SIMULATOR FOR PERFORMANCE ANALYSIS IN UMTS FDD NETWORKS WITH HSDPA

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Abstract—**High Speed Downlink Packet Access (HSDPA) is a technology to extend the peak data rates and capacity of 3G mobile data transmission systems. It targets especially favorable radio channel environments with the possibility to use higher order modulation and higher code rates. Furthermore fast retransmissions and enhanced scheduling algorithms can be used to boost data rates and to provide the required Quality of Service (QoS).**

A dynamic W-CDMA system level simulator has been extended to enable the simulation of packet switched services with special focus on HSDPA. The complete simulation system contains traffic sources that create sequences of packets for each active User Equipment (UE), models the protocol stack and provides the possibility to collect performance indicators, e.g. sector packet data throughput, page throughput, and packet delays, in different scenarios for offline analysis. The simulation tool will be described and some example results concerning packet data performance of HSDPA will be shown.

I. INTRODUCTION

HSDPA allows deploying high bit rate data services and enables a smooth evolution for network capacity increase, while minimizing operators' investments. One of the driving forces for the efficient usage of radio resources is the shared channel concept of HSDPA. This supports especially highly bursty non real time traffic such as variable rate, packet-switched data, like interactive or background traffic classes.

The R5 specifications [5] of HSDPA allow a peak data rate of about 14 Mbps, which is achieved by the introduction of 16-QAM and increased code rates. These physical layer modifications become fully efficient especially in Line Of Sight (LOS) conditions.

A performance increase with HSDPA is further achieved by the introduction of various new Radio Resource Management (RRM) algorithms, the most important of these being:

- Fast Scheduling: It copes with a variety of traffic classes, their priorities and rapidly changing radio channel conditions. The Scheduling algorithm aims on the optimization of the cell capacity while fulfilling the Quality of Service (QoS) requirements and guaranteeing a certain level of fairness. Advanced scheduling solutions adapt to these changing conditions autonomously and can be scaled according to the operator dependent scheduling strategy.
- Channel Type Selection: It decides on the channel type that shall be applied for the transmission of each individual user data flow.
- Resource Allocation: Power and code allocation will make efficient use of the available radio resources.

A. *Impact of HSDPA on R'99*

As HSDPA is planned to be introduced into already deployed UMTS FDD networks as an overlay, the behavior of HSDPA influences the performance of the R'99 services. Especially the downlink power control of dedicated channels may be significantly influenced by the behavior of the HSDPA transmission. Thus adequate solutions need to be found to preclude QoS degradation of the dedicated channels. System simulations have to be carried out to proof the usability and effectiveness of proposed algorithms considering the complex interaction on system level.

B. *Simulation purpose*

Additionally for the current deployment of UMTS Node B it shall be ensured that the network planning is prepared for the HSDPA enhancement and does not withstand the smooth introduction of HSDPA.

In summary the following main objectives for the simulation exist:

- Proof of effectiveness of proprietary and standard algorithms.
- Preparation of network planning for the HSDPA enhancement.
- Prediction of the system performance.

Special attention was paid to the modeling of the entire protocol stack for HSDPA on top of an accurate physical layer while keeping the simulation execution time at a reasonable level. Additionally the flexibility to exchange MAC and RRM algorithms by various implementations was a strong requirement for the simulation tool. To ensure global applicability of the results, the simulation environment comprises multiple moving UEs and multiple Radio Cells supporting soft and softer handover. The scalable traffic sources allow simultaneous transmission of various packet data service types, e.g. FTP and WWW browsing via HSDPA and DCH.

II. HSDPA System Level Simulator

This section describes the developed system level simulator with its features and possibilities.

A. Existing WCDMA Simulator

Especially to enable the comparison of data transmission performance between HSDPA and R'99 technology an existing WCDMA simulator [2] was chosen to be extended for HSDPA packet traffic evaluation. The WCDMA simulator enables the simulation of circuit switched traffic of various bit rates in realistic interference environments (fast power controlled). Advanced ray-optical propagation models are used to determine the radio channels [3].

B. HSDPA extension

The simulator had to be extended by a packet traffic generator that can be parameterized to model different types of packet traffic. HSDPA channel quality reporting and scheduling have been included as well as adaptive modulation and coding. An appropriate model for the HSDPA protocol stack had to be found, e.g. to transform the generated sequence of higher layer data frames into transport blocks to be transmitted over the air interface. Furthermore a flexible link level interface has been developed to evaluate the instantaneous Block Error Rate (BLER) depending on the current Signal to Noise and Interference Ratio (SNIR) and the applied modulation and coding scheme. Additionally fast physical layer retransmissions as well as higher layer retransmission have been included.

C. Packet Traffic Generation

A three stage packet traffic model has been implemented, which allows a flexible parameterization of different traffic types [4], e.g. web browsing or file transfer. For each UE with an active session the generator creates a sequence of packets with different sizes and times of arrival. These arrival times indicate the arrival at the air interface, i.e. the packets have already been transferred from the server over the (fixed) network to the Radio Network Controller (RNC).

The model consists of a session level, a page level, and a packet level. The session level corresponds to the arrival and serving processes of circuit switched mobiles, i.e. location dependent traffic configuration is possible to model 'hot-spots' for example. On page level the number of pages per session, the page size, and the reading time between the pages can be described statistically. On packet level the size of the packets and the inter-arrival time between packets can be specified. Predefined distributions according to [4] can be selected for the statistical processes, or a user defined distribution can be loaded. An example configuration for a web browsing model can be seen in Table I. It is obvious that the packet generator settings and the traffic load will have a big influence on the packet performance indicators (e.g. delays).

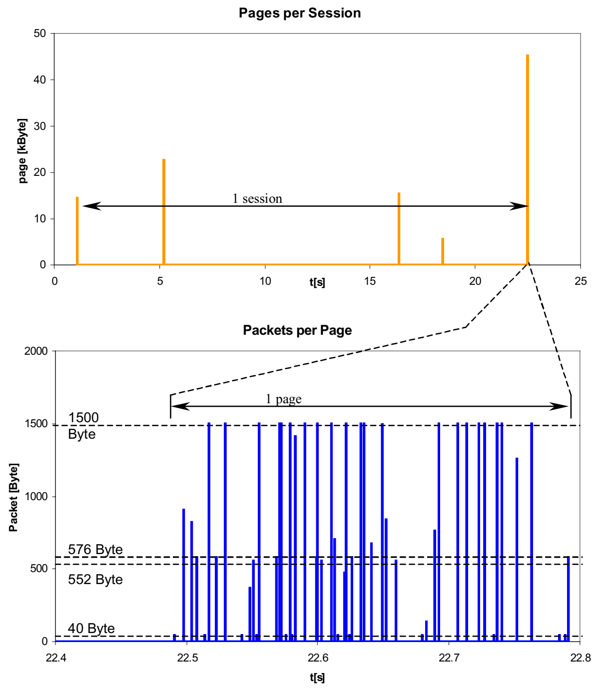

Fig. 1: Packet session example with (a) five pages and (b) all packets of the last page

D. Packet Processing

The arriving packets are split into segments of 8 different possible lengths. These segments are transferred from RNC to Node B and to each segment a header is added. The header size depends on the segment size. If the corresponding UE is scheduled, and the actual Transport Block (TB) size is determined, several segments are concatenated to form a TB. In general, one TB contains segments from one or more packets, and one packet can be split into one or more TB. Segmentation and concatenation is depicted in Fig. 2.

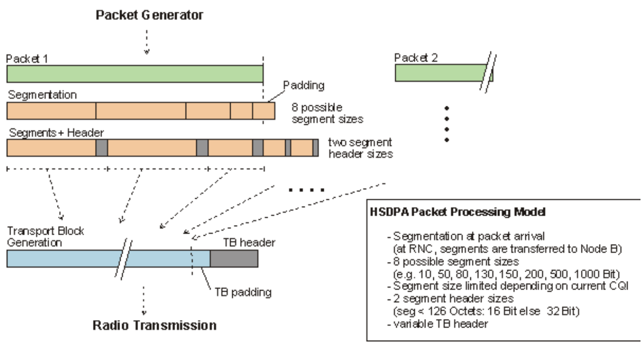

Fig. 2: HSDPA packet processing

E. *Link Level Interface*

Link level simulations are used to determine HSDPA physical layer performance in terms of BLER depending on the Signal to Noise and Interference ratio. A set of several Transport Format and Resource Combinations (TFRC) can be defined for the system simulation. For each possible TFRC one BLER table is required (link level simulations). For the simulations presented below a set of 30 TFRC has been defined. The BLER tables depend also on the channel profile and the speed of the UE.

F. *CDMA Signal Orthogonality*

It is common practice in system simulation tools to model the signal orthogonality by a constant factor α. This turned out to be not acceptable for HSDPA system simulations.

In an ideal CDMA-system signal orthogonality is achieved by multiplying the signals with orthogonal codes. Due to the asynchronous nature of WCDMA networks interference from other cells (Inter-Cell-Interference) is no longer orthogonal, but degrades signal quality, and has to be considered completely in the SNIR. On the other hand orthogonality between signals from the same cell (Intra-Cell-Interference) is reduced by multi-path propagation effects. Therefore the Intra-Cell-Interference is scaled with $1 - \alpha$ (see [1]).

Assuming a constant channel profile for the whole simulation area, and therefore also a constant orthogonality factor α, it is impossible to have on the one hand areas with good orthogonality (resulting in low interference level), that enable the use of 16-QAM, but on the other hand not to be far too optimistic in most of the other areas. Therefore an approach with location dependent orthogonality factor is proposed. In a first simple version of the algorithm areas with Line Of Sight (LOS) condition to the serving cell are extracted. For these LOS areas an ideal orthogonality factor ($\alpha = 1$) is assumed to account for the favorable radio conditions. Furthermore link level simulations performed with LOS profile are used for UE located in these areas. For the rest of the areas (Non Line Of Sight, NLOS) a specified default orthogonality applies and different link level simulations are used (e.g. ITU Vehicular A tap delay profile).

III. Simulation Scenarios and System Settings

A. *Database and Network Layout*

For the examples presented below an urban vector data base with approximately 2000 objects on 8.2 sqkm was used Fig. 3 shows the data base and an exemplary network configuration with 7 omni directional Micro-Cells. The antennas are mounted well below roof top in the street canyons. To demonstrate the influence of the channel profile and the resulting CDMA signal orthogonality on system performance, additionally a second network layout with sectorized cells has been investigated. In this case 21 sector cells were distributed in the simulation environment with antennas mounted above roof top (i.e. 25-30 m above ground level). These antennas have a half power beam width of 60 degrees and a down tilt of 12 degrees.

3-D ray-optical propagation models [3] are applied to determine the radio channel between the antennas and all pixels of the simulation grid. The resolution of the prediction grid is 5 m and the prediction height is 1.5 m.

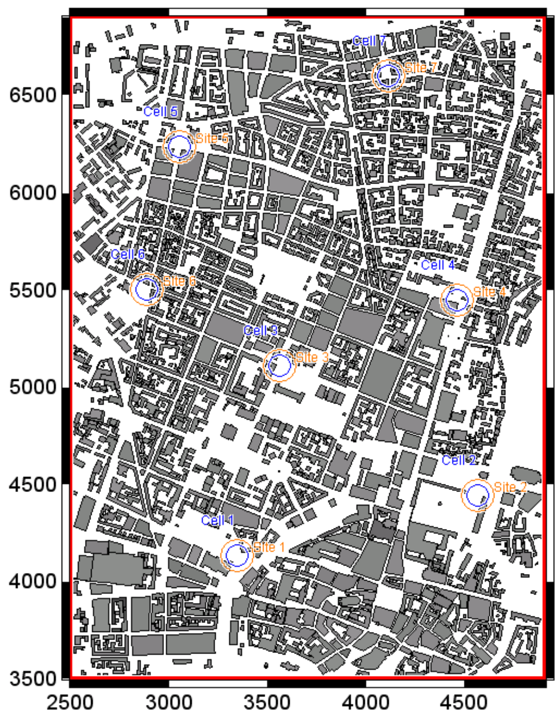

Fig. 3: Downtown Munich data base and example network configuration

B. *System Parameters*

A C/I based scheduler has been used for the simulations. It optimizes system throughput for the expense of fairness, especially in highly loaded systems. RLC retransmissions have been disabled for these simulations and packet losses are counted instead, if the maximum number of four physical layer retransmissions of the Transport Block (TB) does not lead to a successful packet transmission. Retransmissions (of TBs) are handled with a priority higher than other (first) transmissions. A maximum number of 15 HS-PDSCH codes can be assigned (Spreading Factor SF 16) and 4 codes are reserved for HS-SCCH (SF 128). For each sector a CPICH has been configured with 2 W output power in the macro-cell scenario and with 1 W in the micro-cell case. 1 W additional common channel power is transmitted for each sector in both scenarios. The maximum HSDPA power resources are limited to 5 W and 2 W in macro-cell and micro-cell layout, respectively.

The simulated real time is 24 min and more than $8{\cdot}10^5$ packets have been transmitted in this period. The parameterization of the packet generator can be seen in Table I. According to [4] this corresponds to a web browsing session. Single path LOS link level simulations are used for mobiles with LOS condition. For NLOS areas link level simulations with the ITU Vehicular A profile and a speed of 30 kmph are applied.

Table I: Packet Traffic Parameters

Parameter	unit	WWW model
Session Arrival Rate	1/s/sqkm	Poisson Process (mean 2.0)
Number Pages	–	Geometrical (mean = 5)
Page Size	kByte	Cut-Off-Pareto (α = 1.1, k = 4.5, m = 2048)
Page Reading Time	s	Geometrical (mean = 5.0)
Packet Size	Byte	Multi-Modal 40 24% 552 10% 576 10% 1500 35% 40-1500 rest uniform
Packet Inter-Arrival Time	ms	Geometrical (mean = 6.0)

IV. Simulation Results and Evaluation

A. HSDPA peak data rate (static)

An important performance indicator for HSDPA networks is the maximum achievable user throughput distribution within the coverage area. To obtain this map it is assumed that all HSDPA resources (power and codes) can be used to serve a single UE. Considering the bursty nature of important traffic classes (e.g. web browsing) this can be expected in a statistical manner for moderate traffic densities per cell.

For the presented simulations the CPICH transmit power level and a constant additional interference level was specified as described in the previous section. For each pixel the CPICH SNIR is evaluated and an appropriate Transport Format and Resource Combination (TFRC) is selected. Using all HSDPA power of the serving cell the HS-DSCH signal to noise and interference ratio is determined, and with the corresponding link level simulation table the user data rate can be calculated.

Fig. 4 shows the location dependent HSDPA peak rate for the micro-cellular scenario. In areas with good radio channel conditions (e.g. LOS to the serving sector) a data rate of up to 12.8 Mbps can be achieved. In this scenario approximately 8% of the area is in LOS condition. Even though the network is in quite low load the interference level in large parts (NLOS) of the simulation area is too high to utilize 16-QAM because of the poor CDMA signal orthogonality (see chapter II.F). The average maximum bit rate over the whole simulation area is 2.8 Mbps, in 11% of the outdoor area the maximum data rate reaches 12 Mbps and in approximately 50% of the area the peak rate exceeds 1.5 Mbps. Note that these values do not include the indoor areas with its bad channel conditions.

In the macro-cellular example the areas with very good channel conditions are significantly reduced. This is due to the fact that the LOS part of each sector is reduced because of the antenna being mounted over the roof top. Therefore the micro-cellular example benefits significantly more from the 16-QAM than the macro-cellular example. In the macro-cellular layout (not shown in the figure) the peak data rate averaged over the simulation area is now 2.14 Mbps and in 4% of the area more than 12.0 Mbps can be expected. On the other hand low mounted antennas (micro-cells) lead to decreased channel conditions at the cell border. This is reflected in a reduced HSDPA peak rate in these areas compared to the micro-cellular layout. Note also that the available HSDPA power is reduced in the micro-cellular scenario.

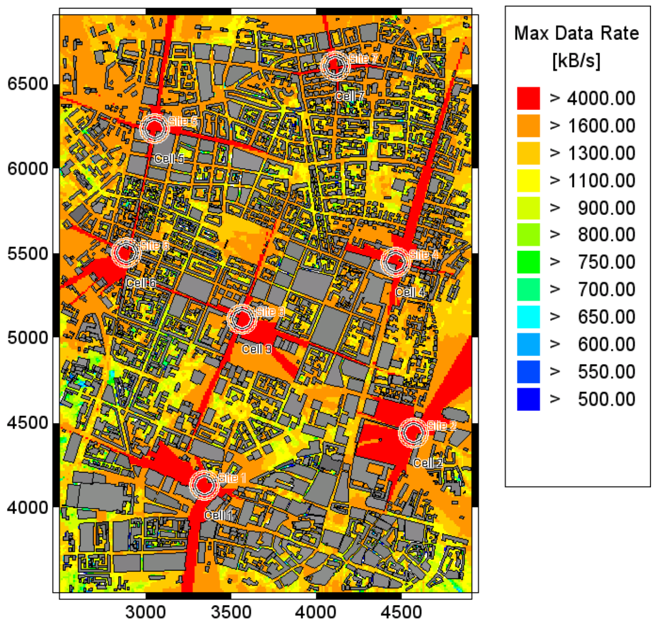

Fig. 4: HSDPA peak data rate in the Micro-Cellular network layout

From preliminary simulations assuming Pedestrian A (3 kmph) channel profile instead of the Vehicular A (30 kmph) a peak data rate increase of approximately 30-50% can be expected in the NLOS areas due to the better link level performance.

B. Packet Performance Statistics (dynamic)

Further packet performance indicators can be derived from the statistics of the transmitted packets. The first value of interest is the packet delay, i.e. the time between packet arrival at Node B and successful reception at UE side. This includes fast physical layer retransmissions of the radio blocks and scheduling delays. Additionally the page throughput (i.e. amount of data per requested page divided by the time between the arrival of the first packet at Node B and successful arrival of the last packet at UE) is monitored, which gives a good performance measure from the subscriber point of view. Furthermore the sector throughput per TTI, the reported CQI, the applied TFRC, and session statistics are collected.

Fig. 5 shows the packet delay distribution for a different macro-/ and micro-cellular scenario (not the Munich example).

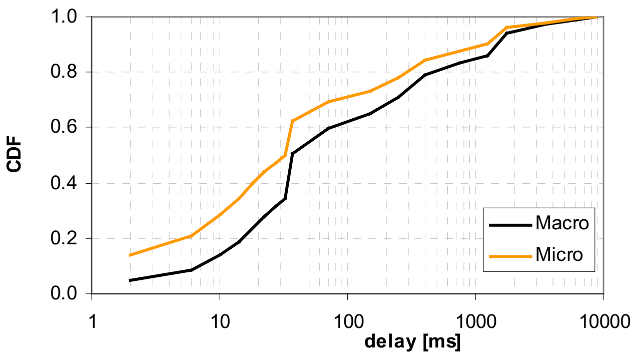

Fig. 5: HSDPA packet delay distribution

Table II: Packet performance with different HSDPA versus interference ratios

P_{tot}	W	20	20	20	20
$P_{CPICH} + P_{CCH}$	W	2+1	2+1	2+1	2+1
P_{DCH}	W	0	2	5	10
P_{HSDPA}	W	13	11	8	3
Mean Packet Delay	s	0.78	1.20	4.33	27.67
L1 Packet Losses	%	0.36	0.48	1.01	5.03
Sector Throughput	kbps	1339	1285	784	403
Mean TFRC	No.	13.0	12.4	10.6	7.3
Mean Page Throughput	kByte/s	20.2	17.9	11.9	4.34
90% Page Throughput	kByte/s	74	65	33	7.5

For a macro-cellular layout different HSDPA versus interference scenarios have been investigated (not the Munich data base). Therefore HSDPA power was reduced while the constantly interfering DCH power part was increased (see Table II). Note that the results presented here are just exemplary numbers to demonstrate the simulation capabilities. The values depend on the parameterization and the scenario quite a lot.

V. Conclusions

A dynamic HSDPA simulation tool based on a existing WCDM simulator has been presented and the required extensions and modifications to handle HSDPA packet traffic in a proper way have been shown. It turned out that a quite realistic modeling of the radio channel is absolutely mandatory for HSDPA performance predictions, especially due to the flexibility in adapting modulation and coding. Therefore a new approach for a location depending orthogonality factor has been introduced. The applied ray-optical propagation models, as the basis for the presented simulator, are perfectly suited for this kind of evaluation, as they deliver realistic distributions of radio channel conditions. This is necessary to consider the use of the interference sensitive 16-QAM in a realistic way.

The simulation tool can be very useful for network planning purpose, as it allows the investigation of different network layouts and parameterizations with respect to their impact on achievable HSDPA peak data rate and packet performance. It can be seen that orthogonality and cell isolation is quite important for overall HSDPA performance. This should be taken into account in the network planning process as early as possible.

On the other hand the simulator has also been developed to investigate and validate HSDPA algorithms (e.g. packet scheduling and resource management). The influence of the transmission power assignment has been demonstrated with one example.

VI. Outlook

The simulator will be extended with an advanced channel profile interface to consider the actual channel profile even more realistically for determining the important location dependent orthogonality factor and to enable the use of better adapted link level simulation results.

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