Joint Optimization of Radio Parameters in HSDPA

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***Abstract*— In this paper we propose two contributions to the field of cross-layer optimization for 3rd generation mobile communication systems. The first chapter derives an analytical bijective system model for the quality of service parameters throughput and delay in an HSDPA system. Link level simulations reveal an excellent match of the new model components. In the second part, the derived model is used to design a cross-layer optimization technique, serving a set of *quality of service* (QoS) demands with minimum necessary transmit power. The optimized system yields the same QoS performance with a significantly lower amount of transmit power, which in future investigations will enable scheduling algorithms to maximize the system capacity.**

I. Introduction

The highly efficient use of radio parameters like bandwidth, transmit power, and air time are of pivotal importance for the design of future wireless communication systems. Expected to support a wide range of demanding services, these systems additionally need to provide different levels of QoS, which makes their design even more challenging. Separating the functions of these communication systems in so-called layers [1] drastically reduces the complexity of describing such systems and thus is the common practice in design and optimization. As this approach is clearly sub-optimal the past years have seen the evolution of so-called cross-layer optimization techniques that work across the borders of different system layers. Allowing a limited exchange of information between the components in the protocol stack provides additional adaptability to changing environment conditions and service application requirements and so can find the optimum in solution sets, that seem equivalent to the single layer. Prominent examples of such approaches include the adaptation of the information rate to the channel condition [2], [3], or the channel dependent allocation of TDMA frames [4] -[7].

We present an approach for the joint optimization of radio parameters in HSDPA. Aiming at a minimization of the scarce system resource transmit power P, the mode of operation $\mathcal{M}$, which consists of CDMA-, *forward error correction* (FEC) code and protocol parameters is optimized through:

$$\{P_1, \mathcal{M}_1 \ldots, P_K, \mathcal{M}_K\} = \underset{P_1,\mathcal{M}_1\ldots,P_K,\mathcal{M}_K}{\operatorname{argmin}} \sum_{k=1}^{K} P_k,$$

$$\text{subject to:} \quad \begin{cases} \tau_k \leq \tau_{\text{rq},k} & \forall k \\ R_k \geq R_{\text{rq},k} & \forall k. \end{cases}$$

The QoS constraints are implemented as requirements on the throughput R, which is defined as the mean net data rate visible to the scheduling unit, and the outage delay τ, i.e. the time that with probability $(1 - \pi_{\text{out}})$ suffices to successfully transmit a data packet.

To explicitly formulate and solve the posed problem, the system components CDMA code channel, FEC code and *hybrid automatic repeat request* (HARQ) protocol are backed with analytical models. As will be shown in Section III the resulting model allows the partitioning of the above program into a mode-dependent user-wise mutually decoupled mode optimization and the subsequent minimization of transmit powers subject to SINR constraints. Relying on the knowledge of how to solve the latter (cf. [8], [9]), the mode optimization can be implemented by table look-ups, providing extremely efficient means for power optimal system configuration.

II. System Model

The proposed system model consists of four components as illustrated in Fig. 1, which are detailed in the sequel of this chapter. Analytical submodels for the CDMA code channels,

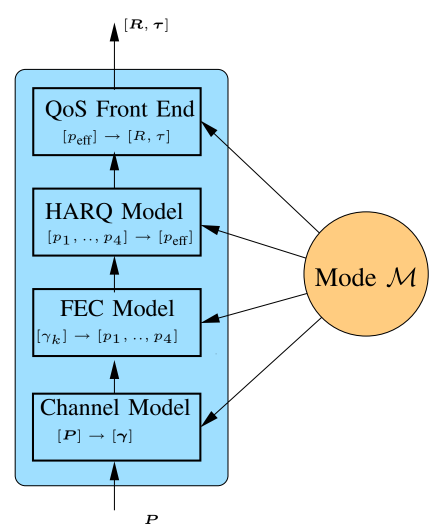

Fig. 1. Components of the System Model

the FEC code and the HARQ protocol allow to efficiently formulate the connection between system parameters and QoS measures. All models are parameterized by the mode of operation $\mathcal{M}$ consisting of modulation and coding scheme.

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A. CDMA Code Channel

We model interference phenomena in the DS-CDMA downlink by the signal to noise and interference ratio:

$$\gamma_k = \frac{\frac{\chi}{n_\chi}|h_k|^2 P_k}{\sigma^2_{n_k} + \sum_{l=1}^{K} \nu_k |h_k|^2 P_l}, \tag{1}$$

at the input of the decoder of the FEC code, in the sequel called channel decoder. The numerator in (1) includes the transmit power $\frac{P_k}{n_{\chi,k}}$ per CDMA code channel, a channel energy of $|h_k|^2$ and a spreading gain of χ. Beside the noise term $\sigma^2_{n,k}$, the denominator also introduces the interference of all $\sum_{k=1}^{K} n_{\chi,k}$ code channels. The received spreading sequences usually become non-orthogonal, due to the frequency selectivity of the wireless propagation channel. The resulting interference is modeled by so called orthogonality factors ν_k. As there are K users present, the complete effective interference power reads $\sum_{l=1}^{K} \nu_k |h_k|^2 P_l$. This model establishes a bijective relationship between the transmit powers P_k and the resulting *signal to interference and noise ratio* SINR γ_k at the input of the channel decoders.

B. FEC Code

Based on the above *discrete memoryless channel* (DMC) model of the CDMA code channel, the cutoff rate theorem [10], [11], [12] allows to formulate an upper bound for the code word error probability of block codes. Through a linearization of the Gallager error exponent, the mode parameterized analytic modeling of the relation between decoder SINR and error probability in coded transmission systems is enabled. Moreover and in contrast to capacity based approaches, it includes the complete mode dependency, i. e. the influence of modulation alphabets with finite cardinality q and finite block lengths n_{eq} beside the binary code rate $R_{\text{b}} = R_{\text{c},k}\text{ld}q$. Aiming for the employment of these very favorable properties within the cross-layer system model, [10] introduces the cutoff rate theorem, that bounds the error probability of a block code with block length n_{eq} and binary code rate $R_{\text{b}} = R_{\text{c},k}\text{ld}q < R_0(\gamma_k)$ in bits per CDMA channel use by:

$$p_{\text{cw}} \leq 2^{-n_{\text{eq}}(R_0(\gamma_k) - R_{\text{b}})}. \tag{2}$$

The cutoff rate $R_0(\gamma_k)$ denotes the maximum of the Gallager error exponent and is defined as a function of the conditional probability density of obtaining a channel output given a certain channel input. For DMCs and a modulation alphabet $\mathcal{A} = \{a_1, \ldots, a_q\}$ of cardinality q the derivations in [13], [14] compute the cutoff rate to:

$$R_0(\gamma_k) = \text{ld}\,[q] - \text{ld}\left[1 + \frac{2}{q}\sum_{m=1}^{q-1}\sum_{k=m+1}^{q} \mathrm{e}^{\left(-\frac{1}{4}|a_l - a_m|^2\gamma_k\right)}\right].$$

As the employed FEC code in HSDPA is not a block code, but rather a turbo decoded convolutional code, Eq. (2) does not apply directly. However it turns out, that the performance of turbo like codes with a word length B can be very well predicted by splitting the turbo code words into a number of $\frac{B}{n_{\text{eq}}}$ sub-words. By applying Eq. (2) to each sub-word independently, the complementary code word error probability of the turbo code, i.e. the probability of correct decoding of all sub-words, can be written as:[1]

$$1 - p_B = (1 - p_{\text{cw}})^{\frac{B}{n_{\text{eq}}}}$$

The equivalent block length n_{eq} thus has to be understood as the length of a $(n_{\text{eq}}, k)_q$ block code, which achieves approximately the same performance as an HSDPA compliant turbo decoder, terminated after B bits. As the performance of concatenated codes depends logarithmically on the employed interleaver length between inner and outer code, the parameter A in the relation:

$$n_{\text{eq}} = A\ln(B), \tag{3}$$

can be used to make Eq. (3) an excellent match to the performance of the actual employed HSDPA turbo decoder. For the HSDPA background, tackled within the remainder of this article, $A = 32$ has proven a suitable constant choice. The resulting FEC code model thus reads:

$$p_B = 1 - \left(1 - 2^{-32\ln(B)(R_0(\gamma_k) - R_{\text{b}})}\right)^{\frac{B}{32\ln(B)}}. \tag{4}$$

Comparing the error performance of an HSDPA FEC turbo code on an AWGN DMC in link level simulations with the cutoff rate based approximation obtained from Eq. (4), each

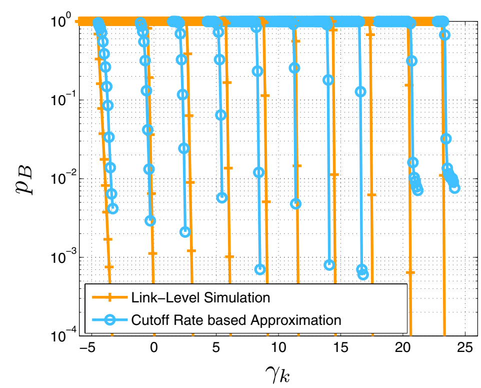

Fig. 2. Validation of Eq. (4) with Link-Level Simulations

neighbouring pair of graphs in 2 visualizes the comparison for one specific HSDPA mode. With the superb match in waterfall regions and slopes, the graphs back the formulated analytical model in Eq. (4).

C. Hybrid ARQ Protocol

Assuming zero error tolerance of the regarded applications, the following considerations now shall elaborate on the probability $f_m[m]$ of necessary HARQ transmissions m, as this will allow the formulation of the QoS parameters throughput and outage-delay.

With the HARQ protocol in the MAC layer [15], HSDPA is given means to acknowledge the successful transmission of

[1]Note, that the involved Bernoulli formulation only assumes the independence of *correct decoding* of consecutive code words and thus does not contradict the phenomena of error propagation.

a packet or to demand the retransmission of lost packets. If m_{max} consecutive transmission attempts fail, the packet has to be rescheduled by the *radio network controller* (RNC). Sparing the *incremental reduncancy* (IR) methods, the following paragraph focuses on modeling the type I mode of HARQ protocols known as *Chase combining* (CC).[2] As the packets in the different transmissions of the CC mode do not differ and all face independent noise realizations on the channel, a soft combining of these packets superimposes noise components incoherently, resulting in a cumulative SINR increase $\Delta\gamma_{k,m}$. Together with the means to quantize this SINR enhancement ([18], [16], [19], [17]), which depends on the employed modulation alphabet and the specifics of the FEC code, the packet error probability after $m \leq m_{\text{max}}$ transmissions results as:

$$p_B[m] = 1 - \left(1 - 2^{-n_{\text{eq}}(R_0(\gamma_k + \Delta\gamma_{k,m}) - R_{\text{b}})}\right)^{\frac{B}{n_{\text{eq}}}}. \quad (5)$$

As the HARQ control discards all received packets after m_{max} unsuccessful transmission attempts and waits for a rescheduling of the packet by the radio network control, the above model can be cyclically extended to $m > m_{\text{max}}$ as:

$$\begin{aligned} \Delta\gamma_{k,m} &= \Delta\gamma_{k,m'} \quad \text{for} \quad m > m_{\text{max}}, \\ \text{with} \qquad m' &= m - m_{\text{max}} \left\lfloor \frac{m}{m_{\text{max}}} \right\rfloor. \end{aligned} \quad (6)$$

This equation allows to formulate the probability, that it takes m transmissions to decode a packet error free, as the product of the probability of loosing $m-1$ consecutive packages and successfully transmitting the mth. The probability $f_m[m]$ thus is given by:

$$f_m[m] = \left(\prod_{m'=1}^{m-1} p_B[m']\right)(1 - p_B[m]) \quad (7)$$

D. Throughput and Outage-Delay

With these model components it becomes possible to express the QoS parameters throughput and outage delay. Defined as the mean net data rate, the throughput directly results from the expected value of m as:

$$R = \frac{R_{\text{b}}}{\text{E}[m]}, \quad (8)$$

where $\text{E}[m]$ is given through (7) as:

$$\text{E}[m] = \sum_{m=1}^{\infty} m \left(\prod_{m'=1}^{m-1} p_B[m']\right)(1 - p_B[m]).$$

Due to the retransmissions of the HARQ protocol additional delay or latency times are introduced. The outage delay is defined as the time, such that a fraction of $1 - \pi_{\text{out}}$ of all transmission attempts are expected to succeed with a delay smaller than τ. Calling m^* the smallest value for m' that fulfills:

$$\sum_{m=1}^{m'} f_m[m] \geq (1 - \pi_{\text{out}}),$$

i.e. bounds the number of necessary transmissions with probability $1 - \pi_{\text{out}}$, we obtain the following expression for the outage-delay:

$$\tau = T_{\text{RNC}} \left\lfloor \frac{m^*}{m_{\text{max}}} \right\rfloor + T_{\text{BS}} \left(m^* - m_{\text{max}} \left\lfloor \frac{m}{m_{\text{max}}} \right\rfloor\right). \quad (9)$$

The additional delay time for RNC rescheduling is denoted by T_{RNC}, while the retransmissions $1, \ldots, 3$ only cause a delay of $T_{\text{BS}} << T_{\text{RNC}}$.

III. Optimization

The derived system model has proven its analytic nature and can be shown to be monotonic with respect to the transmit powers P_k in its components as well as in the overall mapping $\{P_1, \ldots, P_K\} \overset{(\mathcal{M}_k)}{\longmapsto} \{R_k, \tau_k\}$ and thus is bijective. The optimization problem:

$$\{P_1, \mathcal{M}_1 \ldots, P_K, \mathcal{M}_K\} = \underset{P_1, \mathcal{M}_1 \ldots, P_K, \mathcal{M}_K}{\text{argmin}} \sum_{k=1}^{K} P_k, \quad (10)$$
$$\text{subject to} \begin{cases} \tau_k \leq \tau_{\text{rq},k} & \forall k \\ R_k \geq R_{\text{rq},k} & \forall k. \end{cases},$$

therefore has a unique solution. Employing the monotonicity of the downlink power control problem (12) which has been proven in [8] or [9] the above optimization can equivalently be split into K user wise mutually decoupled mode optimization problems (11) and the resulting mode independent joint downlink power control problem in (12).

A. Mode Optimization

With the above results means are available to include the QoS requirements as constraints into the mode optimization:

$$\{\mathcal{M}_k\} = \underset{\mathcal{M}_k}{\text{argmin}}\, \gamma_k, \quad \text{s.t.} \begin{cases} \tau_k \leq \tau_{\text{rq},k} \\ R_k \geq R_{\text{rq},k} \end{cases}, \quad (11)$$

As this problem neither depends on the channel statistics or realizations nor on the requirements of the users $l \neq k$, but only on the finite set of possible system modes, i.e. triples of $\mathcal{A}_k, R_{c,k}, n_{\chi,k}$, the solutions for all tuples $R_{\text{rq},k}, \tau_{\text{rq},k}$ can be obtained from an offline generated lookup table.

To generate the mentioned table, the system model in Section II for all modes $\mathcal{M}$ is sampled in the SINR domain. Explicitly, the cutoff rate, the packet error probability, the probability function of the HARQ transmissions and the QoS parameters R_k and τ_k are computed. Thus, every mode defines a mapping of SINR values γ_k to the tuples $[R_k; \tau_k]$. These mappings are visualized in Fig. 3, where the different lines plot the SINR parameterized loci of different system modes. Given a requirement tuple consisting of R_{rq} and τ_{rq}, a search of the feasibility region $R \geq R_{\text{rq}} \wedge \tau \leq \tau_{\text{rq}}$ shaded in Fig. 3 determines the mode, that attains the feasibility region

[2]Note that publications like [16] and [17] allow to extend the proposed model to IR modes as well.

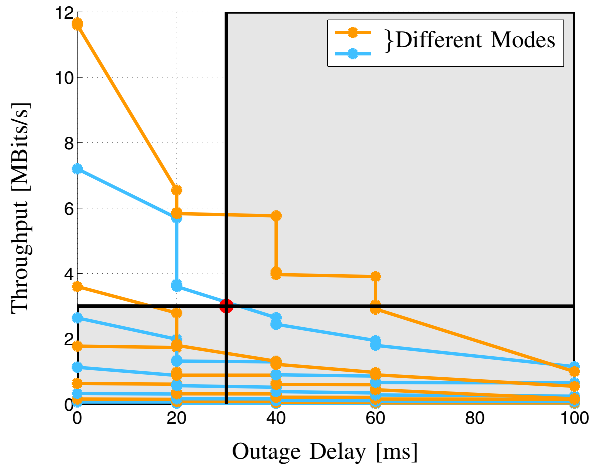

Fig. 3. Feasibility Regions for $\tau = 30$ ms and $R = 3$ MBits/s

with minimum γ_k. Recording these modes for a sufficient mesh of requirements generates the required lookup table. As mentioned before, this table is valid for arbitrary settings of other users and for arbitrary channels and thus can be generated offline, providing a low complexity method for mode optimization.

B. Downlink Power Control

Through the determination of the optimal mode of operation $\mathcal{M}$, the optimization from (10) transforms to:

$$\{P_1, \dots, P_K\} = \underset{P_1,\dots,P_K}{\operatorname{argmin}} \sum_{k=1}^{K} P_k, \quad \text{s.t.} \quad \gamma_k \geq \gamma_{\text{rq},k}, \qquad (12)$$

where $\gamma_{\text{rq},k}$ is the minimum of γ_k, resulting from the optimization in (11). As mentioned in [8], each SINR component γ_k is strictly monotonically decreasing with all $P_l, \forall l \neq k$ and is strictly monotonically increasing with P_k. The corresponding proof is straight forward and can be obtained by partial derivatives of Eq. (1). With this monotony though, the inequality constraints can be converted into equality constraints $\boldsymbol{\gamma} = \boldsymbol{\gamma}_{\text{rq}}$, as the optimum always lies on the boundary of the constraint area. Thus, the problem in (12) can equivalently be written as:

$$[P_1, \dots, P_{K_t}] = \underset{[P_1,\dots,P_{K_t}]}{\operatorname{argmin}} \sum_{k=1}^{K_t} P_k \quad \text{s.t.} \quad \boldsymbol{\gamma} = \boldsymbol{\gamma}_{\text{rq}}. \qquad (13)$$

The optimization of this scalar objective function with respect to the K powers P_k is subject to K constraint equations. As the equality constraints inherently are linearly independent, they uniquely define the solution of Eq. (13). The set of K constraint equations and thus the complete optimization problem in Eq. (13) can be written as:

$$\boldsymbol{\Psi} \begin{bmatrix} P_1 \\ P_2 \\ \vdots \\ P_K \end{bmatrix} = \begin{bmatrix} P_{\eta,1} \\ P_{\eta,2} \\ \vdots \\ P_{\eta,K} \end{bmatrix}. \qquad (14)$$

where the matrix $\boldsymbol{\Psi}$ is defined as:

$$\boldsymbol{\Psi} = \operatorname{diag}\left(\left[\frac{\chi}{N_{\chi,1}} \frac{|h_1|^2}{\gamma_{\text{rq},1}}, \dots, \frac{\chi}{N_{\chi,K}} \frac{|h_1|^2}{\gamma_{\text{rq},K}},\right]\right) - \begin{bmatrix} (1-\nu_1)\frac{|h_1|^2}{\gamma_{\text{rq},1}} & \dots & (1-\nu_1)\frac{|h_1|^2}{\gamma_{\text{rq},1}} \\ \vdots & \ddots & \vdots \\ (1-\nu_K)\frac{|h_K|^2}{\gamma_{\text{rq},K}} & \dots & (1-\nu_K)\frac{|h_K|^2}{\gamma_{\text{rq},K}} \end{bmatrix},$$

The optimization problem in Eq. (12) thus can be solved through a linear system of equations for the transmit powers P_k. As the matrix $\boldsymbol{\Psi}$ and thus the system in Eq. (14) is known to be full rank, the corresponding solution is unique and fulfills one of the following properties:

1) $\boldsymbol{P} \in \mathbb{R}_+^K$ and $\sum_{k=1}^{K} P_k \leq P_{\text{max}}$,
2) $\boldsymbol{P} \in \mathbb{R}_+^K$ and $\sum_{k=1}^{K} P_k > P_{\text{max}}$,
3) $\boldsymbol{P} \notin \mathbb{R}_+^K$.

Note, that only case 1) scenarios are feasible, as the systems in 2) and 3) are noise- and interference-limited, respectively, and the given requirements can not be fulfilled.

IV. Evaluation

To support the theoretical elaborations from above, the performed evaluations demonstrate the potential of the proposed technique for the QoS compliant reduction of transmit power as well as for the enhancement of the system capacity. The underlying simulation environment investigates 1000 longterm settings, with randomly generated locations of uniformly distributed users. The path losses are derived using the Hata pathloss model [20], [21]. Moreover for every longterm scenario user requirements are chosen uniformly from $R_{\text{rq}} \in [0; 12.8]$ Mbps and $\tau_{\text{rq}} \in [0; 100]$ ms, respectively. For all 5000 TTIs within a longterm setting, Rayleigh distributed channel coefficients are generated to compute $|h|^2$ (cf. [22]). An industrially deployed FEC turbo code is used, providing the ACK and NACK messages to the fully implemented HARQ protocol. The numerical values for the used system components are displayed in Tab. I. Moreover, we assumed

χ	ν	T_{BS}	T_{RNC}	$\Delta\gamma$ @ 4QAM	π_{out}	CQI
16	0.05	12 ms	100 ms	[3, 4.77, 6]	0.01	[1 − 30]

TABLE I

a receiver noise level of -100 dBm and a maximum transmit power of 16 W, which together with a fix antenna gain of 18 dBi determines the maximum of the *effective isotropic radiated power* (EIRP) as 60 dBm.

Lacking QoS management capabilities for the MAC and PHY layers, state of the art techniques propose to use the full transmit power, for serving a certain set of user demands. Comparing the proposed mode optimization technique with this brute approach, Fig. 4 visualizes the large scale of possible power savings through the distribution of necessary EIRP in a single user system. Moreover, the figure demonstrates how a modes mismatch of 4 CQI steps does increase the necessary transmit power. Keep in mind, that beside the power savings, the proposed optimization enables the QoS true service of users, which none of the references is capable of.

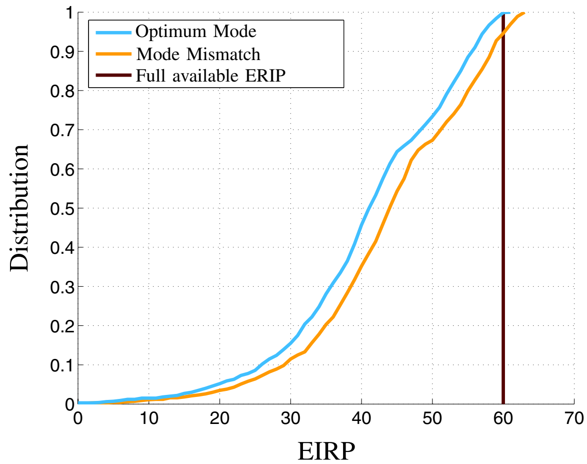

Fig. 4. CDF of necessary EIRP

As transmit power is not an economical key figure itself, Fig. 5 demonstrates the capacity increase that the above cross-layer optimization can achieve through the HSDPA scheduling unit. Within, *cross-layer assisted resource allocation* (XARA) in *time and code domain* (TCD) was applied using the achieved power savings to schedule additional users [23]. The comparison with the prominent *maximum throughput scheduling* (MTS) and *proportional fair scheduling* (PFS) reveals the significant potential, cross-layer optimization has to the scheduling units of these systems.

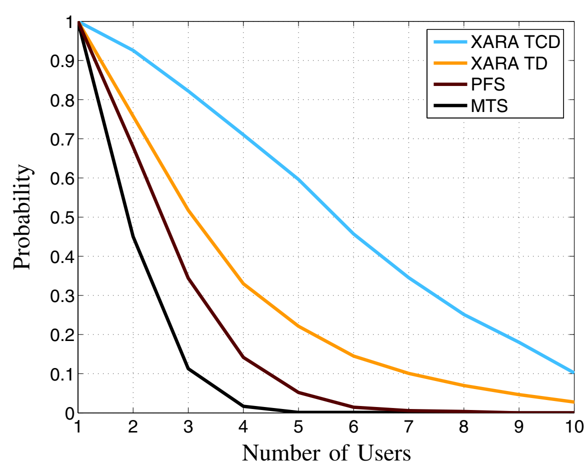

Fig. 5. Capacity Increase through XARA

V. Conclusion and Outlook

Through the analytical modeling of the HSDPA signal processing up to the multi-user scheduler, the joint optimization of radio parameters in HSDPA enabled a power optimal QoS management in throughput and delay. As the central mode optimization can be solved very efficiently and the remaining power control problem is linear, the presented performance enhancements can be achieved with only little additional complexity. Moreover, the integration of the presented method into scheduling algorithms promised significant capacity enhancements to HSDPA systems.

References

[1] D. MacKinnon, W. McCrum, and D. Sheppard, *An Introduction to Open Systems Interconnection*, Computer Science Press, 1990, ISBN: 0716781808.

[2] C. Schurges, *Energy-aware Wireless Communications*, Ph.D. thesis, University of California Los Angeles, 2002.

[3] E. Uysal-Biyikoglu, A. El Gamal, and B. Prabhakar, "Adaptive Transmission of Variable-Rate Data over a Fading Channel for Energy-Efficiency," in *Proceedings of the GLOBECOM*. IEEE, 2002, vol. 1, pp. 97–101.

[4] E. M. Yeh and A. S. Cohen, "Throughput optimal power and rate control for multiaccess and broadcast communications," in *Proceedings of the International Symposium on Information Theory (ISIT)*, June 2004.

[5] D. N. C. Tse, "Optimal Power allocation over parallel Gaussian Channels," in *Proc. Int. Symp. Information Theory, Ulm, Germany*, June 1997.

[6] G. Song and Y. Li, "Utility-bases joint physical-MAC layer optimization in OFDM," in *Proc. GLOBECOM*, 2002, vol. 1, pp. 17–21.

[7] W. Rhee and J. M. Cioffi, "Increase in Capacity of Multiuser OFDM with Adaptive Subcarrier, Bit, and Power Allocation," in *Proc. of IEEE VTC*, 2000, pp. 1088–1089.

[8] Christof Farsakh and Josef A. Nossek, "Spatial Covariance Based Downlink Beamforming in an SDMA Mobile Radio System," *IEEE Transactions on Communications*, vol. 46, no. 11, pp. 1497–1506, November 1998.

[9] Martin Schubert and Holger Boche, "Theoretical and experimental Comparison of Optimisation Criteria for Downlink Beamforming," *European Transaction on Telecommunications and Related Technologies*, vol. 12, no. 5, pp. S.417–426, 2001, ISSN 1120-3862.

[10] R. G. Gallager, *Information Theory and Reliable Communication*, John Wiley and Son, 1968, ISBN: W-471-29048-3.

[11] A. J. Viterbi and J. K. Omura, *Principles of Digital Communications and Coding*, McGraw-Hill Series in Electrical Engineering, 1979.

[12] John G. Proakis, *Digital Communications*, chapter Random Selection of Codes, pp. 390–406, McGraw Hill Inc., 3rd edition, 1995.

[13] M.T. Ivrlac, T.P. Kurpjuhn, C. Brunner, and W. Utschick, "Efficient use of Fading Correlations in MIMO Systems," in *Proceedings of the 54th IEEE Vehicular Technology Conference*, 2001, pp. 2763–2767, Atlantic City, NJ, USA.

[14] M. T. Ivrlac and Josef A. Nossek, "Correlated fading in mimo systems - blessing or curse?," in *39th Annual Allerton Conference on Communication, Controll and Computing*, Monticello, IL, October 2001.

[15] Technical Specification Group Radio Access Network, "TS 25.321 - Medium Access Control Protocol Specifications," Tech. Rep., Third Generation Partnership Project, 2004.

[16] Jung-Fu Cheng, "On the Coding Gain of Incremental Redunancy Over Chase Combining," in *Proceedings of the IEEE Globecom conference*, December 2003, vol. 1, pp. 107–112.

[17] P. Frenger, S. Parvall, and E. Dahlman, "Performance Comparison of HARQ with Chase Combining and Incremental Redundancy for HSDPA," in *Proceedings of the 54th Vehicular Technology Conference*. IEEE, October 2001, vol. 3, pp. 1829–1833.

[18] M. Dottling, T. Grundler, and A. Seeger, "Incremental Redundancy and Bit-mapping Techniques for High Speed Downlink Packet Access," in *Proceedings of the Global Telecommunications Conference*, December 2003, vol. 2, pp. 908–912.

[19] N. Miki, S. Abeta, and M. Sawahashi, "Evaluation of Throughput employing Hybrid ARQ Packet Combining in Forward Link OFCDM Broadband Wirless Access," in *Proceedings of the Conference on 'Personal, Indoor and Mobile Communications'*. IEEE, September 2002, pp. 394–398.

[20] Masaharu Hata, "Empirical Formula jfor Propagation Path-Loss in Land Mobile Radio Services," in *Proceedings of the Vehicular Technology Conference*. IEEE, August 1980, vol. 29, pp. 317–325.

[21] G1, "TS 03.30 8.3.0 - Cell Sizes and RF Budgets," Tech. Rep., Third Generation Partnership Project, 2000.

[22] Benno Zerlin, Michel Ivrlac, Wolfgang Utschick, and Josef A. Nossek, "Joint Optimization fo Radio Parameters - A Top-Down Approach ," submitted to the Eurasip Signal Processing Journal - Special Issue on Advances in Signal-Processing assisted Cross-Layer Design.

[23] B. Zerlin, M. T. Ivrlač, Josef A. Nossek, and A. Klein, "On Cross-Layer Assisted Resource Allocation in HSDPA," submitted to the 12th International Conference on Telecommunication, ICT05.