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Investigating the Impact of Hybrid/SPREAD MIMO-OFDM System for Spectral-Efficient Wireless Networks

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Abstract: This research proposes a novel signal scheme called Hybrid spread MIMO-OFDM system which interface OFDM with CDMA and integrate this CDMA-OFDM to MIMO to generate a system functionally superior to MIMO-OFDM systems are considered as candidates for future broadband wireless service. OFDM may be combined with antenna arrays at the transmitter and receiver to increase the diversity gain and/or to enhance the system capacity on time-variant and frequency-selective channels, resulting in a Multiple-Input Multiple-Output (MIMO) configuration. The multiplexing technique proposed here is the Code Division Multiple Accesses (CDMA) scheme which is considered the solution for eliminating the distortion caused by fast fading and provides the inherent advantage of DS-CDMA systems incorporating a spreading signal based on PN code sequence, by providing user discrimination based on coding at the same carrier frequency and simultaneously. The OFDM component provides resistance to multipath effects making it unnecessary to use RAKE receivers for CDMA and thus avoid hardware complexity. In order to compare their performances, the effects of multipath signal propagation on the capacity, under both single and multi user channel, are examined. The Inter Symbol Interference (ISI) is used as a suitable measure of multipath effect. The obtained results show that the multipath has more influence on the capacity of MIMO than MIMO-OFDM and spread MIMO-OFDM. In addition, spread MIMO-OFDM offers more average capacity than MIMO under both single and multi user channel. In comparison with MIMO-OFDM, the capacity of spread MIMO-OFDM is higher under the condition of the multi user channel scenario. MIMO-OFDM spread system is being implemented using AWG and VSA. Thus making it possible to implement 4G using hardware and MATLAB/SIMULINK.

Key words: AWG, CDMA, MIMO, OFDM, RAKE, VSA

INTRODUCTION

Multicarrier systems have gained an increased interest during the last years. This has been fuelled by a large demand on frequency allocation resulting in a crowded spectrum as well as a large number of users requiring simultaneous access. The quest received a fillip with the onset of CDMA systems. CDMA systems, however, suffer from the “near-far” effect in the uplink (Prasad, 1996). This gave rise to OFDM systems. In such systems very high data rates are converted to very low parallel data rates using a series-to-parallel converter. This ensures flat fading for all the subcarriers i.e., a wideband signal becomes a packet of narrowband signals. This will automatically combat multipath effects removing the need for equalisers and RAKE receivers. Adding to this MIMO has recently been shown to provide the most effective way to increase transmission rate through the wireless fading channel. Investigation (Prasad, 1996) on the capacity of MIMO channels observed that the frequency selectivity of the channel increases the capacity. Furthermore, in case of Orthogonal Frequency Division Multiplexing (OFDM)-based MIMO systems, delay spread boosts both the mean capacity and the outage capacity of multi-antenna systems (Telatar, 1995). In order to obtain appropriate performance of MIMO systems under multiple user scenarios various multiplexing schemes have been proposed. These include MIMO with code division multiple access (MIMO-CDMA), MIMO with orthogonal frequency division multiplexing (MIMO-OFDM) and MIMO with OFDM and CDMA (spread MIMO-OFDM or MIMO MC-CDMA). Irrespective of the choice, similarly to many other wireless communication systems, MIMO systems suffer from multipath signal propagation (Foschini, 1996; Goldsmith *et al.*, 2003). The adverse effect of multipath signal propagation manifests itself through IS1 (Inter-Symbol Interference), which in turn affects the system capacity, as governed by the Shannon capacity theory (Telatar, 1995; Foschini and Gans, 1998;

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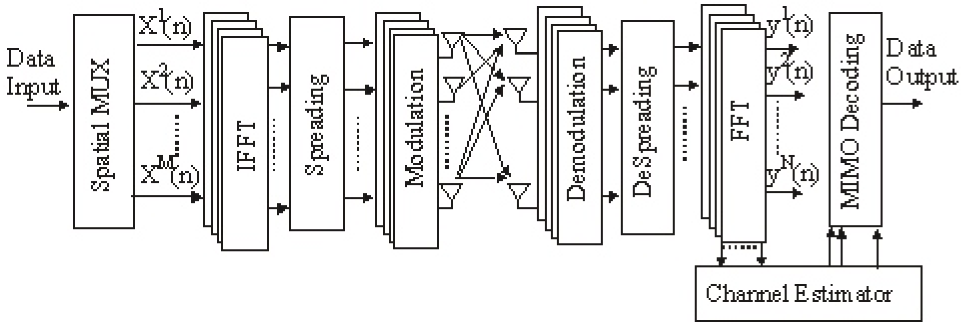

Fig. 1: Block diagram of Hybrid/ CDMA-OFDM-MIMO system

Shin and Lee, 2003; Kassouf and Leib, 2003). In this research, we investigate the effect of multipath on the conventional MIMO, MIMO-OFDM and spread MIMO-OFDM and make suitable comparisons. This study is organized as follows. Further system models for a single and multi user channel are introduced. The capacity for these channel models are derived with proper discussion of results.

MATERIALS AND METHODS

System model: Recently the basic structure of spread MIMO-OFDM is fabricated at CEMK, W.B and SMIT, Sikkim with M antennas are located at a transmitter and N antennas are located at a receiver. The total system architecture is shown in Fig. 1. At transmitter, the bit streams for each of M antennas are coded separately and then mapped to their corresponding symbols. These symbols are next grouped into N_F symbols with a serial to parallel (SP) converter and spread with a size N_c Walsh spreading codes, where $N_F>N_c$. Next, N_F point IFFT is performed and time domain symbols are parallel to serial (PS) converted and transmitted.

CDMA-OFDM-MIMO:

$$\widetilde{Y} = \widetilde{H}_k' \widetilde{x}_k + \widetilde{n}_k' \qquad (1)$$

Where;

$$\widetilde{H}_k' = \widetilde{A}_1 \widetilde{E}_2 \widetilde{H}_k \widetilde{E}_1 \widetilde{A}_k \text{ and } \widetilde{n}_k' = \widetilde{A}_1 \widetilde{E}_2 \widetilde{n}_k \qquad (2)$$

$$\widetilde{Y} = \left[Y(1), Y(2), \ldots, Y(N_F)\right]^T \text{ and}$$

$$Y(t) = \left[Y_1(t), Y_2(t), \ldots, Y_N(t)\right]^T \qquad (3)$$

are the output signals.

$$\widetilde{x} = \left[x(1), x(2), \ldots, x(N_F)\right]^T \text{ and}$$

$$x(t) = \left[x_1(t), x_2(t), \ldots, x_M(t)\right]^T \qquad (4)$$

are the input signals.

$$\widetilde{A}_k = diag\left[A_k(1), A_k(2), \ldots, A_k(N_F)\right] \otimes I_M$$

is Walse code matrix for user k spreading at transmitter and $\widetilde{A}_1 = diag\left[A_1(1), A_1(2), \ldots, A_1(N_F)\right]^+ \otimes I_M$ for user l dispreading by matched filter bank at receiver. IFFT transformation matrix is

$$\widetilde{E}_1 = \left[e_{i,j}\right] \otimes I_M; e_{i,j} = e^{j2\pi ij/N_F}$$

i, j = 0,1,2 ,..., N_F - 1

and FET transformation matrix

$$\widetilde{E}_2 = \left[e_{i,j}\right] \otimes I_N; \quad e_{i,j} = e^{-j2\pi ij/N_F}$$

i, j = 0,1,2 ,..., N_F - 1 (5)

I_M is a M×M identity matrix and I_N is a N×N identity matrix, ^{T} denotes transpose of matrix, $^+$ denotes conjugate and transpose of matrix and $\otimes$ denotes Kronecker product of matrix. The characteristic of multipath fading channel, which produces ISI, depends on delay spread. We can determine a channel matrix with IS1 by changing delay spread into a number of symbols interfered by fading channel. L is defined as the maximum number of interfered symbols corresponding with maximum delay spread. Thus, the channel matrix of user k, $\widetilde{H}_k$ is written as

$$\widetilde{H}_k = \begin{bmatrix} H_k^l & 0 & \cdots & 0 \\ \vdots & H_k^l & \cdots & 0 \\ H_k^L & \vdots & \ddots & 0 \\ 0 & H_k^L & \ddots & H_k^l \\ 0 & 0 & \ddots & \vdots \\ 0 & 0 & \cdots & H_k^L \end{bmatrix} \qquad (6)$$

Where $H_k = [h_{i,j}]$; i = 1,2, ...,N and j = 1,2 ,...,M; is Independent Identical Distributed (i.i.d.) complex Gaussian random variable. ρ is an average Signal to Noise Ratio (SNR) at each receive antenna. Analogous to Eq. (1), conventional MIMO and MIMO-OFDM channels are described by the following relationships:

$$MIMO: \tilde{Y} = \tilde{H}_k \tilde{X}_k + \tilde{n}_k \quad (7)$$

$$MIMO-OFDM: \tilde{Y} = \tilde{H}''_k \tilde{X}_k + \tilde{n}''_k \quad (8)$$

Capacity: The ergodic capacity of the random MIMO channel, which is the Shannon capacity obtained by assuming that it is possible to code over many independent channel realizations, is evaluated by averaging with respect to the random matrix channel (Telatar, 1995; Foschini and Gans, 1998; Shin and Lee, 2003). By using formulas (1) and (6-8), the average capacity of the considered systems, both under single user and multi user condition, are expressed as

Single user channel:

$$C_{MIMO} = E\left[\log_2 \det\left(I_M + \frac{\rho}{M}\tilde{H}_i\tilde{H}_i^{+}\right)\right] bits/s/Hz \quad (9)$$

$$C_{CDMA-OFDM-MIMO} = E\left[\log_2 \det\left(I_M + \frac{\rho}{M}\tilde{H}'_K\tilde{H}'^{+}_K\right)\right] bits/s/Hz \quad (10)$$

$$C_{MIMO-OFDM} = E\left[\log_2 \det\left(I_M + \frac{\rho}{M}\tilde{H}''_K\tilde{H}''^{+}_K\right)\right] bits/s/Hz \quad (11)$$

Where E[ ] denotes expectation, m is min(N,M) and ρ is an average Signal to Noise Ration (SNR) at each receive antenna .We can simplify Eq. (9-11) by using the property of Wishart distribution (Conradsen *et al.*,2001; Scaglione, 2002) and orthogonal frequency coding. By introducing $\rho\lambda\left(\lambda_{m,M}\right)$ as a distribution of a randomly selected Eigen value of the wishart matrix with dimension m×m and degree of freedom M, the new expression is presented as

$$C_{MIMO} = \frac{m}{L}\int_0^{\infty} \log_2\left(1+\frac{\rho\lambda_{m,mL}}{M}\right) P_\lambda\left(\lambda_{m,mL}\right) d\lambda \quad (12)$$

$$C_{MIMO-OFDM} = m\int_0^{\infty} \log_2\left(1+\frac{\rho\lambda_{m,M}}{M}\right) P_\lambda\left(\lambda_{m,M}\right) d\lambda \quad (13)$$

$$C_{CDMA-MIMO-OFDM} = m\int_0^{\infty} \log_2\left(1+\frac{\rho\lambda_{m,M}}{M}\right) P_\lambda\left(\lambda_{m,M}\right) d\lambda \quad (14)$$

Multiuser channel:

$$C_{MIMO} = U\left\{\left(R_1,\ldots,R_k\right): \sum_{i\in s} R_i \le E \left[\log_2 \det\left(I_m + \sum_{i\in s}\frac{\rho}{M}\tilde{H}_i\tilde{H}_i^{+}\right)\right]\right\} \quad (15)$$

$$C_{MIMO-OFDM} = U\left\{\left(R_1,\ldots,R_k\right): \sum_{i\in s} R_i \le E \left[\log_2 \det\left(I_m + \sum_{i\in s}\frac{\rho}{M}\tilde{H}''_k\tilde{H}''^{+}_k\right)\right]\right\} \quad (16)$$

$$C_{CDMA-MIMO-OFDM} = U\left\{\left(R_1,\ldots,R_k\right): \sum_{i\in s} R_i \le E \left[\log_2 \det\left(I_m + \sum_{i\in s}\frac{\rho}{M}\tilde{H}'_k\tilde{H}'^{+}_k\right)\right]\right\} \quad (17)$$

Where K is the number of users, $\forall s \subseteq \{1,2,\ldots,k\}$. We assume that the receiver knows the realization of every user matrix channel. Also we assume that all the transmitting devices generate equal power and use the same number of antennas.

RESULTS AND DISCUSSION

Single user channel: In Fig. 2, the relationship between the ergodic capacity and the number of receive antennas is examined by assuming conventional MIMO without ISI, conventional MIMO with ISI, MIMO-OFDM and spread MIMO-OFDM. The results show that MIMO

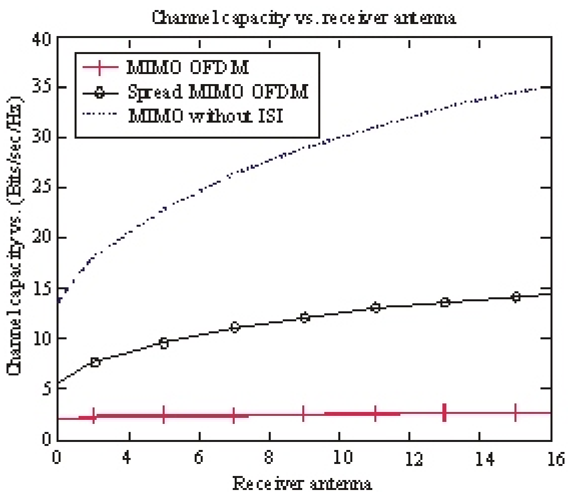

Fig. 2: Channel capacity versus number of receive antennas at M = 2, SNR = 15 dB, L = 5

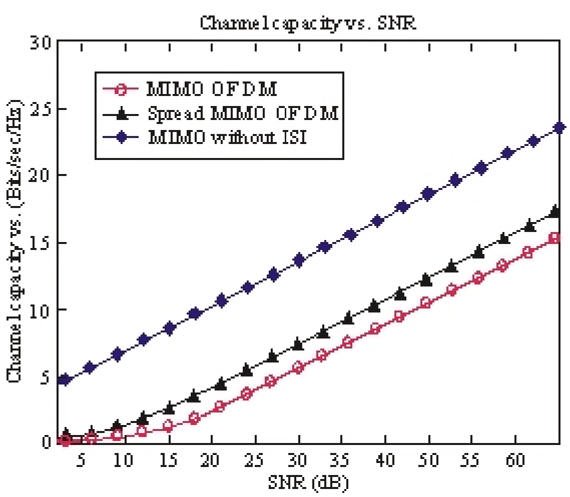

Fig. 3: Channel capacity verses signal to noise ratio at M = N = 10, L = 5

without IS1 gains the highest capacity in comparison with the other schemes. Due to neglecting the effect of signal fading, this model does not describe a practical situation. However, it offers a valuable result, which is the upper bound of capacity limit. The obtained results demonstrate that spread MIMO-OFDM gives more capacity than MIMO with 1%. By using a larger number of receive antennas the capacity of MIMO system is increased.

In Fig. 3, the impact of SNR on capacity of MIMO system is presented. At low levels of SNR, the capacity of spread MIMO-OFDM and MIMO with ISI provide almost the same performance. The capacity of spread MIMO-OFDM increases at a faster pace than MIMO with ISI when the level of SNR is higher. The results reveal that only MIMO with IS1 is affected by delay spread. Its capacity is decreased when the number of interfered symbols is increased. In all the considered cases, the presented results for a single user channel, as given in Fig. 2-3, do not reveal any significant differences between MIMO-OFDM and spread MIMO-OFDM. Therefore, it looks that MIMOOFDM and spread MIMO-OFDM are similarly impacted by multipath signals.

Multi user channel: In multiuser channel the number of users and average capacity is presented, assuming that every user has the same data rate. The obtained results indicate that spread MIMO-OFDM offers more capacity than MIMO with IS1 and MIMO-OFDM. Spread MIMO-OFDM shows the same trend as MIMO-OFDM under single channel. However for a multi user channel, spread MIMO-OFDM provides more capacity than the other schemes.

Implementation: Proposed 4G-communication system is well implemented in our laboratory using AWG hardware, this hardware is programmable from Work Station (WS) using MATLAB/SIMULINK (Fig. 4a, b, c, d).

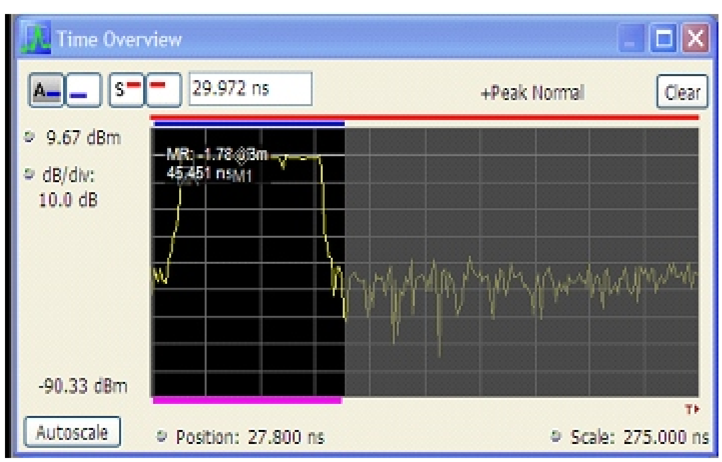

Fig. 4a: Pulsed RF power vs. time plot [duty cycle =6%.]

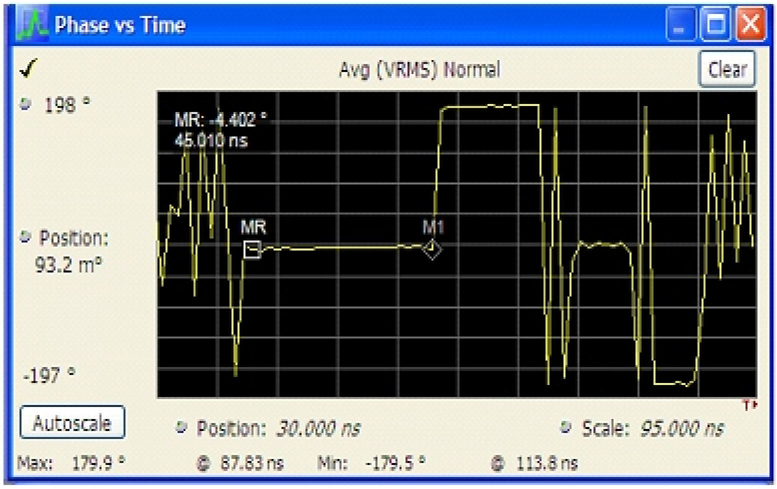

Fig. 4b: Carrier phase vs. time, modulated with 7-bit barker code

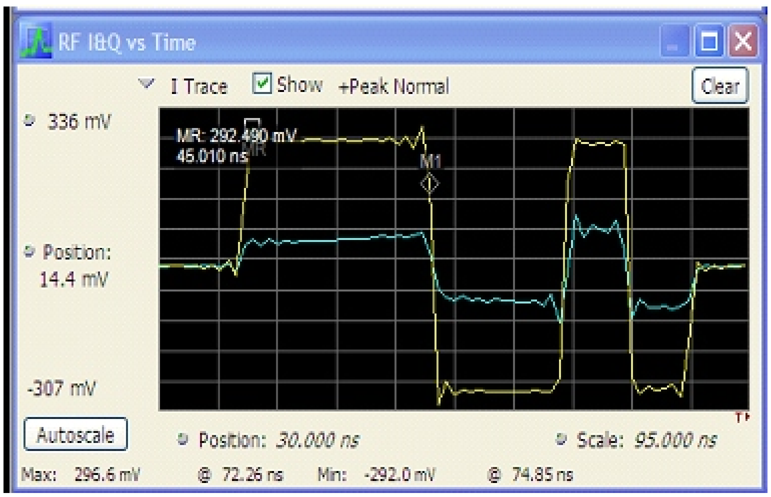

Fig. 4c: Received I-Q amplitude vs. time plot

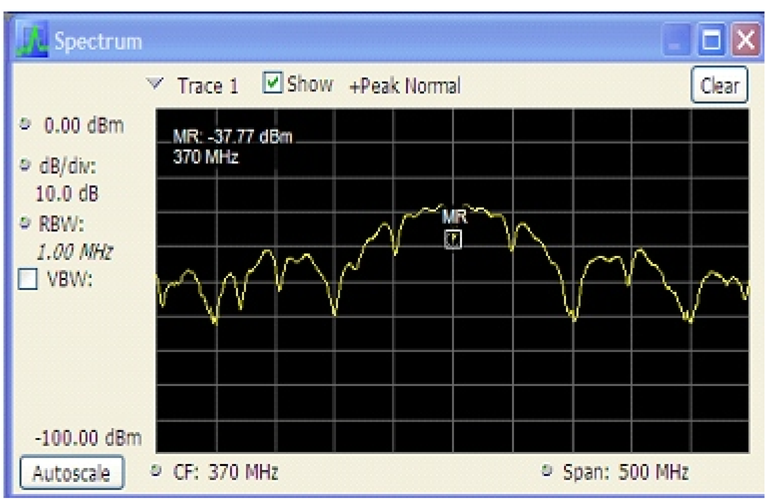

Fig. 4d: Received spectrum vs. frequency plot, [BW = 100 MHz]

Thus making it possible for users to design, simulate and implementation of 4G_MMS transmitter as per the required needs. Similarly VSA hardware is fully programmable (Jeffrey, 2006) using MATLAB/ SIMULINK. This gives us a system where DSP related functions can be well user defined and 4G_MMS becomes flexible at the receiver also. The VSA source API is available with MATLAB and online data is available to the WS from VSA.AWG 5014B is a versatile wave form generator fully programmable via its own embedded RF EXPRESS software or user programmable from PC through MATLAB/SIMULINK. This is being implemented as programmable 4G transmitter. The Simulink *.mdl file is first converted to *.mat and subsequently to *.txt file which is then ported to AWG for the realization of the 4G MMC transmitter. In same way, Agilent VSA is a versatile signal analyzer of a new kind of instruments fully programmable via its own embedded Agilent 89600 VSA software or user programmable from PC through MATLAB/SIMULINK. Over all AWG and VSA simultaneously will enhance the performance of 4G-communication system. Fig. 4(a, b, c, d) shows Barker Coded 4G transmitter using AWG 5014B at 370 MHz RF carrier with a bandwidth of 100 MHz.

CONCLUSION

In this study, the capacity performance comparisons between MIMO, MIMO-OFDM and spread MIMO-OFDM have been investigated under the effects of multipath signal propagation. Both single and multi user channel with ISI have been considered. The obtained results have shown that spread MIMO-OFDM is advantageous over the alternative schemes especially in a multi user channel scenario. The obtained results revealed that the capacity of spread MIMO-OFDM does not depend on the number of users or interfering symbols. The overall results indicate that spread MIMO-OFDM should be the best solution for multiple users' broadband wireless services in a multipath propagation environment.4G communication system is further being implemented using AWG and VSA. Hardware was programmed from Work Station using MATLAB/SIMULINK.

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