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Performance of SIR-Based Power Control in a WCDMA Enhanced Uplink System with the Hybrid ARQ Technique

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Abstract—The power control and the Hybrid Automatic Repeat Request (HARQ) are important techniques in Wideband Code Division Multiple Access (WCDMA) systems. The joint use of these two mechanisms can enable wireless systems to increase throughput and spectral efficiency. In this paper, we will evaluate the performance of the SIR-based power control in a WCDMA Enhanced Uplink system with a turbo coded HARQ technique over multi-path fading channel. We propose, also, an improved Signal-to-Interference power Ratio (SIR) estimation scheme. In the proposed scheme, the SIR is estimated by using the Enhanced Dedicated Physical Data Channel (E-DPDCH) instead of using the Dedicated Physical Control Channel (DPCCH).

I. INTRODUCTION

Power control is a mechanism optimizing the transmitted power to keep a received power constant. It was normalised by the Third-Generation Partnership Project (3GPP) in the Third-Generation (3G) mobile systems such as UMTS, HSDPA and WCDMA Enhanced Uplink (called HSUPA). This apparatus is essential for WCDMA systems since, it let to alleviate the effects of the multi-path fading and that of the near-far problem. The estimation of the received signal SIR is required for power control loops. When the accuracy of the SIR estimation increases, we can reduce the transmitted power without degrading the system performance.

The HARQ technique is one of the promising error controls of the 3G mobile systems. It is used in WCDMA Enhanced Uplink to reach high data rates. In this technique, when a received packet is erroneous, it is saved at the receiver memory and a negative acknowledgement is sent to the transmitter which in response retransmits the packet. The retransmitted packet is combined with the previously saved one. In this manner the obtained packet after combining is more reliable than the individually transmitted packets. This increases the probability of correct decoding.

The combination of the HARQ technique with power control apparatus can be a solution to achieve higher speed with a good quality of service (QoS). In this context, we propose to evaluate the performance of HARQ schemes for the SIR-based power controlled WCDMA Enhanced Uplink system

over a Rayleigh fading channel.

In [5], Y. Kim and J. Han evaluated the performance of HARQ for the CDMA reverse link in a power controlled scenario. D. Das and S. Ananthaiyer [7] discussed general OLPC algorithms for a CDMA reverse link systems with HARQ technique such as EVDO-Rev A and 3GPP2 systems. In [6], D. Lima and C.H.M. proposed a new OLPC algorithm that takes HARQ into consideration for the WCDMA Enhanced Uplink system. In this paper, we evaluate the performance of the SIR-based power control in a WCDMA Enhanced Uplink with HARQ technique.

The remainder of this paper is organized as follows. In the second section, the air-interface of the uplink system is reviewed. Then, in section 3, we will deal with an overview of characterizations of the Hybrid ARQ technique normalized for the WCDMA Enhanced Uplink system. In the fourth section, the behavior of power control apparatus is described. In section 5, we propose an improved instantaneous SIR estimation method. Section 6 contains numerical results corresponding to the evaluation of the system performance. Finally, in section 7, conclusions are drawn.

II. UMTS UPLINK SYSTEM

In this paper, we are concerned with the uplink system including the physical channels introduced by UMTS, HSDPA and WCDMA Enhanced Uplink systems. These physical channels are:

- E-DPDCH: Enhanced Dedicated Physical Data Channel for the WCDMA Enhanced Uplink system. It is spreaded by the spread factor range from 2 to 256.
- E-DPCCH: Enhanced Dedicated Physical Control Channel for the WCDMA Enhanced Uplink system. It is spreaded by a spread factor equal to 256.
- HS-DPCCH: a dedicated uplink control channel for the HSDPA system. It is introduced when the HS-DPDCH is used in the downlink and is spreaded by a spread factor equal to 256.

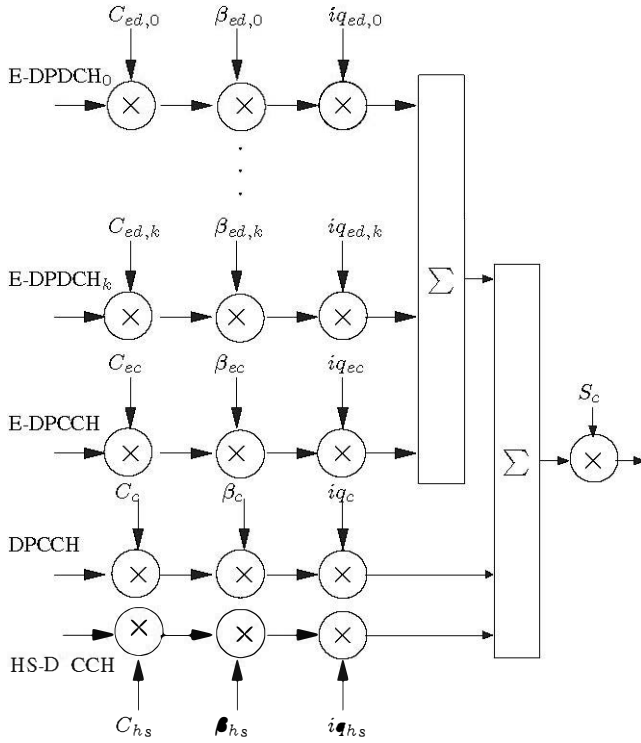


Fig. 1. The air-interface structure of the UMTS uplink system

- DPCCH: a dedicated control channel for the UMTS system. This channel is obligatory for the uplink systems to manage the power control. It is spreaded by a spread factor equal to 256.

The Figure 1 shows the air-interface structure of the uplink system implemented in this paper, where C_k , β_k and iq_k are, respectively, the spreading code, the weighting factor and the I/Q branch for the k^{th} channel. S_c is the complex long scrambling code [2].

The transmitted power $E_{c,tot}$ is the total power chip after the amplifier. It is divided on the DPCCH, E-DPDCH(s), E-DPCCH and the HS-DPCCH with respect to the respective gain factors β_c , $\beta_{ed,k}$, β_{ec} and β_{hs} . For each system configuration, we have power control ratios between DPCCH and both HS-DPCCH, E-DPCCH and E-DPDCH. These ratios called respectively A_{hs} , A_{ec} and $A_{ed,k}$ are fixed by the 3GPP standard in [2]. Hence, there is a relation between β_c and the others weighting factors:

$$\beta_{ec} = \beta_c \cdot A_{ec} \quad (1)$$

$$\beta_{hs} = \beta_c \cdot A_{hs} \quad (2)$$

$$\beta_{ed,k} = \beta_c \cdot A_{ed,k} \quad (3)$$

In order to guarantee that the total transmitted energy $E_{c,tot}$ is not exceeded (i.e. the transmitted energy before power amplifier is equal to 1), we apply, for each gain factor, a

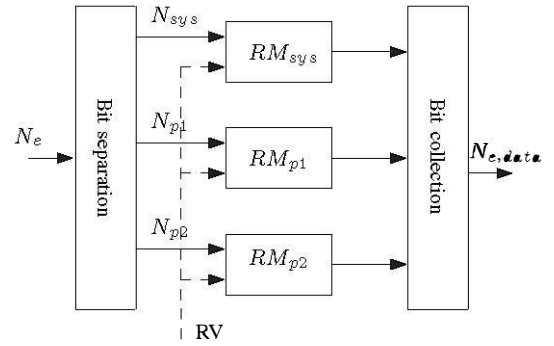


Fig. 2. The rate matching structure

normalization given by the expression below:

$$Norm = \beta_c^2 + \beta_{hs}^2 + \beta_{ec}^2 + \sum_{k=1}^4 \beta_{ed,k}^2 \quad (4)$$

III. OVERVIEW OF THE HARQ TECHNIQUE

The HARQ technique combines ARQ protocols with a turbo encoder which materializes the Forward Error Correction (FEC) in order to provide increased throughput in packet transmissions. The ARQ protocol used is N process Stop-And-Wait (N-SAW) protocol which is an improved version of the protocol Stop-And-Wait. In this paper, several parallel N-SAW HARQ processes are used at the physical layer. The number of the processes is selected in order to leave enough time to decode the packet and to transmit the HARQ ACK/NACK signals [1] and [3].

The HARQ technique is based on the rate matching functionality. It adapts the bits number of the input packet N_e at the bits number $N_{e,data}$ which can carry the different E-DPDCH physical channels. This bits adaptation is done by the rate matching pattern algorithm normalized by 3GPP in [3]. It is based on the Redundancy Versions (RV) parameters s and r . The parameter s can take the value 0 or 1 to distinguish between prioritizing systematic and parity bits. The parameter r changes the punctured or repeated bit index. The Rate matching structure, of the WCDMA Enhanced Uplink system, is shown in Figure 2.

The Table I shows the E-DPDCH RV Index values used in this paper.

TABLE I
Parameters for HARQ rate matching

| RSN value | E-DCH RV Index | |
|-----------|----------------------------|-------------------------------|
| | $N_{sys}/N_{e,data} < 1/2$ | $N_{sys}/N_{e,data} \geq 1/2$ |
| 0 | 0 | 0 |
| 1 | 2 | 3 |
| 2 | 0 | 2 |

The rate matching stage begins with encoded packet separation on three sequences: N_{sys} , N_{p1} and N_{p2} , which are, respectively, the systematic bit sequence, the first parity bits sequence and the second parity bits sequence. These sequences

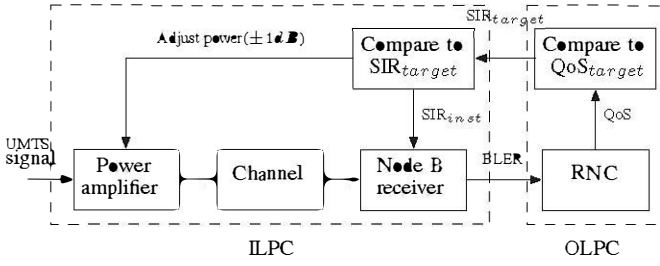


Fig. 3. Uplink power control mechanism

are punctured by a third rate matching pattern algorithms. Then, the adapted output bits are mixed to form the transmitted packet.

IV. UPLINK POWER CONTROL

The power control mechanism used in the WCDMA Enhanced Uplink system can be divided on two loops: the outer loop and the inner loop. The Outer Loop Power Control (OLPC) is used to guaranty a quality of service. It is a slow power control between NodeB and RNC. If the BLER (Block Error Rate) at RNC doesn't meet the requirements of quality of service, the RNC corrects the SIR target value used in the Node B.

The Inner Loop Power Control (ILPC) is used to counteract the fast fading and to alleviate the effects of the near-far problem. It adjusts the User Equipment (UE) transmit power in order to keep the instantaneous received uplink SIR (SIR_{inst}) at a given SIR target (SIR_{target}). If the SIR is bigger (or smaller) than the target value, the Node B sends the Transport Power Control command (TPC) "down" (or "up") to the UE power control algorithm in order to decrease (or increase) the mobile transmit power by a control step size equal to 1dB. Then, the ILPC in the uplink is the ability of the UE transmitter to adjust its output power in accordance with one or more TPC commands received in the downlink. When the UE is not in soft handover, only one TPC command will be received in each timeslot. TPC commands, along with the power control step size and the power control algorithm, shall determine the UE transmit output power. The power change will be applied in the timeslot adjacent to the timeslot in which the TPC command is received [4].

V. THE INSTANTANEOUS SIR ESTIMATION

The SIR is defined as the Received Signal Code Power (RSCP) divided by the Interference Signal Code Power (ISCP). In general, the instantaneous SIR is measured at the input of the NodeB receiver by using the DPCC physical control channel. In this paper, we estimate the instantaneous SIR performed on the E-DPDCH channel which has the smallest spreading factor. It is measured at the output of the RAKE receiver. This improved SIR estimation scheme increases the accuracy of power control apparatus.

The expression of the n^{th} estimated symbol at the output of the RAKE receiver is defined by:

$$Z_{n,i} = \sum_{l=1}^L |h_{l,i}|^2 \cdot SF_k \cdot \beta_{ed,k} \cdot \sqrt{E_{c,tot}} \cdot b_{n,i} + \tilde{n}_{n,i} \quad (5)$$

Where $\tilde{n}_{n,i}$ is the noise plus interference power at the i^{th} ARQ transmission, SF_k is the spread factor of the k^{th} physical channel, $b_{n,i}$ is the transmitted symbol at the i^{th} ARQ transmission and $h_{l,i}$ is the complex attenuation of the l^{th} path at the i^{th} ARQ transmission.

The RSCP and the ISCP of the k^{th} E-DPDCH channel at the i^{th} ARQ at the output of the RAKE receiver are defined by:

$$RSCP_{k,i} = \frac{1}{N} \sum_{n=1}^{N_k} \left| \sum_{l=1}^L |h_{l,i}|^2 SF_k \beta_{ed,k} \sqrt{E_{c,tot}} b_{n,i} \right|^2 \quad (6)$$

$$= \left| \sum_{l=1}^L |h_{l,i}|^2 \right|^2 \cdot SF_k^2 \cdot \beta_{ed,k}^2 \cdot E_{c,tot} \quad (7)$$

$$ISCP_{k,i} = \frac{1}{N} \sum_{n=1}^{N_k} \left| Z_{n,i} - \sum_{l=1}^L |h_{l,i}|^2 SF_k \beta_{ed,k} \sqrt{E_{c,tot}} \hat{b}_{n,i} \right|^2 \quad (8)$$

Where $\hat{b}_{n,i} \in \{\pm 1\}$ is the n^{th} received symbol at the i^{th} ARQ transmission after channel decoding and hard decision.

The estimation of the instantaneous $SIR_{m,i}$ per antenna at the i^{th} ARQ transmission is performed on the E-DPDCH, which has the smallest spreading factor, and is calculated according to :

$$SIR_{m,i} = \frac{RSCP_{0,i}}{ISCP_{0,i}} \quad (9)$$

$$= N \cdot \frac{\left| \sum_{l=1}^L |h_{l,i}|^2 \right|^2 SF_0^2 \beta_{ed,0}^2 E_{c,tot}}{\sum_{n=1}^{N_0} \left| Z_{n,i} - \sum_{l=1}^L |h_{l,i}|^2 SF_0 \beta_{ed,0} \sqrt{E_{c,tot}} \hat{b}_{n,i} \right|^2} \quad (10)$$

In a diversity receiver, $SIR_{m,i}$ must be computed separately to each antenna, and then they are summed up to get $SIR_{inst,i}$:

$$SIR_{inst,i} = \sum_{m=1}^{N_{ant}} SIR_{m,i} \quad (11)$$

The final expression of the SIR_{ARQ} after the $N_{ARQ,max}$ retransmissions is:

$$SIR_{ARQ} = \sum_{i=1}^{N_{ARQ,max}} SIR_{inst,i} \quad (12)$$

VI. SIMULATION RESULTS

For simulating the radio link performance of SIR-Based power controlled WCDMA Enhanced Uplink system, we implement the uplink WCDMA system simulator. This simulator is composed of the normalized transceiver with the air-interface described in the Section 2, multi-paths channel uses the profile of ITU-Pedestrian B with a speed of 3Km/h and WCDMA Enhanced Uplink receiver. This simulator computes the $BLER_{E-DCH}$ of the E-DPDCH channels for each

$E_{c,out,avg} \cdot E_{c,out,avg}$ is the average of the received chip energy, after multi-paths channel. The Table II shows the simulation parameters.

TABLE II
Simulation parameters

| | |
|---|---------------------------|
| Chip rate | 3.84 Mcps |
| HSUPA FRC | 7 and 4 |
| Number of transmitter/receiver antennas | 1Tx/2Rx |
| TTI | 10ms |
| CRC | 24 |
| Modulation | QPSK |
| Channel coder/decoder | Turbo coding/Max-Log-Map |
| Number of decoder iterations | 8 |
| Channel knowledge | Perfect Channel knowledge |
| Soft handover | No |

A. The W-CDMA Enhanced Uplink fixed reference channels (FRC)

The FRCs are a set of E-DPDCH channel configurations defined in 3GPP [4] for performance testing purposes. FRC1 to FRC3 use a TTI (Transmission Time Interval) equal to 2ms, whereas the other FRCs are specified for a TTI of 10ms. The FRC4 and FRC7 used in this paper are shown in the Table III.

TABLE III
WCDMA Enhanced Uplink Fixed Reference Channels

| | N_{info} | SF | Coding rate | β_c | β_{ec} | $\beta_{ed,0}$ |
|------|------------|----|-------------|-----------|--------------|----------------|
| FRC4 | 5076 | 4 | 0.529 | 0.41 | 0.41 | 0.816 |
| FRC7 | 690 | 4 | 0.288 | 0.32 | 0.26 | 0.909 |

B. Performance of the WCDMA Enhanced Uplink system with the SIR-based power control

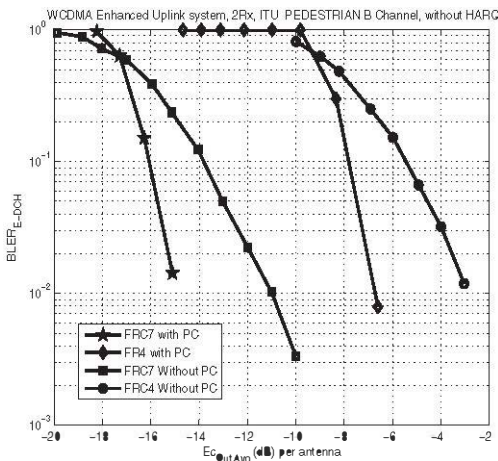


Fig. 4. Performance of the FRC4 and FRC7 with and without the SIR-based power control (without HARQ Technique)

The $BLER_{E-DCH}$ results of the FRC7 and FRC4 with and without the power control mechanism are presented in Figure

4. We see that considerable performance gain is obtained only by the use of a fast power control with an accurate instantaneous SIR estimation. This gain achieves almost 4dB for the FRC7 and FRC4.

C. Performance of the WCDMA Enhanced Uplink system with the HARQ technique

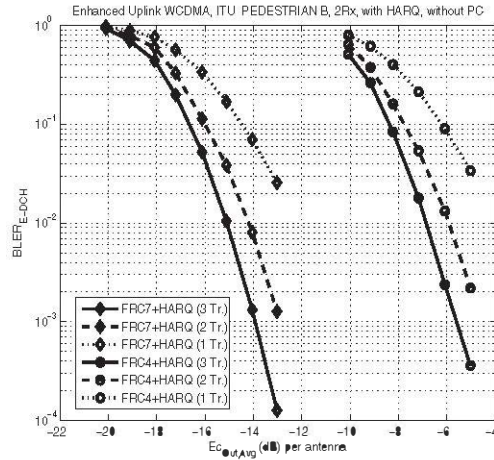


Fig. 5. Performance of FRC4 and FRC7 with HARQ technique (without SIR-based power control)

The Figure 5 shows the $BLER_{E-DCH}$ performance of the FRC7 and the FRC4 with the HARQ technique with a soft packet combining. The maximum number of HARQ transmissions is fixed to 3 and a delay of 40ms between retransmissions is used. We see that considerable gain is achieved after the first and the second retransmission for both FRCs.

D. Performance of the SIR-based power controlled WCDMA Enhanced Uplink with the HARQ technique

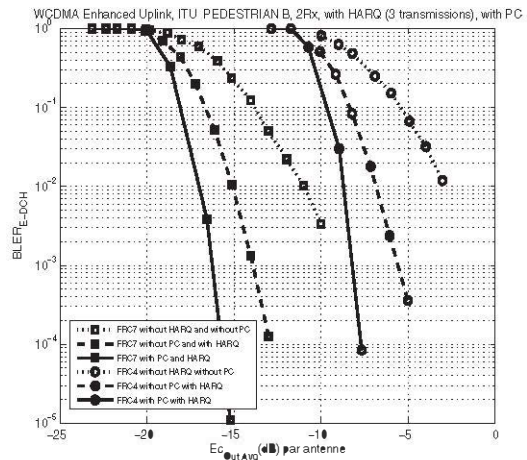


Fig. 6. Performance of the SIR-based power controlled WCDMA Enhanced Uplink with the HARQ technique

The $BLER_{E-DCH}$ results of FRC7 and FRC4 are investigated in Figure 6. We see that considerable performance gain is offered by the combination of SIR-based power control with the HARQ technique. In case of FRC7, for example, we achieved almost 6dB gain of $E_{cout,avg}$ for a $BLER_{E-DCH}$ value equal to 10^{-2} .

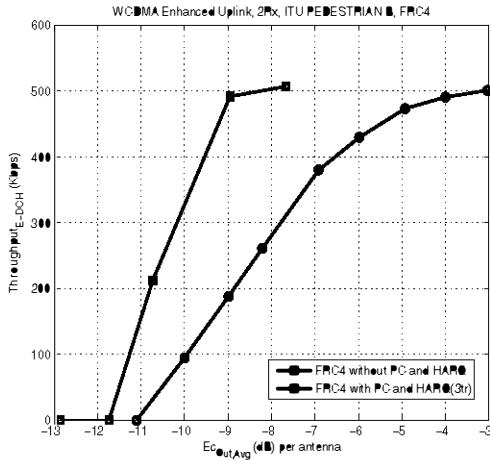


Fig. 7. Throughput performance of FRC4 with and without power control and HARQ techniques

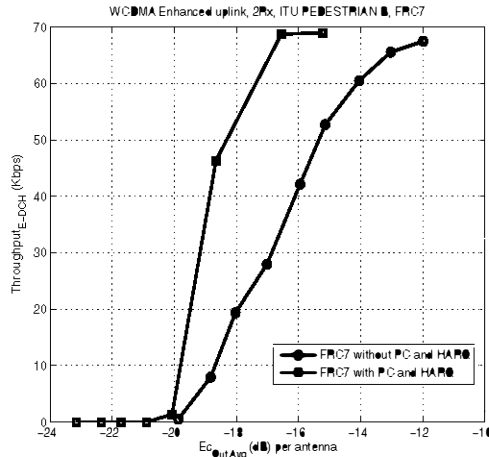


Fig. 8. Throughput performance of FRC7 with and without power control and HARQ techniques

The throughput result of FRC4 and FRC7 are shown respectively in Figure 7 and 8. We observe that the throughput is significantly improved when we use the interworking of the two techniques: the HARQ and the power control. From the results above, it is clear that the using of these techniques can introduce performance benefits compared to pure WCDMA Enhanced Uplink, especially at high $E_{cout,avg}$.

VII. CONCLUSION

In this paper, we evaluated the performance of the SIR-based power control in a WCDMA Enhanced Uplink system

with a turbo coded HARQ technique in a multipath environment. The combination of these techniques was enabling wireless systems to increase throughput and spectral efficiency. In this paper, we showed that considerable BLER and throughput gain is offered by the interworking of the two techniques. In the case of FRC7, we achieved almost 6dB gain of $E_{cout,avg}$ for a $BLER_{E-DCH}$ value equal to 10^{-2} . This is due to the temporal diversities offered by HARQ technique and the counteraction of the fast fading offered by the power control mechanism.

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