System Performance of WCDMA Enhanced Uplink

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Abstract—**We present the potential performance improvements attainable by new enhancements to the WCDMA uplink. Improvements can be expected in both system capacity and end-user perceived performance. In this paper we focus on the capacity gains of short TTI, hybrid ARQ and scheduling in Node-B. The performance is studied from both the link-level and system-level perspectives. The link performance results focus on the gains obtained by the introduction of short TTI and hybrid ARQ with soft combining in Node-B. In the system performance results, we also evaluate Node-B based rate scheduling for both 2 ms TTI and 10 ms TTI. Our studies indicate that with the introduction of enhanced uplink the gain in uplink capacity can be in the order of 70-100%.**

Keywords:* *WCDMA, Enhanced Uplink, Node-B rate scheduling

I. INTRODUCTION

The packet data support in WCDMA is continuously improved to meet future demands. The first step was taken with the introduction of high-speed downlink packet access (HSDPA) in WCDMA release 5 (Rel'5), which provides significant improvements to the downlink packet-data support in terms of reduced delays, increased capacity, and peak rates up to 14 Mbit/s [1][2]. With the second step, the introduction of enhanced uplink [3][4] in Rel'6, substantial gains both in terms of end-user perceived performance and system performance are expected. The enhanced uplink aims at improving the uplink in terms reduced delays, increased data rates and increased capacity. Three basic technical features have been adopted for achieving these objectives.

- Fast hybrid ARQ with soft combining adds robustness to the system and provides reduced retransmission delays compared to RLC-based retransmissions. The soft combining functionality can also be used to increase the capacity and extend the coverage.
- Fast scheduling allows for rapid resource reallocation between UEs (terminals), exploiting the burstiness in packet data transmissions. It also allows the system to admit a larger number of high data rate users and rapidly adapt to interference variations, thereby leading to an increase in capacity as well as an increase in the likelihood that a user will experience high data rates.
- Short TTI (transmission time interval) reduces the latency in the system and improves end-to-end performance for both uplink and downlink oriented traffic. Further it enables more efficient use of hybrid ARQ with soft combining and fast scheduling. The shorter TTI allows for more transmission attempts with a constant delay, and further allows for the scheduler to respond quickly to interference variations.

A detail description of the enhanced uplink concept is given in [4]. The end-user performance is discussed in [5] and real measurements in an enhanced uplink test bed are shown in [7].

In this paper we focus on system capacity when introducing enhanced uplink. We analyze the potential gains achievable by the introduction of shorter TTI, hybrid automatic repeat request (HARQ) and Node-B rate scheduling. In Section II we present the performance gains achieved by Node-B based HARQ with soft combining. In Section III we present fast rate scheduling and combined performance gains achieved by the HARQ and the fast Node-B rate scheduling. Finally the conclusions are presented in Section IV.

II. BENEFITS OF SHORT TTI AND HARQ

The hybrid ARQ operating point has a significant impact on both the end-to-end performance and the system capacity. If the operating point is chosen such that the data with a high probability is successfully received after the first transmission attempt, throughout in this paper denoted as *delay optimized HARQ*, the end-to-end (delay) performance is improved as RLC retransmissions are replaced by fast hybrid ARQ retransmissions. If the operating point is chosen such that multiple transmission attempts are required for successful reception, denoted as *capacity optimized HARQ*, the system capacity and to some extent the data rate coverage are improved. Any operating point can be used in a system and these two alternatives should be seen as examples, illustrating the hybrid ARQ operation. We define an *initial bit-rate* as the information bit rate before any retransmission. These definitions are used in the sections below.

A. Link level performance evaluation

The functions introduced in the Node-B, HARQ and shorter TTI, affect the performance of the physical layer. In Figure 1 we have three different initial bit-rates 1.344 Mbps, 672 kbps and 336 kbps. For the highest initial bit-rate we allow for 4 transmission attempts and hence if all these attempts are used the target bit-rate is 336 kbps. For the case with initial bit-rate of 672 kbps we allow for 2 transmission attempts and hence the target bit-rate is also 336 kbps. Finally for the case with initial bit-rate 336 kbps the target bit-rate is 336 kbps since no re-transmissions are allowed.

In Figure 1 we see residual Block Error Rate (BLER) after the last allowed transmission as a function of accumulated E_b/N_0 per transport block for both TTI lengths (2 ms and 10 ms). The channel model used in the link-level simulation is ITU Pedestrian A with vehicular speed of 3 km/hr and realistic channel estimation.

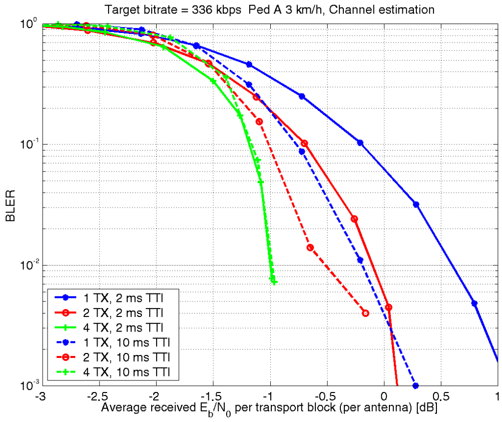

Figure 1: BLER as a function of E_b/N_0 per transport block. Solid curves are 2 ms TTI and dashed lines are 10 ms TTI.

For the cases with no re-transmissions we see that a 10 ms TTI performs approximately 0.8 dB better than a 2 ms TTI at BLER=10^{-2}. This is due to better interleaving and coding for the longer TTI. However, if we allow for more transmission attempts it can be seen that the performance for the two different TTIs are similar. Hence, HARQ will regain what we lost from reduced coding and interleaving for the shorter TTI.

Another interesting point to compare is when the physical layer delay is approximately equal for the two TTI sizes. For example, if the number of HARQ processes is configured to be 6 for 2 ms TTI and 3 for 10 ms TTI, we can limit the total physical layer delay to be 40 ms, and then we will have time for 4 transmissions for the 2 ms TTI case and only 2 for the 10 ms TTI case (see also Figure 3). If we compare the BLER at 10^{-2} it can be seen that we then gain about 0.5 dB with the shorter TTI.

One conclusion from the link-level performance evaluations is that if we run the system in a delay-optimized way (i.e. low initial BLER target and 2 ms TTI) there is a loss in E_b/N_0 compared with Rel'5. However the system can also be run as capacity optimized and in that case we can gain in E_b/N_0 instead compared with Rel'5.

In Figure 2 we see the same results but the throughput is plotted as a function of E_c/N_0. It can be seen that if we start with a higher initial data-rate (1.344 Mbps) and target four transmission attempts (results in 336 kbps) and compare that to the case when we start with 336 kbps, we can gain in throughput for a certain required power. For example, if we target an E_c/N_0 of –10 dB, the data-rate is 336 kbps for Rel'5 while the data-rate is ~450 kbps for E-UL when the initial bit-rate is 1.344 Mbps. The data-rate is increased approximately 35%.

In Figure 3 we show the delay as a function of E_c/N_0 for different TTI lengths and number of transmission attempts. The target bit rate here is also 336 kbps and this data rate is obtained in the E_c/N_0 interval –12 to –10 dB, see Figure 2. Note that no higher layer delays have been considered.

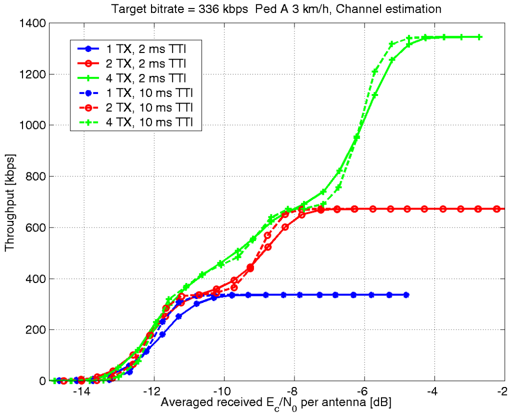

Figure 2: Throughput as a function of E_c/N_0. Solid lines are 2 ms TTI and dashed lines are 10 ms TTI.

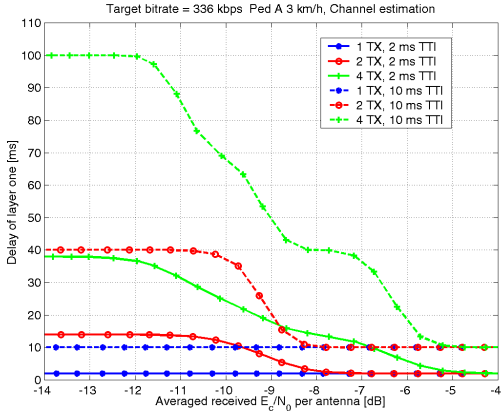

Figure 3: Delay for different number of allowed transmissions and for 2 ms and 10 ms TTI.

When comparing the 2 ms TTI with four transmissions and the 10 ms TTI with two transmissions, the 2 ms TTI with four transmissions has a similar, but typically lower, delay. The reason is that, on average, less than four attempts are required. This is sometimes known as early termination gain. Further, for the 10 ms TTI, the number of retransmissions must be kept small in order not keep the delay reasonable and four transmission attempts is likely only realistic for a 2 ms TTI.

B. System performance simulation

For the system-performance simulations, a 21-cell deployment with a cell radius of 500 meters is modeled. The cell plan is repeated through a wrap-around technique to avoid border effects [8]. The simulation uses detailed models of the radio-propagation characteristics including attenuation, shadow fading and multi-path propagation, where 3GPP Typical Urban delay profile has been assumed. Models for higher-layer protocols such as RLC and TCP are also incorporated. The traffic model models a mixture of 60% Multimedia Message Service (MMS) and 40% e-mail traffic with exponentially distributed packet sizes of mean 12.7 and 60 kbyte, respectively. During a simulation, mobile calls are initiated according to a Poisson process and placed uniformly over the cell plan. Users move with an average velocity of 3 km/h. After the packet is delivered the user exits the system.

An admission control algorithm is included in the system simulations. The admission control is the mechanism responsible for controlling the admission new users into the system in order not to exceed the maximum system load, or equivalently, maximum interference level. In the simulations, the uplink load is estimated based on the interference measurement, which is reported in an interval of 300 ms. The admission control predicts an additional load (the required CIR) caused by an additional channel setup. A new request is admitted provided that the estimated load plus the additional load do not exceed a given maximum load.

The uplink performance is evaluated in terms of system throughput and normalized packet delay. System throughput is expressed as the total number of bits that the system has delivered per second and sector. The packet delay is defined as the time between the requests for the message reaches the TCP sender and the message has successfully been delivered to the TCP receiver. The system capacity is defined as the maximum system throughput for which 90% of the messages have a delay less than a required threshold. The uplink performance is evaluated under the constraint to keep the 95th percentile of noise rise below 7 dB.

First, scheduling is not enabled in order to investigate the gains with hybrid ARQ only. In subsequent sections, scheduling will be used together with hybrid ARQ. Two types of HARQ operations are considered. In the delay optimized HARQ operation the outer-loop power control targets a single transmission attempt with a HARQ block error rate (BLER) of 10%. For the capacity optimized HARQ, as discussed in Section II, a fixed delay budget is imposed. Hence, the outer loop targets four transmission attempts for 2 ms TTI and two transmission attempts for 10 ms TTI. The number of HARQ processes is assumed to be 5 for 2 ms TTI and 3 for 10 ms TTI. In all cases the BLER after the targeted number of transmissions is 10%. One additional transmission attempt is allowed before an RLC transmission is triggered. The initial rate is chosen such that the resulting rate after retransmissions is in the order of 320 kbps.

In Figure 4 we plot the 90th percentile packet delay, normalized to the low load delay, i.e., the packet delay that is obtained when the system load is the lowest, equals 1, versus the system throughput, normalized to the capacity of Rel'5 (curve marked with cross). Here we define the capacity as the maximum system throughput for which 90% of the messages have a normalized delay less than 5. This means that the packet delay must not exceed 5 times the delay obtain in the low load. With the longer TTI, 10 ms, the system capacity can be increased by roughly 15% for delay optimized HARQ and 60% for capacity optimized HARQ compared to that of Rel.5. With the shorter TTI we observe capacity loss of a few percent for delay optimized and 90% gain for capacity optimized HARQ.

The HARQ performance shown in system simulations is agreed with the link level simulation result shown in Section A. For delay optimized HARQ, i.e., only one transmission, we see from Figure 1 that the 10 ms TTI performs approximately 0.5 dB better than the 2 ms TTI at BLER=10^{-1}. While in the system simulation, we see from Figure 4 that the 10 ms TTI has a higher capacity (about 20% higher) than the 2 ms TTI, However, for capacity optimized HARQ, if we allow 2 transmission for 10 ms TTI and 4 transmission for 2 ms TTI, we can see the gain with shorter TTI, 2 ms, both in the link and system level simulations, about 0.2 dB and 20% respectively.

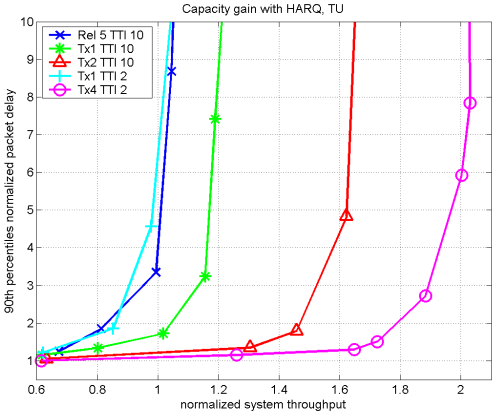

Figure 4: Normalized system throughput versus the 90th percentile normalized packet delay for delay optimized HARQ and for capacity optimized HARQ.

III. FAST RATE SCHEDULING

In the WCDMA system, the shared resource in the uplink is the uplink interference, or, equivalently the noise rise. If the noise rise becomes too high, the system performance, such as coverage, starts to degrade and the fast power control may become unstable. To avoid this, there is a need to limit the maximum noise rise level. When the noise rise of a cell reaches the maximum allowed level, the radio-resource management needs to either reduce the number of users or limit the transmit power of the users by reducing their data rate, e.g., through time scheduling or rate scheduling.

The basic principle of the technique is to allow Node-B to set a new restriction to the set of Transport Format Combinations (TFCs) configured by RNC and to form a subset of TFCs controlled by Node-B. This transport format combination (TFC) subset will be called the *Node-B controlled TFC subset*. Since the Node-B may not have sufficiently accurate information about the power situation in the user terminal, the final selection of the TFC is resided in the terminal. The user selects a suitable TFC from the Node-B controlled TFC subset by applying the Rel'5 TFC selection algorithm. Any TFC in the Node-B controlled TFC subset may be selected by the user if the user has sufficient power and data for the selected TFC. Fast rate scheduling provides a mean for the Node-B to influence the TFC selection in the UE, i.e., to control when and at what maximum rate a terminal is allowed to transmit. With rate scheduling, Node-B estimates an upper limit of the transport-format subset, i.e. the maximum data rate or power that users in the cell can use for transmission, based on the available radio resource and the number of users in the cell. The user selects a suitable transport format from the Node-B controlled TFC subset. Under this rate-scheduling operation, all users in the cell share the available resource. On the other hand, with time scheduling, Node-B schedules one or only a few users at a time to transmit at a given maximum rate or power. In this case, the available resource is used by the chosen one or a few scheduled users, which makes higher data rates feasible.

By providing the Node-B with tools for rapidly influencing the UE TFC selection, tighter control of the uplink interference is possible, which can result in increased capacity and improved coverage. The system performance of Node-B rate scheduling is studied in a typical wide-area cellular scenario with both 2 and 10 ms TTI.

A. Over-all system performance

To study the combined performance of HARQ with soft combining and Node-B scheduling, a simple rate scheduling scheme based on the broadcast TF absolute limit as described in [6] is used.

In Figure 5 we summarize the overall system performance including a capacity optimized HARQ and rate scheduling. If HARQ and Node-B rate scheduling are used with the long 10 ms TTI (curve marked with plus), the system capacity can be increased by 70% compared to that of Rel'5 (curve with cross) in this scenario. When combined with the shorter TTI (curve with circle), a total capacity gain of 100% can be achieved.

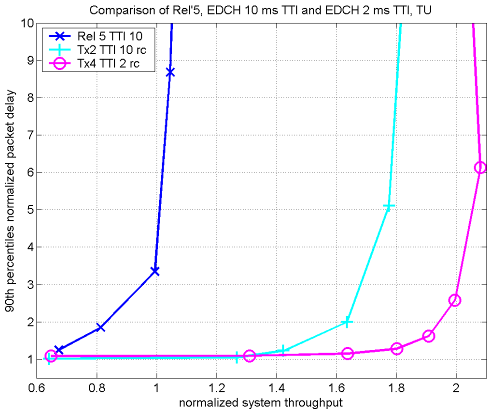

Figure 5: Over-all performance for rate scheduling and capacity optimized HARQ.

B. Combined performance with delay optimized HARQ

In Figure 6 we present simulation results including Node-B rate scheduling for delay optimized HARQ. For a delay optimized HARQ, one single transmission is targeted (with BLER 10%). The capacity gain for delay optimized HARQ is essentially obtained from the Node-B rate scheduling. This is because when a single transmission attempt is targeted, the CIR target and the load estimated for admitting a user in the RNC is high, hence less users can be admitted through the RNC admission. In this case the gain with Node-B rate scheduling, where more users can be admitted, is substantial. It is in the order of 60% for both 2 and 10 ms TTI. The HARQ gain in capacity is very small, about 0-15% depending on TTI length.

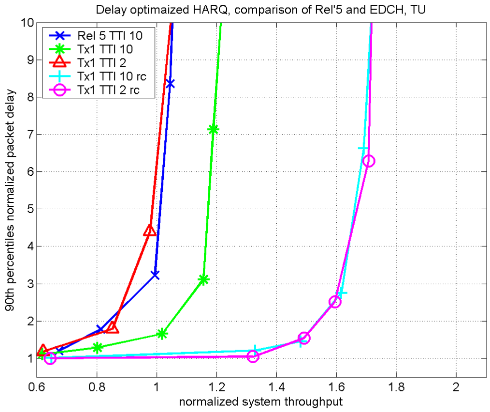

Figure 6: The 90th normalized packet delay versus system throughput for delay optimized HARQ. The figure shows uplink enhancements without and with including Node-B rate scheduling.

C. Combined performance with capacity optimalized HARQ

For a capacity optimized HARQ, the essential capacity gain is obtained through the HARQ in the simulated scenario and the additional gain from the Node-B scheduler is quite small. Allowing several transmission attempts, the CIR target and the estimated load for admitting a user in the RNC is decreased, thus the RNC admission is able to admit more users. In Figure 7 we present simulation results including Node-B rate scheduling for capacity optimized HARQ. For a capacity optimized HARQ, we target two transmission attempts for 10 ms TTI and four transmission attempts for 2 ms TTI, the capacity gain with HARQ is significant, it is in the order of 60-90%. Including the additional gain from the Node-B scheduler, the total capacity gain is about 70%-100%.

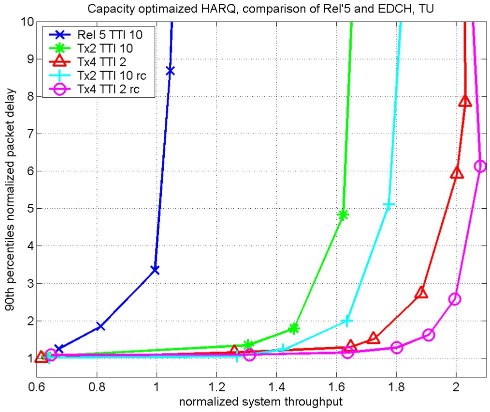

Figure 7: The 90th normalized packet delay versus system throughput for capacity optimized HARQ. The figure shows uplink enhancements without and with including Node-B rate scheduling.

IV. CONCLUSION

The basic techniques considered for enhancing the WCDMA uplink have been evaluated and the potential performance gains have been illustrated with link and system simulations. The results show a substantially improved performance gain in terms of system capacity for data services. The gain in system capacity is obtained from introducing hybrid ARQ with soft combining as well as from Node-B rate scheduling. With delay optimized HARQ, there is no (2 ms TTI) or little (10 ms TTI) gain in capacity from the hybrid ARQ. The capacity gain compared to Release 5 for delay optimized HARQ comes essentially from the Node-B scheduler and is estimated to be in the order of 60%. For the capacity optimized HARQ, the hybrid ARQ also contributes to the capacity gain. For a simple rate scheduling scheme the gain compared to Release 5 is roughly 70%-100%. Our results demonstrate the potential capacity gains obtained with Node-B based HARQ and scheduling both for delay optimized and capacity optimized systems.

The discussed solutions can be gradually integrated into existing networks and the operation of equipment based on earlier 3GPP releases is not affected. Hence, the enhanced uplink is a natural evolution of WCDMA to meet the increasing demand for uplink data traffic.

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