Impact of ACK/NACK Signalling Errors on High Speed Uplink Packet Access (HSUPA)

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***Abstract* - In this paper, the impact of signalling errors on the performance of High Speed Uplink Packet Access (HSUPA) in soft handover (SHO) is investigated. The signalling discussed here is the one related to HARQ operation: acknowledgements (ACK) and negative acknowledgements (NACK) in the downlink. Through simulations, it is shown how ACK/NACK signalling errors affect the throughput in both soft handover and non-soft handover cases.**

***Keywords* - HSUPA, SHO, HARQ, Signalling Errors**

I. INTRODUCTION

In Release 6 of the 3GPP standard, uplink enhancements for UTRAN are being introduced for packet data traffic [1]. These enhancements are referred to as High Speed Uplink Packet Access (HSUPA) and can be seen as the uplink version of High Speed Downlink Packet Access (HSDPA) that was introduced in Release 5 for the downlink [2]. HSDPA brought the efficiency of packet services in UTRAN even further by enhancing the downlink. The purpose of HSUPA is to do the same in the uplink for increased cell throughput and coverage of high data rates, improved quality of service for bursty services and better radio resource usage.

One of the enhancements currently approached for HSUPA is Layer 1 HARQ. Layer 1 HARQ in the Node B allows for much faster retransmissions than what the RLC layer in RNC (Radio Network Controller) facilitates. In order to support Layer 1 HARQ, new signalling needs to be introduced on the physical layer. In the downlink, the new signalling includes ACK/NACK signalling, which takes care of indicating to the UE whether the frame was correctly received or not by the Node B.

In order to maximise the benefits of Layer 1 HARQ the overhead introduced by the additional signalling needs to be kept at a minimum and the resulting new error cases (as for any new signalling) need to be carefully analyzed and impacts assessed. This paper focuses on the later and is organised as follows: in a first section, the simulation setup and assumptions made are described, in the second and third sections an analysis of ACK/NACK errors is made, and finally conclusions are drawn in the last section.

II. ASSUMPTIONS AND SIMULATION SETUP

The system studied includes one E-DCH (the new transport channel introduced for HSUPA) and one DPCCH where layer one signalling is carried [1]. The E-DCH is mapped on three BPSK sub-channels (also referred to as code channels) for high-speed transmission. This is shown on Fig. 1 below where *C* is the channel code, β the weighting factor and *S* the spreading code.

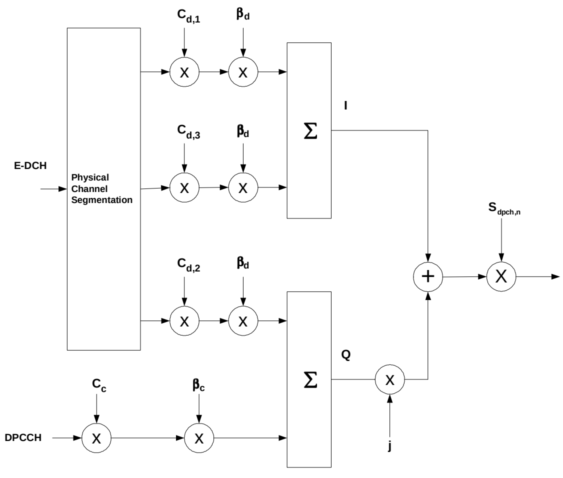

Fig. 1. 3*BPSK channel structure

The SHO cases studied in this paper always assume two Node B actively connecting to the UE (unless otherwise stated). Each Node B decodes the received blocks and sends ACK/NACK signalling in the downlink: if the frame is correctly decoded, an ACK is sent, if the frame is not correctly decoded, a NACK is sent (decoding validity is based on CRC check in the receiver). A retransmission is triggered in the UE if a NACK is received from both Node B. Otherwise, when at least one ACK is received, the frame is considered as correctly received by the network and a new frame is transmitted by the UE. The two uplink channels are of the same kind (e.g. Pedestrian) but uncorrelated. Both *balanced* and *imbalanced* SHO are studied. The *balanced* SHO means that the two Node B have the same path loss, while *imbalanced* SHO means that the two Node B have different path loss. Other simulation parameters are listed in Table 1 below.

TABLE 1 SIMULATION PARAMETERS

Carrier Frequency	2 GHz
Closed loop Power Control	on
Power Control	1dB step size, 1 slot delay
PC error rate	4%
Channel Estimation	6 Pilot symbols
Fast fading model	Jakes spectrum
Channel coding	R'99 Turbo code, rate 1/3
Iterations for Turbo decoder (max)	8
Input to Turbo Decoder	Soft
Rate matching	R'99 Rate matching
Number of Rake fingers	Equal to number of taps in channel model (Ped=2, Veh=6)
Number of Users Simulated	1
Receiver antenna	2
Other L1 Parameters	as for Rel.99

When studying the performance of HARQ, *BLER*, *Throughput* and *Delay* results are always used. In this paper, "*1st BLER*" in axis means the BLER for the first HARQ transmission. In non-SHO cases, such 1st BLER naturally means the first transmission BLER in the Node B. In SHO, the "*1st BLER*" in axis means the BLER of first transmission after macro diversity combining, which means the 1st BLER as seen in RNC (Radio Network Controller).

Throughput means the total of correctly received bits during a certain period of transmission time. In addition, many results in this report are given as a function of *EcN0*. Here the *EcN0* is measured on an individual Node B, averaged over a given period of time, and includes the energy of both first transmission and possible consecutive retransmissions.

III. ACK ⇒ NACK ERRORS IMPACTS

Generally, if one ACK is decoded by the UE as a NACK, one useless retransmission will happen and thus system throughput performance decreases. The study includes the throughput loss due NACK ⇒ ACK in case of single link, balanced SHO, imbalanced SHO and single ACK/NACK in SHO.

A. Single Node B (Non SHO)

Fig. 2 shows the throughput loss caused by ACK ⇒ NACK errors in non-SHO case (single Node B) for different error rates. Here the "loss" is calculated as the offset between the throughput obtained with a given ACK ⇒ NACK error rate and throughput obtained without any ACK ⇒ NACK errors. From Fig. 2 it can be seen that when the BLER is high, which means major part of feedback is NACK rather than ACK, the impact of ACK ⇒ NACK errors is only little. At around BLER = 0.1, the possibilities of ACK is already large enough for the impact of ACK ⇒ NACK errors to be seen. Then with the further decrease of the 1st BLER, throughput loss changes only a little because it already reaches its maximum value. Fig. 3 shows the same simulation results but as a relative throughput loss ratio with respect to the throughput obtained without any signalling error. That is to say: Throughput loss ratio = (arbitrary throughput loss) / (Initial throughput loss).

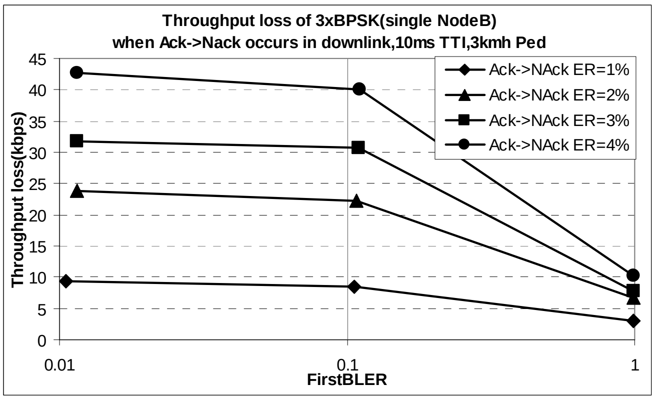

Fig. 2. Throughput loss due to ACK ⇒ NACK errors for single link

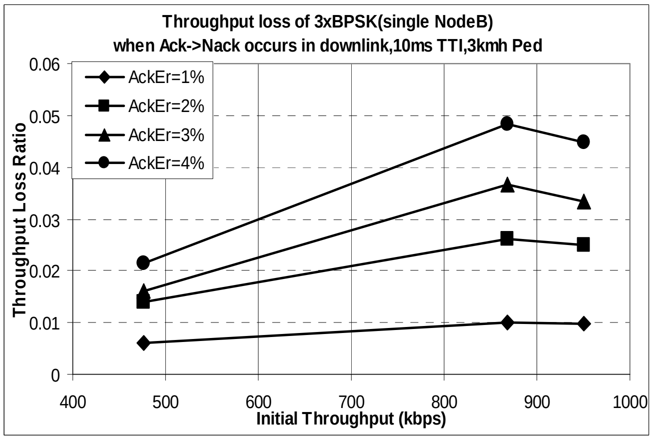

Fig. 3. Relative throughput loss due to ACK⇒NACK errors for single link.

As already mentioned, the relative loss increases when ACK number increases (i.e. BLER decreases throughput increases). At 1st BLER=0.1 and initial throughput of 860kbps, the relative loss reaches its maximum. After that since the arbitrary loss is almost constant when the BLER continues to decrease, the relative loss decreases because the initial (reference) throughput continue to increase.

B. Two Node B (SHO)

In SHO, only one ACK from any of the Node B is needed for the network to acknowledge the frame. For instance if one Node B sends an ACK and the other one sends a NACK, the result from the UE point of view is still an ACK. The total number of ACK is therefore increased. This means with the decreasing of 1st BLER, the influence of ACK ⇒ NACK errors should appear quicker, and after 1st BLER = 0.1, the arbitrary loss curve should become flatter, when compared with that of a single Node B (non-SHO) case. Fig. 4 shows the result in balanced SHO and confirms such statements. When the two Node B send an ACK, but only one ACK is misread as a NACK, the error does not trigger any loss, reducing the error impacts in SHO. But at the same time, more Node B means more signalling, and more signalling errors. To compare the error impact between SHO and non-SHO, throughput loss ratio is used on Fig. 5.

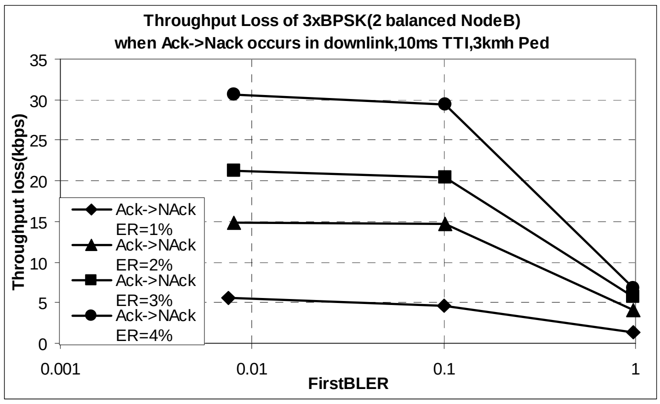

Fig. 4. Throughput loss due to ACK ⇒ NACK errors for balanced SHO.

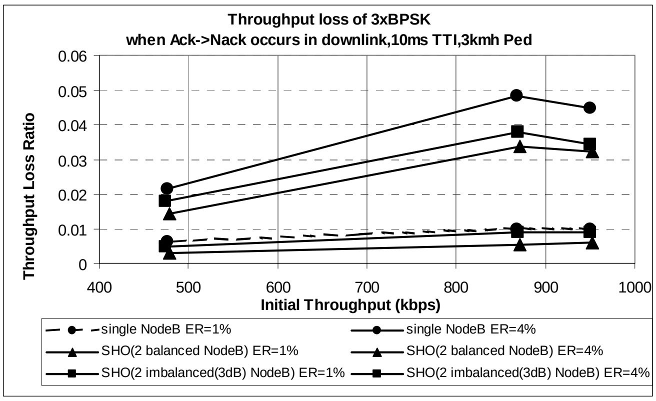

Fig. 5. Relative throughput loss due to ACK ⇒ NACK error for single link, balanced SHO and 3dB imbalanced SHO

In Fig. 5 it is quite clear that the relative throughput loss in SHO is less when compared with non-SHO. Also the error impact on imbalanced SHO is more than for balanced SHO.

The imbalance model assumed that the two Node B have the same signalling error probabilities. However, link imbalance happens when the terminal is inside one cell, rather than at the cell edge, which means that the path loss of one Node B is stronger than the other. Naturally, the signalling error of the two Node B shall be different when the links are imbalanced, which means the stronger the Node B, the smaller ACK ⇒ NACK error probability. Fig. 6 shows the error impacts when different signalling error probabilities are assumed in imbalanced SHO.

"Ack⇒Nack ER=0%&4%" means that the ACK ⇒ NACK error probability of one Node B is 0%, while the weaker one is 4%. From the figure, it is seen that the strongest Node B (the one with less signalling errors) dominates. For example, the error impact of "Ack⇒Nack ER=1%&4%" is between the impact for a probability of 4% for the two Node B, and for a probability of 1% for the two Node B. However the curve is much closer to the error impact for a probability of 1%. This means that only one good link is required in practise to minimise the impacts of ACK ⇒ NACK errors.

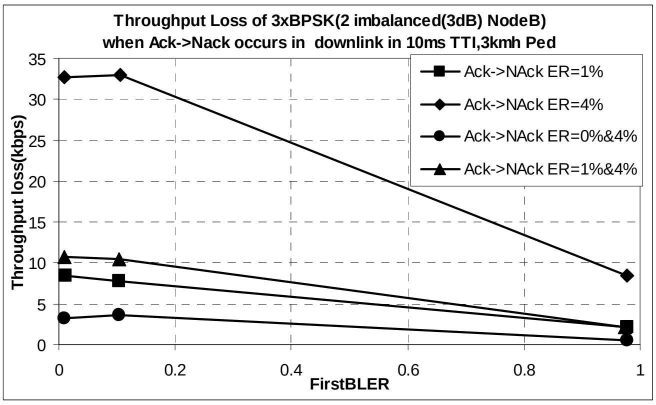

Fig. 6. ACK ⇒ NACK error impacts when different signalling error probabilities assumed in imbalanced SHO

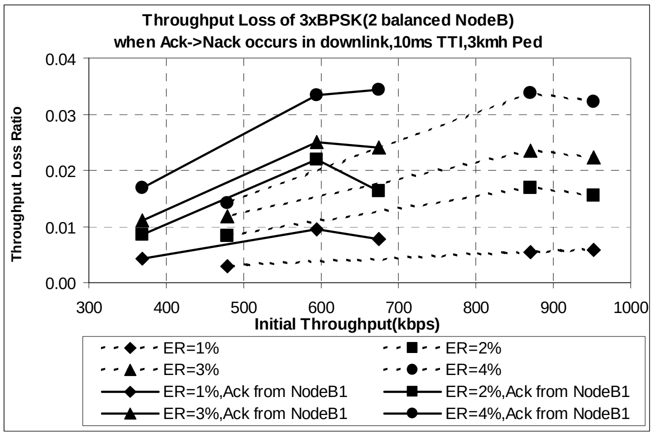

Fig. 7. ACK ⇒ NACK error impact with single ACK/NACK in balanced SHO

Another issue is single ACK/NACK in SHO, meaning that only one Node B in the SHO active set sends ACK/NACK signalling (alternatively, the UE only listens to one Node B). As discussed before, more Node B's ACK/NACK in SHO is helpful to reduce the ACK ⇒ NACK errors impact. The following figures can be used to see how valid this statement is. Fig. 7 shows the ACK ⇒ NACK error impact on throughput performance when single ACK/NACK is monitored in balanced SHO. There is a significant throughput loss when only one ACK/NACK is monitored. The reason is that only one ACK/NACK case is very similar to non-SHO case, removing all the gains obtained from SHO and seen in the previous figures.

Fig. 8 shows the single ACK/NACK result in imbalanced SHO. It can be found that the additional throughput loss caused by monitoring only a single ACK/NACK is not so much, because as discussed already imbalanced SHO provides less gain to reduce the ACK ⇒ NACK error impact.

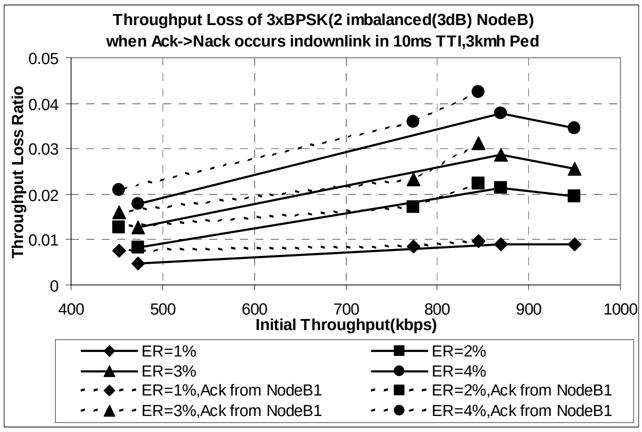

Fig. 8. ACK ⇒ NACK error impact when single ACK/NACK in imbalanced SHO

IV. NACK ⇒ ACK ERRORS IMPACTS

In HARQ, when a NACK is mistaken as an ACK, generally one frame is lost, triggering an RLC retransmission, which increases the maximum delay. In this section, the impact of NACK ⇒ ACK errors are evaluated as how many TTI will lose due to such error.

As for the ACK ⇒ NACK signalling error study of the previous section, the following results includes frame loss due NACK ⇒ ACK in case of single link, balanced SHO, imbalanced SHO and single ACK/NACK in SHO. Here the "frame loss" is calculated as number of fame lost when there are 1000 frames to be transmitted in total. Fig. 9 shows the frame loss in single link, Fig. 10 shows the result in balanced SHO, Fig. 11and Fig. 12 show the results for imbalanced, and Fig. 13 shows the results for single ACK/NACK in SHO.

From these results, generally, the frame loss increases with the BLER from BLER= 0.1 as well as with the error probabilities. The reason is that the amount of NACK will increase when BLER is getting higher, thus the total NACK ⇒ ACK errors will increase. When BLER is below 0.1 there are less NACK, and this is the reason why the frame loss increases a little only.

When comparing Fig. 9 with Fig. 10 and Fig. 11, it can be found that the frame loss increases when the system is active in SHO. The reason is due to error probabilities increase in SHO: the more the Node B, the more the errors.

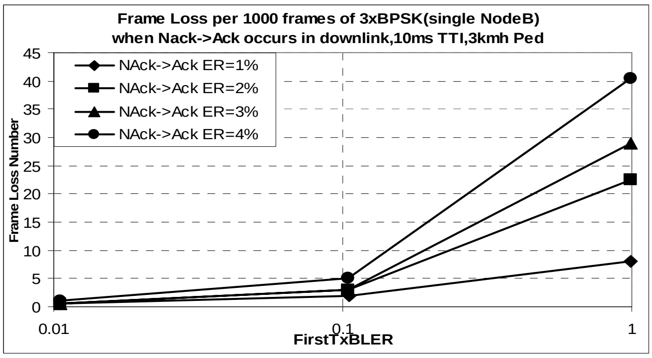

Fig. 9. Frame loss due to NACK ⇒ ACK in single link case

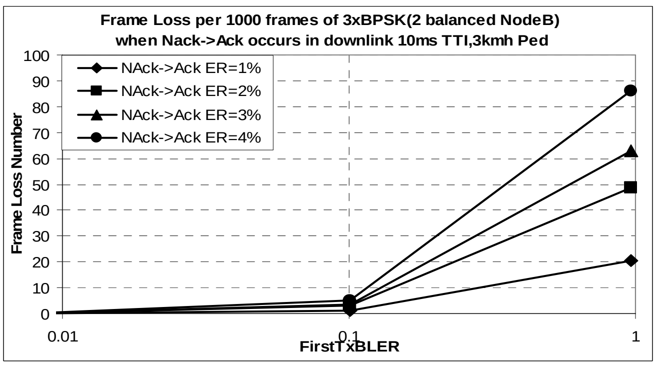

Fig. 10. Frame loss due to NACK ⇒ ACK in single balanced SHO

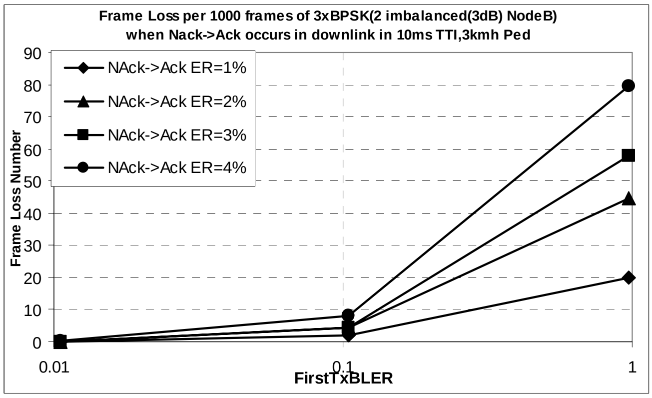

Fig. 11. Frame loss due to NACK ⇒ ACK in imbalanced SHO

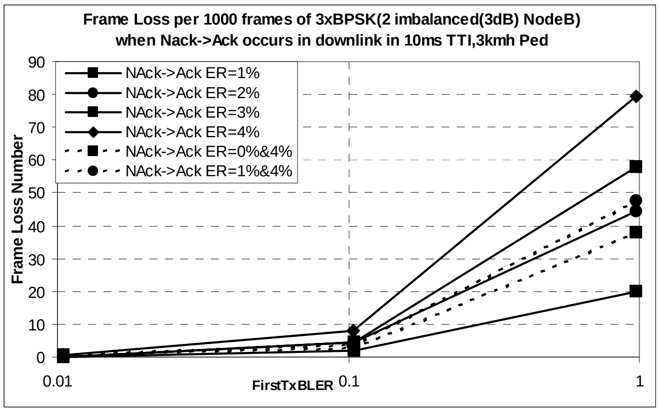

Fig. 12. Frame loss due to NACK ⇒ ACK in imbalanced SHO with different error probabilities

When comparing Fig. 10 with Fig. 11, the performance are seen as quite similar, except for a little more frame loss in balanced SHO than in imbalanced SHO.

From Fig. 12, it is seen that when the NACK ⇒ ACK error probabilities of the two NodeB are different, the result approximates to the average of error probabilities of these two NodeBs. For example, when one Node B has 4% and the other one is 1%, the average NACK ⇒ ACK error probability is 2.5%. Also we can observe that when NACK ⇒ ACK error probabilities are "1%&4%", the frame loss is just a little bit higher than the frame loss when both NACK ⇒ ACK error probabilities are "2%" for the two Node B. This is quite different with the conclusion obtained for ACK ⇒ NACK errors on Fig. 6: the throughput loss due to ACK ⇒ NACK is mainly due to the strongest Node B (the one with less ACK ⇒ NACK error probabilities). In other words, for ACK ⇒ NACK errors, it helps to be in SHO while for NACK ⇒ ACK errors, it does not.

The reason of such difference is the logical operation done in the UE to combine the signalling from the two Node B: for ACK it is a logical "OR", and for NACK it is a logical "AND". In practise this means that even if the strongest Node B(s) have little NACK ⇒ ACK errors, it is not enough to guarantee a small total NACK ⇒ ACK error probabilities because of possible weak Node B.

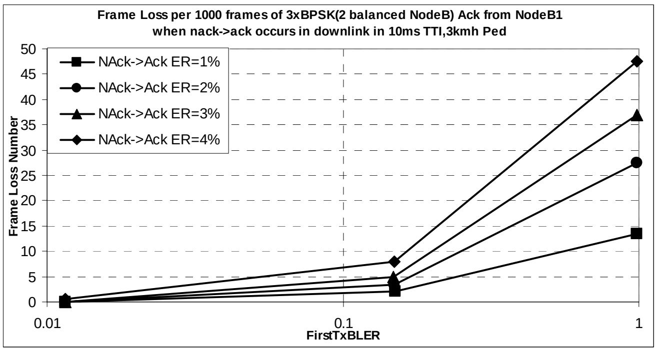

Fig. 13. Frame loss due to NACK ⇒ ACK in balanced SHO (single ACK/NACK in SHO)

Fig. 13 confirms the statement that frame loss due to NACK ⇒ ACK decrease when fewer Node B send ACK/NACK. In this example, when there is a single ACK/NACK in SHO, the frame loss is almost same with that of a single link (no SHO).

IV. Conclusion

In Release 6 of the 3GPP standard, uplink enhancements for UTRAN are being introduced for packet data traffic: HSUPA. One of the enhancements currently approached for HSUPA is Layer 1 HARQ. Layer 1 HARQ in the Node B allows for much faster retransmissions than what the RLC layer in RNC (Radio Network Controller) facilitates. In order to support Layer 1 HARQ, ACK/NACK signalling needs to be introduced in the downlink. This paper has analyzed the resulting new error cases and assessed the their effects on the throughput and frame loss. Through simulations it was shown that for ACK ⇒ NACK errors (ACK misread as NACK):

- In general, the throughput loss is small;
- The loss increases when the BLER decreases;
- SHO helps to reduces the loss.
- in SHO, the strongest Node B dominates.

For NACK ⇒ ACK errors (NACK misread as ACK), it was shown that:

- such errors can cause frame losses,
- SHO increases the frame losses.
- in SHO, the loss is close to the average among the Node B.

So on one hand, the SHO minimizes the errors while on the other hand it increases them. Thus, in practise, one cannot rely on SHO only and has to design the channel coding of the ACK/NACK signalling in order to minimise the error rate. Strong forward error correction is therefore required, and one cannot ignore the overhead introduced by ACK/NACK signalling.

Reference

[1] 3GPP Technical Report TR 25.876, Feasibility Study for Enhanced Uplink for UTRA FDD.

[2] 3GPP Technical Specification TS 25.309, High Speed Downlink Packet Access (HSDPA) Overall Description.