University of Würzburg
Institute of Computer Science
Research Report Series

Towards a Channel Allocation Scheme for SDMA–based Mobile Communication Systems

Notker Gerlich* **Michael Tangemann**‡

Report No. 104 February 1995

* *Institute of Computer Science, Universität Würzburg*
Am Hubland, D-97074 Würzburg, FRG
Tel.: +49 931 888-5513
E-mail: gerlich@informatik.uni-wuerzburg.de

‡ *Alcatel SEL Research Centre*
D-70430 Stuttgart, FRG
Tel. +49 711 869-34166
E-mail: mtangema@rcs.sel.de

Abstract: *Space Division Multiple Access (SDMA) is a new technology by which the capacity of existing cellular mobile communication systems can economically be increased. Based on adaptive array antenna technology the spatial dimension of the existing system is exploited by means of forming independent radio beams in each of the original channels. Operating SDMA, however, requires a suitable channel allocation scheme. In this paper we present simulation results on the influence of two constraints on SDMA system performance arising from* C/I *ratio requirements.*

Keywords: *mobile communication, channel allocation, simulation*

1. Introduction

Adaptive SDMA (Space Division Multiple Access) is a new technology to optimise current and future mobile communication systems. In addition to well-known traditional multiplex schemes such as FDMA or TDMA, where parallelism of channels is introduced in the frequency and time domains, an SDMA system aims at the exploitation of the spatial dimension to increase the number of channels simultaneously available.

This can be achieved if the electromagnetic energy is not received and transmitted omnidirectionally at the base station site. Instead, using array antennas and associated control functions, beams are formed which point to the individual users and follow their movements. The same radio channel can now be shared by multiple users if beam patterns can be formed which guarantee a minimum carrier-to-interference ratio (C/I) for each of these users by appropriate beam forming and nulling of co-channel mobiles.

The C/I requirements can be translated in two conditions for the user locations that must be met. Obviously, the mobile stations using the same radio channel in parallel must be located in different angular positions as seen from the base station. Additionally, however, a second constraint is imposed by the fact that under realistic conditions the adaptive array antennas used for SDMA implementation can attenuate co-channel users within the same cell only up to a given level, i.e. the signals received from users sharing the same channel should have similar power levels.

This paper is focused on the impact of these conditions on the performance of an SDMA system. We use a general simulation approach which permits to select mobility models for the users; it includes a system model taking into account the above constraints for channel allocation and permits to determine performance parameters of interest such as traffic loads, blocking probabilities etc., from which the efficiency gain of SDMA for the scenario selected can be determined.

Previous work on the application of array antennas in mobile communications and SDMA itself includes two early studies by Lee [2] and Stidham [6], who report a remarkable reduction of the fading rate achieved with arrays at the mobile station. Based on extensive work on array antennas from the areas of radar, acoustics and navigation, recently several approaches have been started to exploit this techology to enhance the performance of base stations in mobile communication systems [5, 7, 9, 10, 11].

This paper is organised as follows. In Section 2 channel allocation constraints in SDMA systems are discussed and the two conditions on user locations are introduced. Section 3 presents a simulation tool for SDMA performance evaluation. We present simulation results for the performance of an SDMA system operating under the channel allocation constraints in Section 4 and end up with a conclusion in Section 5.

2. Channel Allocation Constraints in SDMA Systems

The channel allocation must be redefined due to the fact that existing traffic channels in operating SDMA now can be used by several mobile users simultaneously.

For low and moderate load it is sufficient to assign individual channels to the users as long as the actual number of users is smaller than the number of channels available, taking into account some channels that might be reserved for signalling or handovers. With increasing load the users must be grouped to share the channels. For handover and initial login a sufficient number of free channels must be allocated. For both values a threshold can be defined.

Grouping of channels is implemented by exploiting the possibility of intracellular handovers which can be enforced by the SDMA control entity. As indicated in the previous subsection, two constraints exist for the allocation of multiple connections to a common traffic channel:

- ◇ Between any two users sharing the same traffic channel a minimum angular distance must be guaranteed which can be derived from the beamwidth as a function of the array parameters and the angular spread of multipath components of interfering cochannel users which depends on the propagation environment.
- ◇ For the difference between the received signal strengths of any two mobile users an upper limit exists which can again be derived from the array parameters; this prevents that weak signals are interfered by strong cochannel signals because the null depth of the beam pattern is limited.

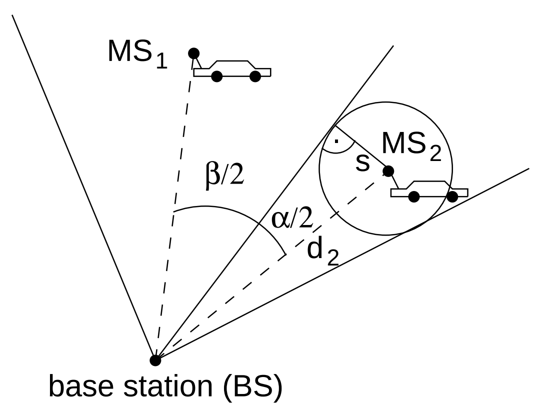

Figure 1: *Angle criterion in SDMA*

An example for the first constraint is depicted in Fig. 1, where MS_1 suffers from interference caused by MS_2. The beamwidth is β. Multipath components of the signals received from MS_2 are assumed to be generated in a circular area around MS_2 with the radius $s = 200\lambda$ [3] which is seen under an angle of α. Therefore, the minimum angular distance between the two mobiles is

$$\varphi_{\min} = \frac{\alpha}{2} + \frac{\beta}{2} . \tag{1}$$

Note that α depends on the distance d_2 of MS_2, i.e. near interfering mobiles require larger minimum angular distances $\varphi_{\min}$. Consequently, the SDMA gain will be larger in cells with larger ratio between cell radius r and the radius s of the spreading area around an interfering mobile station.

The effect of multipath spreading on MS_1 is assumed to be negligible since usually $\alpha < \beta$ (cf. Fig. 2). If required, however, β in the above equations can be replaced by $\max(\alpha, \beta)$ which is a function of the distance d of the mobile.

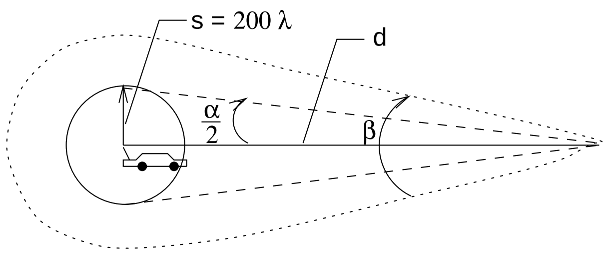

Figure 2: *SDMA beam*

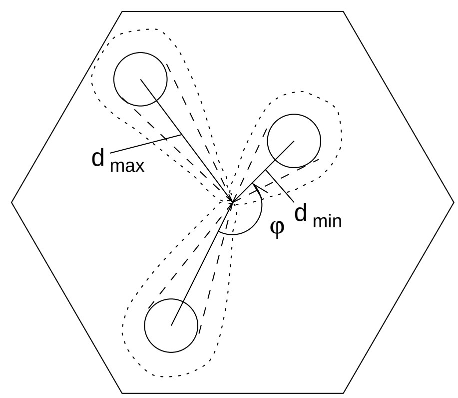

Figure 3: *Distance criterion*

The second constraint is illustrated in Fig. 3. Assuming an exponential propagation law, the requirement of maximum power level differences can be translated into an upper limit of the ratio between the distances

$$\frac{d_{\max}}{d_{\min}} \leq \Delta , \tag{2}$$

which can be checked in the simulation by comparing the distances of the mobiles as obtained from the mobility model described below.

Movements of the users can finally lead to situations where these constraints are violated, and therefore further intra-cellular handovers are required to correct the channel allocation.

3. A Simulation Tool for SDMA Performance Evaluation

An analytical model for the performance evaluation of SDMA would be useful for gaining insight into the operation of the access mechanism. However, since SDMA aims at exploiting the spatial dimension of the radio resource, the spatial distribution of the users is critical for the performance gain of SDMA. Thus, the development of an analytical model for SDMA performance evaluation basically means the development of a sophisticated mobile user mobility model. This is considered as quite a difficult task. For the time being performance evaluation and dimensioning may only be achieved by means of simulation. A simulator is being developed that is able to evaluate the performance of SDMA in different scenarios. Additionaly the simulator will be useful in the development and refinement of a channel allocation scheme for SDMA.

The central part of the simulator in its current state is the user mobility model. The mobility models proposed in literature can be classified in: fluid flow models [4], queueing models (e.g. [8]), and position-velocity models (e.g. [1]), last of which are widely used in simulation. Up to now fluid flow models are limited to one-dimensional scenarios (single lane highway). Since the performance gain of SDMA arises from spatial multiplexing the maximum gain will be reached if the users are uniformly distributed over the whole plane. Therefore, such a model is not well suited to show the benefits of SDMA. The performance of SDMA in a one-dimensional scenario is analysed in [8] by using a queueing network approach. The disadvantage of queueing models is that they need restricting assumptions for tractability e.g. the assumption of an exponentially distributed cell crossing time. These restrictions are partly overcome in position/velocity models. This motivates the choice of this type of model for the simulator. Nevertheless, a few assumptions seem to be inevitable. The particular assumptions in the simulation model are:

- ◇ mobiles arrive at the borders of the road graph as Poisson streams.
- ◇ the velocity of a mobile is chosen from a normal distribution.
- ◇ mobiles in a cyclic manner go through two successive phases — think mode and calling mode — each of which is exponentially distributed.
- ◇ blocked calls are cleared and do not further affect the system .
- ◇ the effects of fading and co-channel interference are not included.
- ◇ interactions among mobiles and among calls (mobile to mobile calls) are not modeled.

The scenario is freely configurable by means of the road graph and the position and parameters of the base and mobile stations. The discrete-event simulator is designed in an object oriented way by using C++ programming language.

4. Results

To study the gain achieved the spectrum efficiency is considered which is defined as the number of users per MHz and km^2. To compare SDMA to a traditional system the *spectrum efficiency gain*, i.e. the ratio of the spectrum efficiency of SDMA and the traditional system, is evaluated. Since both systems are using the same bandwidth of spectrum and are assumed to service the same cell size the spectrum efficiency gain is just the ratio of the offered traffic under the constraint of an upper limit of the bocking probability.

We have chosen two simple scenarios to study in which way the channel allocation constraints described above affect the performance of SDMA. In both scenarios the base station is located in the center of a circular cell of 10 km radius. Non-calling mobiles as well as calling mobiles from surrounding cells (handovers) enter the cell at the intersections of roads and circle. The velocity of mobiles is chosen from a normal distribution with mean 100 km/h and variance 20 km/h. Non-calling and calling phases are exponentially distributed with means of 10000 sec and 150 sec resp. The number of regular channels is 8; the beamwidth of the 4 SDMA beams is 45° (i.e. we assume an 8 elements antenna array where a number of 4 beams is considered to be a sensible choice [9]).

In scenario A four roads are traversing the cell forming a rectangle with the corners on the 10km circle around the basestation. Therefore, the maximum distance ratio of two calls is $\sqrt{2}$. Since Δ by modern beam forming algorithms was found by measurement to range from ca. 3 to 10 the distance criterion imposes no constraint on scenario A.

In scenario B there are two perpendicular roads intersecting eachother at the location of the base station. Thus, having a beamwidth of 45° the angular criterion is met by any pair of calls leaving the distance criterion as the only constraint.

Fig. 4 shows the blocking probability of fresh calls vs. the offered traffic with and without SDMA in scenario A. Note that due to logarithmic scale the 0.95-confidence intervals for small blocking probabilities appear too large. If the maximum load that can be carried is defined by an upper limit of of the blocking probability e.g. $p_B = 0.01$ the traditional system permits around 3 Erlangs, whereas SDMA can carry approximately 19 Erlangs. Thus, the spectrum efficiency gain is approximately 6, which corresponds to the theoretical maximum [9]. The average number of intra-cell handovers per call is smaller than 10^{-6} irrespective of the offered load. Thus, the angular criterion seems to be a small constraint to scenario A.

In Fig. 5 the blocking probability of fresh calls vs. the offered load for several values of the max. distance ratio Δ in scenario B is depicted. For clearity the 0.95-confidence intervals are only shown for $\Delta = 10$, the intervals for the other curves showing a comparable size.

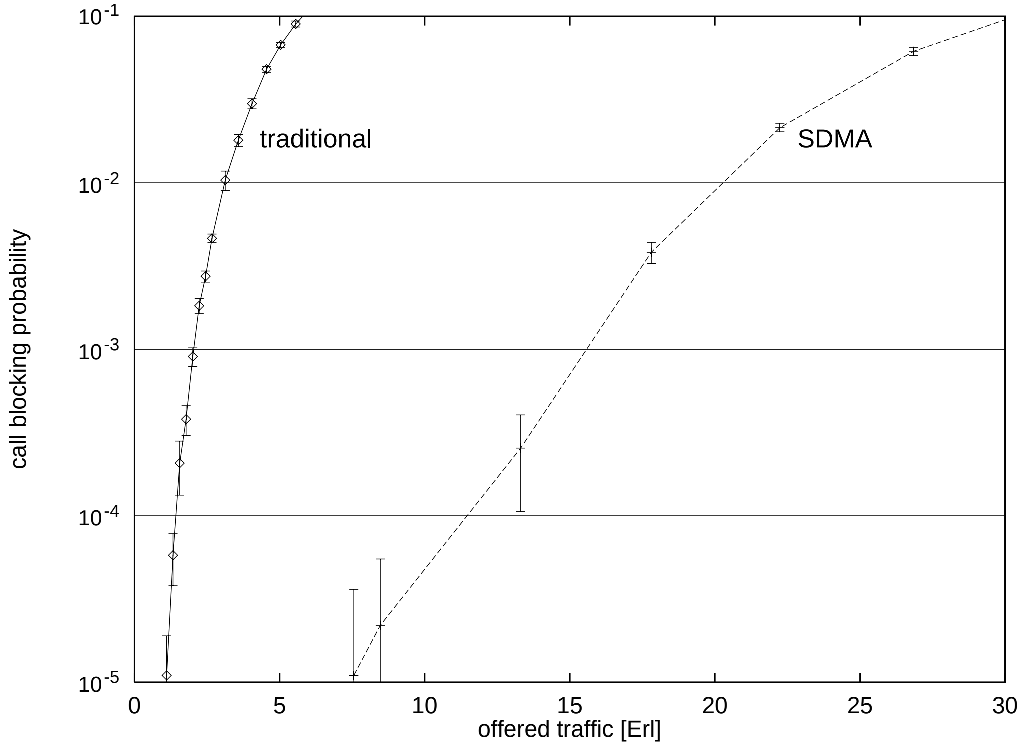

Figure 4: *Call blocking performance in scenario A*

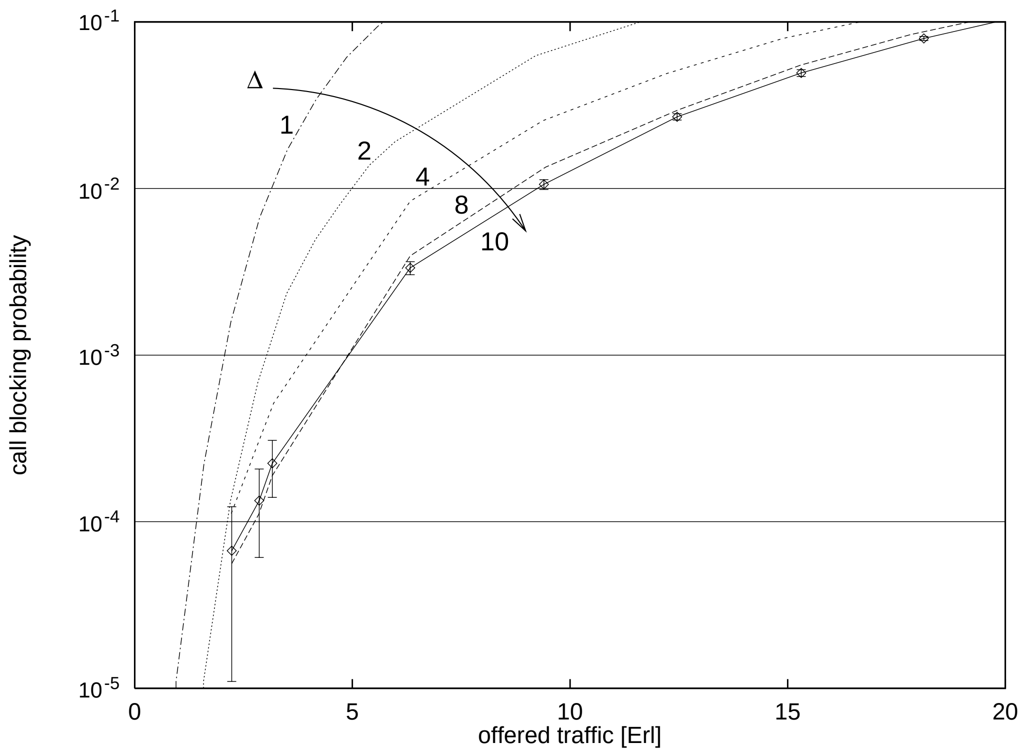

Figure 5: *Call blocking performance in scenario B*

For detailed study Fig. 6 shows the spectrum efficiency gain in scenario B under the constraint of $p_B = 0.01$. Notice that the curve flattens with increasing values of Δ. Therefore, the relative performance improvement gained by better beam forming decreases with Δ increasing. The gain ranging below 3 the distance criterion for $\Delta \leq 10$ is a strong constraint to scenario B. The average number of intra-cell handovers per call is below 0.15 thus remaining relatively small.

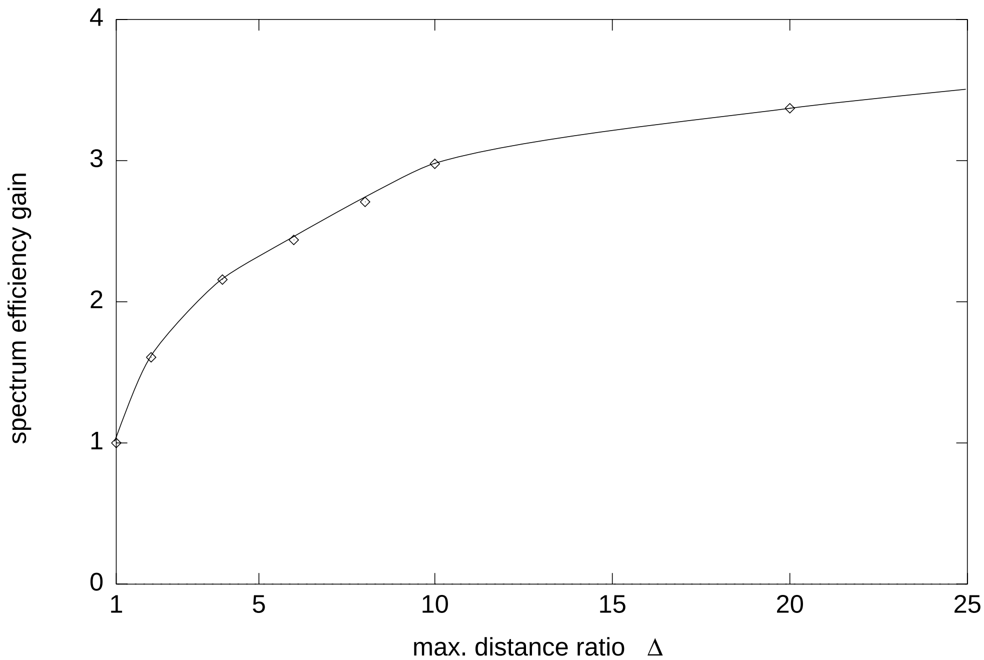

Figure 6: *Spectrum efficiency gain in scenario B*

5. Conclusion

In this paper we have investigated the influence of two constraints on the performance of a channel allocation scheme for SDMA: the angular criterion and the distance criterion. Considering our simulation results of two simplified scenarios we believe the distance criterion to impose a stronger constraint on SDMA system performance.

The number of intra-cell handovers being small in both scenarios it is possible to apply a more sophisticated channel allocation scheme without considerable loss of quality of service. The scheme considered here is kind of a first-choice strategy: if no free regular channel can be found we form a new beam in the first channel by which the two criterions are met. If no such channel can be found the call is blocked. Nevertheless, it may be possible to handle the call by means of channel rearrangement. Applying a rearrangement scheme will increase the average number of inter-cell handovers a call will suffer from. Thererefore, the number of rearrangements should be limited by using a best-choice strategy. To reach the optimum such a strategy would have to take a look into the future of the traffic process. Nevertheless, using advanced array antenna technology the moving direction of a mobile user can be estimated and thus a forecast of the future position will be enabled for practical purposes.

Acknowledgement. The authors would like to thank the team at Alcatel SEL Research Centre Stuttgart and Prof. Phuoc Tran-Gia for the helpful and stimulating discussions.

References

[1] D. Everitt, J. Luo, G. Sawyers, and L. Wedding. Mobility modelling in cellular mobile communication systems. In *5th Australian Teletraffic Research Seminar*, 1990.

[2] W. C. Y. Lee. Preliminary investigations of mobile radio signal fading using directional antennas on the mobile unit. *IEEE Transactions on Vehicular Technology*, 15(2):8–15, Oct. 1966.

[3] W. C. Y. Lee. Increasing system capacity in PCS. In *Proc. PIMRC'94*, pages 38–49, 1994.

[4] W. A. Massey and W. Whitt. The highway PALM: a stochastic model to capture space and time dynamics in wireless communication systems. In *Proc. ITC14*, pages 503–512, 1994.

[5] R. Rheinschmitt, M. Tangemann, and B. X. Weis. A-SDMA: Ein neues Multiplexverfahren für Mobilfunksysteme. In *Proc. ITG-Fachtagung Mobile Kommunikation, Neu-Ulm*, 1993.

[6] J. R. Stidham. Experimental study of UHF mobile radio transmission using a directive antenna. *IEEE Transactions on Vehicular Technology*, 15(2):16–24, Oct. 1966.

[7] S. C. Swales, M. A. Beach, D. J. Edwards, and J. P. McGeehan. The performance enhancement of multibeam adaptive base-station antennas for cellular land mobile radio systems. *IEEE Transactions on Vehicular Technology*, 39(1):56–67, Feb. 1990.

[8] M. Tangemann. Influence of the user mobility on the spatial multiplex gain of an adaptive SDMA system. Proc. PIMRC '94, 1994.

[9] M. Tangemann, C. Hoek, and R. Rheinschmitt. Introducing adaptive array antenna concepts in mobile communication systems. In *Race Mobile Communications Workshop, Amsterdam*, 1994.

[10] M. Tangemann and R. Rheinschmitt. Comparison of upgrade techniques for mobile communication systems. In *Proc. SUPERCOM/ICC '94*, 1994.

[11] B. X. Weis. A novel algorithm for flexible beam forming for adaptive space division multiple access systems. In *Proc. PIMRC'94*, pages 729a–729e, 1994.

Preprint-Reihe
Institut für Informatik
Universität Würzburg

Verantwortlich: Die Vorstände des Institutes für Informatik.

[1] K. Wagner. *Bounded query classes.* Februar 1989.

[2] P. Tran-Gia. *Application of the discrete transforms in performance modeling and analysis.* Februar 1989.

[3] U. Hertrampf. *Relations among mod-classes.* Februar 1989.

[4] K.W. Wagner. *Number-of-query hierarchies.* Februar 1989.

[5] E.W. Allender. *A note on the power of threshold circuits.* Juli 1989.

[6] P. Tran-Gia und Th. Stock. *Approximate performance analysis of the DQDB access protocol.* August 1989.

[7] M. Kowaluk und K.W. Wagner. *Die Vektor-Sprache: Einfachste Mittel zur kompakten Beschreibung endlicher Objekte.* August 1989.

[8] M. Kowaluk und K.W. Wagner. *Vektor-Reduzierbarkeit.* August 1989.

[9] K.W. Wagner (Herausgeber). *9. Workshop über Komplexitätstheorie, effiziente Algorithmen und Datenstrukturen.* November 1989.

[10] R. Gutbrod. *A transformation system for chain code picture languages: Properties and algorithms.* Januar 1990.

[11] Th. Stock und P. Tran-Gia. *A discrete-time analysis of the DQDB access protocol with general input traffic.* Februar 1990.

[12] E.W. Allender und U. Hertrampf. *On the power of uniform families of constant depth threshold circuits.* Februar 1990.

[13] G. Buntrock, L.A. Hemachandra und D. Siefkes. *Using inductive counting to simulate nondeterministic computation.* April 1990.

[14] F. Hübner. *Analysis of a finite capacity a synchronous multiplexer with periodic sources.* Juli 1990.

[15] G. Buntrock, C. Damm, U. Hertrampf und C. Meinel. *Structure and importance of logspace-MOD-classes.* Juli 1990.

[16] H. Gold und P. Tran-Gia. *Performance analysis of a batch service queue arising out of manufacturing systems modeling.* Juli 1990.

[17] F. Hübner und P. Tran-Gia. *Quasi-stationary analysis of a finite capacity asynchronous multiplexer with modulated deterministic input.* Juli 1990.

[18] U. Huckenbeck. *Complexity and approximation theoretical properties of rational functions which map two intervals into two other ones.* August 1990.

[19] P. Tran-Gia. *Analysis of polling systems with general input process and finite capacity.* August 1990.

[20] C. Friedewald, A. Hieronymus und B. Menzel. *WUMPS Würzburger message passing system.* Oktober 1990.

[21] R.V. Book. *On random oracle separations.* November 1990.

[22] Th. Stock. *Influences of multiple priorities on DQDB protocol performance.* November 1990.

[23] P. Tran-Gia und R. Dittmann. *Performance analysis of the CRMA-protocol in high-speed networks.* Dezember 1990.

[24] C. Wrathall. *Confluence of one-rule Thue systems.*

[25] O. Gihr und P. Tran-Gia. *A layered description of ATM cell traffic streams and correlation analysis.* Januar 1991.

[26] H. Gold und F. Hübner. *Multi server batch service systems in push and pull operating mode — a performance comparison.* Juni 1991.

[27] H. Gold und H. Grob. *Performance analysis of a batch service system operating in pull mode.* Juli 1991.

[28] U. Hertrampf. *Locally definable acceptance types—the three valued case.* Juli 1991.

[29] U. Hertrampf. *Locally definable acceptance types for polynomial time machines.* Juli 1991.

[30] Th. Fritsch und W. Mandel. *Communication network routing using neural nets – numerical aspects and alternative approaches.* Juli 1991.

[31] H. Vollmer und K. W. Wagner. *Classes of counting functions and complexity theoretic operators.* August 1991.

[32] R. V. Book, J. H. Lutz und K. W. Wagner. *On complexity classes and algorithmically random languages.* August 1991.

[33] F. Hübner. *Queueing analysis of resource dispatching and scheduling in multi-media systems.* September 1991.

[34] H. Gold und G. Bleckert. *Analysis of a batch service system with two heterogeneous servers.* September 1991.

[35] H. Vollmer und K. W. Wagner. *Complexity of functions versus complexity of sets.* Oktober 1991.

[36] F. Hübner. *Discrete-time analysis of the output process of an ATM multiplexer with periodic input.* November 1991.

[37] P. Tran-Gia und O. Gropp. *Structure and performance of neural nets in broadband system admission control.* November 1991.

[38] G. Buntrock und K. Loryś. *On growing context-sensitive languages.* Januar 1992.

[39] K. W. Wagner. *Alternating machines using partially defined "AND" and "OR".* Januar 1992.

[40] F. Hübner und P. Tran-Gia. *An analysis of multi-service systems with trunk reservation mechanisms.* April 1992.

[41] U. Huckenbeck. *On a generalization of the bellman-ford-algorithm for acyclic graphs.* Mai 1992.

[42] U. Huckenbeck. *Cost-bounded paths in networks of pipes with valves.* Mai 1992.

[43] F. Hübner. *Autocorrelation and power density spectrum of ATM multiplexer output processes.* September 1992.

[44] F. Hübner und M. Ritter. *Multi-service broadband systems with CBR and VBR input traffic.* Oktober 1992.

[45] M. Mittler und P. Tran-Gia. *Performance of a neural net scheduler used in packet switching interconnection networks.* Oktober 1992.

[46] M. Kowaluk und K. W. Wagner. *Vector language: Simple description of hard instances.* Oktober 1992.

[47] B. Menzel und J. Wolff von Gudenberg. *Kommentierte Syntaxdiagramme für C++.* November 1992.

[48] D. Emme. *A kernel for funtion definable classes and its relations to lowness.* November 1992.

[49] S. Öhring. *On dynamic and modular embeddings into hyper de Bruijn networks.* November 1992.

[50] K. Poeck und M. Tins. *An intelligent tutoring system for classification problem solving.* November 1992.

[51] K. Poeck und F. Puppe. *COKE: Efficient solving of complex assignment problems with the propose-and-exchange method.* November 1992.

[52] Th. Fritsch, M. Mittler und P. Tran-Gia. *Artificial neural net applications in telecommunication systems.* Dezember 1992.

[53] H. Vollmer und K. W. Wagner. *The complexity of finding middle elements.* Januar 1993.

[54] O. Gihr, H. Gold und S. Heilmann. *Analysis of machine breakdown models.* Januar 1993.

[55] S. Öhring. *Optimal dynamic embeddings of arbitrary trees in de Bruijn networks.* Februar 1993.

[56] M. Mittler. *Analysis of two finite queues coupled by a triggering scheduler.* März 1993.

[57] J. Albert, F. Duckstein, M. Lautner und B. Menzel. *Message-passing auf transputer-systemen.* März 1993.

[58] Th. Stock und P. Tran-Gia. *Basic concepts and performance of high-speed protocols.* März 1993.

[59] F. Hübner. *Dimensioning of a peak cell rate monitor algorithm using discrete-time analysis.* März 1993.

[60] G. Buntrock und K. Loryś. *The variable membership problem: Succinctness versus complexity.* April 1993.

[61] H. Gold und B. Frötschl. *Performance analysis of a batch service system working with a combined push/pull control.* April 1993.

[62] H. Vollmer. *On different reducibility notions for function classes.* April 1993.

[63] S. Öhring und S. K. Das. *Folded Petersen Cube Networks: New Competitors for the Hyepercubes.* Mai 1993.

[64] S. Öhring und S. K. Das. *Incomplete Hypercubes: Embeddings of Tree-Related Networks.* Mai 1993.

[65] S. Öhring und S. K. Das. *Mapping Dynamic Data and Algorithm Structures on Product Networks.* Mai 1993.

[66] F. Hübner und P. Tran-Gia. *A Discrete-Time Analysis of Cell Spacing in ATM Systems.* Juni 1993.

[67] R. Dittmann und F. Hübner. *Discrete-Time Analysis of a Cyclic Service System with Gated Limited Service.* Juni 1993.

[68] M. Frisch und K. Jucht. *Pascalli-P.* August 1993.

[69] G. Buntrock. *Growing Context-Sensitive Languages and Automata.* September 1993.

[70] S. Öhring und S. K. Das. *Embeddings of Tree-Related Topologies in Hyper Petersen Networks.* Oktober 1993.

[71] S. Öhring und S. K. Das. *Optimal Communication Primitives on the Folded Petersen Networks.* Oktober 1993.

[72] O. Rose und M. R. Frater. *A Comparison of Models for VBR Video Traffic Sources in B-ISDN.* Oktober 1993.

[73] M. Mittler und N. Gerlich. *Reducing the Variance of Sojourn Times in Queueing Networks with Overtaking.* November 1993.

[74] P. Tran-Gia. *Discrete-Time Analysis Technique and Application to Usage Parameter Control Modelling in ATM Systems.* November 1993.

[75] F. Hübner. *Output Process Analysis of the Peak Cell Rate Monitor Algorithm.* Januar 1994.

[76] K. Cronauer. *A Criterion to Separate Complexity Classes by Oracles.* Januar 1994.

[77] M. Ritter. *Analysis of the Generic Cell Rate Algorithm Monitoring ON/OFF-Traffic.* Januar 1994.

[78] K. Poeck, D. Fensel, D. Landes und J. Angele. *Combining KARL and Configurable Role Limiting Methods for Configuring Elevator Systems.* Januar 1994.

[79] O. Rose. *Approximate Analysis of an ATM Multiplexer with MPEG Video Input.* Januar 1994.

[80] A. Schömig. *Using Kanban in a Semiconductor Fabrication Environment — a Simulation Study.* März 1994.

[81] M. Ritter, S. Kornprobst und F. Hübner. *Performance Analysis of Source Policing Architectures in ATM Systems.* April 1994.

[82] U. Hertrampf, H. Vollmer und K.W. Wagner. *On Balanced vs. Unbalanced Computation Trees.* Mai 1994.

[83] M. Mittler und A. Schömig. *Entwicklung von „Due–Date"–Warteschlangendisziplinen zur Optimierung von Produktionssystemen.* Mai 1994.

[84] U. Hertrampf. *Complexity Classes Defined via k-valued Functions.* Juli 1994.

[85] U. Hertrampf. *Locally Definable Acceptance: Closure Properties, Associativity, Finiteness.* Juli 1994.

[86] O. Rose und M.R. Frater. *Delivery of MPEG Video Services over ATM.* August 1994.

[87] B. Reinhardt. *Kritik von Symptomerkennung in einem Hypertext-Dokument.* August 1994.

[88] U. Rothaug, E. Yanenko und K. Leibnitz. *Artificial Neural Networks Used for Way Optimization in Multi-Head Systems in Application to Electrical Flying Probe Testers.* September 1994.

[89] U. Hertrampf. *Finite Acceptance Type Classes.* Oktober 1994.

[90] U. Hertrampf. *On Simple Closure Properties of #P.* Oktober 1994.

[91] H. Vollmer und K.W. Wagner. *Recursion Theoretic Characterizations of Complexity Classes of Counting Functions.* November 1994.

[92] U. Hinsberger und R. Kolla. *Optimal Technology Mapping for Single Output Cells.* November 1994.

[93] W. Nöth und R. Kolla. *Optimal Synthesis of Fanoutfree Functions.* November 1994.

[94] M. Mittler und R. Müller. *Sojourn Time Distribution of the Asymmetric $M/M/1//N$ – System with LCFS-PR Service.* November 1994.

[95] M. Ritter. *Performance Analysis of the Dual Cell Spacer in ATM Systems.* November 1994.

[96] M. Beaudry. *Recognition of Nonregular Languages by Finite Groupoids.* Dezember 1994.

[97] O. Rose und M. Ritter. *A New Approach for the Dimensioning of Policing Functions for MPEG-Video Sources in ATM-Systems.* Januar 1995.

[98] T. Dabs und J. Schoof *A Graphical User Interface For Genetic Algorithms.* Februar 1995.

[99] M.R. Frater und O. Rose. *Cell Loss Analysis of Broadband Switching Systems Carrying VBR Video.* Februar 1995.

[100] U. Hertrampf, H. Vollmer und K.W. Wagner. *On the Power of Number-Theoretic Operations with Respect to Counting.* Januar 1995.

[101] O. Rose. *Statistical Properties of MPEG Video Traffic and their Impact on Traffic Modeling in ATM Systems.* Februar 1995.

[102] M. Mittler und R. Müller. *Moment Approximation in Product Form Queueing Networks.* Februar 1995.

[103] D. Rooß und K.W. Wagner. *On the Power of Bio-Computers.* Februar 1995.

[104] N. Gerlich und M. Tangemann. *Towards a Channel Allocation Scheme for SDMA-based Mobile Communication Systems.* Februar 1995.