BLAST/MIMO PERFORMANCE WITH SPACE-TIME PROCESSING RECEIVERS

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Abstract - The use of antenna arrays at both ends of the link has attracted significant attention of the researches on space-time equalization and coding techniques for so called multiple-input-multiple-output (MIMO) channels. The presence of strong co-channel interference (CCI) in addition to inter-symbol interference (ISI) in current wireless (mobile) communication systems places a significant challenge to MIMO space-time equalizers. In this work we assess performance of BLAST/MIMO on frequency-selective MIMO channel model in the presence of CCI. Space-time processing is used in order to deal with the frequency selectivity and to provide more degrees of freedom to deal with co-channel interference. We consider two non-linear space-time processing-based receivers. The first one is a MIMO space-time decision feedback equalizer (MIMO ST-DFE) and the second one is a space-time delayed decision feedback sequence estimator (MIMO ST-DDFSE) with actual adaptive algorithms for channel acquisition. Noise-limited as well as interference-limited situations are evaluated

Keywords - BLAST, space-time processing, MIMO, equalization, frequency selectivity and co-channel interference

I. INTRODUCTION

Recently, very high spectral efficiencies and unprecedented data rates achieved on a wireless environment have been demonstrated to be practical when both the transmitter and receiver employ multiple antennas [1-5]. With rich multipath propagation and appropriate signal processing at the receiver side, these sub-streams can be separated so that the wireless channel can be viewed at the receiver as virtual parallel independent space-time channels.

As in the BLAST architecture, the use of antenna arrays at both ends of the link has attracted significant attention of the researches on space-time equalization and coding techniques for so called multiple-input-multiple-output (MIMO) channels. The presence of strong co-channel interference (CCI) in addition to inter-symbol interference (ISI) in current wireless (mobile) communication systems places a significant challenge to MIMO space-time equalizers. Most of works concerning the performance of BLAST/MIMO system assume the availability of perfect channel state information at the receiver or at both transmitter and receiver. Moreover, usually, the MIMO channel is modeled as a matrix of independent complex Gaussian gains underlying the assumption of flat (narrowband) fading and a high degree of spatial diversity available on the propagation environment. Recently, the performances of different receiver structures on BLAST/MIMO systems on frequency selective wireless channels have been evaluated by several authors [6, 7]. However, all these works have not considered the presence of co-channel interference, which may not be realistic in mobile communication systems.

In this work we assess performance of BLAST/MIMO on frequency-selective MIMO channel model in the presence of CCI. Space-time processing is used in order to deal with the frequency selectivity and to provide more degrees of freedom to deal with co-channel interference. We consider two non-linear space-time processing-based receivers. The first one is a MIMO space-time decision feedback equalizer (MIMO ST-DFE) and the second one is a space-time delayed decision feedback sequence estimator [8] (MIMO ST-DDFSE) where actual adaptive algorithms are used for channel acquisition. Noise-limited as well as interference-limited situations are evaluated.

This paper also discusses the range of achievable data rates under the physical layer framework of the EDGE (Enhanced Data Rates for Global Evolution) 3rd generation air interface when employing such techniques. BLAST/MIMO architectures can be viewed as an option for future upgrades of existing and proposed 2.5G and 3G air interfaces in the pursuit of higher data rates.

The focus of the paper is on relatively low complexity space-time detection structures. Essentially only linear space-time processing is employed but separate temporal processing is allowed to employ non-linear techniques such as decision-feedback and maximum likelihood sequence detection. While optimum MIMO detection is based on vector-Viterbi structures, their complexity is prohibitive for the type of modulation and channel dispersion typical in currently existing and proposed wireless systems.

This paper is organized as follows. Channel and system-model is established on Section II. The MIMO ST-DFE and MIMO ST-DDFE receiver structures for data detection are illustrated in section III. Section IV discusses the application of BLAST/MIMO architectures on the context of EDGE/EGPRS system. Section V presents the simulation results and finally section VI presents the conclusions of this work along with future perspectives.

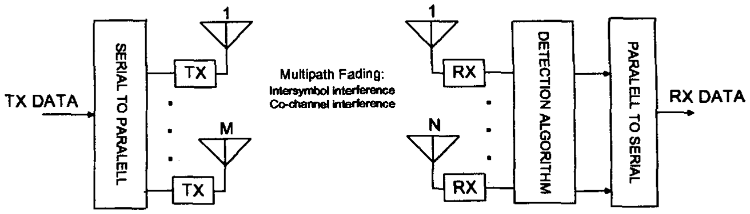

Fig. 1. Multiple Transmit-Receive Antenna Communications Architecture.

II. CHANNEL AND SYSTEM MODELS

A high-level system block diagram is shown in Fig. 1 in its equivalent baseband model, concerning a single-user link. All transmitters (1 to M) operate co-channel at the same symbol rate with synchronized symbol timing. The transmission procedure is simple: transmission data is split into M sub-streams and independently transmitted by transmit antennas 1 to M. The total transmitted power is fixed and normalized to 1. For simplicity we assume all transmitters operating with the same 8-PSK modulation.

In the receiver side, an antenna array of $N \geq M$ antennas is connected to a bank of M space-time equalizers, for the recovery of each data sub-stream. After detection, the data sub-streams are re-ordered and converted to the serial unique stream that constitutes the estimated transmitted data. We assume symbol-rate sampling and perfect synchronization among all receivers. Furthermore, the fading in the channel is assumed to be quasi-static over every sub-stream of data and it is independent between the transmission of each set of sub-streams. We can represent the discrete-time channel impulse response from the transmit antenna m to the receiving antenna n as follows:

$$\mathbf{h}_{nm} = [h_{nm}(0)\ h_{nm}(1)\ \ldots\ h_{nm}(L)]^T \tag{1}$$

where $L+1$ is the number of taps in the channel impulse response. The channel "seen" by the N-element antenna array from the transmit antenna m is obtained by arranging into an channel matrix , so that the received signal vector is expressed as:

$$\mathbf{x}(k) = \sum_{m=1}^{M} \mathbf{H}_m \mathbf{a}_m(k) + \mathbf{v}(k) \tag{2}$$

where $\mathbf{a}_m(k) = [\mathbf{a}_m(k)\ \mathbf{a}_m(k-1)\ \ldots\ \mathbf{a}_m(k-L)]$ is an $L+1$ vector representing the symbol sequence transmitted by the mth antenna. The power of each transmitted sub-stream is equal to $\frac{P}{M}$, where P is the total average transmitted power. Finally, the vector denotes the temporally and spatially additive white Gaussian noise (AWGN). Considering pure spatial processing at the receiver, the output signal is denoted by $\mathbf{y}_m(k) = \mathbf{w}_m \mathbf{x}(k)$, where $\mathbf{w}_m = [\mathbf{w}_{m1}\ \mathbf{w}_{m2}\ \ldots\ \mathbf{w}_{mN}]$ is the array weight vector for the mth transmit antenna.

III. SPACE-TIME RECEIVERS

A. MIMO ST-DFE

The MIMO space-time decision feedback equalizer, called here MIMO ST-DFE, is shown in Fig. 2 [9, 6]. It consists of a bank of M linear space-time feedfoward filters of N branches and $F+1$ taps per branch, followed by M multiple-input-single-output (MISO) feedback filters of B taps. The MIMO ST-DFE may be considered as an extension of the narrowband V-BLAST concept [2] to the case of frequency selective channels if the ordered successive interference cancelling technique is employed. However, we work here with a simplified approach, a "parallel" detection, so that all the M sub-streams are detected simultaneously. The parallel detection is a simplified approach where no mechanism of detection ordering is applied. This approach is therefore less complex and induces no detection delay when compared to the successive technique. All the sub-streams $\hat{a}_m(k-d)$ are detected simultaneously, where d is the training delay. The comparison of the performance of an ordered detection MIMO space-time equalizer with the current approach are left to a future work.

B. MIMO ST-DDFSE

Figure 3 illustrates the employed MIMO ST-DDFSE structure. Ideally in terms of optimum MIMO detection, a vector DDFSE equalizer should be used to perform sequence estimation. A vector DDFSE (V-DDFSE) involves a vector Viterbi algorithm sequence estimator of memory μ and a MIMO feedback scheme of memory $B-\mu$. Note that when $\mu = 0$, a MIMO ST-DDFSE reduces to the MIMO ST-DFE of the last paragraph. On the other hand, if $\mu = B$, it becomes a full state vector Viterbi detector. The complexity of the MIMO ST-DDFSE also grows exponentially with the number of transmit antennas M. Thus, another free parameter to control the complexity of this algorithm, and a consequently compromise between μ and M should be taken into account.

In this work, looking into low complexity schemes, we deal with a simplified approach by employing M parallel and independent ST-DDFSEs . By "independent" we mean that, for each transmitted sub-stream, the maximum likelihood sequence estimation (MLSE) portion of DDFSE does not deal with channel state information associated to other

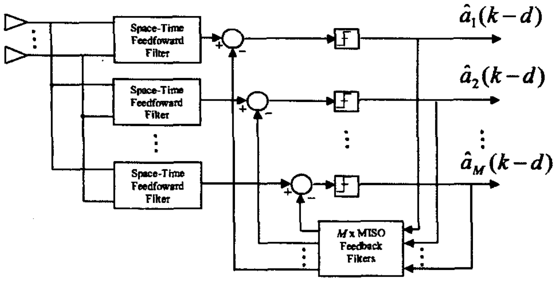

Fig. 2. MIMO ST-DFE structure.

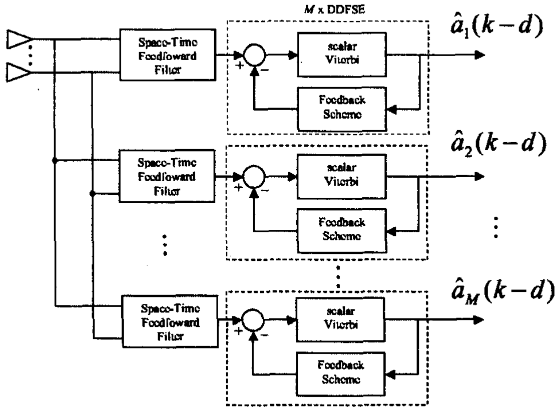

Fig. 3. MIMO ST-DDFSE structure.

sub-streams, resulting in a single-user scalar Viterbi algorithm. Improved performance is expected if we use a vector Viterbi, but complexity would be quite high even for a moderate number of transmit antennas and considering the 8-PSK modulation assumed. Presented originally in [8], the DDFSE strategy has been the focus of several recent studies [10-12] concerning the equalizer design for the EDGE air interface. Due to modulation and symbol-rate employed in EDGE, optimum MLSE temporal equalization becomes impractical and this type of reduced-complexity detection scheme should be considered. The DDFSE is a promising candidate due its good performance-complexity tradeoff.

IV. APPLICATION ON THE EDGE/EGPRS CONTEXT

The physical layer model used for simulations of the next section is inspired on the EDGE (Enhanced Data Rates for Global Evolution) air interface [13, 14]. Except for the pulse shaping, which is assumed here as 35% raised cosine, all other features of the EDGE physical-layer at the time-slot level are assumed (e.g. 8 PSK modulation). A brief discussion on how BLAST/MIMO architectures could be used to improve the performance of the EDGE air interface now takes place.

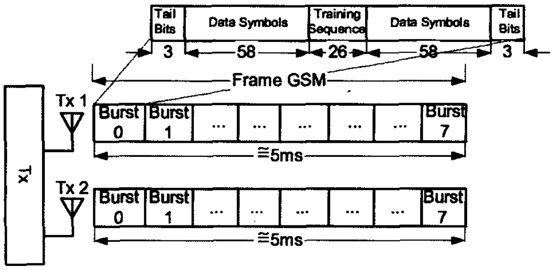

Fig. 4. Possible MIMO system (transmission) architecture for downlink transmission on the EDGE air interface.

The use of BLAST/MIMO architectures could reduce the time of transmission of a radio link control (RLC) block in the physical layer of EDGE. In its traditional form, a RLC block that corresponds to 4 frames, is transmitted in about 20ms, taking into account the idle frames. The use of BLAST/MIMO can reduce this time by a factor of four when four antennas are used in transmission. For example, in MCS-7 a block containing 896 bits is transmitted in four consecutive frames that corresponds to 20ms, so the maximum throughput achieved is 896 bits/20ms = 44.8Kbps. As an example, if a BLAST/MIMO architecture with 4 transmit antennas is used, the same RLC radio block is transmitted now in about 5ms. The throughput is increased by a factor of four respectively, achieving a new throughput of 179.2 Kbps, respectively. The system architecture for two transmit antennas is shown in Fig. 4.

V. SIMULATION RESULTS

Simulations are either noise or interference-limited. Downlink is considered, so that the angle spread is assumed to be 360°. This is reasonable, since local scattering around the mobile station leads to large angle spread values. For the noise-limited case, the bit energy-to-noise spectral density ratio (E_b/N_0) is fixed on the value perceived by most connections in a typical EDGE link-budget [15], e.g. 18 dB. For the interference-limited case, a single co-channel source with a signal-to-interference ratio (SIR) of 10 dB is assumed. Both the desired user and the co-channel interferer channels are frequency-selective, following the typical urban (TU) GSM channel profile [15]. Our benchmark for comparison is the case of flat Rayleigh faded channels with pure spatial processing.

The recursive least squares (RLS) algorithm [16] with a forgetting factor of 0.98 is used for channel estimation and equalizer training. After training, equalizer coefficients are held fixed over one entire burst. There is no channel coding and perfect burst and symbol timing is assumed. Concerning the multiple antenna architecture, we work with $M = 2$

transmit (Tx) antennas, varying the number of receive (Rx) antennas N from 3 up to 6. The space-time feedfoward filters have 2 taps per Rx antenna and we employ 2 feedback taps in both MIMO ST-DFE and MIMO ST-DDFSE. The feedback scheme of MIMO ST-DDFSE are characterized by $\mu = 1$, i.e., the MLSE portion of DDFSE has 8 states. Higher values of would not increase performance significantly, at the cost of a higher complexity [11]. All the above-related parameters are the same for all M.

In Fig. 5 we present the BER as a function of E_b/N_0 on TU profile, in the absence of CCI. Considering the same M and N, the MIMO ST-DFE has the best performance on all antenna configurations. This is reasonable, since MIMO ST-DDFSE ignores the interference between the transmitted sub-streams. Note that the two equalization strategies present similar results if we employ an additional Rx antenna for the MIMO ST-DDFSE case. In terms of receiver complexity, if we used the vector DDFSE the number of states (NS) would increase exponentially with M. As an example, for 8-PSK modulation and working with 2Tx-3Rx configuration, NS $=$ 64 states per Rx antenna, which gives a total of NS $= M$ x $64 = 192$ states. By using the proposed approach (scalar DDFSE) with one additional Rx antenna, NS $=$ 8 states per Rx antenna, resulting in a total of NS $= N$ x $8 = 32$ states. Even with two more receive antennas (2Tx-5Tx configuration), NS $=$ 40 states. In this case the MIMO ST-DDFE outperforms MIMO ST-DFE, as shown in Fig. 5.

Observe that, in the scalar DDFSE approach, the complexity does not depend on the number of Tx antennas, and grows linearly with the number of Rx antennas N. Furthermore, for increased values of M, the MIMO ST-DFE may degrade its performance due to the large number of equalizer coefficients to be adapted, (M times the number of coefficients of MIMO ST-DDFSE). These results justify our preliminary choice of a scalar DDFSE scheme for BLAST/MIMO systems. The performance on flat Rayleigh fading channel (narrowband case) with pure spatial processing is plotted as a benchmark for comparison.

We now consider the presence of CCI. From Fig.6 it can be seen that the MIMO ST-DFE with 2TX-4Rx outperforms the MIMO ST-DDFSE with the same antenna configuration. Comparing Figs. 5 and 6 we verify that, for a target uncoded BER of 10^{-3}, the E_b/N_0 loss of MIMO ST-DFE due to CCI is about 4 dB with 2Tx-5Rx configuration. This loss is almost 13 dB with MIMO ST-DDFSE and the same antenna configuration. Concerning the performance comparisons between the two equalization strategies, the same comments done for Fig. 5 are also valid for Fig. 6.

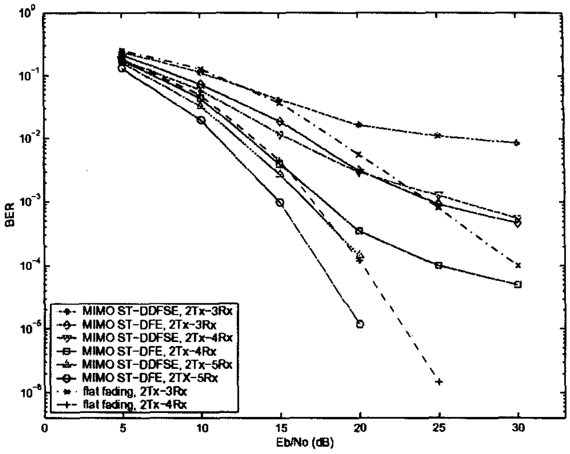

Fig. 5. Performance results of MIMO ST-DFE and MIMO ST-DDFSE on TU profile in the absence of CCI, for different antenna configurations.

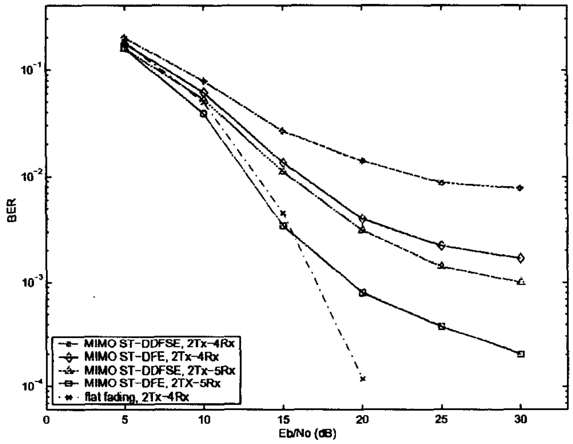

Fig. 6. Performance results of MIMO ST-DFE and MIMO ST-DDFSE on TU profile with CCI, for different antenna configurations. (SIR=10dB, 1 co-channel interferer)

Concerning the noise-limited results, we present in Fig. 7 the bit-error-rate (BER) as a function of the input SIR for a fixed E_b/N_0=18 dB. Observe that the BER decreases almost linearly with E_b/N_0 with an increasing SIR. The MIMO ST-DDFSE tends to exhibit a BER floor for the 2Tx-4Rx configuration. For a target uncoded BER of 10^{-2}, the SIR gain of MIMO ST-DFE compared to MIMO ST-DDFSE is nearly 7 dB for the 2Tx-4Rx and 2Tx-5Rx configurations. We also verify that the MIMO ST-DDFSE with one additional Rx antenna provides SIR gains between 2-4dB compared to MIMO ST-DFE.

VI. CONCLUSION AND PERSPECTIVES

In this work, we have evaluated the performance of BLAST/MIMO systems with space-time processing receivers, on frequency-selective fading channels with co-channel interference. Both interference- and noise-limited

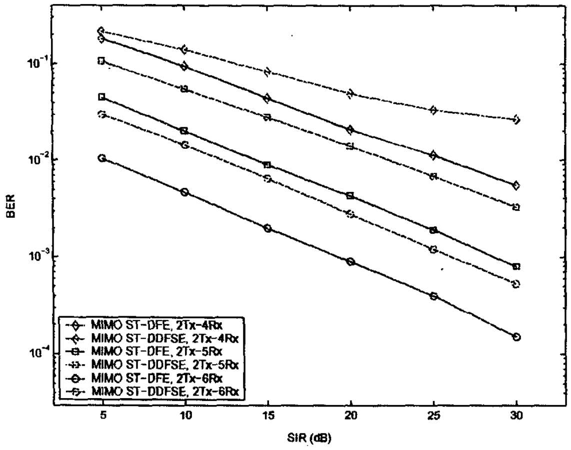

Fig. 7. Performance results of MIMO ST-DFE and MIMO ST-DDFSE for a noise-limited scenario, TU profile, as a function of the input SIR, for different antenna configurations.

cases were considered. For the same number of Rx antennas, the MIMO ST-DFE outperformed the MIMO ST-DDFSE with scalar Viterbi detection, in all antenna configurations. The performance of MIMO ST-DDFSE with one more Rx antenna has showed to be equivalent to that of MIMO ST-DFE. The proposed MIMO ST-DDFSE, with scalar DDFSE detectors, may constitute a reduce-complexity detection scheme for EDGE, if BLAST/MIMO architecture is deployed. On TU profile with CCI, the MIMO ST-DDFSE has presented satisfactory results with low complexity, compared to the vector DDFSE case. The use of this type of multiple antenna technique can potentially provide an M-fold capacity gain in terms of channel bit rate when M transmit antennas are used. This is interesting when viewed in the context of the evolution of currently proposed 3G systems, such as EDGE, in the direction of higher data rates.

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