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HIGH SPEED UPLINK PACKET ACCESS EVALUATION BY DYNAMIC NETWORK SIMULATIONS

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ABSTRACT

High Speed Uplink Packet Access (HSUPA) improves the cell throughput by faster scheduling, L1 HARQ and enhanced bit rates. This paper introduces a dynamic system simulator for studying HSUPA system performance. This simulator is used to analyze the effect on the cell throughput of increasing the BLER target and the target number of transmissions. The L3 cell throughput increases when the target number of transmissions increases, while the control overhead in terms of transmission power is estimated to be approximately 25%.
KeyWords: Enhanced DCH, HSUPA, performance, simulations.

I. INTRODUCTION

The downlink of 3GPP WCDMA was improved significantly in terms of cell and user throughput with the introduction of High Speed Downlink Packet Access (HSDPA) [1]. The next logical step in the evolution of future packet access is to improve the uplink direction of WCDMA. This is done by the introduction of the Enhanced Dedicated Channel (EDCH), which is also referred to as High Speed Uplink Packet Access (HSUPA).
HSUPA is introduced in Rel. 6 of the 3GPP specifications [2]. HSUPA enhances the peak data rates of the connection up to 5.8 Mbps and gives a throughput gain over 3GPP Rel '99 DCH channels [3]. This gain is achieved by three key features: Node-B based packet scheduling, the introduction of HARQ, and the capability of the User Equipment (UE) to send higher bit rates. In order to reduce the end to end delay, EDCH specifications facilitate the use of 2 ms TTI length besides the normal 10 ms setting.
Node-B based packet scheduling makes it possible to track the traffic needs of the users even under very bursty traffic conditions. In case of Rel '99 RNC based scheduling this is hard due to the relative long round trip time of RRC signaling between the RNC and the UE. This can lead to over-allocation of bit rates to the users in order to cope with the variations in the traffic. When Node-B handles the scheduling, the scheduler does not need to over-allocate the bit rates, since it can react fast to changes in the traffic pattern. This way, a cell throughput gain can be achieved [4].

Another key feature being introduced with HSUPA is HARQ. HARQ is located on the MAC layer and gives the benefit of shorter delays from retransmissions compared to the slower RLC retransmissions. HARQ enabling a higher BLER operating point for initial transmissions while maintaining the same total delay as in 3GPP Rel' 99. An additional gain is achieved from the combining of the original transmission with retransmissions by using incremental redundancy or chase combining techniques.
The third feature introduced with HSUPA is higher bit rate availability. Peak bit rates up to 5.8 Mbps are possible with HSUPA by allowing multicode transmission from the UE. These peak data rates are however only achievable under very favorable channel conditions.
In this article a dynamic network simulator is introduced which is used for studying the system performance of HSUPA. The outline is as follows: Section II describes the simulator and a typical simulation setup. Section III contains an example of an EDCH performance study and section IV contains the conclusion.

II. DYNAMIC SYSTEM LEVEL SIMULATOR

In order to evaluate the RRM algorithms needed for HSUPA, the performance in terms of network throughput and end user performance under dynamic network conditions need to be evaluated. The complexity of the dynamic network behavior makes it virtually impossible to calculate the performance of the overall system analytically. Two alternatives exist: network trials and dynamic network simulations. The first one has the disadvantage that it is rather expensive to test different versions of the algorithms due to the needed implementation in the test system, and the network would need to be artificially loaded by test users. Network simulations, on the other hand, are much simpler and will give reliable results when based on accurate link and network models. The network simulator, which is used to study the performance of HSUPA, is described in this section. First, the general aspects of the simulator are described followed by a description of the HSUPA implementation.

A. Dynamic System Level Simulator

The simulator includes parameterized models of data traffic, user mobility, and radio wave propagation such that a

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large variety of user behavior and propagation environments can be tested.
The time resolution is one slot (667 µs). The power levels in the radio propagation model are constant over one slot, so power changes below slot level are modeled in link level simulations. The receiver chain is modeled using Actual Value Interface tables [5], which map signal to noise levels to frame error probabilities. In case of RX diversity, maximum ratio combining is used.
Traffic generators create user PDUs according to parameterized probabilistic models, which make it possible to simulate all kinds of traffic like constant bit rate streaming, FTP, MMS, with and without TCP protocol aspects included. These PDUs are forwarded to the RLC layer at the UE in uplink and at the RNC in the downlink, where they are handled according the RRM algorithm specifications and sent via the MAC layer and the air interface to the receiving end.
A typical scenario for simulations consists of 18 cells and 9 Node-B's and is depicted in **Figure 1**. The UEs are uniformly distributed over the cells. Only the statistics of the four center cells are used in order to avoid border effects.

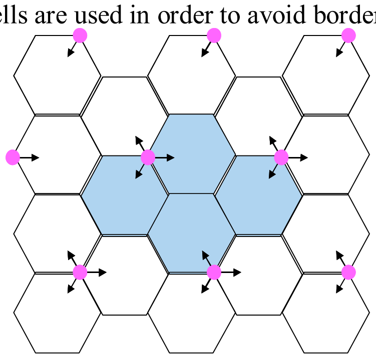

Figure 1 Simulation cell layout. Only the four center cells are considered for statistics collection.

B. HSUPA Implementation

An overview of the RRM functionalities related to HSUPA, which are implemented in the simulator, can be seen in Figure 2. The different functions are distributed over the Radio Network Controller (RNC), Node-B, and UE. The different functions are shortly described in the following.
Admission Control for HSUPA is located in the RNC and decides whether a new user should be admitted or not based on the required Quality of Service (QoS) of the new user and existing users.
Handover Control takes care of the mobility of the users, including decision of the HSUPA serving cell and active set maintenance, based on power and load measurements.

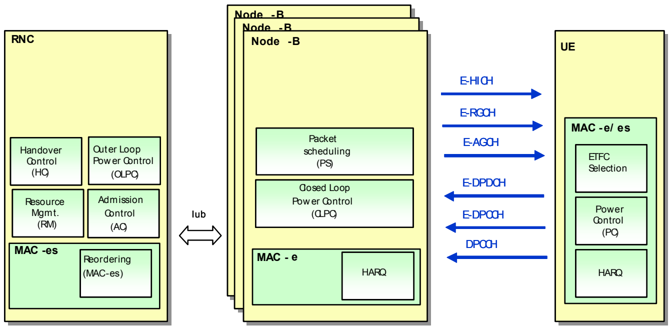

Figure 2 Overview of the different RRM functions related to HSUPA, which are implemented in the simulator.

The main task of the *Resource Manager* for HSUPA is the allocation of the maximum target Received Total Wide Band Power (RTWP) to each cell. The maximum target RTWP indicates the maximum target UL interference for a certain cell, including received wideband power from all sources, including HSUPA. The *reordering* function in the RNC takes the MAC-es PDUs, arriving from the Node-Bs, and forwards them in the right order upwards to the higher layers.
Outerloop power control adjusts the SIR target in the Node-B. The algorithm in the simulator is based on the Redundancy Sequence Numbers (RSN) of the MAC-es PDU received from the Node-B. The RSN number of a PDU indicates at which transmission the PDU was received correctly at the Node-B[1]. The outerloop power control is run for every PDU and adjusts the *SIRtarget* upwards when the RSN value of a PDU is larger or equal to the target number of transmissions, the *RSNtarget*, while it decreases the *SIRtarget* when the RSN of a PDU is lower than the *RSNtarget*. The steps used in the adjustments can be different in up and downlink and are following the thinking of [7]:

$$\text{Stepup} = \text{Step} * (1-\text{BLERtarget}) \quad \text{(dB)} \qquad (1)$$
$$\text{StepDown} = \text{Step} * \text{BLERtarget} \quad \text{(dB)} \qquad (2)$$

where *Step* is a parameter in dB and *BLERtarget* is the target BLER for the transmission indicated with the *RSNtarget*.
Packet Scheduling for HSUPA is located in the Node-B. The scheduling considered in the simulator upgrades the allocation to a UE when cell resources are available and when the user has requested a higher allocation. A UE requests a higher allocation when it has capability to send with a higher bit rate and when it has more data in its buffer than it can send within *Happy_Bit_Delay_Condition* ms with its current allocation. The packet scheduler continuously monitors the utilization of the allocated resources and can downgrade users when their utilization is low.
Another key function in the Node-B is HARQ which takes care of the retransmissions over a N channel stop and wait

[1] The RSN numbering starts at zero, indicating a PDU was received correctly at the first transmission.

synchronous HARQ scheme, as specified in [2]. The re-trans-mission delay from HARQ retransmissions is much smaller than the retransmission delay from RLC retrans-missions, thus enabling a higher BLER operating point for initial trans-missions. A higher BLER means that required Eb/No of the data channel can be lowered and thus more users can be added to the system or bit rates can be in-creased.

Besides this the Node-B takes care of the inner loop power control. Its modeling includes SIR measurement errors and errors on the power control commands.

In the UE, TFC selection and elimination [2] are done together with the UE part of the power control algorithm and L1 HARQ. TFC selection and elimination are mod-eled such that the highest bit rate which the UE can send given its maximum transmission power, the amount of data in its buffer and the allocation from the Node-B, is used.

On the air interface the EDCH channel consists of one or several E-DCH Dedicated Physical Data Channels (E-DPDCH(s)) and the E-DCH Dedicated Physical Control Channel (E-DPCCH). The E-DPCCH is modeled together with the DCH channel consisting of a DPCCH and a DPDCH. The powers of the different channels are set ac-cording to power ratios between the different channels, which are determined by the HSUPA power ratio's [8]. Inner loop power control operates on the DPCCH, while outer loop power control performs as described in section II. In the downlink the three different signaling channels, the Hybrid ARQ Indicator CHannel (E-HICH), the Abso-lute and Relative Grant CHannels (E-AGCH and E-RGCH) are each modeled with a configurable delay and an error probabilities for the different error cases.

III. PERFORMANCE STUDY EXAMPLE

This section shows an example of an HSUPA perform-ance study in which the gain from HARQ as function of the *RSNtarget* and the *BLERtarget* is studied. Also an es-timation of the control overhead is made. First an over-view of the simulation setup is given.

A. Simulation Setup

The network setup, as shown in **Figure 1** is used. The site to site distance equals 2800 meters. The traffic considered in this study is MMS traffic, which is modeled as an ex-ponentially distributed packet call size with a mean of 12.7 kB and a cutoff of 5 seconds. No TCP protocol ef-fects are included.

Admission control is simply based on the maximum num-ber of users per cell, while packet scheduling and HARQ are modeled as described in section II. The packet sched-uling period is set to 10 ms and the allocation to users is downgraded when the utilization (which equals the ratio between utilized and allocated received power at the Node-B) is lower than 50% for 40 ms. The packet sched-uler upgrades the allocation when the UE has more data in its buffer than it can send with its current allocation within 100 ms and when the UE has the capability to use a larger allocation. The most important parameters, which are used, can be seen in Table 1.

B. HARQ

This section shows the performance results analyzing the gain from HARQ as function of the *RSNtarget* and the *BLER target*. The cell throughput gain from HARQ is coming from being able to send with a larger BLER. This leads to a lower Eb/No which can be turned into a cell throughput gain [9].

Table 1 Parameter settings

Parameter	**Value**
Packet scheduling period	10 ms
Happy_Bit_Delay_Condition	100 ms
Utilisation threshold	50%
RSN target	0, 1, 2
BLER target	1%, 10%, 50%
Fast loop power control step size	1 dB
Closed loop power control step size	0.5 dB
Maximum Target RTWP	6 dB
Maximum UE bit rate	1 Mbps
Maximum UE power	21 dBm
Combining method for HARQ	Chase Combining.
Error probability DL control channels	0%
Delays on DL control channels	10 ms
Channel Profile	Veh A
UE speed	30 kmh
2 branch Rx Diversity	Yes

One should, however, remember that when sending data in the uplink with HSUPA, at least three different chan-nels are sent [10]:

One or more E-DPDCH(s), containing the data. Original transmissions and retransmissions are combined by chase combining or incremental redundancy at the Node-B. There may exist more than 1 E-DPDCH per UE.

The E-DPCCH is a physical channel used to transmit con-trol information associated with the E-DCH. There is at most one E-DPCCH on each radio link.

The DPCCH is used to carry control information gener-ated at Layer 1. The Layer 1 control information consists of known pilot bits to support channel estimation for co-herent detection and transmit power-control commands among others.

When the *RSNtarget* increases, then the required energy for the E-DPDCH decreases, but the required energy for the E-DPCCH and the DPCCH remains the same, since no combining is performed for the control signaling, hence the overhead increases when *RSNtarget* increases. The quantity of the overhead depends on the power ratios, which specify the relation in power between the E-DPDCH and E-DPDCH relative to the DPCCH. This is estimated in the next subsection, while in this subsection the control channels are ignored to simplify the analysis.

If we look at the total bit rate on L1 in a cell, which is depicted in Figure 3, then we can see that the L1 bit rate increases with an increasing *RSNtarget* and *BLERtarget*. Also the average number of transmissions increases as expected. When looking at the distribution of the selected TFC for the case of an average number of 10 users per cell, which is shown in Figure 4, the same conclusion can be drawn. Higher *RSNtarget* values lead to larger L1 bit rates.

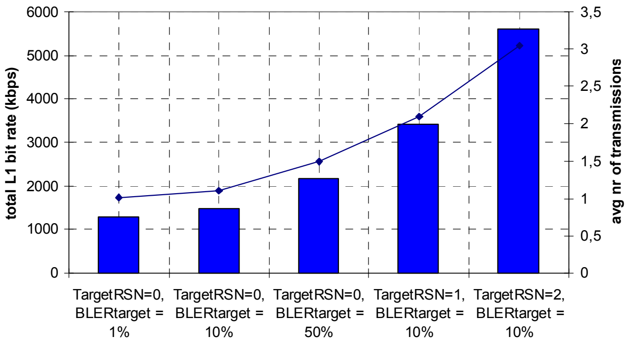

Figure 3 L1 cell bit rate per cell and average number of transmissions versus *RSNtarget* and *BLERtarget*

The L3 useful throughput is depicted in Figure 5. It can be seen that the L3 throughput increases for increasing *BLERtarget* and *RSNtarget* values. Reason for this is that both increased *BLERtarget* and *RSNtarget* values lead to a lower required Eb/No. This means more capacity is available, which can be used by either increasing the bit rates of the existing users or allowing more users into the system, leading to increased L3 cell throughputs. Note that when the gain is turned into more allowing more users to access the system, the interference will increase, leading to degradation compared to the maximum gain. Therefore the maximum bit rate supported by the users in terms of UE capability and amount of data in the buffers impacts the gain from increased *BLERtarget* and *RSNtarget* values.

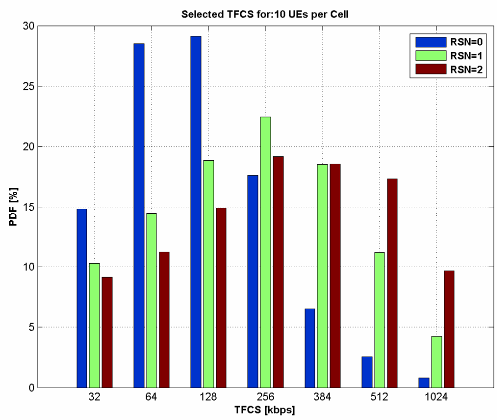

Figure 4 Bit rate distribution for different *RSNtarget* thresholds for a *BLERtarget* of 10%.

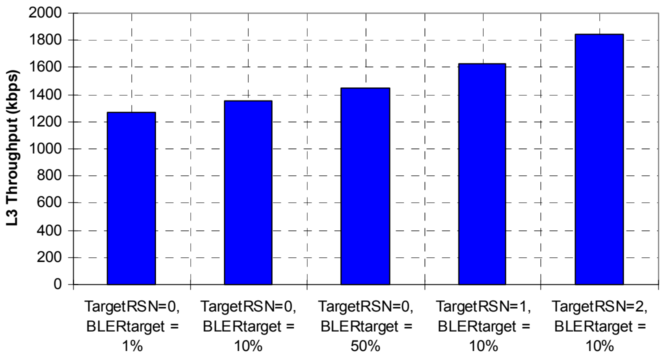

Figure 5 L3 cell throughput per cell versus *RSNtarget* and *BLERtarget*

C. Control Overhead Estimation

As mentioned in the previous subsection, in the simulations the control overhead was not taken into account. In this section it is estimated what the impact is of the control overhead on the cell throughput for the different setups.
The signaling overhead is caused by the DPCCH and the E-DPCCH. The EDCH channels and DPCCH are related to each other by the quantized amplitude ratios A_{ec} and A_{ed}[11]:

$$A_{ec} = \beta_{ec}/\beta_c \qquad (3)$$

$$A_{ed} = \beta_{ed}/\beta_c \qquad (4)$$

where the β_c , β_{ec} and β_{ed} are the gain factors for the DPCCH, E-DPCCH and E-DPDCH respectively. These gain factors are applied after channelisation [8], as shown in Figure 6 for the EDCH channels.

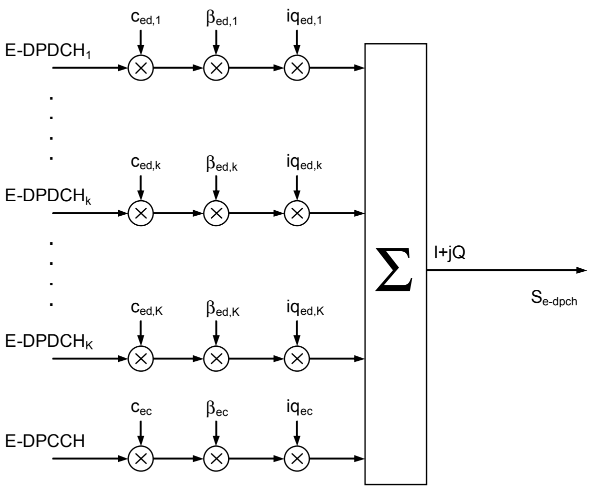

Figure 6 Spreading for E-DPDCH/E-DPCCH [5]

A_{ec} is calculated from higher layers. In the rest of this contribution A_{ec} , expressed in dB, is set equal to -2 dB [9]. β_{ed} shall be computed as specified in [11] based on the reference gain factors ($\beta_{ed,ref}$), the spreading factor for E-DPDCH$_k$, and the HARQ offsets. For the *j*:th E-TFC, $\beta_{ed,j,harq}$ is then computed as:

$$\beta_{ed,j,harq} = \beta_{ed,ref}\sqrt{\frac{L_{e,ref}}{L_{e,j}}}\sqrt{\frac{K_{e,j}}{K_{e,ref}}}\cdot 10^{\left(\frac{\Delta_{harq}}{20}\right)} \quad (5)$$

where $L_{e,j}$ denotes the number of E-DPDCHs used for the j-th E-TFC, $K_{e,j}$ is the number of data bits in a TTI used for the j-th E-TFC and Δ_{harq} is based on an offset in order to support different HARQ profiles. A maximum of eight references can be defined per UE.

The signaling overhead is defined as:

$$Overhead = \frac{P_{control}}{P_{data}} \quad (6)$$

where $P_{control}$ is the power spent on the DPCCH and E-DPCCH and P_{data} is the power spent on the E-DPDCH(s). This can be written as:

$$Overhead = \frac{1 + A^2_{ec}}{A^2_{ed}} \quad (7)$$

The values of A_{ec} and A_{ed} depend on the beta factors, as shown in (3) and (4). The values for A_{ed} for a *RSNtarget* value equal to one are optimized by a link simulator and the corresponding power ratios can be seen in Table 2. The optimization criterion has been to minimize the total UE transmission power at 10% BLER. The values for two and three transmissions are achieved by applying a one and two dB offset to the values used for a *RSNtarget* value of one. These are used in the rest of this control channel overhead estimation.

Table 2 Optimal power ratio between the E-DPDCH and DPCCH as function of the bit rate and number of transmissions.

Bit Rate (kbps)	Power ratio $\frac{E-DPDCH}{DPCCH}$		
	1 transmission	2 transmissions	3 transmissions
32	6.0 dB	5.0 dB	4.0 dB
64	8.1 dB	7.1 dB	6.1 dB
128	8.9 dB	7.9 dB	6.9 dB
256	8.9 dB	7.9 dB	6.9 dB
384	9.9 dB	8.9 dB	7.9 dB
512	11.0 dB	10.0 dB	9.0 dB
1024	14.0 dB	13.0 dB	12.0 dB

Taking the bit rate distributions of Figure 4 the overhead can be calculated. The results can be seen in Table 3.

Table 3 Overhead for different *RSNtarget* values. The *BLERtarget* equals 10%

Case	**Overhead**
RSNtarget=0	0.24
RSNtarget=1	0.24
RSNtarget=2	0.25

This means that the L3 user throughput is further reduced. The throughput of *RSNtarget* value equal to zero and a *BLERtarget* equal to 10% is reduced from 1350 to 1026 kbps, while the throughput in the case of *RSNtarget* equal to two and a *BLERtarget* equal to 10% is reduced from 1850 to 1388 kbps. So running larger values of the RSNtarget lead to a higher throughput, but it will also require a larger amount of hardware since this is related to the L1 throughput.

IV. CONCLUSIONS

In this paper a dynamic system simulator, including the radio resource management algorithms for HSUPA, is introduced. This simulator was used to analyze the effect on the cell throughput of increasing the BLER target and the target number of transmissions. The L3 cell throughput increases when the *BLERtarget* or the *RSNtarget*, which together control the average number of transmissions, increases. Reason for this is that both increased *BLERtarget* and *RSNtarget* values lead to a lower required Eb/No. This means more capacity is available, which can be used by either increasing the bit rates of the existing users or allowing more users into the system, leading to increased L3 cell throughputs. The control overhead in terms of transmission power is estimated to be approximately 25%.

ACKNOWLEDGMENT

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REFERENCES

[1] T. Kolding, K. Pedersen, J. Wigard, F. Frederiksen, P. Mogensen, "High Speed Downlink Packet Access: WCDMA Evolution", IEEE Vehicular Technology Society (VTS) News, February, 2003, Vol. 50, No. 1.

[2] 3GPP, "TS25.309, FDD Enhanced Uplink, Overall Description" V6.5.0, december 2005.

[3] S. Parkvall, J. Peisa, J. Torsner, M. Sagfors, P. Malm, "WCDMA Enhanced Uplink – Principles and Basic Operation", IEEE proc VTC'05 Spring.

[4] C.Rosa, J. Outes, K. Dimou, T.B. Sørensen, J. Wigard, F.Frederiksen and P. Mogensen, "Performance of fast Node-B scheduling and L1 HARQ schemes in WCDMA uplink packet access", IEEE Proc VTC'04 Spring.

[5] S. Hamalainen, P. Slanina, M. Hartman, A Leppetelainen, H.Holma and O. Salonaho, "A novel interface between link and system level simulations", Proc ACTS Mobiel Summit'97, Aalborg.

[6] 3GPP, "TR25.942, Radio Frequency (RF) system scenarios", V6.4.0, marts 2005.

[7] H. Holma, A. Toskala, "WCDMA for UMTS", second edition, 2002.

[8] 3GPP,"TS 25.213, Spreading and modulation", V6.4.0, september 2005.

[9] K.W. Helmersson, E. Englund, M. Edvardsson, C Edholm, S. Parkvall, M. Samuelsson, Y.-P.E Wang, J. Cheng, "System Performance of WCDMA Enhanced Uplink, IEEE proc VTC'05 Spring.

[10] 3GPP, "TS25.211, Physical channels and mapping of transport channels onto physical channels (FDD)" V6.7.0, december 2005.

[11] 3GPP, "TS25.214, Physical Layer Procedures (FDD)" V6.7.1, december 2005.

[12] 3GPP, "TS25.104, Base Station (BS) radio transmission and reception (FDD)" V6.11.0, december 2005