2003.

[2]R. L. Choi, K. Benletaif, and R. Murch, ``MISO CDMA transmission with simplified receiver for wireless communication handsets," in IEEE Trans. Communications, pp. 888-898. 2001.

[3]Y. Li, J. C. Chuang, and N. R. Sollenberger, ``Transmit diversity for OFDM systems and its impact on high data rate wireless networks," IEEE Journal on Selected Area Com. JSAC, vol. 17, no. 7, pp. 1233-1243, Jul. 1999.