Highly Efficient Simulation Approach for the Network Planning of HSUPA in UMTS

L. Zhao\textsuperscript{1}, M. Koonert\textsuperscript{2}, A. Timm-Giel\textsuperscript{1}, and C. Görg\textsuperscript{1}

\textsuperscript{1}Communication Networks, University of Bremen, Otto-Hahn-Allee NW1, 28359 Bremen, Germany
\textsuperscript{2}Nokia Siemens Networks Sp. z o.o.
ul. Strzegomska 46a, 53-611 Wroclaw, Poland
{zhaol, atg, cg}@comnets.uni-bremen.de
Michael.Koonert@nsn.com

Abstract—In this paper, a novel approach of HSUPA modeling for static simulation is proposed. This approach is based on the simulation results from time-based simulation and combines the well-known snapshot procedure for R99 with corresponding enhancements for the specific features of HSUPA. The detailed simulation structure and required deduction of multi-cell system equation group are described, respectively. The simulation results show that the new static approach can yield significant performance evaluation for a network much faster than the time-based approach and have comparable quality of the results at the same time. The presented approach is as well applicable for detailed system-level simulations as for incorporation in network dimensioning and planning tools.

Index Terms—HSUPA, snapshot simulation, scheduling, network planning.

I. INTRODUCTION

HIGH Speed Uplink Packet Access (HSUPA) was being standardized in Release 6 of 3GPP Technical specification (e.g. [1] [2] and [3]). As a complementation for the downlink packet enhancements in HSDPA, HSUPA aims to provide significantly higher data rates and lower latency than Release 99 systems, especially for some applications requiring more transmission in uplink such as FTP upload, numerous VoIP users, and peer-to-peer applications like interactive online gaming.

HSDPA is recently deployed widely around the world, and many commercial applications have been provided. Correspondingly, the deployment of HSUPA is also ongoing, and HSUPA-capable devices are becoming available from different vendors. Since HSUPA is proposed to support many users which can experience high data rates in uplink simultaneously, efficient management of radio resource in uplink is crucial. During the deployment and operation of UMTS networks, planning and optimization are very important to maximize the utilization of the limited radio resource. Particular issues are considered by the network dimensioning, e.g. the required number of Node B; the number of cells in each Node B; the direction of the antennas; and the output power of the sites. Furthermore, the optimization and tuning are continual in all the time of the operation of one network [4]. Thus, an efficient and credible approach for the evaluation and simulation of mobile networks is required.

Time-based (or dynamic) method is the seeming option which is simulating the actual events and behaviors of the system and can provide most reliable results. However, the exceeding time consumption in dynamic simulation is unacceptable, especially for realistically large scenarios to obtain convergent enough results. In order to speed up the simulation, we try to accomplish an approach to model not only R99 but also the main features of HSUPA for the static snapshot. We will introduce the time-based structure firstly, and from that we propose a way to model the dynamic features of HSUPA. This new approach is an enhancement from [5], in which the corresponding snapshot method has been applied for the evaluation of Release 99 systems. In [6], a similar approach has been investigated for the fast HSDPA performance analysis, where a two-stage process including snapshot simulation and dynamic analysis of HSDPA channel is given.

This paper is organized as follows: Section II describes the fundamentals about the main features of HSUPA, the structure of the system-level simulator for HSUPA and the procedure of rate adaptation in snapshot simulation. The modeling approach of HSUPA is the topic of Section III, and in Section IV the configurations of simulation and the simulation results will be shown. At last, the main conclusions are described in Section V.

II. FUNDAMENTALS AND SYSTEM STRUCTURE

A. Main Features of HSUPA

To fulfill the requirements of HSUPA, several new features are discussed and introduced in Release 6. A feasibility study for HSUPA for UTRA FDD has been done in [2], in which some technical candidates are proposed and their performance are simulated. It is proven that three basic features can bring a significant improvement in system capacity, end-user packet call delay and user packet call throughput compared to Release 5. Thus, they have been adopted by Release 6 of 3GPP specifications. The three features are:

- Hybrid ARQ (HARQ);
- Node B controlled scheduling;

-
Shorter TTI (Transmission Time Interval).

Fast scheduling enables the system to maintain a large number of higher data rate users simultaneously and quickly adapt to interference variations of the air interface. The Node B (NB) can control the maximal output power of user equipment (UE) to adjust its data rates. This scheduling commands are represented by two kinds of grants, Absolute Grant (AG) and Relative Grant (RG), where AG is an indication of absolute value of power level that can be used by UE and RG consisting of ‘DOWN’, ‘HOLD’ and ‘UP’ means the relative adjustment of output power level. In uplink, the HARQ gives the capability to the Node B to rapidly request retransmission of erroneously received data unit. In this way, the system capacity and/or the coverage of a given data rate can be increased. The introduction of shorter TTI is for the purposes of latency reduction and rapid adaptation. Note that in this paper for the sake of comparability to R99 we are focusing on the 10ms TTI only and the proposed approach can be applied for the applications with 2ms TTI, straightforwardly.

B. Structure of System-level Simulator

For the simulation of network planning two issues have to be considered: the dimension of the simulation and the time consumption of the simulation. These two issues are related to each other.

In the study of link-level simulation, normally we have only one Node B and one (or several) UE to observe the performance of, for example, channel coding or modulation. However, for network dimensioning in UMTS the simulation has to at least consider multiple NBs and hundreds even thousands of UEs in the system. Employing link-level simulation cannot satisfy the dimensioning of network planning because of the limited memory and calculating capability of PC.

Fig. 1 shows the overview of the system-level simulator which is applied for dynamic (time-based) simulation for our work. There are 19 NBs in the area for the simulation and the layout of the NBs are symmetrically hexagonal, that means each NB has 3 cells. Note that real scenarios with arbitrary layout of the networks can be also evaluated by the simulator, and the scope of this paper focuses on the introduction of the novel approach. The whole scenario is divided into small grids or pixels so that the simulation and calculation are always pixel-based. In order to focus the main purpose following assumptions have been employed: perfect power control, fixed number and position of users during the run-iteration. From run to run, the number and location of users are redistributed randomly. From TTI to TTI, the Node B controlled scheduling and interference calculations for each cell are processed. At the end of simulation, typical evaluations can be done.

As mentioned previously, time consumption is always the bottleneck for the simulation. Besides running the program on more powerful processors the static simulation method is employed for the simulation of network planning in order to obtain the evaluations in relatively short time frame. Unfortunately, the static method cannot be employed for the simulation of HSUPA straightforwardly, because considering the behavior of HSUPA scheduling the data rates of users are adjusted by the Node B from TTI to TTI. The highly dynamic process is difficult to be expressed by one or multiple static snapshots.

Our solution is to obtain some meaningful results from time-based simulations and apply them into snapshot simulation. In this way the main features of HSUPA can be modeled for the static methods. Here it has to be mentioned that the structure in Fig. 1 can be also applied for the snapshot simulation, and the only difference is the shadowed TTI-iteration part, which will be substituted by the calculation of cell-based system equation group. The details of cell-based equation group and snapshot approach are introduced in the following sections.

C. Cell-based Uplink Equation Group

If one snapshot has been generated, which means the status of the system on one time instant including cells, UEs, path loss and traffic, the whole scenario can be described by one linear equation group consisting with link-based equations. Each equation represents the transmission from one UE to one cell, and the interference $I_c$ at cell $c$ is the sum of received power from all UEs in the area plus background noise $N_0$.

This relationship can be described as

$$P_{i,c}^r = P_i^t \cdot G_{i,c}, \quad i = 1,2,\ldots,M,$$

and

$$I_c = \sum_{i=1}^{M} P_{i,c}^r + N_0 \quad c = 1,2,\ldots,K,$$

where $P_{i,c}^r$ is the received power of user $i$ at cell $c$. $P_i^t$ is the transmit power of user $i$ and $G_{i,c}$ is the link gain between user $i$ and cell $c$. In the area there are $M$ users and $K$ cells all together. Normally, $M \gg K$, so the idea in [5] is trying to reduce the dimension of equation group from order of $M$ to $K$. In this way, the system equation can be solved much faster.
Let $SIR^T$ be the signal to interference plus noise ratio target for one link to achieve the required BLER. $SIR^T$ are real measured and saved as lookup table for different data rates. Because of perfect power control we say that each link has

$$SIR^T_i = \frac{P^r_{i,c}}{I_i - P^r_{i,c}}.$$  

(3)

From (3) we can define

$$SIR^r_i = \frac{P^r_{i,c}}{I_i} = \frac{SIR^T_i}{1 + SIR^r_i}.$$  

(4)

According to (1) and (4) there is

$$P^r_i = \frac{SIR^r_i}{G_{i,c}} \cdot I_c.$$  

(5)

In general, let $j = 1, 2, \ldots, K$ and $j \neq c$, put (5) into (1) we have

$$P^r_{i,j} = P^r_i \cdot G_{i,j} = \frac{G_{i,j}}{G_{i,c}} \cdot SIR^r_i \cdot I_c.$$  

(6)

Rewriting (2) with the consideration of (6) we obtain

$$I_c = I_{\text{own}} + I_{\text{other}} + N_0 = \sum_{i \in C} SIR^r_i \cdot I_c = \sum_{j \neq c} \sum_{i \in J} \frac{G_{i,j}}{G_{i,c}} \cdot SIR^r_i \cdot I_j + N_0.$$  

(7)

In (7), $I_{\text{own}}$ means the interference generated by the users in own cell as well as $I_{\text{other}}$ is the interference caused by neighboring cells. Because the link gain and SIR target are already known, then we obtain the linear system equation group

$$\mathbf{I} = \mathbf{G} \cdot \mathbf{I} + \mathbf{N}$$  

(8)

with the dimension as the number of cell $K$, and this equation group can be solved with standard iterative methods like Gauss-Seidel method.

D. Rate Adaptation for Snapshot

According to the deduction in the previous subsection we know that if the system, including user distribution, path loss and traffic, has been given the interference level of each cell can be calculated instantly. However, for a realistic stable system, the expectation of $I_c$ should be below the limitation set by system parameterization (RNC). Or, in other words, the interference level of most of cells at the most of the time should be below the specific limitation in order to keep the whole network working properly.

Thus, the resource scheduling is required for the snapshot simulation to get a convergent result. Fig. 2 shows the procedure of rate adaptation for resource scheduling. The idea is that if one or more cells are still overloaded, then one random user is picked up from one of the overloaded cells for the downgrading of its data rates. The step of downgrading is according to service type. On the other hand, if the cell is not in overload, the free radio resource might be allocated to one user which requests upgrading of its data rates. After every change of the data rates the system equations are updated and re-solved correspondingly. This rate adaptation is repeated until the system is convergent.

Note that the resource scheduling mentioned here is different from actual HSUPA scheduling. The former is the approach to obtain a convergent distribution of traffic, and the latter controls the instant data transmission. However, this comparability between them gives us the possibility to model HSUPA scheduling in snapshot simulations.

III. MODELING OF HSUPA

In Section II we recall the main features of HSUPA, in which HARQ and Node B controlled scheduling, are the main points to be modeled for the static simulation.

A. Modeling of HARQ

Due to the noise, fading and interference, it is almost inevitable that more or less errors occur during the transmission of data units. Besides channel coding, ARQ is an effective technique to correct the erroneous transmissions. Additionally, soft combining, which means that information formerly received correctly is combined with additional (soft or delta) information sent repeatedly, can greatly improve the decoding performance. The Node B controlled HARQ with soft combing is a scheme with multiple parallel stop-and-wait (SAW) processes. That means one process is waiting the acknowledgment and other processes can send data units in parallel. The Node B would not discard the fail-received data unit but combines it with retransmitted data units to enhance the probability of successful decoding.

In Fig. 1 we noticed one input from link-level simulation, i.e. SIR targets. This is actually the interface [7] between link-level and system-level simulation. Some researches [8] show that HARQ in HSUPA can improve the link quality. What we need for the modeling of HARQ is the improved BLER curves or the required SIR targets for different transmit data rates.

2ms TTI is not considered in this paper, but the impacts from the length of TTI can be included into the interface between link-level and system-level simulation. Most probably the equipments from different providers have different link performance, but this modeling procedure for HARQ is straightforward.
B. Modeling of Scheduling

In uplink, the shared resource between multiple UEs is the total received power at the Node B. This power level in a way represents the tolerance of the interference at Node B. Thus, the mission of the scheduler is to adaptively keep an acceptable interference level of whole system and at the same time to advise multiple active UEs at when and with which rate to transmit their data. Because the mobile environment and the data rate requirements of each active UE may change very quickly, the scheduler should have the capability to track these quick variations and to adjust the user’s data rates with scheduling grants. The fast scheduler can allocate a majority of the shared resource to the users requiring high data rates and at the same time avoid large interference peaks happening at Node B.

Consideration of soft and softer handover (SHO) is also another important characteristic of HSUPA scheduling. Not only the serving cell has the main responsibility to schedule the behavior of one user in SHO, but also the neighboring cells in the active set of this user can affect its data rates. Especially, the ‘DOWN’ command from neighboring cells is treated as an overload signaling. In this way, multiple cells can ‘exchange’ the loading information to each other, which means multiple cells can interact according to their actual cell load. But this highly dynamic procedure gives us the difficulty to model it into static snapshot. From statistic point of view users in SHO will get ‘DOWN’ command with higher probability, therefore their average data rates should be lower than that of users not in SHO.

In Section II.D we have mentioned that the process of data rates adaptation in snapshot is quite similar as the process of HSUPA scheduling. With following three additional prerequisites the modeling of HSUPA scheduling can be accomplished:

1. Pre-downgrading of data rates for users in SHO: because for one snapshot the position of active users are fixed, then we can find the users in SHO based on path loss. According to the results from time-based simulation, we know the offset of data rates between users in SHO and not in SHO. Before the snapshot rate adaptation the pre-downgrading for the users in SHO can be done.
2. Principle of user selection: this principle should be same as the one employed in the time-based simulation, e.g. random selection, Round-Robin or Proportional Fairness etc. Note that if the principle of scheduling has been changed in time-based simulation, pre-downgrading must be re-designed carefully.
3. The step size of the data rates adaptation: the step size should be same with the one applied in the scheduling of time-based simulation.

IV. SIMULATION RESULTS

A. Simulation Configurations

Table 1 lists the configurations applied for snapshot and time-based simulation. Employing same settings is for the reliable comparisons between them. The simulator is programmed in MATLAB and runs smoothly on a PC with AMD Athlon 64 4000+, 1GB RAM.

TABLE I

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>SIMULATION CONFIGURATIONS</th>
</tr>
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<tr>
<td>Network</td>
<td>Cell layout</td>
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<tr>
<td>Node B</td>
<td>19 Node Bs with 3 cells per site; Evaluation on inner 21 cells; Symmetrical hexagonal distribution</td>
</tr>
<tr>
<td>UE</td>
<td>Hardware limitation of output power</td>
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<tr>
<td>Propagation</td>
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<td>Path loss</td>
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<td>Slow fading</td>
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<tr>
<td>SHO</td>
<td>Soft and softer handover</td>
</tr>
<tr>
<td>Mobility</td>
<td>Fixed number of users in each run; Fixed position; Uniformly distributed; Changed run by run</td>
</tr>
</tbody>
</table>

1. The whole scenario consists of 19 NBs with 57 cells. For the sake of simulation time, shown results contain only inner 7 NBs with 21 cells, but this has no impacts on the generality of the results.

2. For snapshot simulation there is no consideration on fast fading.

B. Simulation Results

Fig. 3 shows the average UE output power which is obtained from time-based simulation. To get this result there were 1000 runs and 100 TTIs in each run. LRE method (Limited Relative Error) can be employed for the checking of convergence of each run to save the running time. Considering a real system with 10ms TTI, the simulated time should be around 15 minutes. But due to the interference estimation and scheduling process in multiple cells, the actual required time consuming for this simulation is over 30 hours. We can see that the power map is still coarse and the result is not convergent enough. There are some white spots in the maps, which means after 1000 runs no active users are distributed in that pixels. Translating the simulator from MATLAB to C/C++ is also one option to strive for the time reduction in the order of 5 to 10 times, but the corresponding workload is heavy and insignificant compared to the alternative of considering

![Image](image_url)
snapshots.

With the proposed snapshot simulation, the same distribution of average UE output power can be obtained, too. Fig. 4 illustrates the result which is obtained from 5000 snapshots in 3 hours. It is obvious that with much shorter time the enhanced snapshot method can get more convergent result than the dynamic one. Fig. 3 and Fig. 4 have quite similar distribution, and this also gives the evidence of the valid modeling of HSUPA. In general description, the users near to the Node B need less output power for the transmission, and the users far away from the Node B requires higher power to send the signal. Due to the hardware limitation, some UEs with high path loss might be dropped from the transmission.

Besides the output power, other meaningful evaluations for network planning can be also obtained with this snapshot approach. Fig. 5 represents the average data rates distribution obtained by the snapshot simulation. From the map we can observe that the pixels in the centre cells have similar average data rates, if the size of the cell is not extraordinary large. The pixels in the intersection area among cells have relative low data rates, because they are in SHO situation and affected by the ‘DOWN’ grants from surrounding cells. The simulation runs for inner 7 NBs, and it is reasonable that the cells at the edge of the area have higher average data rates than others, because they receive less interference from neighboring cells. Actually more evaluations, e.g. noise rise of each cell, throughput of specific cell, data rates of individual UE and so on, can be done by the snapshot simulation. This depends on the different purposes of network dimensioning.

V. CONCLUSION

An efficient approach of HSUPA modeling for the snapshot simulation has been proposed in previous sections. The dynamic features of HSUPA, HARQ and scheduling, can be represented in a static way by SIR target table and rate adaptation in resource scheduling, respectively. The time required for the simulation is remarkably reduced by employing the snapshot simulation for the network evaluation of HSUPA, and the corresponding evaluations such as average user data rates and distribution of output power show that the modeling of HSUPA is valid. The snapshot simulation is by nature more efficient than the dynamic simulation. However, for the evaluation of realistic planning scenarios with hundreds to thousands of Node Bs a more analytical approach would be an enhanced option, which can be pure analytical or semi-analytical based on lookup tables obtained from previous exemplary simulations. The validation of such an analytic approach for HSUPA dimensioning is currently under investigation and scope of further work.

REFERENCES