Errors on the HSUPA E-HICH channel and their effect on System Performance

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***Abstract*—The E-HICH is a downlink control channel associated to the HARQ procedure in HSUPA. It allows the MAC-e entity in the NodeB to signal the correct or incorrect reception of a given MAC-e PDU by transmitting ACKs or NACKs. Errors on this channel can cause misinterpretations and impact the overall system performance. This paper looks at the performance impact caused by two types of errors: ACK misinterpreted as NACK and vice versa. Detailed user and system performance results versus the error levels on the E-HICH are provided for both cases. A2N errors cause a direct degradation of the user throughput that increases with the probability. N2A errors have a more intricate impact that leads to opposite effects. On the one hand, it causes the level of RLC retransmissions to increase. On the other hand, the missing PDUs change the HARQ operating point which will then decrease the RLC retransmission level. The overall consequence is a lowered cell and user throughput for lowly loaded networks, whereas it is almost imperceptible in fully loaded networks.**

***Index Terms*— E-HICH, HARQ, HSUPA, Signaling Error**

I. Introduction

HSUPA allows enhanced system and user performance compared to 3GPP R'99 [1] through the introduction of a number of key features [2]: NodeB based Packet Scheduling (PS), higher UE bit rates, 2ms TTI, and L1 HARQ. Those features require the introduction of new physical channels such as E-DCH, E-AGCH, E-RGCH and E-HICH. The latter of these channels is used by the MAC-e entity located at the NodeB to request retransmissions of a given transport block, upon notification by the physical layer. The message on the E-HICH channel can be positive acknowledgements (ACK) or negative ones (NACK). Upon reception of the latter, the MAC-e entity located at the UE will re-issue the concerned transport block.

The impact of ACK/NACK signaling errors has been studied in [4] by means of link level simulations for different SHO scenarios and for low error probabilities. In this paper, the influence of both a wider range of errors on the E-HICH (whatever the cause might be) and different HARQ operating points is looked at. Their impact on the user and system level performance will be measured through the use of a fully dynamic system-level HSUPA simulator.

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The paper continues with the section 2 which introduces of the E-HICH channel, the possible errors on it and the common simulation assumptions. Then sections 3 and 4 will respectively focus on ACK to NACK (A2N) errors and NACK to ACK errors (N2A). Those sections describe the type of error, the expected behavior, the corresponding simulation results and their analysis. Eventually, section 5 gives the conclusion of the conducted work.

II. Preliminary Considerations

A. E-HICH Description

The E-HICH is a feedback downlink channel meant to carry the acknowledgements consecutive to the reception of a transport block at the physical layer. An UE can receive more than one E-HICH at the same time, when the UE is connected to more than one radio link set (RLS) [3]. One RLS is the serving RLS, which contains the cells for which the packet scheduling is performed. Other RLS's are non serving RLSs. A serving RLS sends both ACK and NACKs, whereas a non serving RLS only sends ACKs, i.e. DTX indicates a NACK.

B. Error Type on the E-HICH

Misinterpretations occur at the L1 and can have various reasons as seen in Table 1.

Table 1 Some error types related to E-HICH

Error Type	Consequence
A2N	Causes unnecessary L1 HARQ retransmissions
ACK seen as DTX (sent from nonserving RLS)	Identical to A2N (in case of SHO, so the effect cannot be seen if one of the other cells sends an ACK which is received correctly)
N2A	Causes the L1 HARQ retransmission procedure to stop prematurely and triggers RLC retransmissions
DTX seen as NACK (sent from serving RLS)	Happens when the UE has sent a transport block that is not detected by the NodeB. The UE expects a ACK/NACK and misinterprets DTX as a NACK. This is desirable since the block needs to be retransmitted.
DTX seen as ACK (Sent from serving RLS)	Happens when the UE has sent a transport block that is not detected by the NodeB. The UE expects an ACK/NACK and misinterprets DTX as a ACK. This is the same as a N2A.
DTX seen as ACK	Can cause L1 HARQ retransmission to

(Sent from nonserving RLS)	stop prematurely, which in turn can trigger RLC retransmissions (from nonserving cells in SHO).

The present work focuses on ACK seen as a NACK, and NACK seen as an ACK since they cover all of the possible error cases.

C. *HARQ and OLPC in HSUPA*

In HSUPA, the OLPC operates on the outcome of the HARQ procedure. At the L1, the HARQ procedure requires a BLER Target as well as a maximum number of allowed transmissions to be able to operate. Each MAC-es PDU successfully transmitted to the NodeB, will be forwarded to the RNC in which the OLPC takes place. Upon examination of the RSN contained in the MAC-es PDU, the OLPC will adjust the SIR target to be followed by the Fast Power Control. The adjustment will be done based on the outcome of the comparison of the RSN of the received MAC-es PDU and the RSN Target, which is a network setting. The SIRtarget is adjusted upwards when the RSN value of a PDU is larger or equal to the target number of transmissions, the *targetRSN*, while the SIRtarget is decreased when the RSN of a PDU is lower than the *targetRSN*. The steps used in the adjustments are different in up and down direction:

$$Stepup = Step * (1-BLERtarget) \qquad (dB)$$
$$StepDown = Step * BLERtarget \qquad (dB)$$

where *Step* is a parameter in dB and *BLERtarget* is the target BLER for the transmission indicated with the *targetRSN*.

D. *Simulation Assumptions*

The used simulator has been previously described in [5] and is a fully dynamic network simulator including 18 cells and 6 NodeBs. RRM mechanisms such as AC, LC, PS, HC, PC are implemented. Users arrive according to a Poisson arrival process and are distributed uniformly in the network. The data traffic is MMS with exponentially distributed packet call size averaging at 50KB. The model truncates the distribution to packet calls included in the range 1KB, 200KB. The HARQ procedure, together with the required OLPC is fully implemented. The usual parameters are presented in Table 2.

Table 2 Simulation Assumptions

Parameter	**Value**
Packet scheduling period	10 ms
Happy_Bit_Delay_Condition	100 ms
Utilisation threshold	50%
RSN target	0, 2
BLER target	10%
Fast loop power control step size	1 dB
Closed loop power control step size	0.5 dB
SHO add window	2dB
SHO drop window	4dB
Maximum Target RTWP	6 dB
Maximum UE bit rate	1 Mbps
Maximum UE power	21 dBm
Combining method for HARQ	Chase Combining.
Channel Profile	Veh A
UE speed	30 kmh
2 branch Rx Diversity	Yes
Number of Users in the system	18, 270
A2N Error Probability	0, 5, 10, 50%
N2A Error Probability	0, 5, 10, 50%

The RSN Target is an important parameter to vary as it determines the number of ACK/NACKs that will be sent per transport block. The total number of users in the system has been chosen such that the resulting load is low or high.

The L3 User Throughput is defined as the amount of user data in the call divided by the total call duration. Note that the RLC headers are counted as data, so strictly speaking this could be called L2 User Throughput. This also means that the actual RLC throughput is lower than what is shown

The RLC Retransmission Rate is defined as the number of RLC retransmissions divided by the number of PDUs transmitted.

III. ACK TO NACK ERRORS

A. *Description and Expectations*

A2N errors lead to unnecessary L1 HARQ retransmissions, which degrade the end-user and cell throughput. This degradation directly depends on the increase in the average number of transmissions caused by an increased A2N error probability. It is possible to predict the average number of transmissions.

$$Nr\_Transmissions = 1 + P_{AK} + \sum_{i=1}^{max\_nr\_transmissions} \left(BLER_i + (1 - BLER_i) \cdot P_{AK} \cdot BLER_{i-1} \right)$$

where $BLER_i$ is the residual BLER after the *i*th transmission ($BLER_0$ = 1), P_{AK} is the probability of a ACK being misinterpreted as a NACK and *max_nr_tranmissions* is the maximum number of L1 transmissions, which is set by the RNC.

The total number of transmissions is shown as a function of the A2N error probability in Figure 1. For the numbers it has been assumed that the BLER target reached at the RSN target is 10% whereas the residual BLER at lower transmission numbers is assumed to be 100%. Moreover, transmission numbers larger than the RSN target have a residual BLER equal to 0%.

The cases with SHO were generated assuming that 100% of the users are in SHO, therefore the real number can be found between the SHO and non SHO curves. It can be seen that in the case where the RSN target is equal to 0, the average number of transmissions increases from 1.1 to up to 2 when the A2N error increases from 0% to 50%. This effect will directly affect the number of unnecessary retransmissions.

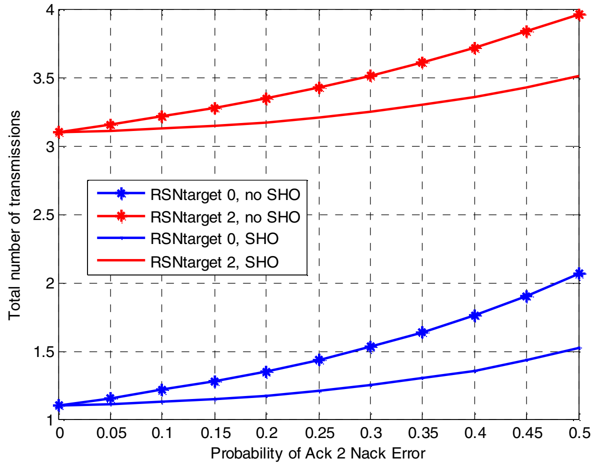

Figure 1 Nb of Transmissions as a function of the Probability of A2N Errors

Furthermore, the throughput with A2N can be expressed as fraction of the throughput without errors (the normalized throughput):

$$Norm\_throughput(P_{AN}) = \frac{Nr\_transmissions(P_{AN})}{Nr\_transmissions(P_{AN} = 0)}$$

Again, cases with and without SHO are shown with the purpose of giving a range in which to find the value of interest. The results are shown in Figure 2. The throughput degradation increases with the A2N error probability up to 45% for the case without SHO checked for a A2N error probability of 50%.

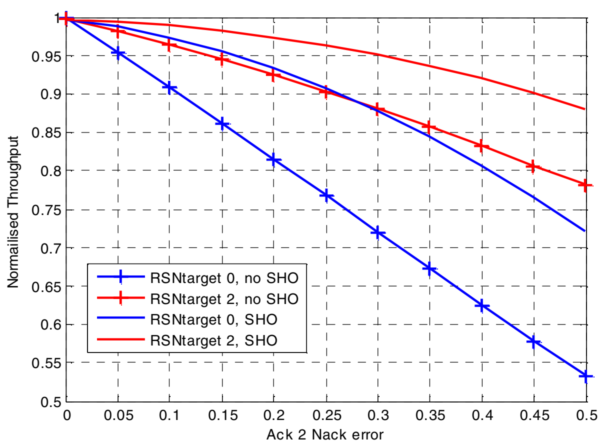

Figure 2 Normalised throughput as a function of the A2N error probability

B. Simulation Results

In this section the N2A error probability is set to zero. The impact of the A2N error probability can be understood from Figure 3 which shows the CDFs of the L3 User Throughput for the various A2N error cases.

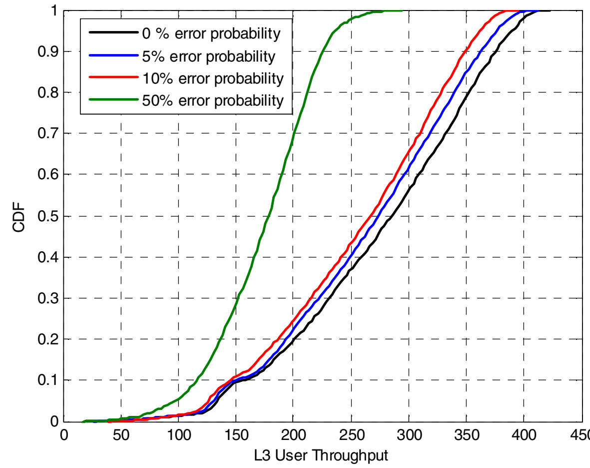

Figure 3 CDF of the L3 User Throughput as a function of the A2N error probability for 18 users in the system and RSN target = 0

It can be observed that the L3 User throughput suffers from a significant reduction when the A2N error probability is set as high as 50%. Looking at the average user throughput displayed in Table 3, one can notice that the throughput degradation is slightly lower than expected. This can be explained by the fact that the SHO lowers the effect from the A2N errors as seen in Figure 2 and in [4].

Table 3 Normalised Throughput for 18 users and RSN Target = 0

A2N Error Probability	Average User Throughput [kbps]	Normalised Throughput
0%	274	100%
5%	266	97%
10%	254	93%
50%	174	64%

Similarly, Table 4 and Table 5 show corresponding results for the cases with 270 users and RSN 0 and 2. One can clearly see that the user throughput is obviously lower (due to the high load in the system).

Table 4 Throughput Degradation for 270 users and RSN Target = 0

A2N Error Probability	Average User Throughput [kbps]	Normalised Throughput
0%	71	100%
5%	67	94%
10%	66	93%
50%	41	58%

Table 5 Throughput Degradation for 270 users and RSN Target = 2

A2N Error Probability	Average User Throughput [kbps]	Normalised Throughput
0%	62	100%
5%	61	98%
10%	60	97%

50%	48	77%

IV. NACK TO ACK ERRORS

A. Description and Expectations

N2A errors lead to the premature interruption of the HARQ retransmission procedure. These errors lead to missing PDUs in the RNC which will have two effects. Firstly, in case of AM RLC, the missing blocks will be retransmitted by the UE to the RNC. Due to retransmission delays, the L3 user throughput will decrease. If the N2A error probability equals x, the RLC retransmission rate should increase with x times the probability of a NACK. Secondly, the OLPC will increase the SIR Target for every missing PDU. This will lead to an increase of the EbN0 and thus a decrease of the BLER. A lower BLER means that less NACKs will be transmitted and thus there will be less impact from the N2A errors. Note that this should only give a difference in the case where RSN Target is strictly greater than 0. The overall expected impact is summarized in Figure 4.

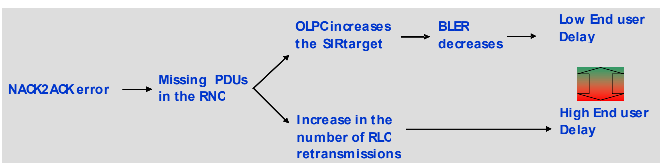

Figure 4 Expected impact of the N2A errors

B. Simulation Results

For this part, the A2N error probability is set to 0%. To start with, the RLC retransmission rate is extracted from the simulations. Figure 5 shows the CDFs of the RLC retransmission rate for the case with 18 users in the system and an RSN target equal to 0. As expected, the RLC retransmission rate increases with the N2A error probability. The corresponding EbN0 target shows absolutely no difference. This hints that there is no impact on the OLPC, which is natural considering that the OLPC will increase the SIR target if a PDU is not received correctly at the first transmission (RSN Target is 0), which is the case N2A errors are introduced.

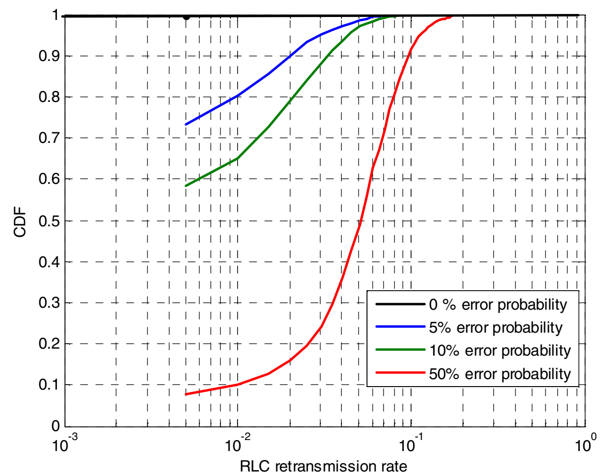

Figure 5 CDF of the RLC Retransmission Rate for 1 user and RSN Target 0

The average user throughput is displayed in Table 6 and show that low N2A error probabilities have nearly no effect. Only a high N2A probability (e.g. 50%) significantly impacts the user throughput. The amount of the degradation depends on the number of RLC retransmissions and the associated delay.

Table 6 Average user throughput for 18users and RSN Target 0

N2A Error Probability	Average User Throughput [kbps]	Normalised Throughput
0%	277	100%
5%	276	99%
10%	275	99%
50%	241	87%

Although not shown here, the average RLC retransmission rate for the case with 270 users follow the same behavior than the 18 users case. Similarly, the EbN0 target CDF show no variations with the N2A error probability. On the other hand, the user throughput is not affected by an increased N2A error. This is explained by the presence time gaps within the transmissions of data by users, which are exploited by the PS to allocate higher bit rate to other users, hence nullifying the degradation otherwise cause by a large N2A error probability.

The case with a RSN target of 2 proves to be more interesting. Looking at Table 7 reveals that having increased the RSN target, the RLC retransmission rate is significantly higher than the previous cases. However, the absolute values obtained are still lower than expected as a N2A error probability of 50% should lead to more than 50% retransmissions.

Table 7 Average RLC Retransmission Rate for 15 users and RSN Target 2

N2A Error Probability	Average RLC Retransmission Rate
0%	0.0%
5%	9.0%

10%	13.3%
50%	33.4%

This behavior can be explained by looking at the EbN0 target CDF shown in Figure 6. It can be seen that the OLPC increases the SIR target as the N2A error probability increases. This would lead to a lower BLER and consequently a lower number of NACKs. Having less NACKs also means that the influence of the N2A error will decrease as well.

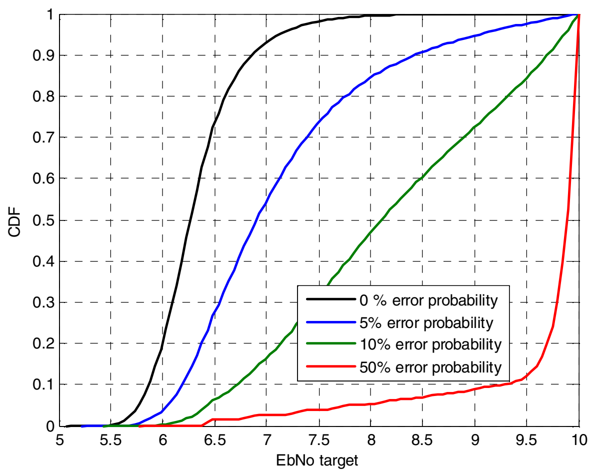

Figure 6 CDFs of the EbN0 for 270 users and RSN Target 2

Looking at Figure 7 reveals the influence of the N2A error probability on the cell throughput. It can be observed that in case of RSN target equal to zero, the overall effect is negligible and the system is able to fully utilize the available capacity. On the other hand, a high RSN target proves to be more sensitive to the N2A probability and exhibits a cell throughput degradation in the order of 50%. This is a consequence of the increase of the EbN0 target by the OLPC which reacts on missing PDUs.

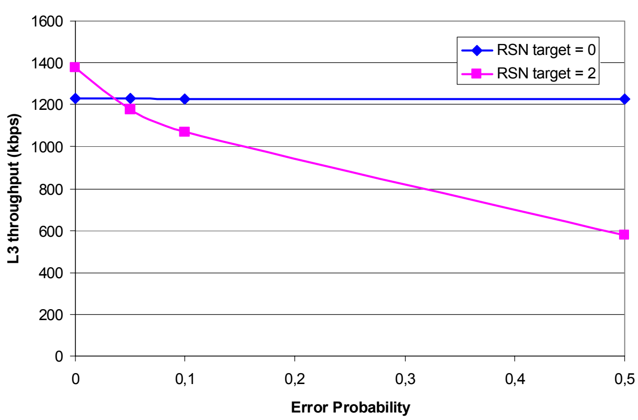

Figure 7 Cell Throughput as a function of the N2A error probability for 2 values of the RSN Target

V. Conclusion

The present work suggests that A2N and N2A errors are representative of the main type of error the E-HICH can suffer. Simulation results proved to fit the expectations. N2A errors lead to RLC retransmissions and for RSN target larger than 0, they also lead to an artificial increase in the SIR target.

In case of a RSN Target equal to zero, the effect from an increase in the number of RLC retransmissions can only be seen in a lowly loaded (in terms of lower user throughput) network. For a fully loaded network, the RLC retransmissions cause gaps in the transmissions of one user, which are then exploited by larger bit rates for the other users which implies that the overall effect for the user throughput is null.

In case of a RSN target larger than zero, the OLPC tries to compensate for the errors by increasing the SIR target. While for a large error probability (e.g. 50%), this may be desirable (since otherwise, the system and user throughput would suffer significantly from the very large number of retransmissions), for low error probabilities (e.g. 5-10%, which are also the expected error probabilities in the real system) the increase in the SIR target leads to a loss in user and cell throughput, which is not desirable.

To conclude, the negative effects of the N2A errors are similar to that of the A2N, except that for the latter no RLC retransmissions occur which means that the lost blocks are not recovered. Most unacknowledged services can cope with a certain amount of lost packets. This amount needs to be considered when setting the power of the E-HICH channel (setting which will have a direct impact on the error probability) and traded-off with the amount of power required in the downlink.

In a real system one will experience both A2N and N2A errors simultaneously. This will lead to a mix of the effects described in this article. Both will lead to longer end user delays, especially the A2N errors will lead to lower cell throughputs.

Acknowledgment

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References

[1] H. Holma and A. Toskala, "WCDMA for UMTS: Radio Access for Third Generation Mobile Communications", John Wiley and Sons, Third Edition 2004

[2] H. Holma and A. Toskala, "HSDPA/HSUPA for UMTS – High Speed Radio Access for Mobile Communications", John Wiley and Sons, First Edition 2006

[3] 25.321 MAC Protocol Specification

[4] X. Zhaoji, B. Sébire, "Impact of ACK/NACK Signalling Errors on High Speed Uplink Packet Access (HSUPA)", published in ICC 2005

[5] J. Wigard, M. Boussif, N. A. Madsen, M. Brix, , S. Corneliussen, E. Laursen "High Speed Uplink Packet Access Evaluation by Dynamic Network Simulations," published in PIMRC2006