Turbo Coded MIMO Multiplexing with Iterative Adaptive Soft Parallel Interference Cancellation

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Abstract— **Iterative adaptive soft parallel interference canceller (ASPIC) is proposed for turbo coded multiple-input multiple-output (MIMO) multiplexing. ASPIC is applied to transform a MIMO channel into single-input multiple-output (SIMO) channels for maximum ratio diversity combining (MRC). In the iterative ASPIC, replicas of the interference from different transmit antennas are generated and subtracted from the received signals. The log-likelihood ratio (LLR) sequence obtained as the turbo decoder output is fedback for iterative interference cancellation. At the transmitter, the information bit sequences and parity bit sequences are transmitted from different antennas. The achievable bit error rate (BER) performance of the turbo coded MIMO multiplexing with the proposed iterative ASPIC in a Rayleigh fading channel is evaluated by computer simulation.**

Keywords- ***MIMO multiplexing, Iterative ASPIC, Turbo coding, Log-likelihood ratio***

I. INTRODUCTION

Recently, there have been tremendous demands for high-speed data transmissions in mobile communications [1]. However, the available bandwidth is limited, so higher spectrum efficiency is required. One of the promising techniques is the multiple-input multiple-output (MIMO) system [2], [3] that uses multiple transmit and receive antennas. One such technique to provide high speed data without requiring additional bandwidth is space division multiplexing [4], [5]. In such MIMO multiplexing, transmit data sequence is transformed into parallel sequences and each sequence is transmitted from a different transmit antenna at the same time with the same carrier frequency. Therefore, the total transmission rate increases in proportion to the number of transmit antennas. At the receiver, it is necessary to separate the signals transmitted from different antennas. Various methods for the separation of the transmitted signals are known, e.g., maximum likelihood detection (MLD) [6], minimum mean square error (MMSE) [6], zero forcing (ZF) [6], V-Bell Laboratories layered space-time architecture (V-BLAST) [7] and so on.

In mobile radio communications, channel state is changing every moment. This phenomenon is called multipath fading [6]. In a multipath fading environment, bit error rate (BER) performance degrades drastically. Effective techniques to reduce the adverse effect of fading are antenna diversity combining and channel coding. Recently, turbo coding [8],[9] that has powerful error correcting capability is the center of attention. Therefore, it is desirable to incorporate channel coding and antenna diversity combining into MIMO multiplexing for increasing the transmission data rate while improving the transmission performance. In this paper, an iterative adaptive soft parallel interference canceller (ASPIC) is proposed for turbo coded MIMO multiplexing. At the receiver, for the generation of soft decision values, the MIMO channel is transformed by ASPIC into the single-input multiple-output (SIMO) channels for maximum ratio diversity combining (MRC) [6] to reduce the effect of fading. The log-likelihood ratio (LLR) sequence obtained as turbo decoder output is fedback for iterative interference cancellation. At the transmitter, the information bit sequences and parity bit sequences obtained by turbo coding are transmitted from different antennas. The achievable bit error rate (BER) performance of the turbo coded MIMO multiplexing with the proposed iterative ASPIC in a Rayleigh fading channel is evaluated by computer simulation.

The remainder of this paper is organized as follows. Section 2 describes the turbo coded MIMO multiplexing with the iterative ASPIC. Section 3 presents the computer simulated BER performance of turbo coded MIMO multiplexing with iterative ASPIC in a Rayleigh fading channel. Section 4 concludes the paper.

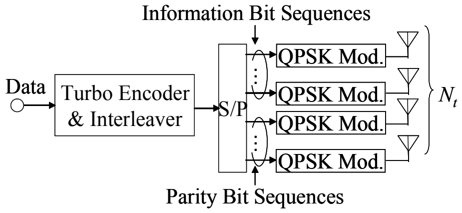
II. MIMO MULTIPLEXING WITH ITERATIVE ASPIC

Figure 1 shows a transmission system model of (N_t, N_r) MIMO multiplexing with iterative ASPIC, where N_t and N_r represent the number of transmit antennas and that of receive antennas, respectively. The binary information bit sequence $\{b_i; i=0\sim(I-1)\}$ of length I (for simplicity we assume that I is an even integer) is turbo coded into the coded sequence $\{x_j; j=0\sim(I/R-1)\}$ by a rate-R turbo encoder. The turbo coded sequence after interleaving is transformed into N_t parallel sequences such that information (systematic) bit sequences and parity bit sequences are transmitted at the same time from different antennas as much as possible. This ensures that the LLR of the information bits at the receiver can be used to increase the reliability of the parity bits transmitted at the same time but from a different antenna. This is further explained in detail here with an R=1/2 turbo code.

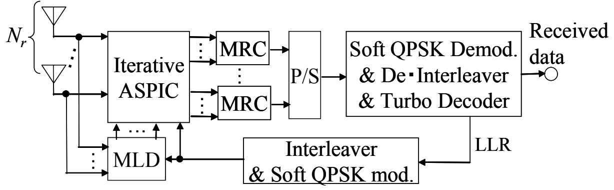
The interleaved turbo coded sequence is divided into $N_t/2$ information (or systematic) bit sequences and $N_t/2$ parity bit sequences by serial-to-parallel (S/P) conversion. Each sequence is transformed into QPSK modulated symbol sequence. The information symbol sequences are transmitted from the 0th~(N_t/2-1)th transmit antennas and the parity symbol sequences are transmitted from the N_t/2th~(N_t-1)th transmit antennas. The symbol transmitted from the nth antenna is denoted as d_n. It is assumed that the signals transmitted from N_t transmit antennas experience independent Rayleigh fading and are received by N_r receive antennas. The signal r_m received by the mth receive antenna can be expressed using the equivalent low-pass representation as

$$r_m = \sqrt{2S}\sum_{n=0}^{N_t-1}\xi_{n\_m} d_n + n_m \quad , \qquad (1)$$

for m=0~N_r-1, where S is the average received signal power on each antenna, ξ_{n_m} is the complex gain of the fading channel between the nth transmit antenna and the mth receive antenna, and n_m is the additive white Gaussian noise (AWGN) process at the mth receive antenna, which has a zero mean and a variance of $2\sigma^2=2N_0/T$ (N_0 is the single sided AWGN power spectrum density and T is the QPSK symbol length). MLD is performed to output the hard decision symbols $\{\hat{d}_n; n=0\sim N_t-1\}$ for the N_t transmitted symbols using the N_r received signals $\{r_m; m=0\sim N_r-1\}$. When turbo coding is used, it is necessary to generate soft values for the input to the turbo decoder. In this paper, the soft values are generated by using the iterative ASPIC and MRC.



(a) Transmitter



(b) Receiver

Figure 1. System model of (N_t, N_r) MIMO multiplexing with iterative ASPIC.

A. ASPIC and MRC

Figure 2 shows the ASPIC and MRC structure that generates the soft decision values. The sum of signals transmitted by N_t antennas is received by each of the N_r receive antennas (see Eq.(1)). In ASPIC, the symbol transmitted by the nth antenna, n=0~N_t-1, is extracted from the received signal for each receive antenna. Thus, a MIMO channel is transformed into N_t SIMO channels. The N_r signals received by each SIMO channel is equivalent to N_r antenna diversity reception with single antenna transmission. The N_r signals received by each SIMO channel are coherently combined using MRC to generate the soft value needed for turbo decoding. The operation principle of ASPIC is described below.

Using the N_t hard decision symbol outputs $\{\hat{d}_n; n=0\sim N_t-1\}$ of MLD, the ASPIC generates the replicas of interference and performs the parallel interference cancellation (PIC). When MLD is incorrect, hard PIC excessively subtracts the interference, so the use of hard PIC increases the interference. Therefore, the adaptive soft cancellation weight based on the decision reliability of MLD is introduced. The output $\hat{r}_{n\_m}$ from ASPIC for the signal transmitted from the nth transmit antenna and received by the mth receive antenna can be expressed as

$$\hat{r}_{n\_m} = \{r_m - \sqrt{2S}\sum_{n=0}^{N_t-1}\hat{\xi}_{n\_m}\tilde{d}_n\} + \sqrt{2S}\hat{\xi}_{n\_m}\tilde{d}_n, \qquad (2)$$

for m=0~N_r-1, where $\hat{\xi}_{n\_m}$ represents the channel gain estimate for ξ_{n_m} and $\tilde{d}_n$ is given by

$$\tilde{d}_n = \lambda_{n\_c}\,\mathrm{Re}[\hat{d}_n] + j\lambda_{n\_s}\,\mathrm{Im}[\hat{d}_n], \qquad (3)$$

where λ_{n_c} and λ_{n_s} are the adaptive soft cancellation weights $(0 \le \lambda_{n\_c}$ and $\lambda_{n\_s} \le 1)$. The use of $\lambda_{n\_c} = \lambda_{n\_s} = 1$ leads to hard PIC. $\hat{r}_{n\_m}$, m=0~ N_r-1, are coherently combined using MRC. The MRC output $\tilde{r}_n$ for the signal transmitted from nth transmit antenna can be expressed as

$$\hat{r}_n = \sum_{m=0}^{N_r-1}\hat{r}_{n\_m}\hat{\xi}^*_{n\_m}, \qquad (4)$$

where * denotes the complex conjugate operation.

After MRC, the MRC outputs are parallel-to-serial (P/S) converted into a serial sequence and soft QPSK demodulation is performed, followed by turbo decoding.

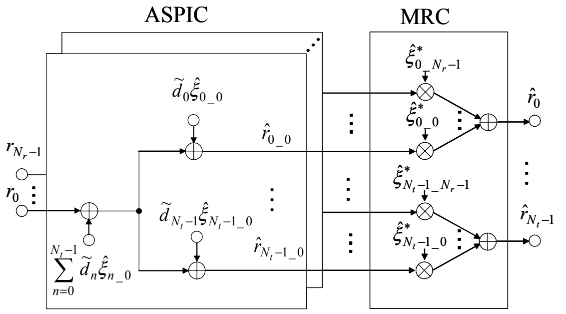


Figure 2. ASPIC and MRC.

B. Adaptive Soft Cancellation Weight

As stated in Sec.2A, when MLD detection is incorrect, the use of hard PIC increases the interference. Hence, adaptive soft cancellation weight is introduced to avoid the increase in the interference.

It is difficult to theoretically find the optimal weight, so we take a heuristic approach based on the decision reliability of MLD. When the decision reliability of MLD is high (otherwise), we use a large (small) cancellation weight. The operation principle is as follows. MLD is carried out to output the hard decision symbol vector $\hat{\mathbf{d}} = [\hat{d}_0, \hat{d}_1, \cdots, \hat{d}_{N_t-1}]$ that minimizes the log likelihood L:

$$L = \sum_{m=0}^{N_r-1} \left| r_m - \sqrt{2S} \sum_{n=0}^{N_t-1} \hat{\xi}_{n\_m} \hat{d}_n \right|^2 . \tag{5}$$

Then, MLD finds two candidate symbol vectors, the most reliable symbol vector that has the lowest log likelihood value and the second most reliable symbol vector that has the second lowest log likelihood value, and they are compared bit-by-bit. We use the following adaptive soft cancellation weight:

$$\lambda_{n\_c}(\lambda_{n\_s}) = \begin{cases} 1 \quad , & \text{if the 1st (2nd) bits} \\ & \text{in the two symbols are the same} \\ 1 - \exp(-\alpha \Delta L) \quad , & \text{otherwise} \end{cases} \tag{6}$$

for QPSK, where ΔL is the difference of log likelihood between the most reliable candidate vector and the second most reliable one, and α is the adaptivity parameter that controls the extent to which ΔL contributes to the cancellation weight.

C. Iterative Process

In an iterative process, the soft decision information symbol sequence is generated from the LLR sequence given by the turbo decoder, and the parity symbols are again detected in MLD using the soft decision information symbols. These information and parity symbol sequences are input into the ASPIC again. The ASPIC transforms the MIMO channel into SIMO channels, and MRC combining is performed again. Below this ith iterative process is explained, i<0.

After the LLR sequence, obtained as the turbo decoder output, is channel-interleaved by an interleaver, the soft decision value $\tilde{d}_n^{(i)}$ of the information symbol sequence transmitted by the nth antenna, n=0~N_t/2-1, is generated as

$$\tilde{d}_n^{(i)} = {}^1\!/\!_{\sqrt{2}} \Omega(\beta \Lambda_{n\_c}^{(i-1)}) + j \, {}^1\!/\!_{\sqrt{2}} \Omega(\beta \Lambda_{n\_s}^{(i-1)}) , \tag{7}$$

where

$$\Omega(x) = [1 - \exp(-x)] / [1 + \exp(-x)] . \tag{8}$$

In Eq.(7), $\Lambda_{n\_c}^{(i-1)}$ and $\Lambda_{n\_s}^{(i-1)}$ are the LLRs of turbo decoder output, obtained after the i-1th iteration of ASPIC, that correspond to the QPSK information symbol (of 2 bits) transmitted by the nth antenna and β is the parameter which is optimized by computer simulation. Then, the N_t/2 parity symbols are separated by performing MLD to obtain the hard decision parity symbols $\{\hat{d}_{n'}^{(i)}; n' = N_t/2 \sim N_t - 1\}$ by using the N_r received signals. The estimated parity symbols obtained after MLD can be expressed as

$$L = \sum_{m=0}^{N_r-1} \left| r_m - \sqrt{2S} \left(\sum_{n=0}^{N_t/2-1} \hat{\xi}_{n\_m} \tilde{d}_n^{(i)} + \sum_{n'=N_t/2}^{N_t-1} \hat{\xi}_{n'\_m} \hat{d}_{n'}^{(i)} \right) \right|^2 , \tag{9}$$

After MLD is performed, the soft decision parity symbols $\tilde{d}_{n'}^{(i)}$, $n' = N_t/2 \sim N_t - 1$, are generated by using LLR of information bit corresponding to that parity bit, as

$$\tilde{d}_{n'}^{(i)} = |\Omega(\beta \Lambda_{n'\_c}^{(i)})| \, \mathrm{Re}[\hat{d}_{n'}^{(i)}] + j \, |\Omega(\beta \Lambda_{n'\_s}^{(i)})| \, \mathrm{Im}[\hat{d}_{n'}^{(i)}] , \tag{10}$$

where $\Lambda_{n'\_c}^{(i)}$ and $\Lambda_{n'\_s}^{(i)}$ are the LLRs of information bits in the QPSK symbol corresponding to the QPSK parity symbol transmitted by n' th transmit antenna.

These soft decision information and parity symbols are again input to the ASPIC which again generates the replicas and cancels the interference. The output $\hat{r}_{n\_m}$ from ASPIC can be expressed as

$$\hat{r}_{n\_m} = \{ r_m - \sqrt{2S} \sum_{n=0}^{N_t-1} \hat{\xi}_{n\_m} \tilde{d}_n^{(i)} \} + \sqrt{2S} \hat{\xi}_{n\_m} \tilde{d}_n^{(i)} , \tag{11}$$

Note that $\tilde{d}_n^{(0)} = \tilde{d}_n$. Then, MRC is performed by using Eq.(4). After MRC, turbo decoding is performed. The repetition of the above process is called iterative ASPIC.

For R>1/2, since the number of parity bits is less than the number of systematic bits, sometimes, only systematic bits will be transmitted from all the antennas. This does not harm the ASPIC performance, as the reliability of all systematic bits can be improved in ASPIC by using LLRs obtained from the turbo decoder. However, for R<1/2, the number of parity bits is more and sometimes only parity bits will be transmitted from all that antennas. For such parity bits, the reliability cannot be improved as turbo decoder output consists of the systematic-bit LLR only.

III. SIMULATION RESULTS

Table 1 shows the simulation condition. The transmission of information bit sequence of length I=996 bits is considered. Figure 3 shows the structure of the turbo encoder. A rate-1/3 turbo encoder consisting of two (7,5) recursive systematic convolutional (RSC) encoders [9] is employed. The input to the second RSC encoder is the interleaved version of the information sequence input to the first RSC encoder. The internal interleaver is an S-random ($S=\sqrt{I}$) interleaver [10]. The two parity bit sequences obtained by the two RSC encoders are punctured to increase the coding rate to R=1/2. The turbo coded sequence length is 2000-bit and a 50×40-bit block channel interleaver is used. MIMO channel is assumed with $N_t \times N_r$ independent frequency-nonselective Rayleigh fading channel, and channel estimation is assumed to be ideal. The maximum Doppler frequency f_D normalized by the coded bit rate $1/T_b$ is assumed to be $f_D T_b$=0.001.

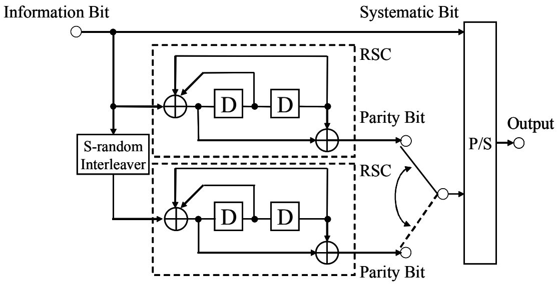


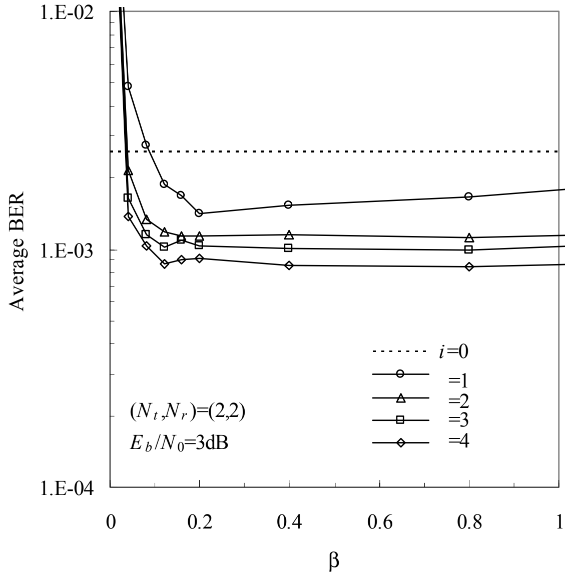
Figure 3. Turbo encoder.

TABLE I. SIMULATION CONDITION

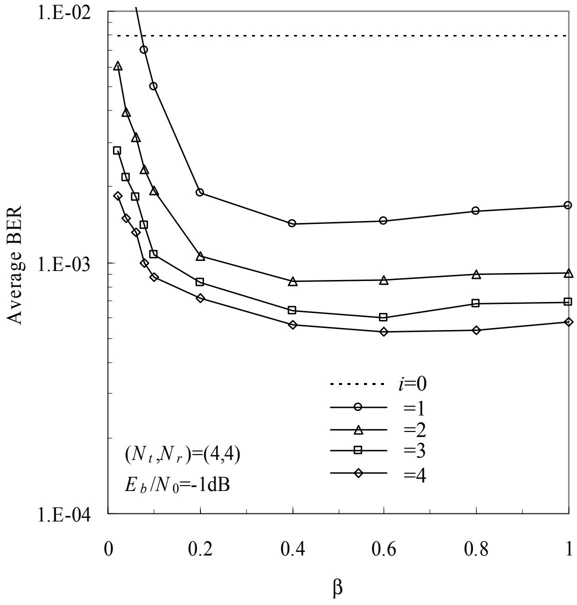
Transmitter	Turbo encoder	(7,5)RSC component encoder
		Rate 1/2
		S-random interleaver
	No. of antennas	N_t=2,4
Receiver	Channel estimation	Ideal
	Turbo decoder	Log-MAP
		9 iterations
	No. of antennas	N_r=2,4

Fig.4 plots the average BER of turbo coded (N_t,N_r)MIMO multiplexing with iterative ASPIC as a function of β. It is assumed that α is optimized in all the simulation results. A broad optimum is seen in β, but the optimum value is seen to be β=0.2 and 0.4, when (N_t,N_r)=(2,2) and (4,4), respectively.

Fig.5 plots the average BER performances of turbo coded (N_t,N_r) MIMO multiplexing with iterative ASPIC as a function of the average received E_b/N_0 per receive antenna. Here, perfect SIMO refers to the condition when PIC is ideal. It can be seen that ASPIC provides better BER performance than hard PIC. As the number of iterations increases, the BER performance improves, but almost no additional improvement is seen after 4 iterations. When (N_t,N_r)=(2,2), the required E_b/N_0 for average BER=10^{-4} can be reduced by about 0.7 dB with 4 iterations from that without iteration, and the degradation from perfect SIMO is as small as 2.6dB. On the other hand, when (N_t,N_r)=(4,4), the required E_b/N_0 for average BER=10^{-4} is about 1.1dB less than that without iteration, and the E_b/N_0 degradation from perfect SIMO can be reduced by about 2.2dB.

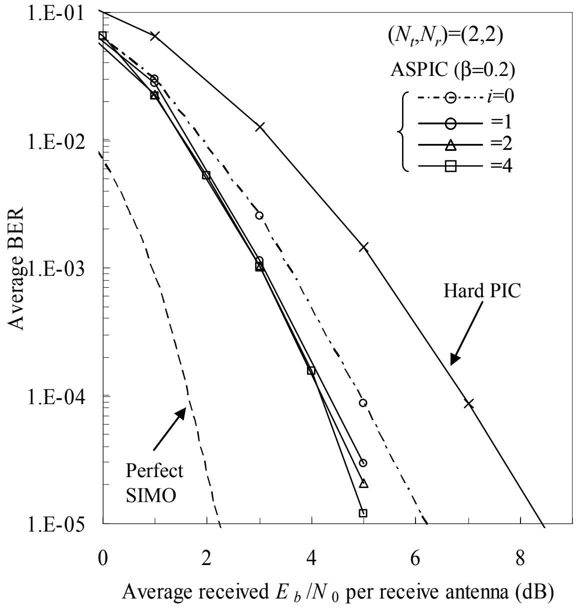


(a) (N_t,N_r)=(2,2)

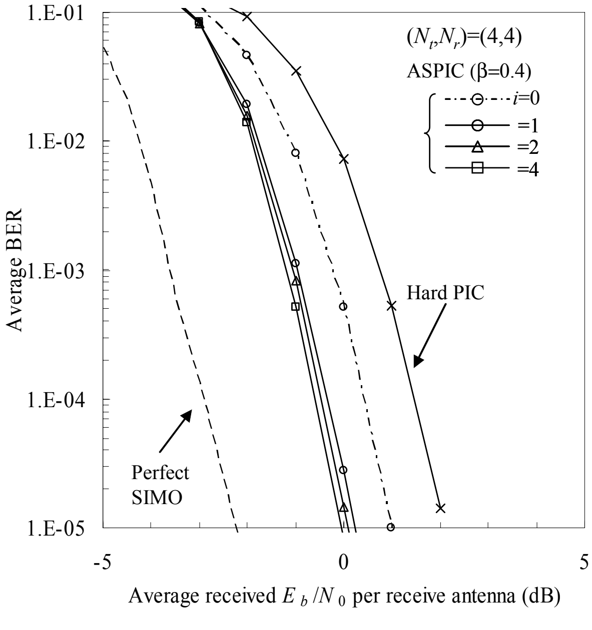


(b) (N_t,N_r)=(4,4)

Figure 4. Impact of adaptivity parameter β on average BER.



(a) (N_t,N_r)=(2,2)



(b) (N_t,N_r)=(4,4)

Figure 5. Average BER performances of turbo coded (N_t,N_r)MIMO multiplexing with iterative ASPIC.

IV. CONCLUSION

In this paper, MIMO multiplexing with iterative ASPIC, which transforms the MIMO channel into SIMO channels for MRC diversity combining, was proposed. The soft decision values needed for turbo decoding is generated by using the ASPIC. The achievable turbo coded BER performance of MIMO multiplexing using iterative ASPIC was evaluated by computer simulation assuming a Rayleigh fading channel. Introduction of ASPIC improves the BER performance significantly. Further performance improvement can be achieved by the use of iterative ASPIC. For (2,2) or (4,4) MIMO multiplexing, the iterative ASPIC can achieve the BER performance close to the perfect SIMO by about 2.6dB or 2.2dB, respectively.

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