Enhanced HARQ Scheme based on Rearrangement of Signal Constellation and Frequency Diversity for OFDM Systems

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***Abstract*— In multi-carrier modulation systems such as OFDM, several subcarriers are used for transmission and their received signal quality is different from one subcarrier to others in frequency selective fading channel. In this paper an enhanced hybrid ARQ scheme for OFDM systems is proposed. When data is requested for retransmissions, we change the bit interleaving mode in such manner that the data sequence is changed. Since the coded bit is assigned to different subcarriers and positions of a modulation symbols in different retransmissions we can take advantage of this effect, and achieve both frequency- and modulation constellation diversity. Results from computer simulations confirm that the proposed scheme improves the throughput performance. After two transmissions and with packet error rate (PER) of 10^{-4} the proposed scheme gain approximate 3 dB compared to a scheme employing Chase combining. The performance gain is even more for three transmissions (2 retransmissions).**

I. INTRODUCTION

High data rate wireless access systems offering data rates over 25 Mbit/s is currently discussed since the demand for wireless multimedia communication is rapidly increasing due to strong advances in portable computer hardware and different Internet services. In such systems severe degradation is caused by the inter-symbol interference (ISI) generated by multipath propagation in the wireless channel. Orthogonal frequency division multiplexing (OFDM) is a promising technique to combat ISI even when the delay spread is large compared to the symbol duration [1]. OFDM is a type of multi-carrier transmission which splits the nominal frequency band into a suitable number of subcarriers, each modulated with a low modulation rate. Moreover, the OFDM signal allows us to insert adequate guard intervals between successive OFDM symbols which mitigates the effect of ISI. OFDM is adopted in several wireless systems such as the digital audio/video broadcasting (DAB/DVB), HIPERLAN/2 [2], IEEE 802.11a [3], and the Japanese WLAN standard MMAC have decided to adopt OFDM in wireless access systems for 5 GHz band.

To achieve high quality or error free transmission for multimedia services in the wireless network some error control techniques is adopted, and automatic repeat request (ARQ) is one of the most familiar schemes and conventional ARQ schemes provides a time diversity. Conventional ARQ schemes are based on utilizing simple error detection code of transmitted data and transmits the data in form of a packet. The receiver then check the transmitted data by the error correction code and send a positive or negative acknowledgment (ACK or NACK) to inform the transmitter whether or not the packet was correct decoded. It is well known that the throughput of an ARQ scheme can be improved by using packet combining. In packet combining all received copies of the data packet are combined to form a more reliable estimate of the transmitted data. In Chase's combining scheme [4], a codeword from a code of rate R is repeated K times to form a codeword from a lower rate code of rate R/K. Each copy is weighted by its corresponding reliability which depends on the instantaneous gain of the channel. Cyclic redundancy check (CRC) bits usually form an error detection code and it is used by the receiver to determine if the packet has been decoded correctly. In [5] the author showed that packet combining can increase the system performance in OFDM based wireless LAN. In [6] Kumagi et al presented a maximal ratio combining frequency diversity ARQ scheme where a certain OFDM symbol within a packet is transmitted by using different subcarriers in each retransmissions and then combine the packets. By utilizing this technique frequency diversity was added. Another type of ARQ scheme is called hybrid ARQ scheme which incorporates forward error correction (FEC) and ARQ in order to benefit from both these schemes. Hybrid ARQ can be categorized into two classes: type I Hybrid ARQ (HARQ-1) and type-II Hybrid ARQ (HARQ-II) [7]. In HARQ-I schemes received packet with uncorrectable packets are discarded. In HARQ-II schemes these erroneous packets are stored and combined with future retransmissions of the same packet. Depending on network resources, the code rate and the terminal capabilities, either Chase combining, partial or full incremental redundancy (IR) is used in retransmissions [8].

Another way of achieving diversity can be to rearrange the signal constellation and in that way achieve signal or modulation constellation diversity. In [10] Wengerter et al evaluated an advanced hybrid ARQ scheme for high speed downlink

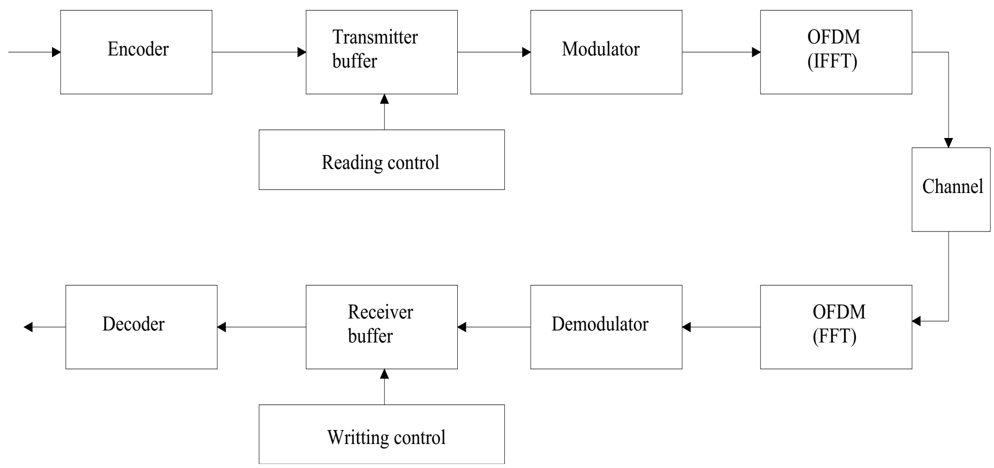

Fig. 1. Block diagram of used system model.

packet access (HSDPA) based on signal rearrangement. That scheme take advantage of modulation constellation diversity (mapping diversity) by rearranging the signal constellation in retransmissions.

In this paper, we propose a hybrid ARQ scheme for OFDM systems which both employs frequency- and modulation constellation diversity. By shifting the code bit stream by a suitable step, i.e., corresponding subcarriers frequency shift is larger than the channel coherent bandwidth. Frequency diversity is then achieved and we add the rearrangement of signal constellations to achieve further diversity gain. The obtained simulation results show that this proposed scheme outperforms the schemes proposed in [6] and [10].

The paper is organized as follows: Section II describes the OFDM system model. The signal constellation and bit reliability properties for the new scheme is described in Section III. Section IV provides simulation results and finally in Section V we conclude the work.

II. System Model

The block diagram of the multi-carrier modulation system discussed in this paper is illustrated in figure 1. We assume a OFDM system with N subcarriers, a bandwidth of W Hz, a symbol length of T seconds, of which T_{cp} seconds is the length of the cyclic prefix, the transmitter uses the following waveforms

$$\phi_t = \begin{cases} \frac{1}{\sqrt{T-T_{cp}}} e^{j2\pi \frac{W}{N} k(t-T_{cp})} & \text{if } t \in [0,T] \\ 0 & \text{Otherwise} \end{cases}$$

where $T = N/W + T_{cp}$ and $\phi_k(t) = \phi_k(t+N/W)$ when t is within the cyclic prefix $[0, T_{cp}]$, since $\phi_k(t)$ is rectangular pulse modulated on the carrier frequency kW/N. Using an M-QAM modulation scheme for each carrier, we can assume that mutually independent equiprobable symbols belonging to the alphabet

$$\mathcal{A} = \{[(2m-1-\sqrt{M})+j(2n-1-\sqrt{M})], m, n = 1, 2, ..., \sqrt{M}\}$$

The waveforms $\phi_k(t)$ are used in the modulation and the transmitted baseband signal for OFDM symbol number i is

$$s_i(t) = \sum_{k=0}^{N-1} x_{k,i}\phi_k(t - iT)$$

where $x_{0,0}, x_{1,i}, \cdots, x_{N-1,i}$ are complex numbers from a set of signal constellation point. When an infinite sequence of OFDM symbols is transmitted, the output from the transmitter are then

$$s(t) = \sum_{l=-\infty}^{\infty} s_i(t) = \sum_{l=-\infty}^{\infty} \sum_{k=0}^{N-1} x_{k,i}\phi_k(t - iT).$$

The reading control logic controls the output sequence according to the interleaving table and the shift step specified by the modulation level and transmission time. The output of the first transmission, the interleaved data stream and the sequence of subsequent transmission is the result of cycle shift of interleaved data. Then the bitstream is mapped to complex-valued symbols according to certain modulation constellations. The mobile radio channel is modelled as a tapped delay line with impulse response

$$h(t) = \sum_{i=0}^{P-1} \alpha_i(t)\delta(t - \tau_i),$$

where α_i is complex Gaussian random variable tap weight, τ is the relative time delay of the ith path, and P is the number of paths. Then the received signal can be expressed as

$$r_{i,k}(t) = h_k(t)x_{i,k}(t) + \eta_{i,k}(t)$$

where $\eta_{i,k}$ is additive white Gaussian noise with variance $\sigma^2 = N_0$ and h_k is the gain of the k-th subchannel. At the receiver the packet is demodulated and the outputs are soft information of code bits which is required by the decoder. The soft outputs are added into the receiver buffer with an order corresponding to the variable interleaving scheme used at the transmission end. Note that the addition of soft information at bit level is

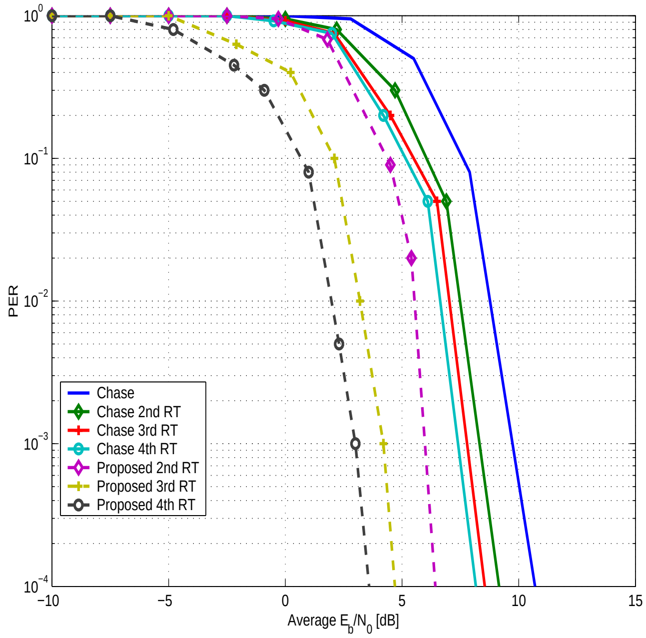

Fig. 2. PER performance between the proposed scheme and a scheme employing Chase combining. In this case 64 QAM is used as modulation technique.

somewhat equal to maximal ratio combining (MRC) at symbol level. The MRC at bit level can be done by direct addition of demodulation of soft information. We can define the log-likelihood-ratio (LLR) of a demodulated bit b from a received modulation symbol $r = x + jy$ as [9]:

$$LLR(b) = \ln\left(\frac{Pr\{b=1|r\}}{Pr\{b=1|r\}}\right).$$

III. Enhanced HARQ Scheme

In [6] the authors presented a method which regularly changes the subcarrier assignment pattern at each retransmission, so one modulation symbol can be mapped to different subcarriers. It is well known that the fading channel between any pair of OFDM subcarriers is independent of each other, provided that the frequency separation is wider than the channels coherent bandwidth. If so, then frequency diversity can be achieved besides time diversity. This is equivalent to shift the code bits mapped to the same symbol collectively, which can be done at bit level.

If we shift the coded bitstream by some suitable step, i.e. the corresponding subcarriers frequency shift is wider than the channel coherent bandwidth, frequency diversity is achieved. Then we make further cyclic shift to the subcarrier assignment and the bits are mapped to different positions of a modulation symbol. Consequently the modulation constellation is added to the frequency diversity effect.

If we assume an OFDM system with bandwidth 5 MHz and one code frame is encapsulated exactly in one OFDM symbol. A shift of $\frac{1}{2}$ frame at bit level results in that all subcarriers shift of 2.5 MHz and this indicates that a minimal multipath delay

TABLE I

Parameters of specific modulation

Modulation	8PSK	16QAM	64QAM
Shift step (bits)	1	2	2
Cycle no.	3	2	3

of $0.4\mu s$ can be accepted to fully realize the diversity effect. In our proposed scheme we consider that a $\frac{1}{2}$ frame is cyclic shifted in the first retransmission. In the second retransmission, $\frac{1}{4}$ frame relative first retransmission is cycle shifted, and in the third retransmission, $\frac{3}{4}$ frame relative first retransmission is cyclic shifted. For the subsequent transmission narrower shift step can be chosen, but then the frequency diversity decreases. Now we make additional cycle shift, based on the specific modulation constellations property. After certain shifts, no more diversity can be achieved. The shift step for different high level modulation techniques are listed in table 1.

The proposed scheme is compatible to various multi-level modulation techniques. However, if QPSK is used in OFDM system, the modulation constellation diversity effect will not be useful and the scheme degenerates into a scheme of subcarrier rearrangement. This proposed scheme have minor impact of the transmitter respectively the receiver and we need to store the different mapping rules. Furthermore, this proposed scheme does not require any extra information other than modulation mode and transmission number, no subcarrier assignment and MRC is needed at symbol level. The logic control device can be added to the bit level buffers.

IV. Simulation Results

To evaluate the performance of the proposed HARQ scheme, we consider an OFDM system with M-QAM modulation. We evaluate the proposed scheme in terms of packet error rate (PER) and throughput performance. The throughput is measured in terms of bits per second and is obtained by $T = R\left(\frac{1-FER}{N}\right)$, where R is the transmitted bit rate, *FER* is the residual frame error rate beyond the maximum number of transmissions and N is the average number of transmissions. In these simulations we have considered the HIPERLAN/2 physical layer and the most important parameters are shown in table II. The multipath radio channel considered in this paper is specified in [11]. The ETSI BRAN channel models contains different channel models, representing different environments, with tapped delay lines modelled as Rayleigh or Rician as indicated in table III. Channel time variance was modelled with a classical Jake's doppler spectrum [12]. We assumes perfect CSI and reliable ACK/NACK feedback channel. If a transmitted packet cannot be decoded the receiver requests a retransmission in order to increase decoding probability, where a maximum of 10 retransmission attempts per packet is allowed. The data is Chase combined in the receiver. In figure 2 we compare our proposed scheme with a scheme based on Chase combining when 64 QAM is used. Our proposed scheme lower the required E_b/N_0 by 3.5 dB, 3.9 dB and 4.5 dB for 2nd, 3rd and 4th retransmissions respectively at a PER

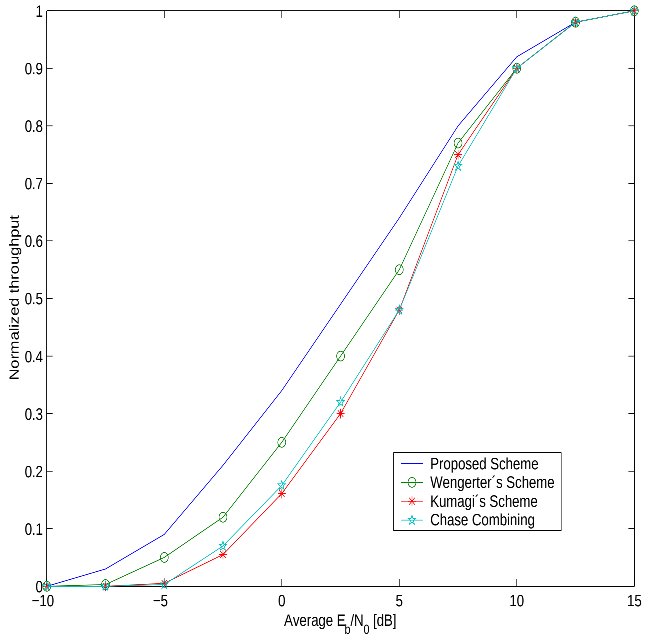

Fig. 3. Throughput performance between the proposed scheme, Wengerter's scheme [10], Kumagi's scheme [6] and Chase combining. In this case 64 QAM is used as modulation technique. Channel model A is used in this case.

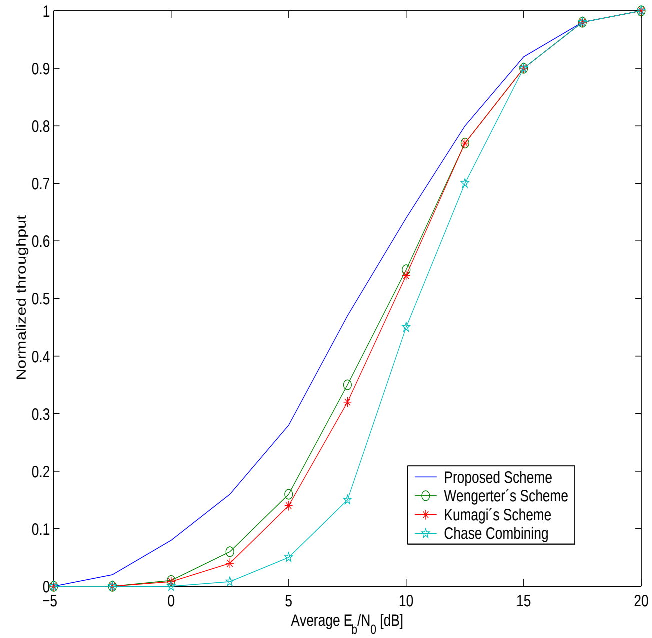

Fig. 4. Throughput performance between the proposed schemes when Channel model E is used. Still 64 QAM is used as modulation technique.

of 1%. We can see that it requires only 2 transmissions for our proposed scheme while 4 transmissions are required for Chase combining.

In figure 4 the system throughput is plotted as function of average E_b/N_0 in a slow fading channel with modest frequency fluctuation where the modulation constellation diversity contribute more than frequency diversity. It is also noted that the scheme utilizing only subcarrier reassignment implies lower average SNR and the performance is the worst of all schemes. The largest gain is obtained when the channel are in bad condition and for good condition channel the performance of the different schemes are the same. When the frequency fluctuations are more intensive the effect of subcarrier are more evident as can be seen in figure 5. Here the proposed scheme takes full effect of both the modulation constellation diversity and frequency diversity effect.

Figure 6 shows the packet transmission delay performance normalized by the packet length under the condition where the normalized delay period τ/T_s is 0.0156, where T_s is defined as the symbol duration. Furthermore, we assumed that five users are transmitting simultaneously at the same power level. The packet transmission delay is defined as the average time from the packet is generated until it is successfully decoded at the receiver. It is observed that even for small values of E_b/N_0 the proposed scheme can achieve smaller transmission delay. These results confirms that the proposed scheme is effective to reduce frequent packet retransmissions in the lower region of E_b/N_0.

The average number of transmissions is plotted in figure 5. When the throughput is less than $\eta = 0.2$ which corresponds to the region where the average number of retransmissions is equal to 3, the improvement of our proposed scheme is superior compared to the other schemes. This improvement is due to the modulation constellation and frequency diversity effect.

V. Concluding Remarks

In this paper we have proposed an enhanced hybrid ARQ scheme for OFDM systems employing both modulation constellation (symbol mapping) and frequency diversity. In frequency selective fading channel of mobile radio environment, each subcarrier of the OFDM signal is subject to different distortion and its received signal quality is different. Considering this feature rearrangement of signal constellations and "bit interleaving" can improve the diversity effect. The proposed scheme in this paper is evaluated by means of computer simulation and compared to other proposed schemes for OFDM systems. The obtained results show that the proposed scheme are significantly better than a scheme employing Chase combining at the receiver, especially when the channel conditions are poor. For good channel conditions the schemes are performing equally. The scheme do not need operations at symbol level which reduces the hardware cost by sharing the bit level buffer with the decoder.

References

[1] R. V. Nee and R. Prasad, *OFDM for Wireless Multimedia Communications,* Artech House publishers, Dec. 1999.

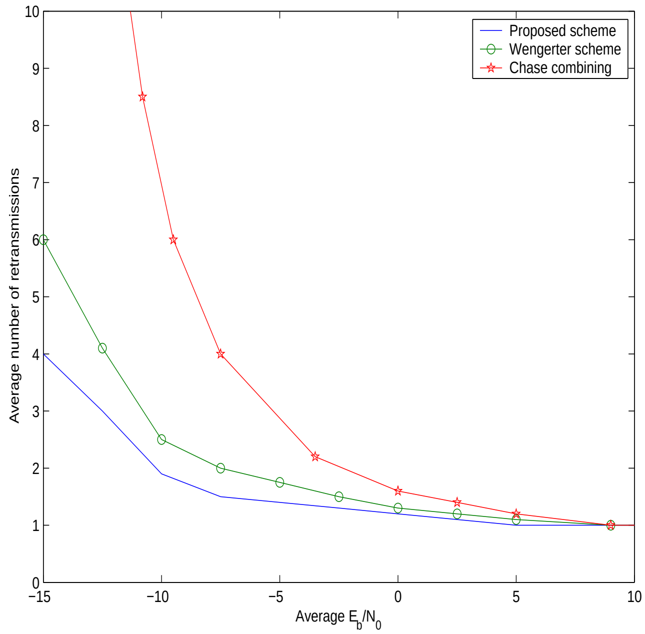

Fig. 5. Number of retransmissions vs E_b/N_0. Comparison between the proposed scheme, Wengerters scheme [10] and Chase combining.

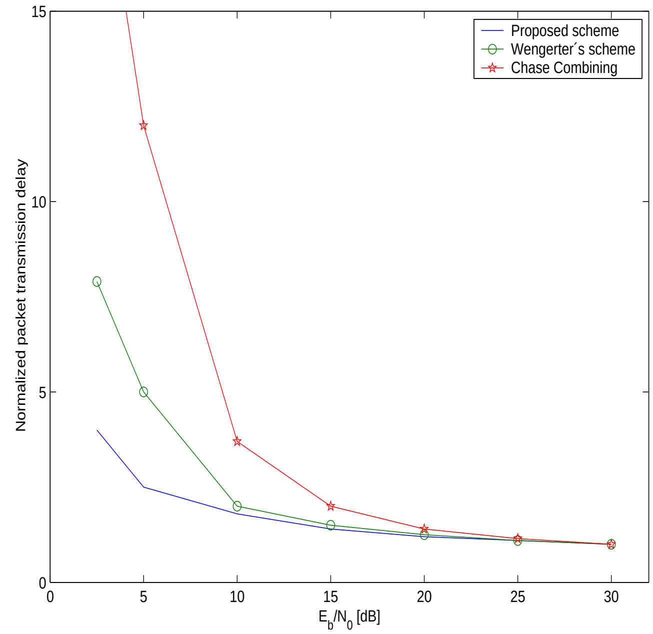

Fig. 6. Packet transmission delay vs E_b/N_0. Comparison between the proposed scheme, Wengerters scheme [10] and Chase combining

TABLE II
SIMULATION ASSUMPTIONS

Parameter	Explanation/Assumption
No. of subcarriers	64
No. of active subcarriers	52, 48 (data) and 4 (pilots)
Channel spacing	20 MHz
Sampling rate	20 Msample/s
Guard interval	800 ns
Code rate	1/2
Demodulation	coherent
Max. transmission number	10
Retransmission delay	0.5 ms

TABLE III
ETSI BRAN CHANNEL MODELS

Name	RMS DS	Characteristics	Environment
A	50ns	Rayleigh	Office NLOS
B	100ns	Rayleigh	NLOS
C	150ns	Rayleigh	NLOS
D	140ns	Rician (K=10dB)	LOS
E	250ns	Rayleigh	NLOS

[2] ETSI. Broadband radio access network (BRAN); HIPERLAN type 2 technical specification; physical (PHY) layer. Technical specification ETSI TS 101 475 v1.1.1, ETSI, Sophia-Antipolis Cedex, France, April 2000.

[3] IEEE Standard 802.11a, PART II. Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: High Speed physical layer in the 5 GHz band. Technical specification ANSI/IEEE Std. 802.11, 1999 Edition, IEEE, Piscataway, New Jersey, USA, August 1999.

[4] D. Chase, ”Code combining - a maximum-likelihood decoding approach for combining an arbitrary number of noisy packets,” *IEEE Trans. Commun.*, vol. COM-33, no. 5, pp. 385-393, May 1985.

[5] M. Gidlund, ”Receiver-based packet combining in 802.11a Wireless LAN,” in *Proc. RAWCON03, Boston, USA, Augusti 2003*.

[6] T. Kumagi, M. Mizoguchi, T. Onizawa, H. Takanashi and M. Morikura, ”A Maximal ratio combining frequency diversity ARQ scheme for OFDM signals,” In *Proc. PIMRC'98*, Lissaboa, Portugal 1998.

[7] S. B. Wicker, *Error Control Systems for Digital Communications and Storage*, Englewood Cliffs, N. J., Prentice-Hall 1995.

[8] P. Frenger, S. Parkvall and E. Dahlman, ”Performance comparison of HARQ with Chase combining and incremental redundancy for HSDPA,” in *Proc. IEEE VTC'01*, 2001.

[9] A. Burr, *Modulation and Coding for Wireless Communications*, Essex, UK: Pearson Education, Prentice-Hall, 2001.

[10] C. Wengerter, A. Von Elbart, E. Seidel, G. Velev and M. P Schmitt, ”Advanced hybrid ARQ technique employing a signal constellation rearrangement,” in *Proc. IEEE VTC'02-fall*, Vancouver, Canada, Sept. 2002.

[11] J. Medbo and P. Schramm, ”Channel models for HiperLAN/2,” ETSI BRAN document no. 3ERI085B, 1998.

[12] W. C. Jakes, *Microwave Mobile Communication*, IEEE Press 1974.