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Iterative Soft Multipath Interference Cancellation Assisted by Hybrid ARQ with Constellation rearrangement for HSDPA System

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Abstract— High Speed Downlink Packet Access (HSDPA) is the major evolution of UMTS downlink. It provides peak data rates up to 10.8 Mbps. This is reached by radio link adaptivity, which includes fast scheduling, adaptive modulation and coding (AMC), and hybrid automatic repeat request (HARQ). The performance of AMC suffers from multipath interference introduced by the channel especially when using 16-QAM modulation. This is because of the variation in bit reliabilities caused by the bit-mapping onto the signal constellation. In this paper, we present a soft iterative multipath interference canceller (MPIC) for suppressing the multipath interference. We also propose to use HARQ Chase combining with the constellation rearrangement technique in joint application with MPIC. This can equalize the variation of bit reliabilities by using different mapping rules over HARQ transmissions. It is proven that the performance of adaptive modulation and coding is significantly improved after only two HARQ transmissions.

I. INTRODUCTION

The major evolution of the UMTS standard in recent year is the high speed downlink packet access (HSDPA). It is designed to provide services at high data rates. The use of multicode transmission principle with adaptive modulation and coding (AMC) as well as hybrid automatic repeat request (HARQ) makes it possible to reach peak data rates up to 10.8 Mbps.

In the AMC technique, the base station adapts the modulation and the coding rate to the channel conditions. The coding rates are obtained by the puncturing operation at the output of the turbo code. The modulation is selected between QPSK and 16-QAM. The use of high order modulation (16-QAM) increase significantly the bit-rate. However, this type of modulation is very sensitive to interference. This leads to a severe performance degradation in multipath fading channel due to the multipath interference. As a solution to mitigate the performance degradation when using 16-QAM modulation is the implementation of a multipath interference canceller (MPIC) at the receiver. Through last years, many studies were carried out on the MPIC. In [3], authors proposed a multipath interference canceller (MPIC) which generate the multipath

interference based on hard-decision results at the output of the Rake receiver. Although the interference rejection weight used in [3] reduces the impact of generation error of the MPI replica, the optimum of this replica cannot be generated. A soft MPIC combined with HARQ were proposed in [4]. It was proven that more accurate replica is generated. In this paper, we propose an iterative soft MPIC combined with HARQ Chase combining and constellation rearrangement. In our approach, more reliable packets are delivered to turbo decoder by changing the signal constellation mapping from transmission to transmission and making soft combining after interference cancellation. This decrease significantly the data-decoding error. The paper is organized as follows. In section II, we describe the principle of the iterative soft MPIC. We present the iterative soft MPIC combined with Chase combining and constellation rearrangement in section III. In section IV, we present the simulator configuration. After, simulation results and discussion are given in section V, concluding remarks are made in section VI.

II. ITERATIVE SOFT MULTIPATH INTERFERENCE CANCELLER

A. Principle of iterative soft MPIC

The iterative soft multipath interference canceller used in this work is presented in Fig. 1. The interference is generated using a soft symbol estimation after the SISO demapper.

For multicode DS-CDMA system, the received signal can be written as

$$r(t) = \sum_{l=1}^L g_l(t) \sum_{k=1}^K s_k(t - \tau_l) \cdot c_k(t - \tau_l) + n(t) \quad (1)$$

where g_l and τ_l are the complex channel coefficient and the time delay of l^{th} path, L and K are the number of paths and the number of physical channels respectively, s_k and c_k represent

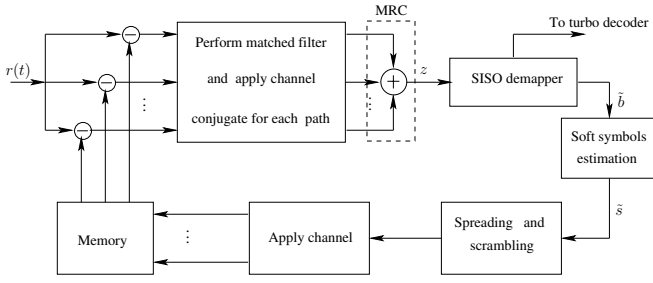


Fig. 1. Iterative soft MPIC structure

the modulated signal and spreading code of the k^{th} physical channel, and $n(t)$ is the complex AWGN noise. In this paper we assumed perfect channel knowledge.

The iterative soft MPIC works in an iterative manner. Its purpose is to eliminate the multipath interference of each Rake finger. For each iteration, the MPIC estimates the multipath interference and subtract it from the received signal at the input of each finger which then performs descrambling, despreading, and apply the channel conjugate. After that, a maximum ratio combining (MRC) is done for all fingers outputs [5], [8]. The combined sequence is then taken by the SISO demapper to estimate the log-likelihood ratios (LLR) of transmitted bits. The demapper output is delivered to a soft symbols estimation function in order to reconstruct the data modulated sequence. This reconstructed sequence is spread, scrambled and processed by a channel emulator which generates all paths interference contributions [6], [7]. This multipath interferences are stored in a memory to be used in succeeding iterations. At p^{th} stage, the Rake combined sequence of the n^{th} symbol of the k^{th} physical channel is written as

$$z_k^{(p)}(n) = \sum_{l=1}^L y_{k,l}^{(p)}(n) \cdot (g_l^*)^{(p)} \quad (2)$$

The estimated multipath interference (MPI) associated with the l^{th} path at p^{th} iteration can be expressed as

$$\hat{I}_l^{(p)}(t - \tau_l) = g_l^{(p-1)}(t) \cdot \sum_{k=1}^K \tilde{s}_k^{(p-1)}(t - \tau_l) \cdot c_k(t - \tau_l) \quad (3)$$

The input signal to the l^{th} finger in the p^{th} ($p \geq 2$) iteration is represented as

$$r_l^{(p)} = r(t) - \sum_{\substack{j=1 \\ j \neq l}}^L \hat{I}_j^{(p-1)}(t - \tau_j) \quad (4)$$

At the final iteration the soft output sequence of the MPIC is delivered to the turbo decoder to recover the transmitted information sequence.

B. Soft symbol estimation

Note $s = [s_1, s_2, \dots, s_M]$ the modulated data sequence formed after the bit to symbol mapping of the data sequence $b = [b_{1,1}, b_{1,2}, \dots, b_{1,m}, \dots, b_{i,1}, b_{i,2}, \dots, b_{i,m}, \dots, b_{M,1}, b_{M,2}, \dots, b_{M,m}]$. M is the number of modulated symbols, and $m = 4$ in case of 16-QAM modulation. The LLR of the i^{th} bit of the n^{th} symbol at p^{th} iteration is expressed as

$$\tilde{b}_k^{(p)}(n, i) = \ln \frac{Pr(b_k(n, i) = +1 | z_k^{(p)}(n))}{Pr(b_k(n, i) = -1 | z_k^{(p)}(n))} \quad (5)$$

Note that the LLR of each bit is updated from iteration to iteration. This helps to generate a more accurate soft MPI replica. At p^{th} iteration and for k^{th} physical channel, the n^{th} estimated soft modulation symbol, $\tilde{s}_k^{(p)}(n)$, is calculated by taking the mathematical expectation of the data symbol, $s_k(n)$, given the output of the SISO demapper. It is written as

$$\begin{aligned} \tilde{s}_k^{(p)}(n) &= E\{s_k(n) | \tilde{b}_k^{(p)}(n, 1), \dots, \tilde{b}_k^{(p)}(n, 4)\} \\ &= \sum_{s_k(n) \in \mathcal{A}} s_k(n) Pr(s_k(n) | \tilde{b}_k^{(p)}(n, 1), \dots, \tilde{b}_k^{(p)}(n, 4)) \end{aligned} \quad (6)$$

where $Pr(\cdot)$ is the probability. The estimated soft symbol, $\tilde{s}_k^{(p)}(n)$ can be rewritten as

$$\tilde{s}_k^{(p)}(n) = \tilde{s}_{k,I}^{(p)}(n) + j \tilde{s}_{k,Q}^{(p)}(n), \quad (7)$$

Where $\tilde{s}_{k,I}^{(p)}(n)$ and $\tilde{s}_{k,Q}^{(p)}(n)$ are the in-phase and quadrature-phase components of $\tilde{s}_k^{(p)}(n)$ which are expressed as

$$\begin{cases} \tilde{s}_{k,I}^{(p)}(n) = \frac{-1}{\sqrt{5}} \left[(\tanh(\tilde{b}_k^{(p)}(n, 1))) (2 + \tanh(\tilde{b}_k^{(p)}(n, 3))) \right] \\ \tilde{s}_{k,Q}^{(p)}(n) = \frac{-1}{\sqrt{5}} \left[(\tanh(\tilde{b}_k^{(p)}(n, 2))) (2 + \tanh(\tilde{b}_k^{(p)}(n, 4))) \right] \end{cases} \quad (8)$$

By substituting $\tilde{s}_k^{(p)}(n)$ into (3), we obtain the soft multipath interference replica.

III. SOFT ITERATIVE MPIC COMBINED WITH HARQ AND CONSTELLATION REARRANGEMENT

A. Soft iterative MPIC with HARQ

The HSDPA introduced the HARQ technique as an other link adaptation in order to enhance the AMC performance. Fig. 2 shows the principle of HARQ with interference cancellation. The received packet is first processed by the iterative soft MPIC for interference cancellation. Then, it is delivered to the turbo decoder. A CRC detector is used for error detection. When the packet is erroneous, it is saved at the receiver and a NACK is sent to the transmitter which retransmits the packet.

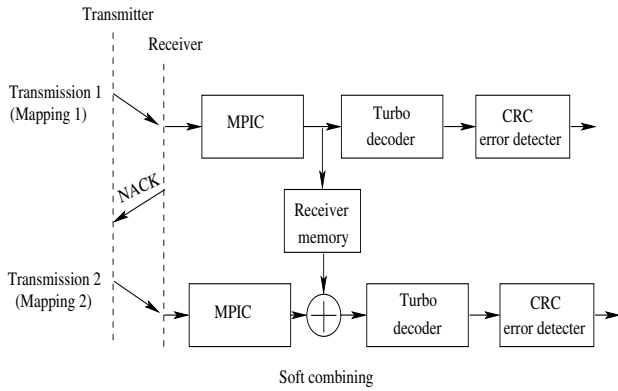


Fig. 2. Iterative soft MPIC combined with HARQ

At the receiver, the retransmitted packet is combined with the original one before turbo decoding.

The most known of HARQ algorithms is Chase combining which is first proposed in [9]. It was proven that Chase approach offers time diversity and provides a significant signal to noise ratio gain after retransmissions combining. In Chase combining, retransmissions are identical to the original transmission [11]. In addition to its reduced complexity, Chase combining requires a small memory.

B. Constellation rearrangement

In [13], it has been proven that there are variations in the bit reliabilities for 16-QAM modulation. These variations depend on the significance of the bit within a symbol: the two most significant bits are more reliable than the two least significant bits [12], [13]. In case of Chase combining employing the same signal constellation mapping for all transmissions, the variations in bit reliabilities remain when soft-combining the received transmissions at bit level.

In this paper we propose an interworking of Chase combining and constellation rearrangement (CoRe) technique in order to combat the reliability variation problem. The constellation rearrangement averages the bit reliabilities by employing different signal mapping constellations for the HARQ transmissions (see Fig. 2). In this manner, some less protected bits becomes more protected. The bits within a 16-QAM symbol at the input of constellation rearrangement are denoted here by $i_1 q_1 i_2 q_2$. The obtained signal constellation mappings are summarized in TABLE I [1]. The mapping #1 represents the

TABLE I
CONSTELLATION REARRANGEMENT

Mapping	Output bit sequence	High reliable bits
Mapping #1	$i_1 q_1 i_2 q_2$	$i_1 q_1$
Mapping #2	$i_2 q_2 i_1 i_2$	$i_2 q_2$
Mapping #3	$i_1 q_2 i_2 q_2$	$i_1 q_2$
Mapping #4	$i_2 q_2 i_1 q_1$	$i_2 q_2$

standard 16-QAM constellation (no rearrangement is made). The over-score on bits in TABLE I indicates that the logical values of this bits changes ($\bar{1} = 0$ and $\bar{0} = 1$).

IV. SIMULATOR CONFIGURATION

For testing our scheme, we implemented the HSDPA link level simulator. It computes the residual BLER (Block Error Rate) and throughput for each SNR using monte carlo method. The throughput is given by this expression :

$$Throughput = D.(1 - BLER_{(HARQ)}), \quad (9)$$

where D is the information bit rate and $BLER_{(HARQ)}$ is the block error rate which takes into account Hybrid ARQ transmissions. At the transmitter, every function is performed according to 3GPP technical specifications [1], [2].

At the receiver, a Rake receiver using MRC (Maximum Ratio Combining) was applied to recover the transmitted signal. The iterative soft multipath interference canceller (MPIC) was implemented using soft interference estimation and 4 iterations. It includes the soft output demapper for updating the soft bits values through MPIC iterations. The turbo decoding uses the Max-Log-MAP algorithm with 10 iterations. The channel model utilizes the profile of ITU-Pedestrian B channel with the speed of 3 Km/h (see Fig. 3). The receiver assumed a perfect channel knowledge. For HARQ, the Chase combining approach with constellation rearrangement technique was used. The maximum number of HARQ transmissions is fixed to 2. A delay of 12 ms is used between HARQ transmissions. The simulations were run using the radio link parameters summarized in TABLE II.

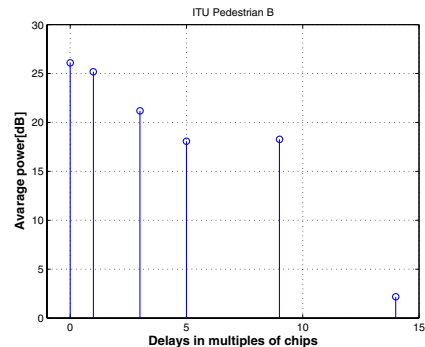


Fig. 3. The profile of ITU-Pedestrian B channel

TABLE II
SIMULATION PARAMETERS

Chip rate	3.84 Mcps
Symbol rate	240 Ksps
Spreading Factor (SF)	16
Transmission Time Interval (TTI)	2 ms
Power Control	None
Spreading code	OVSF codes
Modulation	16-QAM
Channel coding/decoding	Turbo coding / Max-Log-MAP
Number of turbo decoding iterations	10
HARQ	Chase with CoRe
CRC	24 bits
Max. Number of HARQ processes	2
Delay between HARQ retransmissions (RTD)	12 ms

V. SIMULATION RESULTS

Simulations were done for several channel quality indicator (CQI) modes to observe the performance enhancement. The predefined CQI modes used in this work are shown in TABLE III [2]. Performance is presented in terms of the residual BLER

TABLE III
MCSS CONFIGURATION

CQI	Transport blocs size	Number of codes	Modulation	D (kbit/s)	R
16	3565	5	16-QAM	1794.5	0.3739
18	4688	5	16-QAM	2344.0	0.4883
22	7192	5	16-QAM	3596.0	0.7492
23	9743	7	16-QAM	4871.5	0.7249
24	11442	8	16-QAM	5721.0	0.7449

and throughput in function of the sum of code symbol signal to noise ratio which expressed as :

$$SNR = 10 \log_{10} \left(K \frac{E_s}{\sigma^2} \right) \quad (10)$$

where K is the number of codes (physical channels), E_s is the symbol energy and σ^2 represents the noise variance.

BLER results of CQI_16, CQI_18 and CQI_22 are presented in Fig. 4, Fig. 5 and Fig. 6 respectively. We see that considerable performance gain is offered by MPIC when combined with Chase combining. An additional performance gain is obtained with the constellation rearrangement which, in case of CQI_16 for example, achieved almost 2 dB gain over the technique using the interworking of MPIC and Chase combining without CoRe. For CQI_18, with the Rake, we

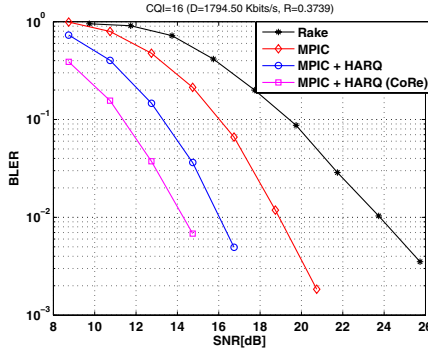


Fig. 4. BLER for CQI_16 in ITU-Pedestrian B channel

observe a performance floor which limited the BLER to a value above 10^{-1} . With the MPIC and other techniques, the floor is completely removed. In case of CQI_22, the MPIC curve presents a performance floor due to the severe multipath interference caused by the ITU-Pedestrian B channel. This floor is suppressed when using HARQ. The use of CoRe with CoRe resulted in great performance enhancement over the MPIC. This is due to the diversities offered by Chase combining and CoRe.

BLER results for CQI_23 and CQI_24 are shown in Fig. 7 and Fig. 8 respectively. We see that for CQI_23 the error floor observed in MPIC curve, is removed by HARQ, whereas the HARQ curve for CQI_24 have a lowered floor compared

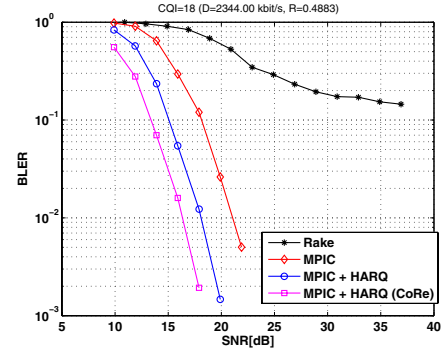


Fig. 5. BLER for CQI_18 in ITU-Pedestrian B channel

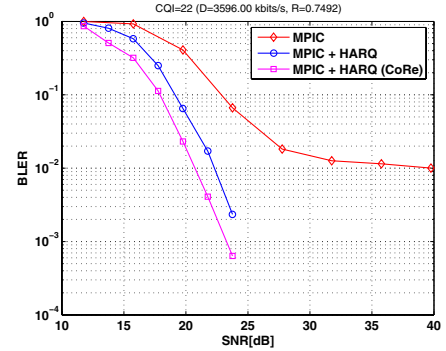


Fig. 6. BLER for CQI_22 in ITU-Pedestrian B channel

with the MPIC. This is due to the higher coding rate used by CQI_24 ($R=0.7449$). It is also shown that best performance gain is offered by CoRe for both CQIs.

In order to see the impact of constellation rearrangement over

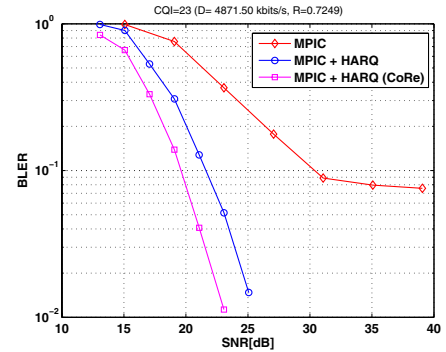


Fig. 7. BLER for CQI_23 in ITU-Pedestrian B channel

the throughput, simulations are done for CQI_16 and CQI_18. The throughput results of these CQIs are presented by Fig. 9 for CQI_16 and Fig. 10 for CQI_18. By analyzing these results, we observe that the throuput is significantly improved at low signal to noise ratio.

VI. CONCLUSIONS

In this paper, we have shown that the performance of HSDPA CQIs modes using 16-QAM modulation are not very

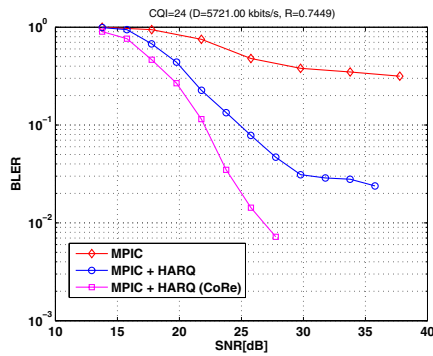


Fig. 8. BLER for CQI₂₄ in ITU-Pedestrian B channel

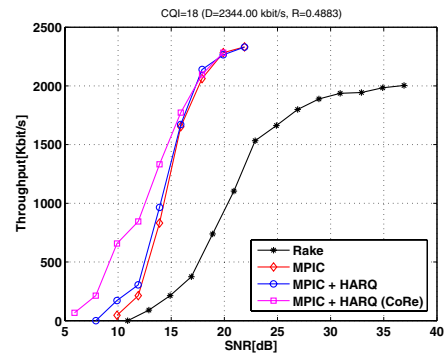


Fig. 10. Throughput for CQI₁₈ in ITU-Pedestrian B channel

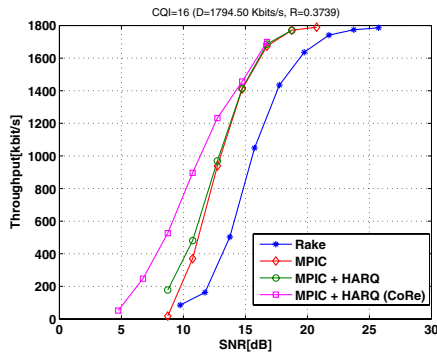


Fig. 9. Throughput for CQI₁₆ in ITU-Pedestrian B channel

well in multipath environment. This is due to high sensitivity of this modulation to interference. A soft iterative multipath interference canceller was used for suppressing this interference. It was shown that this interference canceller resulted to a considerable performance enhancement. Besides, the use of HARQ technique and constellation rearrangement offered a great performance gain.

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