# Combined Packet Retransmission Diversity and Power Adjustment Scheme for High Speed Wireless Networks

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***Abstract*—The introduction of *High Speed Downlink Packet Access* (HSDPA) in the 3GPP R5 standard will greatly improve the bearer capacity of the mobile network and make the dream of multimedia communications, anytime and anywhere, come true. One of the central features of HSDPA concept is advanced physical layer retransmission scheduling employing soft combining gain, incremental redundancy, and low retransmission delays. This paper studies symbol mapping diversity in combination with power adjustment for HSDPA. If retransmission are requested, the bit-to-symbol mapping and transmission power is changed in every re-transmission. Compared to the conventional HARQ schemes, our proposed scheme increases the throughput and decreases the average number of retransmissions significantly and reduce the power consumption in HSDPA.**

***Index Terms*—Constellation rearrangement, Diversity, LLR, Power adjustment, MQAM, BER**

## I. Introduction

IP-based and wireless-based services are the two most appealing services for current telecom subscribers. With the popularity of ADSL and Wireless LAN (WLAN), mobile broadband service is also rapidly entering a stage of fast development. Most subscribers are no longer satisfied with just basic services such as, voice and SMS, instead, subscribers demanding to experiences and enjoy a range of multimedia services which are more exciting and colorful such as, video chat, network TV, high-speed Internet access, and so on. However, because of insufficient bearer capacity, charge restrictions and quality of service (QoS), low-speed data services such as GPRS and CDMA 1X, which are provided through 2G/2.5G, will no longer be able to meet the requirements of mobile multimedia service subscribers.

Third generation (3G) wireless systems, based on wideband code-division multiple access (WCDMA) radio access technology, are now being deployed on a broad scale all over the world. The first step in the evolution of WCDMA has also been taken by the Third Generation Partnership Project (3GPP) through the introduction of high-speed downlink packet access and enhanced uplink. HSDPA is a part of the UMTS standard release 5 and provides a high data rate packet-oriented downlink channel for non-realtime service [1].

HSDPA provides impressive enhancements over WCDMA R99 for the downlink. It offers peak data rates of up to 10 Mbps, resulting in a better end-user experience for downlink applications, with shorter connection and response times. More importantly, HSDPA offers three-to-five fold sector throughput increase, which translates into significantly more data users on a single frequency (or carrier). The substantial increase in data rate and throughput is achieved by implementing a fast and complex channel control mechanism based upon *multi-code transmission, adaptive modulation and coding (AMC), fast scheduling,* and *fast hybrid automatic repeat request (HARQ)*. HSDPA has some difference from WCDMA, for example, downlink power control control is not necessary since the HSDPA adopts AMC technology. For AMC, 16-QAM is used in addition to QPSK and also the code rate is adapted to the different channel conditions [2].

In packet communication systems such as HSDPA, packet retransmission is often requested when a received packet is detected to be in error. This scheme, termed automatic repeat request (ARQ), is intended to ensure extremely low packet error rate. During the ARQ process, the same data is sent until recovered without errors. The efficiency of ARQ can be improved by reusing the data from previous (re)transmissions instead of discarding them, this technique creates a diversity gain. This technique is termed hybrid ARQ and has been well investigated in literature [3]. Type II HARQ introduces the idea of combining based. In HSDPA, HARQ combines the UMTS turbo code with a $N$-channel Stop-and-Wait (SW) protocol for automatic repeat request. Retransmissions of packets in HSDPA use either Chase combining, partial, or full Incremental Redundancy (IR) [2], [4], [5].

An effective method to achieve diversity is to vary the bit-to-symbol mapping in higher order modulations such as phase-shift keying (PSK) or quadrature amplitude modulation (QAM) for each packet (re)transmission. This results in improved packet combining performance in terms of reduced packet error rate (PER) compared to a system without symbol mapping [6], [7]. Otnes and

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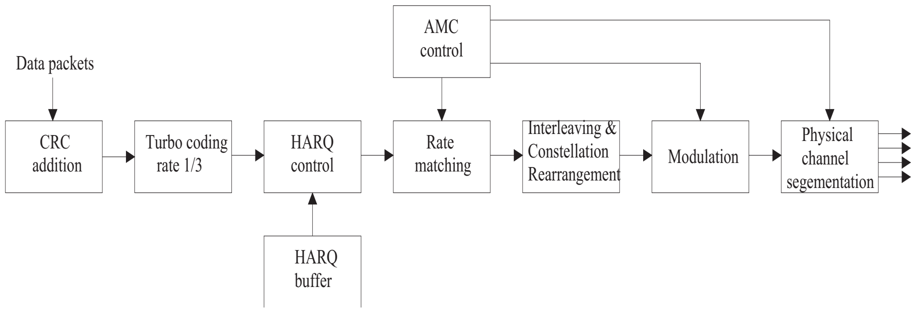


Fig. 1. The HS-DSCH transmission scheme. Observe that re-constellation arrangement is only employed when 16QAM is active.

Maseng proposed the use of nonuniform constellations for retransmitted packets in systems that require unequal error protection [8]. In [9], Gidlund and Xu proposed a mapping scheme that view the signal constellations of the modulation scheme in an augmented signal space formed by the modulation signal dimension and the number of retransmissions. That augmented signal space provided a good spread of the modulation signal points and the error probability was increased. In [10], Gidlund and Åhag presented a HARQ scheme for OFDM with take advantages of both the rearrangement of signal constellations and frequency diversity. A similar scheme for OFDM was presented by Kumagi *et al.* in [11]. In [12] and [13], Wengerter *et al.* considered *constellation rearrangement* (CoRe) for 16QAM and adopted in HSDPA. CoRe consist of swapping the positions and/or negation of the least significant bits (LSB) and aims at ”equalizing” the protection degree experienced by the bits transmitted in 16-QAM. In [14], Semenov presented a modified *maximal ratio combining* (MRC) method which allowed decreasing the impact of the errors in the channel estimates to the performance of HSDPA.

Power control is vital in wireless communications. On one hand, it mitigates the effects of fading channel and multiple access interference (MAI) and/or cochannel interference [15]; on the other hand, it lowers the power consumption and hence the interference to ther users. The throughput and system capacity is thus increased by using power control schemes [16].

In this paper, we propose a HARQ technique that introduces power adjustment based on constellation rearrangement of symbols (symbol mapping diversity). If a packet is correct decoded, a ACK is transmitted to the transmitter. If the first packet is not correct decoded, a NACK is sent and a new transmission is requested. Instead of using the same bit-to-symbol mapping as in the first transmission, i.e. Chase combining, we both change the bit-to-symbol mapping and the retransmission power in the requested retransmission. Performance results show that the proposed HARQ scheme can enhance the performance quite significantly. We also derive expressions for the uncoded bit error rate (BER) of packet combining with CoRe.

The rest of the paper is organized as follows: A brief description of HSDPA is described in Section II. The used system model is described in Section III and in Section IV a detailed desciption of the bit-to-symbol mapping is given with bit error rate calculations. Section V describes the combination of symbol mapping diversity and power adjustment. In Section VI we discuss obtained simulation results and finally in Section VII, we conclude our work.

## II. HSDPA SYSTEM DESCRIPTION

The HSDPA concept introduces few additional physical channels. They are High Speed Physical Downlink Shared Channel (HS-PDSCH) and a HS-Physical Control Channel (HS-DPCCH). HS-PDSCH channels is both time and code shared between users attached to Node-B. It is the transport mechanism for additional logical channels; the downlink shared channel (DSCH) and the radio bearer is thus denoted the high speed DSCH (HS-DSCH) [18]. The basic transmission chain used for HS-DSCH is illustrated in Fig. 1. The HS-DSCH code resources consist of one or more canalization codes with a fixed spreading factor (SF) of 16. At the most 15 such codes can be allocated leaving sufficient room for other required control and data carriers. The available codes resources are primarily shared in time domain but it is possible to share the code resources using code multiplexing. When it is both time and code shared, two or four users can share the code resources with the same TTI. The HS-DPCCH channel is an uplink channel used to carry ACK signals to the Node-B for each block. It is also used to indicate the *channel quality* (CQI) which is used for adaptive coding and modulation.

The HSDPA concept introduces several adaption and control mechanisms in order to enhance peak data rates, spectral efficiency, as well as QoS control for bursty and downlink asymmetrical packet data [19]. With HSDPA, two of the most fundamental features of WCDMA, variable spreading factor (VSF) and fast power control, are disabled and replaced by means of AMC, fast scheduling, multi-code transmission, short packet size and fast L1 HARQ [20], [21].

### A. Adaptive Modulation and Coding

The replacement of fast power control by fast AMC yields a power efficiency gain due to an elimination of the inherent power control overhead. Specifically, the

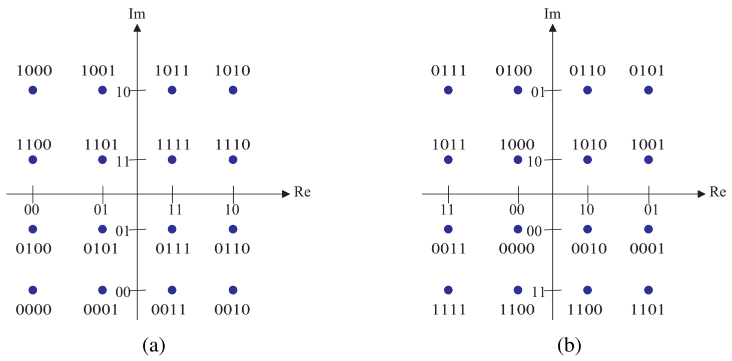


Fig. 2. a) Initial symbol mapping for 1st transmission. b) Optimized mapping for 2nd transmission (1st retransmission).

spreading factor (SF) has been fixed to 16, which gives a good data rate resolution with reasonable complexity. The data rate is adjusted depending on measured channel quality in each subframe [22]. The HS-DSCH encoding scheme is based on the $1/3$ turbo encoder but adds rate matching with puncturing and repetition to obtain a high resolution on the effective code rate. In order to facilitate very high peak data rates, HSDPA adds 16QAM on top of the existing QPSK scheme available in Release 99. The use of 16QAM and e.g. rate-3/4 channel encoding enables a peak data rate of 712 kbps per code (SF=16). By using QPSK, higher robustness is available with a QPSK rate-1/4 but a penalty of having only a 119 kbps data rate per code.

### B. Fast Hybrid ARQ (HARQ)

The *user equipment* (UE) can rapidly request for a retransmission of missing data and combine information from the original transmission with that of the later transmission before attempting to decode the message. This approach called, soft combining, increases capacity and provides robustness. The HSDPA concept supports both the *Chase combining* (CC) [5] and *incremental redundancy* (IR) retransmission strategies. The basic idea with the CC scheme is to transmit an identical version of an erroneously detected data packet and then for the decoder to combine the received copies weighted by the SNR prior to decoding. With different parameters, the transmissions will not be identical and then the principle of incremental redundancy is used. In this case, for example, the first transmission could consist of systematic bits, while the second transmission would consist of only parity bits. Incremental redundancy has better performance but it also needs more memory in the receiver, as the individual retransmissions cannot be just added.

The terminal default memory requirements are done on the basis of Chase combining, and at maximum data rate (supported by the terminal). Hence, at the highest data rate, only Chase combining may be used, while with lower data rates, also incremental redundancy can be used.

When 16QAM is used, two of four bits constructing the received symbols will have higher probability of error than the other two bits. In order to compensate for this effect it is possible to use constellation rearrangement for retransmissions, which provides a swapping of the bit streams in a way that all bits experience the same average level of error probability after the retransmission combining. This will be discussed more in detail in Section IV.

### C. Fast Scheduling

The fast scheduling feature determines to which user equipment the shared channel transmission should be directed at any given moment. The objective to is to transmit to users favorable radio conditions.

The scheduler determines overall HSDPA performance. For each *transmission time interval* (TTI) which is determined to 2 ms, the scheduler decides which users the HS-DSCH should be transmitted to, and in close cooperation with the fast link adaptation mechanism, which modulation and how many codes should be used [23], [24]. Instead of sequentially allocating radio resources among users (round-robin scheduling), capacity can be increased significantly using channel-dependent scheduling. The aim of channel dependent scheduling is to transmit to used with favorable instantaneous channel conditions.

## III. System Model

Let $c_k$ be a sequence of bits to be transmitted for time $k = -\infty, \ldots, +\infty$. The bits are grouped into codewords $\mathbf{c}(n) = [c_B(n), \ldots, c_1(n)]$ of length $B$, which are further transferred into rearranged codewords $\mathbf{c}^{(l)}(n) = \mathcal{D}^{(l)}[\mathbf{c}(n)]$, where the rearrangement operator $\mathcal{D}^{(l)}[\cdot]$ negates bits and changes their position within the codeword and $l$ denotes the number of transmissions, $l = 1, \ldots, L$. The codeword $\mathbf{c}^{(l)}(n)$ is next mapped onto symbols $s^{(l)}(n)$ via a memoryless mapper $\mathcal{M}[\cdot]$, $s^{(l)}(n) = \mathcal{M}[\mathbf{c}^{(l)}(n)] \in \mathcal{S}$, where $\mathcal{S} = \{a_1, \cdots, a_M\}$ is the power normalized constellation with Gray mapping bit assignment. In this article, we have focused on QAM modulation and it is a well known that a square $2^{2m}$-QAM constellation can be generated from *pulse amplitud modulation* (PAM) where the real and imaginary parts are both taken from a PAM symbol.

At the receiver, the received signal is given as $r^{(l)}(n) = s^{(l)}(n) + z^{(l)}(n)$, where $z^{(l)}(n)$ is a zero-mean, white Gaussian noise with variance $\frac{1}{\gamma^{(l)}}$, thus $\gamma^{(l)}$ has a meaning of the SNR in the $l$-th transmission.

In order to exploit the full amount of information available at the receiver, we assume a soft demodulator which gives the probability metric for each bit within a received modulation symbol. The Log-likelihood ratio (LLR) is a probability metric at the receiver for the $k$-th transmitted bit in the codeword $\mathbf{c}^{(l)}(n)$ and is obtained as [17]

$$\begin{aligned}\bar{\lambda}_k^{(l)}(n) &= \frac{Pr(c_k^{(l)}(n)=1|r^{(l)}(n))}{Pr(c_k^{(l)}(n)=0|r^{(l)}(n))}\\ &= \ln\frac{\sum_{\mathbf{b}\in\mathcal{C}_1^k}\exp(-\gamma^{(l)}|\mathcal{M}[\mathbf{b}]-r^{(l)}(n)|^2)}{\sum_{\mathbf{b}\in\mathcal{C}_0^k}\exp(-\gamma^{(l)}|\mathcal{M}[\mathbf{b}]-r^{(l)}(n)|^2)}\end{aligned}$$

where $\mathcal{C}_\beta^k = \mathbf{b} : b_k = \beta$ is the set of codewords $\mathbf{b} = [b_B, \ldots, b_1]$ with the $k$-th bit equal to $\beta \in \{0,1\}$. The above expression can be further simplified by using the approximation $\log(\sum_l \exp(-x_l)) \approx -\min_l(x_l))$ in [25], and we obtain the following expression

$$\bar{\lambda}_k^{(l)} = \gamma^{(l)}\left(\min_{\mathbf{b}\in\mathcal{C}_0^k}|\mathcal{M}[\mathbf{b}]-r^{(l)}|^2 - \min_{\mathbf{b}\in\mathcal{C}_1^k}|\mathcal{M}[\mathbf{b}]-r^{(l)}|^2\right), \tag{1}$$

and the LLR expression in (1) can be further simplified to

$$\begin{aligned}\bar{\lambda}_k^{(l)} &= \gamma[(r-\hat{s}_0^k)^2-(r-\hat{s}_1^k)^2]\\ &= 2\gamma r[\hat{s}_1^k-\hat{s}_0^k]+\gamma[(s_0^k)^2-(\hat{s}_1^k)^2],\end{aligned} \tag{2}$$

where $s_x^k$ is the symbol with the $k$-th labelling bit equal to $x$, closest to the received signal $r$, i.e.,

$$\hat{s}_x^k = \mathcal{M}[\arg\min_{\mathbf{b}\in\mathcal{C}_x^k}|r-\mathcal{M}[\mathbf{b}]|^2]. \tag{3}$$

## IV. SYMBOL MAPPING DIVERSITY

A recently investigated method to achieve packet combining diversity is the bit-to-symbol mapping diversity which is suitable for systems employing higher-order modulation as $M$-PSK and $M$-QAM. By varying the bit-to-symbol mapping for each packet retransmission, the diversity is enhanced among $L$ transmissions.

In HSDPA, two different approaches has been adopted: equalizing the bit reliabilities after retransmissions (denoted as constellation rearrangement) and a dedicated mapping of systematic bits to high reliable bit positions (bit distribution). The used technique averages the bit reliabilities after retransmissions by changing the mapping for consecutive bits onto the symbol. Symbol mapping diversity gain is only achieved after retransmissions and provides increasing advantages with increasing similarity of the transmitted bits in all transmissions (e.g., Chase combining [5], or $R \approx 1/3$).

One solution to select new mappings is to determine a BER upper bound. The BER upper bound can be written as [7]:

$$\begin{aligned}P_b(L) &\leq \frac{1}{M}\sum_{B=0}^{M-1}\sum_{C=0}^{M-1}\mathcal{N}(B,C)\\ &\cdot\ Q\left(\sqrt{\frac{1}{4\sigma^2}\sum_{l=1}^{L}\mathcal{D}^2[\mathcal{M}(B),\mathcal{M}(C)]}\right),\end{aligned} \tag{4}$$

where $\mathcal{N}(B,C)$ is a function to account for the number of bit errors caused by the block error and $\mathcal{D}$ is the Euclidean distance between bit block $B$ and $C$. This approach chooses the mappings that minimize only a bound on the BER (not exact BER) and hence better mappings may be possible. Our approach in this paper will be to find optimized mappings based on *log-likelihood ratio* (LLR) of the bits forming a $M$QAM symbol. By choosing the the mappings for multiple (re)transmissions such as the sum of the magnitudes of the LLR of the bits forming the $M$QAM symbols in different (re)transmissions are maximized.

### A. Mappings based on bit LLR

To find the new mappings for retransmissions, we will take advantage of the soft information given by the LLRs of the bits forming a symbol (could be PAM, QAM or PSK). This procedure will create bit-to-symbol mapping diversity. We will iteratively compute the $L$th mapping from the previous $L-1$ previous mappings. We define the sum of LLRs of a given bit in the previous $L-1$ mappings as

$$\epsilon_k = \sum_{l=1}^{L-1}\overline{\Lambda}_k^l, \tag{5}$$

where $\overline{\Lambda}_k^l$ is the soft metrics of the bits forming the modulated symbol and is averaged over the noise samples. Furthermore, we define $\Psi$ as the set of mappings ($|\psi| = M!$). To choose the $L$th mapping, we need to solve the following optimization problem

$$\max_{\psi_L\in\Psi}\sum_{k=1}^{M}\sum_{k=1}^{\log_2 M}|\epsilon_k+\overline{\Lambda}_k^l|. \tag{6}$$

By using the above optimization procedure, we can construct new constellations for the next retransmissions. To show the results of this procedure, we consider 16QAM and the obtained constellations are shown in Fig. 2a. If an error is caused, we can construct the next retransmission as outlined above and the result is showed in Fig. 2b. With a close inspection, we can see that the squared Euclidean distance has increased between the signal points in the second mapping compared to if we should have been using the same mapping as in the first transmission (i.e. Chase combining). Note that all new mappings produced by this method is Gray mapped. This is a significant difference between compared to the method proposed in [7].

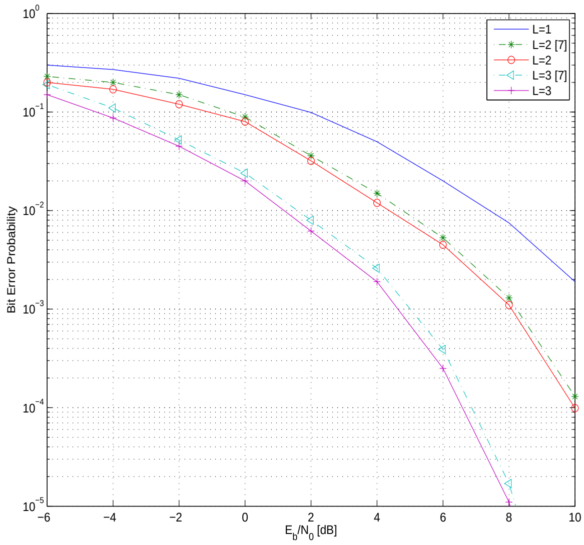


Fig. 3. BER performance of the LLR-based mappings compared to the symbol mapping diversity scheme presented in [7] for $L = 1 - 3$ transmissions.

### B. Bit Error Rate Calculations

In this section we will evaluate the exact BER expression for uncoded modulation. The bit error rate averaged over the bits positions is given by [17]

$$P_b = \frac{2}{B}\sum_{k=1}^{B/2} P_b(2k), \tag{7}$$

where $P_b(k)$ is the bit error probability at position $k$ within the codeword. Since bits "0" and "1" do not have, in general, the same probability of error at all positions within the codeword, the probability of error $P_b(k)$ can now be written as [6]

$$\begin{aligned} P_b(k) &= \frac{1}{2}Pr\{\epsilon_k \geq 0 | c_k = 1\} \\ &+ \frac{1}{2}Pr\{\epsilon_k > 0 | c_k = 0\} \\ &= \frac{1}{M}\sum_{\mathbf{b}\in\mathcal{C}_1^k} Pr\{\epsilon_k \geq 0 | \mathbf{b}\} \\ &+ \frac{1}{M}\sum_{\mathbf{b}\in\mathcal{C}_0^k} Pr\{\epsilon_k \geq 0 | \mathbf{b}\}. \end{aligned} \tag{8}$$

Note that the same codeword $\mathbf{b}$ is used as a condition in the pdf of $\epsilon_k$ because the codeword used in first transmission uniquely defines all the subsequent (rearranged) codewords and the corresponding symbols.

Due to the fact that LLRs from different transmissions conditioned on $\mathbf{b}$ are independent, we can write [26]

$$p\left(\lambda_k^{(1)}, \ldots, \lambda_k^{(L)} | \mathbf{b}\right) = \prod_{l=1}^{L} p_k(l)\left(\lambda_k^{(l)} | \mathcal{M}_{\mathcal{R}}^{(l)}[\mathbf{b}]\right) \tag{9}$$

where the sign of $\lambda_k^{(l)}$ should be changed if the $k$-th bit from the codeword $\mathbf{b}$ is negated before swapping to the position $k^{(l)}$, and where $\mathcal{M}_{\mathcal{R}}^{(l)}[\mathbf{b}] = \Re\{\mathcal{M}^l[\mathbf{b}]\}$. We can now evaluate (10) by integrating over the region in the $L$-dimensional space, defined by the sign of the aggregate LLR in (11).

We must enumerate only the codewords $\mathbf{b}$ in the equation (11) which produces different real values of the modulated symbols. Thus, instead of summing over $M = 2^B$ codewords, it is enough to enumerate $\sqrt{M} = 2^{B/2}$ of them which will indeed simplify the implementation a lot.

In HSDPA, 16QAM is used and then CoRe can be applied and the maximum number of transmissions with different constellation mappings is four. Therefore, if more retransmissions should be considered, the mappings from Table I could be used in repeated manner and the LLRs of the bits corresponding to the combining could be carried out at the symbol-level [12]. Computing the expression (11) was considerably faster than the simulation of the entire transmission setup but, the implementation complexity is an issue due to a multi-fold integral.

Instead of using a multi-dimensional integration, we may simplify (11) by using Gaussian approximation [27], [6] and we can now calculate

$$\bar{P}_b(k) = \frac{2}{M}\sum_{\mathbf{b}\in\mathcal{C}} Q\left(\frac{|\mu_k(\mathbf{b})|}{\sqrt{v}}\right), \tag{12}$$

where $Q(t) = \frac{1}{2\pi}\int_t^\infty \exp(-\tau^2/2)d\tau$ and $v = \sum_{l=1}^{L}\omega^{(l)}$ is the variance and the mean is defined as $\mu_k(\mathbf{b}) = \sum_{l=1}^{L}\mu_{k^{(l)}}^{(l)}(\mathcal{M}_{\mathcal{R}}^{(l)}[\mathbf{b}])$ . The average BER can now be calculated similarly to (7) and follows as

$$\bar{P}_b(k) = \frac{2}{B}\sum_{k=1}^{B/2}\bar{P}_b(2k). \tag{13}$$

In Fig (3), we show the BER performance for different number of transmissions compared to using the proposed scheme by Samra in [7]. We can observe that the proposed constellation rearrangement scheme based on the LLR metric performs slightly better.

## V. Combination of Symbol Mapping Diversity and Power Adjustment

One way of conserving the power is to use some power adjustment scheme, that allows to vary transmit power in order to reduce energy consumption. Many studies have shown that in a real-life network power control schemes can achieve better power conservation and higher system throughput through better spatial reuse of the spectrum [16].

For the most common HARQ scheme the retransmission power is the same as the new transmission. In a time varying channel, it can be convenient to use power adjustment where the new transmission starts a lower power and if any further retransmissions are requested, the transmitter will increase the transmission power according

TABLE I
BITS ARRANGEMENT FOR 16QAM [ [21], SEC. 4.5.7].

| Transmission | Operation | Label |
|---|---|---|
| 1 | None | $[c_4, c_3, c_2, c_1]$ |
| 2 | Swap MSBs with LSBs | $[c_2, c_1, c_4, c_3]$ |
| 3 | Invert LSBs | $[c_4, c_3, \overline{c_2}, \overline{c_1}]$ |
| 4 | Swap MSBs with LSBs and invert LSBs | $[c_2, c_1, \overline{c_4}, \overline{c_3}]$ |

$$P_b(k) = \frac{1}{M}\sum_{\mathbf{b}\in\mathcal{C}_1^k}\int\cdots\int_{\epsilon_l\le 0}\prod_{l=1}^{L}p_k(l)\left(\lambda_k^{(l)}|\mathcal{M}_{\mathcal{R}}^{(l)}[\mathbf{b}]\right)d\lambda_k^{(1)}\cdots d\lambda_k^{(L)} + \frac{1}{M}\sum_{\mathbf{b}\in\mathcal{C}_1^k}\int\cdots\int_{\epsilon_l\ge 0}\prod_{l=1}^{L}p_k(l)\left(\lambda_k^{(l)}|\mathcal{M}_{\mathcal{R}}^{(l)}[\mathbf{b}]\right)d\lambda_k^{(1)}\cdots d\lambda_k^{(L)} \quad (11)$$

TABLE II
SIZE OF $\Delta_I$ IN THE POWER ADJUSTMENT.

| Adjustment No. | $\Delta_1$ | $\Delta_2$ | $\Delta_3$ |
|---|---|---|---|
| 1 | 1...5 | 1...5 | 1...5 |
| 2 | 1.5 | -1 | -2 |
| 3 | 0.5 | 1 | 1.5 |

to a predefined scheme. This technique will increase the probability of successfully decoding the packet and the average number of retransmission will be reduced.

One of the key questions is how to adjust the transmission power. Let us define $\Delta_l$ as the step size while adjusting the $l^{th}$ retransmission power. In this paper we consider different step sizes, $\Delta_1 = 0.5\ dB,\ \Delta_2 = 1\ dB,\ \Delta_3 = 1.5\ dB$ and $\Delta_1 = 1\ dB,\ \Delta_2 = 2\ dB,\ \Delta_3 = 3\ dB$. In the proposed scheme, if a retransmission is requested, we first need to solve the equation (6) to find the best possible bit-to-symbol mapping and also adjust the transmission power by using $\Delta_1$. This procedure continues until a packet is correct decoded or exceeded the time limit. The $E_b/N_{0_{init}}$ is the $E_b/N_0$ of the new transmission. This means that the $E_b/N_0$ of the $l$th transmission is the sum of $E_b/N_{0_{init}}$ and $\Delta_l$.

## VI. PERFORMANCE RESULTS

To asses the performance of the proposed scheme a full scale link level simulation has been done. We have mainly used the throughput and number of retransmissions as performance measure in this paper. The step size for the power adjustment scheme is given in Table II and the simulation parameters are given in Table III.

### A. Frequency Selective Rayleigh Fading Channel

For simulations with a frequency-selective Rayleigh fading channel, the International Telecommunication Union (ITU) Pedestrian-B channel model is used [20]. This channel model defines a power delay profile with 6 paths at specified delays. The mobile speed is 3 km/h $\approx$ 0.83 m/s. The $L$ Rayleigh fading channels coefficients $h_i$ are normalized to unit gain $\mathcal{E}\left(\sum_{i=1}^{L}|h_i|^2\right) = 1$. The received signal can be written as

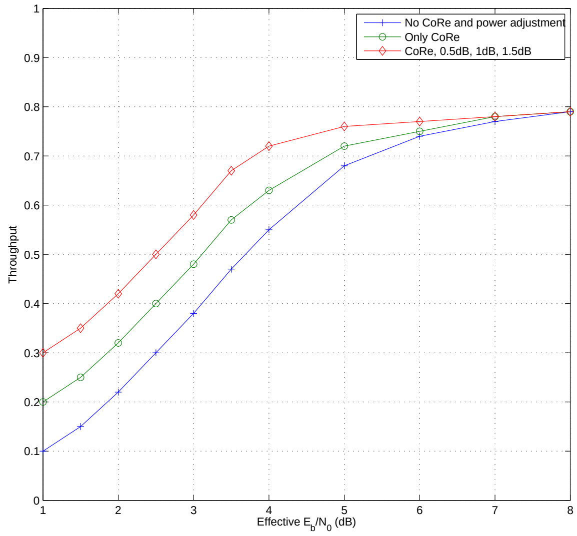


Fig. 4. Throughput performance vs effective $E_b/N_0$

$$r(t) = \tau\sum_{i=1}^{L}h_i s(t-\tau_i) + n(t) \quad (14)$$

where $\tau_i$ denotes the delays in sample durations. For collecting, the entire received energy, the number of RAKE fingers is set to the number of propagation paths.

### B. Simulation Results

Simulation results is shown as throughput versus effective $E_b/N_0$, where $E_b$ is defined as the energy per bit information bit. We define the effective $E_b/N_0$ as the average total transmitted $E_b/N_0$ per encoder packet and can be calculated as

$$E_b/N_{0eff} = 10\log_{10}\left(\frac{\sum_{i=1}^{N_{total}}10^{\frac{E_b/N_{0,i}}{10}}}{N_{delivered}}\right), \quad (15)$$

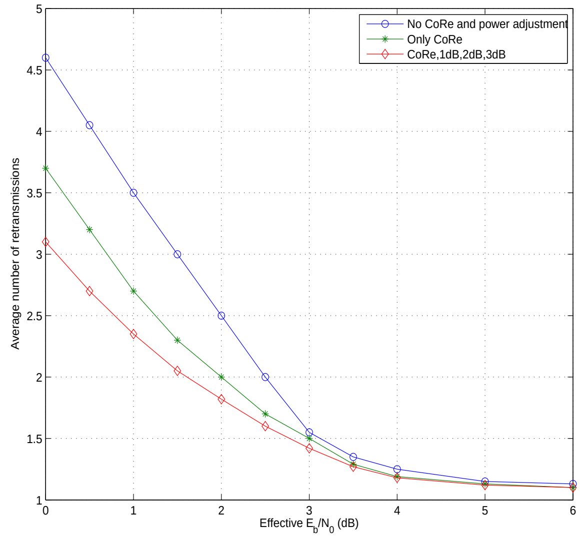


Fig. 5. Number of retransmissions vs effective $E_b/N_0$

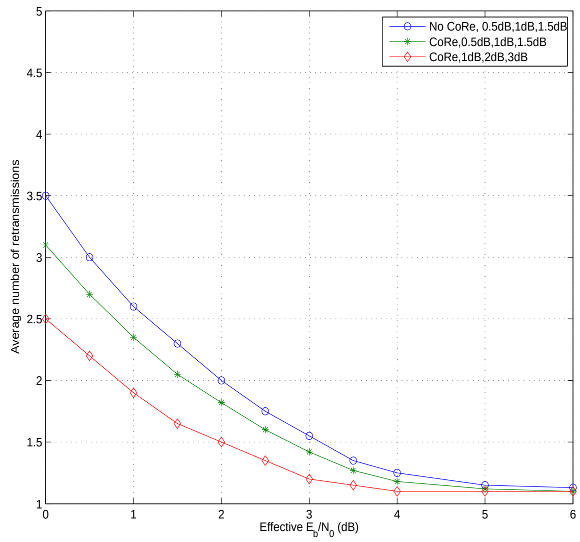


Fig. 6. Average number of retransmissions vs effective $E_b/N_0$.

where we have defined $N_{total}$ as the sum of new transmitted encoder packets and retransmitted encoder packets, while $N_{delivered}$ is defined as the number of new transmitted encoder packets.

In Fig. 4, we have plotted the throughput as a function of the effective $E_b/N_0$. We have considered three different schemes, namely Chase combining (no CoRe and no power adjustment), only CoRe and then our proposed scheme with both CoRe and power adjustment. The results clearly show that our proposed method performs better than Chase combining, especially for low values of effective $E_b/N_0$ the gain is substantial. It can also be observed that the proposed scheme performs better than only using rearrangement of signal constellations.

TABLE III
SIMULATION PARAMETERS

| Parameter | Value |
|---|---|
| Chip-rate | 3.84 Mcps |
| Channel estimation | Ideal |
| Allocated power for HS-DSCH | 80% (-1 dB) |
| Spreading factor | 16 |
| Number of codes for HS-DSCH | 1 |
| Number of slots per TTI | 3 |
| Frame length | 2 ms |
| Channel coding | Turbo code (rate 3/4) |
| CRC | 24 bits |
| Tail bits | 12 |
| Number of decoder iterations | 8 |
| Max number of retransmissions | 8 |

We can calculate the average number of transmission times per encoder packet and it is given by

$$N_{average} = \frac{N_{total}}{N_{delivered}}. \tag{16}$$

In Fig. 5, the average number of transmissions vs effective $E_b/N_0$ is shown for three different cases. The obtained results clearly show that both schemes employing rearrangement of signal constellations decreases the number of transmissions in the system. Then the proposed scheme which also adds power adjustment to the CoRe can for an $E_b/N_0 = 0\ dB$ decrease the the number of retransmissions by 50%. By decreasing the number of retransmissions the energy consumption will decrease which is important in wireless communications systems. In Fig 6, have compared different step sizes for the power adjustment.

## VII. CONCLUSION

In this paper, we have proposed a combined symbol mapping diversity scheme with power adjustment. The mapping diversity is effective in retransmissions since it can provide a diversity gain and by adding power adjustment to that technique, we obtain an efficient HARQ scheme for HSDPA. The new signal mappings is based on optimizing the log-likelihood ratio. The proposed scheme take advantage of the channel variations in an intelligent way to increase the system performance. For new retransmissions, the bit-to-symbol mapping is changed and the transmission power is adjusted according to a predefined pattern. Our simulation results show that the proposed scheme is superior to a scheme using Chase combining. Although, it should be mentioned that the buffer size will increase since more information needs to be stored.

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