Effect of TNL flow control schemes for the HSDPA network performance

Thushara Weerawardane
TZI ComNets, University of Bremen, Otto-Hahn-Allee NW1, 28359 Bremen, Germany,
tlw@comnets.uni-bremen.de

Andreas Timm-Giel[1], Carmelita Görg[1], Gennaro C. Malafronte[3], Stephan Hauth[2],
[1]TZI ComNets, University of Bremen, Otto-Hahn-Allee NW1, 28359 Bremen, Germany,{tlw/atg/cg}@comnets.uni-bremen.de
[2]Nokia Siemens Networks GmbH & Co. KG, Lise-Meitner-Str. 7/2, 89025 Ulm, Germany, stephan.hauth@nsn.com
[3]Nokia Siemens Networks S.P.A., Via Monfalcone 1, Cinisello Balsamo, Italy, gennaro.malafront@nsn.com

Abstract— **HSDPA (High Speed Downlink Packet Access) is an extension of the current UMTS (Universal Mobile Telecommunications System) technology with the objective to increase the data rate and to reduce the latency in the downlink. The main focus of this investigation is to optimise the Iub interface to provide the best end user performance at minimum cost for UMTS HSDPA network. An adaptive credit-based flow control mechanism for UTRAN transport has been developed, tested and validated in the HSDPA simulation model. In this paper, the HSDPA performance with the new adaptive credit-based flow control mechanism is compared with the generic ON/OFF flow control mechanism. The results confirm that the adaptive credit-based flow control mechanism can significantly improve the performance and therefore reduce the required bandwidth at the Iub interface meeting a specified performance: The better bandwidth utilisation and improved statistical multiplexing is achieved by reducing the burstiness of the traffic over the Iub interface. Finally, a recommendation for the required bandwidth at the Iub interface is given for bursty HSDPA traffic.**

Index Terms—**HSDPA, RNC, Node-B, Flow Control**

I. INTRODUCTION

HSDPA provides higher data rates in the downlink to UMTS users. It has been specified as extension of UMTS in 3GPP Release 5 [1]. HSPDA supports higher data rates with lower delay to mobile users by providing several physical layer improvements such as Adaptive Modulation and Coding (AMC), Hybrid ARQ (HARQ) and a substantially shorter TTI (Transmission Time Interval) of 2ms [1].

However, achieving above objectives at minimum cost is a challenge for the Mobile Network Operators (MNO). This accounts in particular for the Transport Network Layer (TNL) network. Due to the bursty nature of the (HSDPA) packet-switched traffic, the accurate dimensioning of TNL bandwidth is a difficult task. UMTS MNOs are facing many challenges to optimise the performance of the TNL network to achieve best end user performance at minimum cost. Reducing the burstiness of the traffic over the TNL network and handling adequate buffer requirements at the MAC-hs buffers, can optimise the capacity requirement at the Iub interface [2, 3, 5, 6]. The Transport Network Layer optimisation needs to be performed by deploying suitable flow control and congestion control techniques to minimise the bandwidth requirement on the Iub link and to provide better QoS to the end user [5, 6]. When compared to Release 99, HSDPA uses two buffering points: at the Node-B and at the RNC. Since the transport capacity is limited, the data flow over the Iub should be handled effectively to cope with varying capacities at the air interface [2, 5]. Thus, adequate queuing in the Node-B buffers is required. Less buffer capacity at the Node-B might lead to frequent buffer under-runs due to large fluctuations of the time varying channel at the air interface and such situations can cause wastage of the scarce radio resource [5, 6, 7, 8]. On the other hand, large buffer levels at the Node-B can result in over-dimensioning the Iub and the need for a large capacity requirement at the Node-B [6]. Therefore, intelligent flow control mechanisms are needed to satisfy the demands identified above. In the Communication Networks group at TZI_ikom of Bremen University, there are several projects focusing on the TNL dimensioning and TNL features development for the HSPA network [2, 13, 14, 19, 20, 21]. The impact of the TNL network on the performance of UMTS, HSDPA and HSUPA are the key research area [2, 5, 13, 14, 19, 20, 21, 22, 23] of these projects. Flow control, congestion control and Iub dimensioning are some of them. This paper shows that developing such adaptive credits based flow control algorithm can reduce capacity requirement at the Iub interface significantly.

The remainder of this paper is structured as follows. Chapter II present the introduction to the HSDPA simulation models and flow control algorithms. The details about the generic ON/OFF and adaptive credit-based flow control algorithms are given in chapter III and IV respectively. The description of the traffic models and simulation configurations are presented in chapter V. Chapter VI and chapter VII elaborate the detailed simulation results for the selected simulation models. Chapter VIII summarises the bandwidth recommendations for all simulation configurations and finally chapter IX presents the conclusion about the achievements.

II. INTRODUCTION TO THE HSDPA SIMULATION MODEL AND TNL FLOW CONTROL MECHANISMS

A comprehensive HSDPA simulation model as shown in the Fig. 1 has been developed by the authors under the OPNET simulation environment.

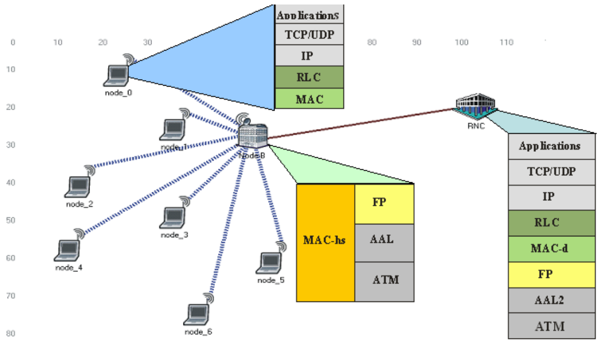

Fig. 1: Simplified UTRAN Architecture (HSDPA)

Even though the model is specially designed and developed for the TNL feature analysis, it provides broader coverage of performance analysis for HSDPA due to the implementation of all UTRAN protocols and end user protocols within the same simulator. Therefore, in addition to the TNL performance analysis, it allows Radio Link Controller (RLC), Transmission Control Protocol (TCP) and application layer protocols performance analysis. End user as well as overall performance on these different layers can be investigated. The complete simulation model is developed according to the Fig. 1 which depicts the simplified UTRAN architecture including end user protocols. In a real system the model would include both, the internet nodes and the core network, which contains the servers which also can provide the different network services to the users.. Since the core network and the internet aspect is not the focus of the study, they are not explicitly modelled. The respective protocol stacks normally be located in the internet servers are included in the RNC model: The application, TCP and IP layers which are shown in the simplified model generate Radio Access Bearer (RAB) connections to the UTRAN network and represent the load, generated by the core network and Internet nodes in the real system. A variable number of users can be assigned to a cell, communicating over the radio interface (Uu interface) to the Node-B. The simplified model is designed in a way, that a Node-B can support up to 3 cells - each with a maximum of 20 users. The main protocol entities in the RNC are the Radio Link Control (RLC), the Medium Access Controller (MAC-d), the frame protocol (FP) and the ATM based transport layers. In addition to the transport layers, the Node-B consists of MAC-hs, FP layers as shown in Fig. 1. Since the physical layers are not the focus of the investigation, a simplified model has been implemented. The wireless channel characteristics are emulated using a MAC-hs scheduler with the MAC-d probability distributions taken from dedicated radio interface simulations. The correlation of the channel quality of consecutive TTIs caused by similar position of the UEs is taken into account. In summary statistics from the radio interface simulations for the number of consecutive TTIs occupied, the number of MAC-d frames transmitted and retransmitted for each TTI, are taken for the air interface model.

In the next section, the theoretical aspects and the implementation of the two flow control mechanisms are discussed. The main focus of the flow control is to adapt the Iub flow rate to the available air interface user throughput for the individual user. The flow control mechanisms are implemented in MAC-hs and FP layers of the HSDPA UTRAN network. The flow control mechanism uses the frame protocol for the purpose of flow control over the Iub interface and adapts the per-user Iub flow rate to the air interface capacity. The MAC-hs user buffers at Node-B have to be monitored continuously to guarantee the data availability and avoid buffer overflow.

III. ON/OFF FLOW CONTROL

The ON/OFF flow control mechanism is considered to be the most simple mechanism which can be applied for the purpose of flow control for HSDPA traffic on the Iub link. The flow control mechanism monitors the filling levels of the MAC-hs buffers for each user flow. It uses an upper and a lower threshold to control the MAC-d flow rate over the Iub. The MAC-hs buffer with the two thresholds is shown in Fig. 2. It is assumes that the incoming data flow rate to the MAC-hs buffer is λ_S and the outgoing flow rate from the MAC-hs buffer is λ_D. The upper and lower buffer limits are determined by an approximated value of the round trip time (RTT) between Node-B and RNC and by the Source/Drain rate as shown in formula (1).

$$\begin{aligned} th_{Upper} &= [i-1]\cdot \lambda_S \cdot RTT \\ &\quad \text{where } i = 3, 4, ..., 10 \\ th_{Lower} &= \lambda_D \cdot RTT \end{aligned} \tag{1}$$

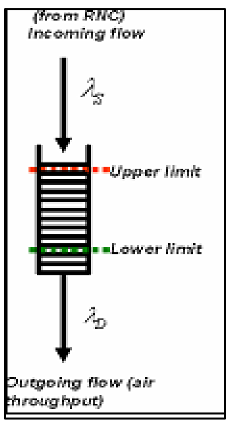

Fig. 2: ON/OFF flow control MAC-hs queue

The per-user ON/OFF flow control mechanism assigns credits to each individual user in the Node-B based on the maximum achievable data rate over the air interface. If the upper limit of the buffer is exceeded, the data flow over the Iub link is stopped and if the buffer limit reaches the lower limit, data over the Iub is transmitted. This ON/OFF flow control mechanism protects the MAC-hs buffers from overflowing as well as emptying. However, when the incoming traffic becomes bursty in nature, the delay variation is increased. For such situations, the ON/OFF flow control mechanism turns out to be unstable [5], hence it becomes difficult to meet the requirements at the radio interface. On the other hand the ON/OFF flow control mechanism increases the burstiness of the traffic rather than mitigating it.

IV. ADAPTIVE CREDIT-BASED FLOW CONTROL

The adaptive credit-based flow control mechanism is developed to optimise the Iub utilisation while providing required QoS to the end user in the HSDPA network. It smoothes down the HSDPA traffic and reduces the burstiness over the Iub interface. This flow control mechanism introduces two new aspects with respect to the ON/OFF flow control algorithm. First, the frame protocol capacity allocation message is sent periodically from the Node-B to the RNC. Second, the credit allocation algorithm is based on the provided bit rate (PBR) of the per-user queues in the Node-B.
The HS-DSCH Provided Bit Rate (PBR) measurement is defined as follows: "*For each priority class the MAC-hs entity measures the total number of MAC-d PDU bits whose transmission over the radio interface has been considered successful by MAC-hs in Node-B during the last measurement period (cycle time), divided by the duration of the measurement period*" [1].

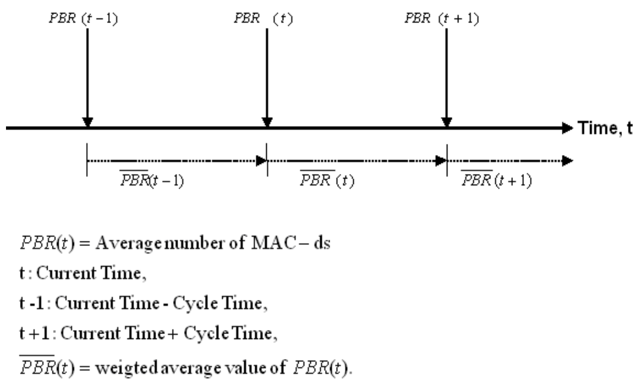

Fig. 3: PBR calculation procedure

The above Fig. shows the calculation of the PBR based credit allocation. Credit allocations are sent periodically after the cycle time. The PBR calculation is done at time t for the next allocation message sent after one cycle time considering the current and the previous successful transmissions.

PBR(t) is the average number of MAC-d PDUs for each priority successfully sent over the air interface during a cycle time. Then, the average PBR rate ($\overline{\text{PBR}(t)}$) is calculated using the following formula:

$$\overline{\text{PBR}}(t) = w \cdot \overline{\text{PBR}}(t-1) + (1-w) \cdot \text{PBR}(t) \qquad (2)$$

with w: weighting factor with default = 0.7.

The filling level of the Node-B priority queue is calculated using the measured MAC-hs queue size (qs(t)) and the calculated PBR average according to the given formula below.

$$Filling\_level = f(t) = \frac{qs(t)}{\overline{\text{PBR}}(t)} \quad (\text{ms}) \qquad (3)$$

As in the ON/OFF flow control mechanism, there are two thresholds that are maintained to control the flow over the Iub interface, namely upper and lower threshold. Both the upper and the lower buffer limits are set according to the estimated value of the RTT. The credits to be sent over the Iub interface are calculated by using the MAC-hs filling levels and the upper/lower limit of the Node-B user priority queues. With the employment of the upper and lower queue thresholds, the filling level can be in three regions: less than the lower limit, higher than the upper limit or between these two thresholds. The number of credits allocated to the RNC for data transfer is calculated according to the three active regions of the MAC-hs buffer fillings and is given by the following three cases.

Case 1: if $Filling\_level, f(t) \le Lower\_Limit$, then $Credits = 2 * PBR_{Avg}(t) \quad (\text{MAC}-\text{d}/10\text{ms})$.

Case 2: if $Lower\_Limit < Filling\_level < Upper\_Limit$, then $Credits = factor \cdot PBR_{Avg}(t) \quad (\text{MAC}-\text{d}/10\text{ms})$
Where, the factor is the value between 0 and 2 which is varying continually upon the variation of filling level in the MAC-hs buffer.

Case 3: if $Filling\_level \ge Upper\_Limit$ then $Credits = 0 \quad (\text{MAC}-\text{d}/10\text{ms})$

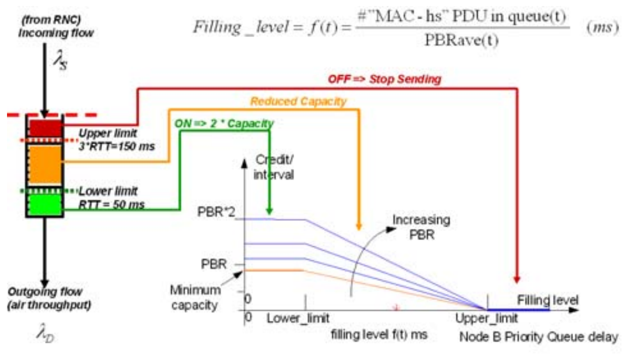

Fig. 4: Flow control mechanism and credit calculation

The credits (= number of MAC-d PDUs) are sent to the RNC as a Capacity Allocation (CA) message to regulate the data transfer over the Iub interface. The complete MAC-hs buffer management for adaptive credit-based flow control mechanism is shown in the Fig. 4. The three different colors of MAC-hs buffer represent the three regions where flow control is active. The initial credit/interval calculation is performed using the Channel Quality Indicator (CQI) value and the rest follows the description mentioned above. Once the CA messages are received by the RNC, the data flow over the Iub is granted to the Node-B via the Iub interface. The functional description of the flow control is illustrated by the Fig. 5.

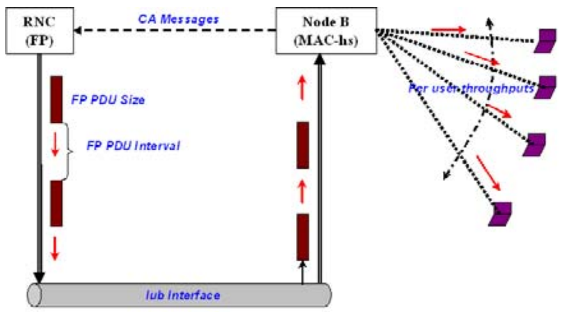

Fig. 5: Functional description of flow control in HSDPA

The FP PDU is formed according to the allocated credits and sent to the Node-B using the interval specified by the CA message. The above mentioned two flow control mechanisms are implemented in the HSDPA simulation model and simulated using appropriate traffic models. The next section discusses these traffic models for the HSDPA simulations.

V. TRAFFIC MODELS AND SIMULATION CONFIGURATIONS

The most common type of HSDPA packet traffic consists of web and FTP traffic using TCP (Transmission Control Protocol) as a reliable end-to-end transport layer protocol. The web traffic model, defined by the ETSI standards [1, 2], is selected to evaluate the performance of HSDPA traffic under moderate network load. The FTP traffic model is the worst case traffic scenario. It is used to overload the network in order to analyse the impact of the above features on end user performance as well as the overall network performance.

TABLE I
ETSI TRAFFIC MODEL PARAMETERS

Parameters	Distribution and values
Packet call interarrival Time	Geometric distribution μ_{IAT} = 5 seconds
Packet call size	Pareto distribution Parameters: α=1.1, k=4.5 Kbyte, m=2 Mbyte μ_{MPS} = 25 Kbyte
FTP Parameters	
File size	Constant Distribution μ_{MFS} = 12 Mbyte and 100 Mbytes
**IAT = Interarrival Time, MPS = Maximum packet size, MTU= Maximum Transfer Unit*	

Under this traffic configuration, all users in the cell are downloading a large file and utilising the network resources up to the maximum available capacity. The parameters of the web traffic model defined by ETSI and the FTP traffic model are given in the table I. These traffic models are configured and deployed at the application layer of the end user entity so that all the other protocol effects can be included into the overall analysis. Especially, RLC and TCP protocols effects are particularly investigated.

Two simulation scenarios are defined to analyse the effect of the adaptive flow control algorithms for the performance of HSDPA network. Further simulation configurations are defined and simulated to find the bandwidth recommendations for the Iub interface for these two different flow control schemes. The summary of the those simulations are presented in chapter VIII whereas chapter VI and chapter VII provide details simulation results to elaborate the effect of the adaptive flow control algorithm in comparison to the ON/OFF flow control algorithm. The two simulation scenarios are defined according to the type of traffic model: simulation scenario 1 is based on the FTP traffic model and simulation scenario 2 is based on the more moderate ETSI traffic model. Each simulation scenario consists of two simulation configurations which are defined according to the configured flow control mechanism. The simulation scenario 1 is used to study the effect of the two flow control mechanisms under worst network load situation and simulation scenario 2 is used to study the effect of the two flow control mechanisms under moderate HSDPA network load which is normally bursty in nature. The simulation configuration is shown in table II.

TABLE II
SIMULATION CONFIGURATION

	Simulation configurations	TNL flow control
Simulation scenario-1 (FTP)	Configuration-1	ON-OFF
	Configuration-2	Credit-based FC
Simulation scenario-2 (Web-ETSI)	Configuration-3	ON-OFF
	Configuration-4	Credit-based FC

All configurations in two simulation scenarios are configured with same set of parameters except the different flow control mechanisms and the different traffic models. The NewReno version of the TCP protocol is configured with default windows XP settings and RLC protocol is configured to run in acknowledge mode with its default settings. Each cell is configured with 20 users being active in the cell until end of the simulation time.

VI. SIMULATION RESULTS FOR THE SIMULATION SCENARIO-1

The simulation results for the simulation scenario-1 are presented in this section. As mentioned in the previous chapter, the model is configured with FTP traffic model and with two different flow control schemes. The ATM link is configured to 4Mbit/s bandwidth. Only one cell in the Node-B is configured with 20 UEs performing FTP download. The simulation results are analysed from system level to application level.

1) ATM Link Throughput

The downlink ATM throughput (in bit/s) is shown in Fig. 6. The red curve shows the ATM link throughput using the ON-OFF flow control mechanism and the blue curve shows the ATM link utilisation with the adaptive credit-based flow control mechanism.

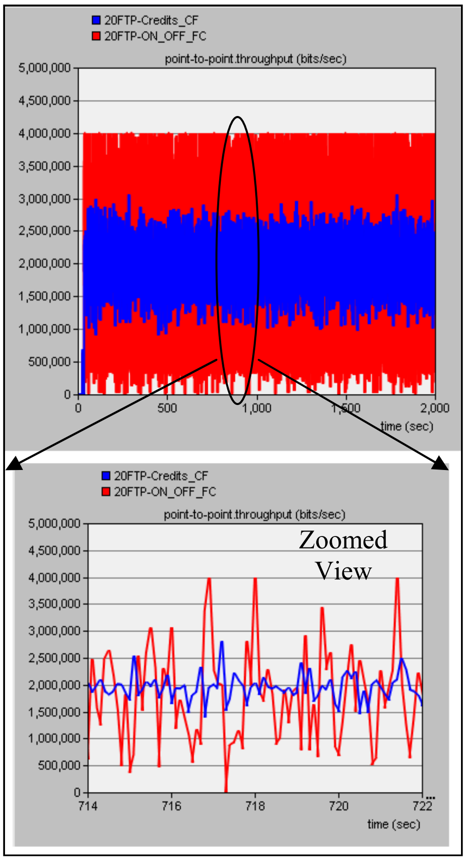

Fig. 6: ATM link throughput

Accordingly in Fig. 6, it is shown that the burstiness on the ATM network is significantly reduced for the configurations-2, based on credit-based flow mechanism compared to the configurations-1 based on ON/OFF flow control mechanism.

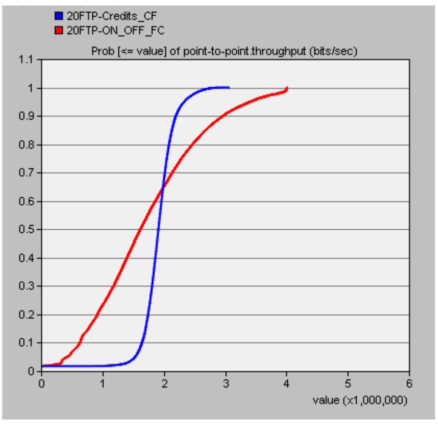

Fig. 7: CDF of ATM link throughput

This effect is also shown in Fig. 7 showing the cumulative distribution function (CDF) of the ATM link throughput. High burstiness leads to a high congestion probability at bandwidth limited networks. Further it requires high bandwidth and large buffers in the TNL network in order to meet the end user QoS. By introducing the credit based flow control algorithm, the efficient use of network resources can be increased, the effective bandwidth and ATM buffer requirements can significantly be reduced and with this the cost for the operator.

Fig. 8 shows average ATM throughput for the two different flow control algorithms investigated. It depicts even slightly higher average ATM throughput for the adaptive flow control based simulation compared to the ON/OF flow control. All results at ATM network show better performance for the credit-based flow control mechanism in all aspects in comparison to the ON/OFF flow control mechanism.

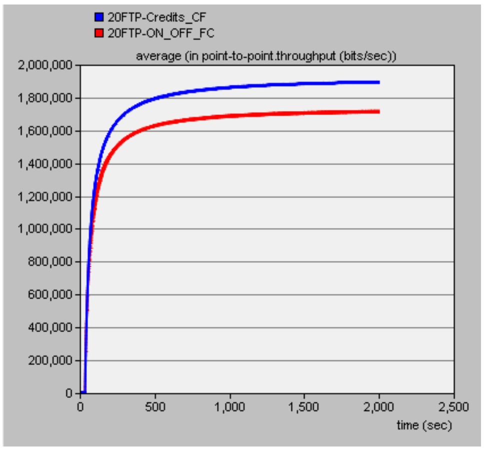

Fig. 8: Average ATM link throughput

2) TNL delay performance

The end-to-end delay of the FP PDUs for the downlink is shown in Fig. 9. This statistic is measured from the point of time when an FP PDU is sent from the FP layer in the RNC to the point of time when it is received by the FP layer in the Node-B.

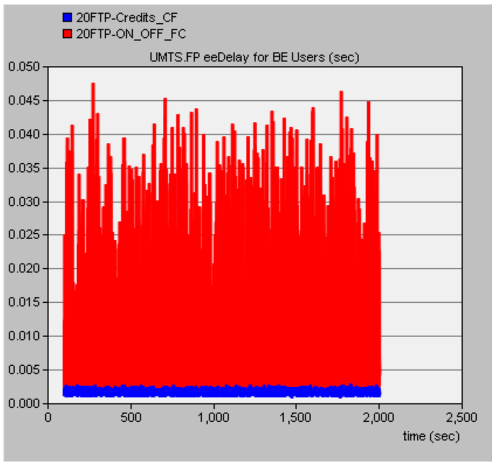

Fig. 9: FP end-to-end delay

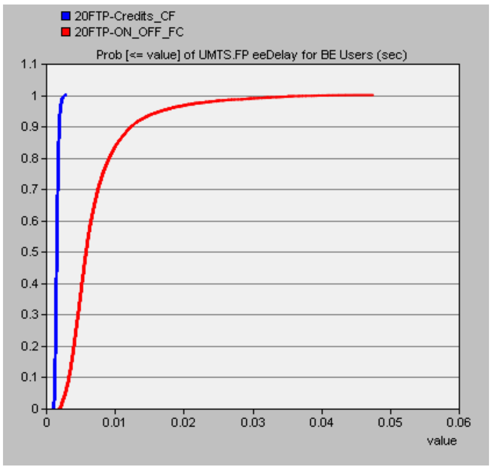

Fig. 10: CDF of FP end-to-end delay

Fig. 10 shows the cumulative distribution function for the FP PDU downlink delay. These results show that the adaptive credit-based flow control mechanism experiences lower FP downlink delay compared to the ON/OFF mechanism.

3) MAC-d end-to-end delay

The MAC-d end-to-end delay measures the delay between MAC-d entity at RNC to MAC-d entity at Node-B. Adaptive credit-based flow control shows significantly lower MAC-d delay compared to ON/OFF flow control. The ON/OFF flow control mechanism has a very high buffer occupancy at the MAC-hs buffers and ATM buffers. These high buffering is due to high burst at the TNL network. All these facts lead to a very high MAC-d end-to-end delay and it includes all intermediate buffering delays as well. The credit based flow mechanism has very efficient buffer management mechanism. It requests/allows to send data from RNC only required to extend and to satisfy the demand of the available channel capacity. Hence the MAC-d end-to-end delay is significantly reduced.

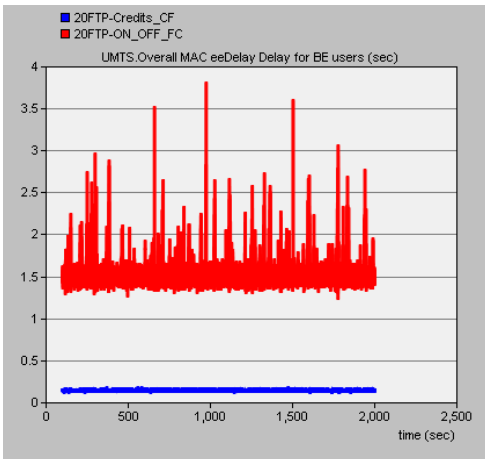

Fig. 11: MAC-d end-to-end delay

The CDF in Fig. 12 shows the MAC-d end-to-end delay for the two configurations. The adaptive credit-based flow mechanism exhibits a lower delay and delay variation compared to the ON/OFF flow mechanism.

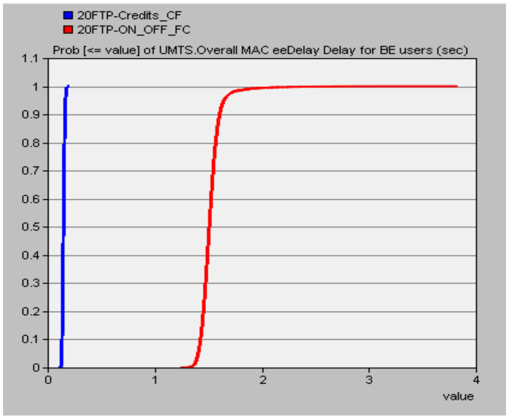

Fig. 12: CDF of MAC-d end-to-end delay

4) End user performance

The overall IP throughput for all users is shown in Fig. 13. The IP throughput is measured between end user entities and is averaged over all users. It reflects the overall performance of the UTRAN.

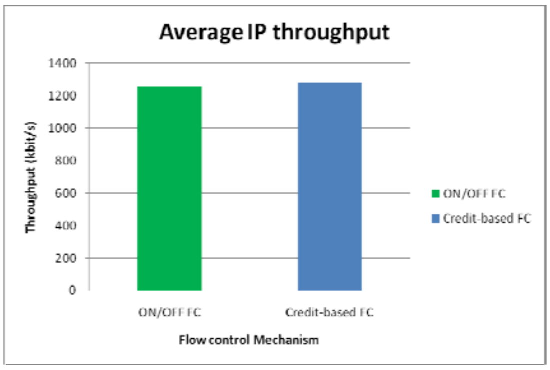

Fig. 13: Average IP throughput

The above figure shows that the achieved IP throughputs for both flow control mechanisms are similar and even slightly higher for the adaptive credit-based flow mechanism. That means both configurations achieve same end user performance for different TNL conditions. The adaptive credit-based flow control mechanism requires a significantly lower Iub capacity to achieve same end user performance compared to ON/OFF flow mechanism.

VII. SIMULATION RESULTS FOR THE SIMULATION SCENARIO-2

This section presents simulation results for the simulation scenario-2. In this The model the ETSI traffic model is applied. The Node-B is connected to a cell along with 20 users. The ATM link is configured to 3 Mbit/s capacity.

5) ATM Link Throughput

The downlink ATM throughput (in bit/s) and its zoomed view are shown in Fig. 14. As in the previous configurations, there is a clear reduction of the burstiness over the TNL network when the adaptive credit-based flow control mechanism is used. However, this traffic model is bursty in nature. Therefore the burstiness on the TNL network cannot be reduced for the FTP traffic model.

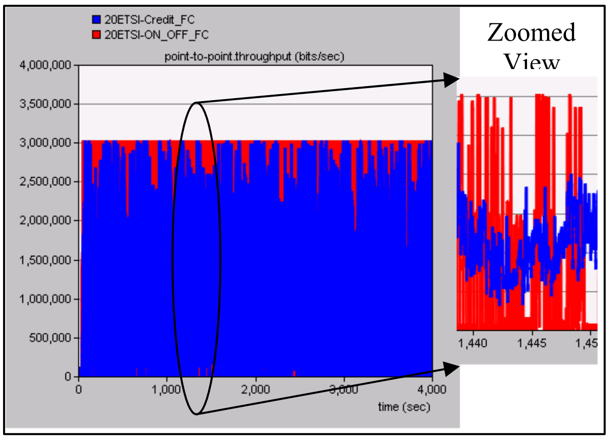

Fig. 14: ATM link throughput

Fig. 15 shows the cumulative distribution function (CDF) of the ATM link throughput which exhibits the variations of the ATM throughput distribution.

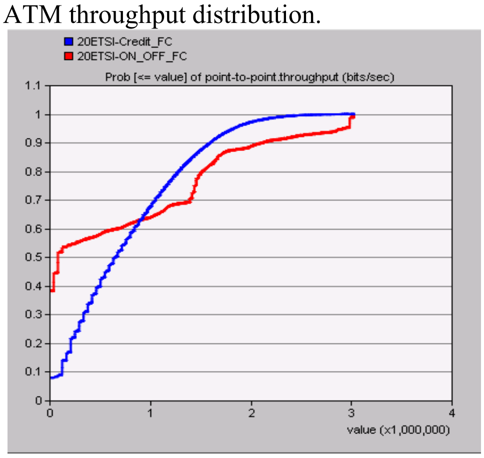

Fig. 15: CDF of ATM link throughput

The configuration which is based on ON/OFF flow control has a large number of zero throughput occurrences. This means, the link is idle a long period of time due to the frequent bursty fluctuations of the traffic. Fig. 16 shows the average ATM throughput. The average throughput is ~750 kbit/s for both configurations. The adaptive credit-based flow control algorithm depicts slightly higher performance at the TNL network compared to ON/OFF flow mechanism for this traffic model.

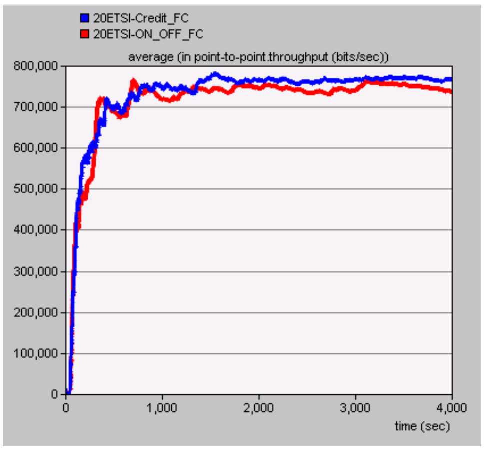

Fig. 16: Average ATM link throughput

6) TNL delay performance

The end-to-end delay of the FP PDUs for the downlink is shown in Fig. 17.

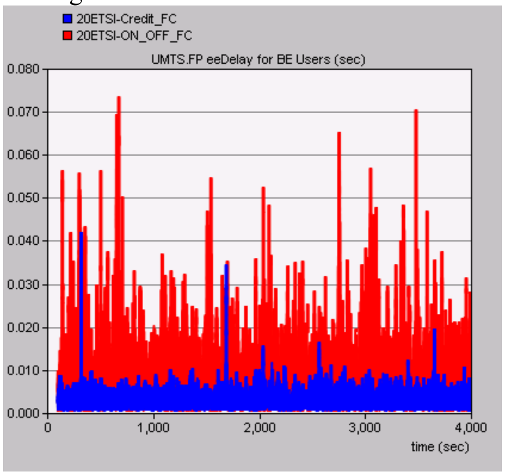

Fig. 17: FP end-to-end delay

The adaptive credits-based flow control configuration shows lower burstiness compared to ON/OFF flow control algorithm. Fig. 18 shows the CDF of the FP end-to-end delay. As in the previous simulation model, the ON/OFF flow algorithms shows higher delay and delay variation compared to credit-based flow algorithm. The average FP end-to-end delay is 5.5 ms for credit-based flow control simulation configuration and is 3.7 ms for ON/OFF flow control simulation configuration.

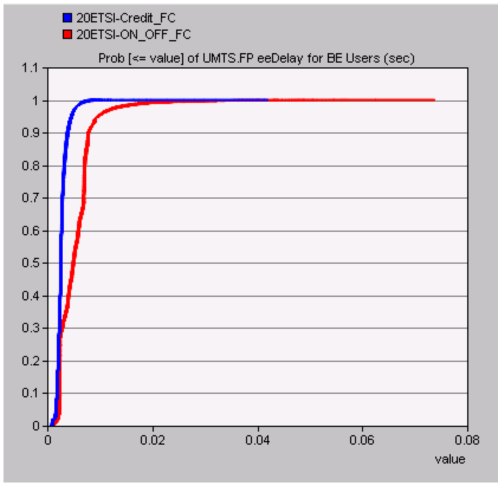

Fig. 18: Average FP end-to-end delay

7) MAC-d end-to-end delay

The MAC-d end-to-end delay is shown in Fig. 19 for two simulation configurations. The adaptive credit-based flow control shows significantly lower delay compared to ON/OFF flow control at MAC-d level.

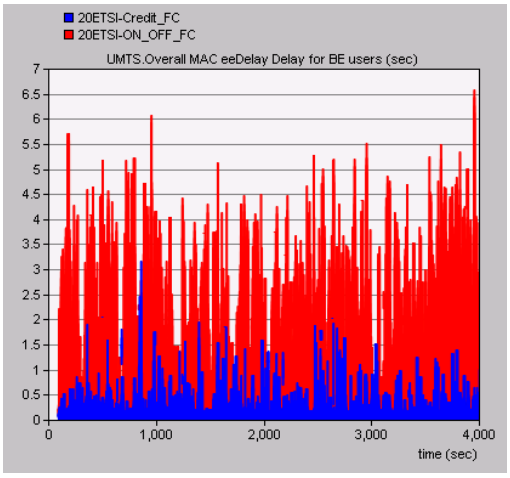

Fig. 19: MAC-d end-to-end delay

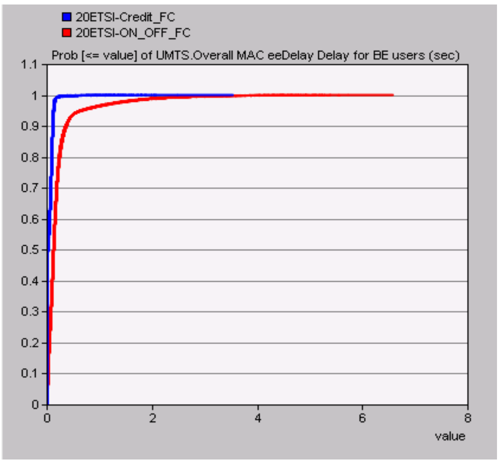

Fig. 20: The CDF of MAC-d end-to-end delay

The CDF of MAC-d end to end delay is shown in Fig. 20. It shows that 99% of the delay is less than 50 ms for credit based algorithm whereas 99% of the delay is less than 220 ms for ON/OFF flow algorithm.

8) End user performance

The average IP throughputs for the two simulation configurations are shown in Fig. 21.

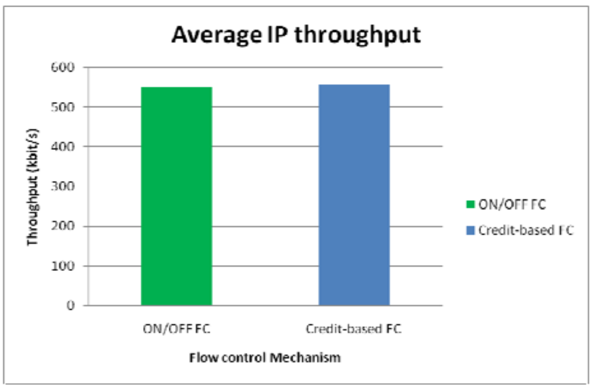

Fig. 21: Average IP throughput

This statistic shows the overall performance of the UTRAN. The achieved IP throughput is approximately equal for simulation configurations and even slightly higher for the adaptive credit-based flow mechanism. This means, the adaptive credit-based flow control achieved the same application throughput with less congestion probability and with lower TNL capacity requirements.

VIII. TNL BW RECOMMANDATION

The TNL bandwidth recommendation is issued by deploying the ETSI traffic model which is the most moderate traffic for the HSDPA networks. The main quality of service criterion for the BW recommendation is 1% of the packet loss rate experienced at the TNL network. Two air interface scheduler types, round robin and channel-dependent, are used for the simulation analysis along with 3 cells attached to a single Node-B. In each cell there are 20 users active generating traffic throughout the complete simulation time. All configured configurations are listed in the following table.

TABLE III
SIMULATION CONFIGURATIONS

Traffic model	MAC-hs Scheduler type	# cells	Flow control type
ETSI based web traffic model	Round robin	1	ON/OFF
			Credit-based
		2	ON/OFF
			Credit-based
		3	ON/OFF
			Credit-based
	Channel dependent	1	ON/OFF
			Credit-based
		2	ON/OFF
			Credit-based
		3	ON/OFF
			Credit-based

The Round Robin scheduler is a completely fair scheduler whereas the channel-dependent scheduler is an unfair scheduler which is used to optimise the throughput in the HSDPA network.

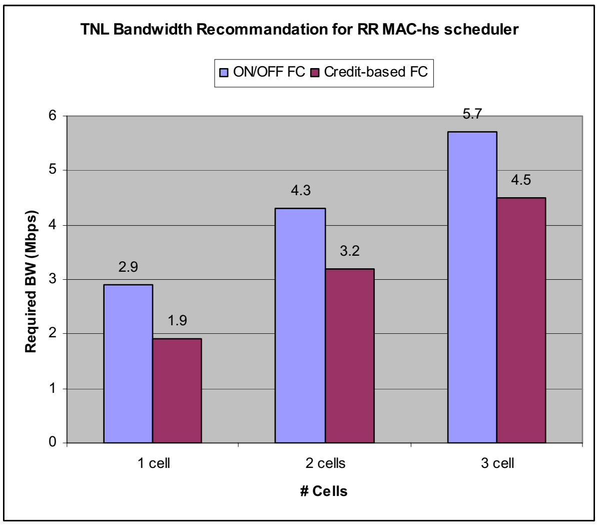

Fig. 22: TNL BW recommendation for RR MAC-hs scheduler based configuration

The bandwidth recommendation is issued by varying the configured Iub ATM capacity and achieving the same QoS for two different flow control algorithms. Fig. 22

shows the bandwidth recommendations when the round robin scheduler is deployed for three different cell configurations (1 cell, 2 cells and 3 cells) and two different flow control mechanisms. The required bandwidths are 2.9Mbit/s, 4.3Mbit/s and 5.7Mbit/s for 1 cell, 2 cells and 3 cells configuration respectively when ON/OFF flow control is used. These results also confirm the multiplexing gain of the ATM network. To add one additional cell with 20 users under this configuration requires approximately additional half of the capacity being added to the previous cell capacity. This means approximately 50% of statistical multiplexing gain can be achieved for ON/OFF based simulations.

The required bandwidths applying the credit-based flow control are 1.9 Mbit/s, 3.2 Mbit/s and 4.3 Mbit/s for 1 cell, 2 cells and 3 cells configuration respectively. These results show that by applying the adaptive credit-based flow control algorithm the required BW at the TNL network can be reduced about 33%. Fig. 23 shows the BW recommendations with the channel dependent scheduler used for three different cell configurations.

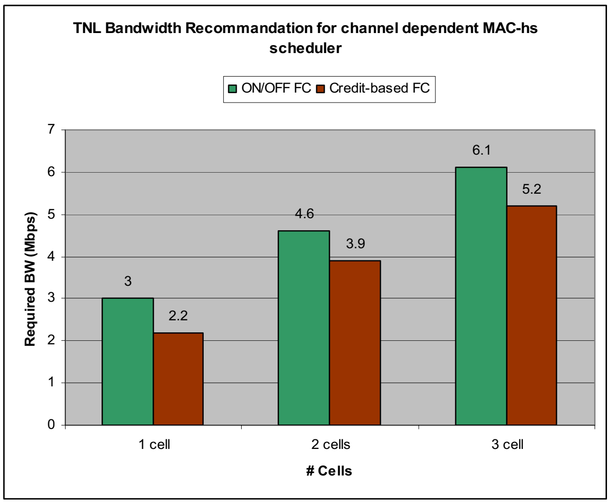

Fig. 23: TNL BW recommendation for channel dependent MAC-hs scheduler based configuration

The bandwidth requirements are 3.0 Mbit/s, 4.6 Mbit/s and 6.1Mbit/s for ON/OFF based simulation configuration for the 1-cell, 2-cells and 3-cells configurations respectively. The bandwidth recommendations when credit-based flow control is used are 2.2 Mbit/s, 3.9 Mbit/s and 5.2 Mbit/s for 1 cell, 2 cells and 3 cells configurations respectively. These results also confirm that by applying the adaptive credit-based flow control algorithm the TNL BW requirement at the TNL network can be significantly reduced.

IX. CONCLUSION

In this paper, the theoretical and modeling aspects of the ON/OFF and the adaptive credit-based flow control mechanisms are shown in detail. The performance of both mechanisms is presented, simulated and validated using an HSDPA simulation model developed by the authors in OPNET Simulator.

When evaluating the simulation results for both simulation models which are based on ETSI traffic and FTP traffic, it is confirmed that the adaptive credit-based flow control mechanism achieves lower burstiness over the Iub link, lower buffer occupancy, lower FP delay and lower delay variation at the TNL network in comparison to the ON/OFF flow control mechanism. Upon above achievements, the required capacity for bandwidth recommendations is significantly reduced when credit-based flow control is used. That means, by applying adaptive credit-based flow control over the Iub interface, the Iub bandwidth requirement and the utilization of resource at the transport network layer of the UTRAN can be optimised while achieving the same end-user performance.

If the Iub capacity is limited in comparison to the cell capacity, congestion on the TNL network may occur and the impact of it will be reduced by introducing congestion control techniques for the TNL network as addressed in upcoming publication.

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Thushara Lanka Weerawardane received bachelor (B.Sc.) degree in Electrical Engineering at the University of Moratuwa, Sri Lanka in 1998 and master degree in Communication and Information Technology at University of Bremen, Germany in 2004.

He worked as an assistant network manager in the department of electrical engineering and as a system engineer for Lanka Educational And Research Network (LEARN) in Sri Lanka from 1999 to 2002. After completing his master degree, he joined Center for Computer Science and Information Technology (TZI) of the University of Bremen in the Communication Networks group as a scientist researcher in 2004. He led the industrial research project funded by Siemens Networks on performance optimization of UMTS/HSPA radio networks and transport networks from 2004 to 2007. His main responsibilities are UMTS/HSPA based protocol design and development, HSPA (HSDPA/HSUPA) simulator design and development for performance analysis of HSPA radio networks and transport networks, optimization of the HSPA transport network (Iub/Iur) by deploying different congestion control and flow control features. Currently, he is leading an LTE simulation research project funded by Nokia Siemens Networks. In this ongoing research project, LTE system level simulator design and development for the optimization of LTE transport networks are the main consideration.

Mr. Thushara Weerawardane has published many scientific papers in the field of communication networks and is a member of IEEE.

Andreas Timm-Giel, Dipl.-Ing in Electrical Engineering/Information Technology (EE/IT) at University of Bremen, Germany, 1994, Dr.-Ing. (PhD) in EE/IT on radio channel modeling, University of Bremen, 1999.

From 1994 – 1999 he led a group at the University of Bremen, that participated in several European R&D projects on mobile and satellite communications. Starting in January 2000 he joined Media Mobil Communication GmbH as Technical Project Leader of the EU funded project SATISFY2000. He was involved in the technical and commercial set up of the mobile satellite network and service provider M2sat Ltd. as Technical Product Manager and Manager Network Operations. In December 2002 he joined the Communication Networks Group at the University of Bremen as senior researcher and lecturer. He is leading several industry, national and EC funded research projects at the university. Since October 2006 he is additionally directing the interdisciplinary concerted activity "Adaptive Communications" of the Center for Computer Science and Information Technology (TZI) in Bremen. His research interests are adaptive mobile and wireless communication and sensor networks.

Dr Timm-Giel is author or coauthor of 10 book contributions and more than 65 reviewed publications in journals and on international conferences. Dr. Timm-Giel is frequent reviewer and TPC member for international conferences and journals and is Member of IEEE and VDE/ITG.

Carmelita Görg received her diploma degree from the Department of Computer Science, University of Karlsruhe and the Dr. rer. nat. degree and the appointment as lecturer from the Department of Electrical Engineering, Aachen University of Technology.

From 1985 until 1989 she worked as a consultant in the field of communication networks. Since 1989 she has been working as a group leader and since 1997 as an Assistant Professor at the Communi-cation Networks Institute, Aachen University of Technology. Since 1999 she is leading the Communication Networks Group (ComNets) at the University of Bremen within tzi (Center for Computer Science and Information Technology) and MRC (Mobile Research Center). Her research interests include: Performance Analysis of Communication Networks, Stochastic Simulation, Rare Event Simulation, High Speed

Networks, Personal Communication, Wireless Networks, Mobility Support, New Services and Applications in Telecommunication Networks, Network Virtualization.

Prof. Görg has been active in European projects starting with the RACE programme. She has been an evaluator and auditor for the European Commission. The research group in Bremen consists of about 15 Ph.D. students / research assistants, which are funded by the state of Bremen and third-party projects (European projects, DFG projects, BMBF projects, bilateral industry projects). Prof. Görg has published a large number of scientific papers in the field of communication networks. She is a member of the board of the ITG (Information Technology Society, Germany) and speaker of the ITG working group 5.2.1 on "System Architecture and Traffic Engineering".

Gennaro Ciro Malafronte received master degree in Electronic Engineering in 1999 and PhD in Electrical Engineering on Electrical and Electronic Measurements in 2003 at the University of Naples “Federico II”.

In 2001, he joined the Italian COM division of the Siemens Corporation, then merged in the Nokia Siemens Networks in 2007. He started his activity at Siemens COM for concept analysis of Smart Antennas and Software Radio Technology. He then worked as Sales Support for some UMTS service providers in Europe. He was involved in special projects in collaboration with the European Space Agency (ESTEC) for requirement specifications of satellite transmission paths in the terrestrial Siemens UMTS systems. Since 2004 he joined the Siemens System Engineering Transport Expert Group and he focused his activity in the optimization of the transport features of UMTS terrestrial interfaces (Iub,Iur, Iu). In that field he was responsible for the definition of HSDPA/HSUPA Iub/Iur congestion control algorithms and he contributed to the 3GPP for the definition of standardized procedures for Iub/Iur congestion control.

Dr. Gennaro Ciro Malafronte holds a number of patents in the field of Iub/Iur HSDPA/HSUPA congestion control as “Method for congestion control with macro diversity” (EP 1 816 879 A1), “Controlling congestion over a non-serving branch” (EP 1 901 493 A1), “Method for decoupling congestion control in a cascade of network elements of an UMTS radio access network” (WO 2008/064983 A2) “Controlling congestion detection in HSDPA systems” (WO 2008/037357 A1), He is co-author of a number of papers in the field of Iub/Iur HSDPA/HSUPA congestion control. His current field of interest is Transport Optimization for LTE systems.

Stephan Hauth received his diploma degree in Electrical Engineering at the University of Karlsruhe in 1992.

In 1993, he joined Siemens AG, Communications, Mobile Networks R&D in Munich, where he worked in SW development and testing for GSM base stations. After an intermediate period of systems engineering for broadband data networks (ATM and IP) within Siemens Com, he joined the Siemens Mobile Networks R&D center in Ulm in 1998, where he focused on systems engineering for the terrestrial transport in UMTS radio access networks. His particular interest is in bringing transport solutions to the UMTS network elements and developing end-to-end solutions for efficient, QoS-aware, reliable and robust transport over UMTS terrestrial interfaces, both when using ATM and IP/Ethernet transport technologies.