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Agenda Item: **15.7**
Source: **Fujitsu**
Title: **Grouped and Encoded Packet based HARQ for LTE-Advanced**
Document for: **Discussion and Decision**

1. Introduction

In the ordinary HARQ system, once a retransmission is in request, the transmitter has to assign a full packet based on the current channel realization, which in general costs too much channel resource. Statistically, Statistically, 10~80% packets need to be recovered by HARQ retransmission process if a mobile is travelling at 3~30km/h, while the most packets only require a little bit additional energy or redundancy. This extremely wastes the channel resource, directly causing the system performance loss. To resolve this problem, one research on turbo coded HARQ (TC-HARQ) has been proposed [1] that is concerned with HARQ behaviors in conjunction with LLR of turbo codes. The motivation of the TC-HARQ is to potentially increase system throughput with more sophisticated use of log-likelihood ratio (LLR), but compensatively at the cost of large amount of control channels.

The challenge in this contribution is to provide a new HARQ scheme by harmonizing the channel coding and HARQ, which may reap substantial throughput gain to meet the fairly aggressive performance targets [2], but without increasing control channel burden much. The proposed HARQ so called grouping based H-ARQ (G-HARQ) is to group the information bit portion from failed packet and the new information bit portion from new transmit packet, and then both portions are encoded by cyclic redundancy check (CRC) and turbo code. With G-HARQ, we may highly consider that the user equipment (UE) receiver successfully decodes the grouped and encoded packet due to the partial energy combining between the failed packet and the new transmit packet. If it is true, then, the information bit portion from failed packet can be considered with 100% reliability, and their LLR can be set to be infinite. With such an improved LLR to decode again, the failed packet can be easily recovered so as to achieve a grouped coding gain for HARQ.

The system level simulation confirms that with 50% retransmit portion, G-HARQ may achieve 15% sector throughput gain as opposed to ordinary Chase-combining HARQ at UE speed of 30km/h, by slightly suffering transmit latency and only adding an ACK/NAK bit. 15% system level sector throughput gain, in general, can be considered as a significant number, similar to the MIMO gain from 1x2 to 2x2 antenna configuration.

2. Packet Grouping based HARQ

G-HARQ is concerned with a partial HARQ process by grouping an information bit portion from failed packet and an information bit portion from the new packet, in order to form an encoded retransmit packet with a certain number of parity check bits depending on the available code rate. The intention is to recover the failed packet and simultaneously deliver a certain number of new information bits. As a high level concept, G-HARQ uses a small redundant portion to recover the failed packet as Chase-combining does so that the system throughput can be significantly increased only by sacrificing negligible transmit latency and costing a single ACK/NAK bit.

Figure 1 depicts the G-HARQ transmission, considering the initial transmit packet (consisting of information bits and parity bits) and retransmit packet (consisting of retransmit information bits, new information bits and parity bits). Both packets are encoded by CRC and turbo code. The retransmit packet is delivered only if the initial transmit packet is received in error. In the information bits of both packets, there is a common portion, which aims to improve the retransmit packet quality by simply implementing energy combining, and in addition, efficiently recover the failed initial transmit packet. The high coding gain is only achieved for the failed initial transmit packet when the retransmit packet is successfully received.

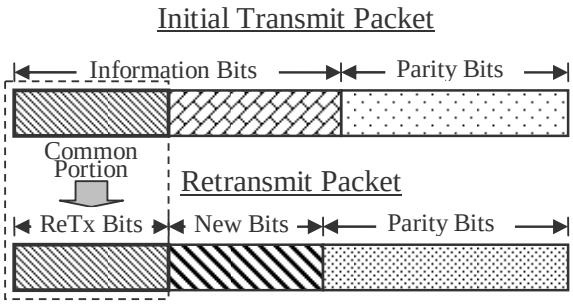

Figure 1: G-HARQ based transmission.

It is worthwhile noting that the information bits in both packets are virtually positioned and should be interleaved.

2.1. Some Definitions

In what follows, some terminologies and parameters defined for G-HARQ are utilized throughout this contribution:

- Retransmit portion (common portion): a portion from the information bits of the failed packet, which is used to recover the unsuccessful packet.
- New information portion: a portion from the information bits of the new data traffic.
- Retransmit packet: a packet formed by the retransmit portions and the new information portion, which are CRC and turbo encoded with parity check bits.
- Failed initial packet: a packet which is failed in the first initial transmission, and required for retransmission.
- M_F: the number of information bits in the retransmit portion.
- M_N: the number of information bits in the new information portion. In conventional Chase-combining HARQ as a special case, $M_N = 0$.
- R: the code rate for the transmit packet.
- α: the ratio of the information bits from the retransmit portion to all the information bits in the retransmit packet, which is defined by

$$\alpha = \frac{M_F}{M_N + M_F}. \tag{1}$$

2.2. G-HARQ based Reception

To simplify the description, throughout this paper, we focus on the Chase-combining based G-HARQ (CC-G-HARQ), although the incremental redundancy based H-ARQ (IR-HARQ) works as well.

Figure 2, Figure 3 and Figure 4 exemplify the packet reception with the unique G-HARQ combining process. In this example, the retransmit packet corrupted by the channel noise is recovered hierarchically, i.e., retransmit packet and then failed initial packet. Three decoding processes are taken into account.

Firstly, as depicted in Figure 2, to decode retransmit packet, the retransmit portion (common portion) from the received retransmit packet is energy combined with the retransmit portion (common portion) from the failed initial packet which is stored in the receiver buffer. This aims to enhance the SNR for retransmit packet and reduce its block error rate (BLER).

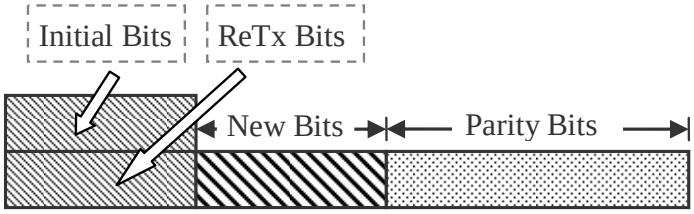

Figure 2: Retransmit packet reception with G-HARQ.

Thereafter, we consider recovering the failed initial packet, depending on whether the retransmit packet is in error or not.

If the retransmit packet is detected in error, as depicted in Figure 3, the retransmit portion (common portion) from the failed initial packet is energy combined with the retransmit portion (common portion) from the retransmit packet. This aims to enhance the SNR for failed initial packet and reduce its BLER.

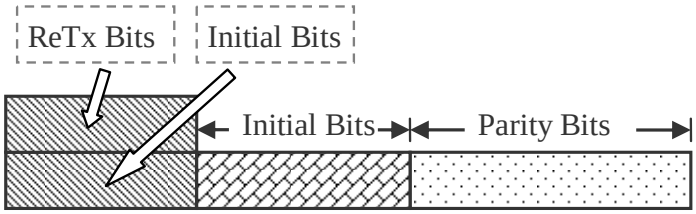

Figure 3: Failed initial packet reception if the retransmit packet is received in error.

If the retransmit packet is successfully detected, as depicted in Figure 4, the retransmit portion (common portion) in the failed initial packet no longer belongs to noise corrupted bits, but with 100% reliability bits and the corresponding LLR could be updated to infinite value. With the newly updated LLR value then, the failed initial packet is decoded again so that the significantly HARQ coding gain can be expected.

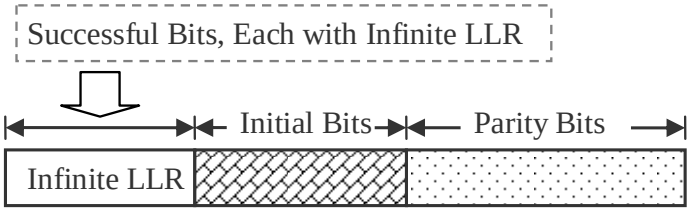

Figure 4: Failed initial packet reception if the retransmit packet is successfully received.

2.3. SNR Gain from G-HARQ

In this section, we attempt to clarify where the gain comes from for G-HARQ. Firstly, we describe the SNR gain for the retransmit packet with G-HARQ (it includes the new bit portion) as compared to the new transmit packet without HARQ. As a high level discussion, it is simply assumed that the channel condition is unchanged, meaning that a signal with constant power corrupted by noise is always received. (With regard to dynamic fading channel, system level evaluation as will be discussed in section 3 gives more evidence to confirm the grouped HARQ coding gain.) Thus, each received packet experiences the same SNR. Thanks to the energy combining from the common portion in G-HARQ, the SNR of the retransmit packet can be gained. Compared to un-combined packet with pure new information bits, the SNR gain G_{RxTx} can be expressed as

$$G_{RxTx} = 10\log_{10}\left(1 + R\alpha\right). \tag{2}$$

Secondly, we describe the SNR gain for the failed initial packet with G-HARQ as compared to the ordinary Chase-combined packet. With regard to the SNR gain for the failed initial packet, it depends on whether the retransmit packet is correctly detected or not. If the retransmit packet is received in error, the SNR gain for the failed initial packet, considered as the worst case for G-HARQ, is the same as G_{RxTx}, which is smaller than the gain as Chase-combining achieves. However, compared to un-combined packet, the BLER for retransmit packet with G-HARQ is much smaller due to the SNR gain, which will be confirmed in the system level simulation in section 3. If the retransmit packet is correctly received, the overall gain is no longer equal to G_{RxTx}, and additional G-HARQ coding gain is obtained. As will be discussed in section 3, the G-HARQ coding gain is around 3dB with α = 0.5, which is almost the same as the ordinary HARQ Chase combining does. From the perspective of transmit efficiency, beneficially, only half channel resource is involved.

2.4. Some Other Issues: Latency and Overhead

With G-HARQ, the performance gain can be expected but some other issues in terms of transmit latency and control channel overhead have to be taken into account. In order to clarify such an issue, we give an example in Figure 5, where a retransmission flow with Chase combining based G-HARQ process is illustrated. In this example, we simply assume that the G-HARQ operation is implemented by combining retransmit portion and new information portion in 4-channel HARQ process. In the flow, the packet #1 is initially transmitted in the first TTI, and the corresponding NAK is received. Thus, the information portion from the failed packet #1 and the new portion are grouped and encoded by CRC and turbo code, in order to form a retransmit packet. Due to four TTI channel delay for acknowledgment, the resultant retransmit packet has the first opportunity to be transmitted in the 5th TTI. This G-HARQ process is contiguously operated until either the packet is successfully delivered or the maximum retransmission number is finally reached.

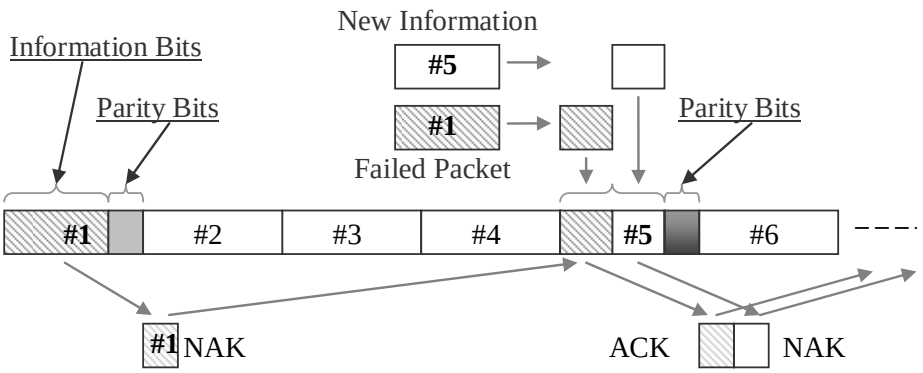

Figure 5: Chase-combining based G-HARQ retransmission flow.

With this example, firstly, we think of what is additional latency that the receiver experiences. We notice that the additional latency depends on the BLER for the retransmit packet. According to the system level simulation results, with G-HARQ, it will be confirmed that the BLER can be significantly reduced by one quarter, which ensures the similar gain as Chase-combining. Considering new data can be also delivered in the retransmit packet, the overall latency should not be a big issue as compared to the ordinary HARQ system.

Secondly, we think of how many additional control bits are required in order to realize ACK/NAK process for G-HARQ. As depicted in Figure 5, two ACK/NAK bits in total are necessarily used to indicate the reception status for both failed packet and retransmit packet (due to the inclusion of new information portion). As a consequence, to accomplish G-HARQ process, it is required to introduce one additional control bit for ACK/NAK indication.

3. Performance Evaluation

To evaluate the performance of the G-HARQ system by compared to the Chase-combining based ordinary HARQ system (denoted *baseline* scheme for simulation reference), a system level simulation is taken into account. The system level simulation is implemented in a cell network formed by 7 clusters; each cluster consists of 19 hexagonal cells and each cell contains 3 sectors. The antenna of the sector is orientated with bore-sight point to the side of hexagon. To accurately model the interferences incident from outer-cells, a wrap around network structure with 7 copies of the centre hexagonal cluster is employed, where the original cluster is placed in the middle and 6 copies are attached on the side symmetrically. The detailed description of the wrap around network structure can be referred to [3].

3.1. Simulation Assumptions

The system level simulation focuses on the down-link with the detailed assumptions listed in Table 1. The simulation mainly relies on LTE methodology, defined in LTE release-8 study item [4].

Table 1: LTE based system level simulation assumptions.

Number of Cells	19
Number of Sectors per Cell	3
Number of UEs per sector	10
Antenna Configuration	1x2
Inter-site Distance (ISD)	500 meters
Transmit Antenna Correlation	0.3
Receive Antenna Spacing	0.5λ
Max Retransmission Number	3

HARQ Type	Chase-Combining (CC)
Centre Frequency	2 GHz
Bandwidth	10MHz
Transmission Power	40 Watts (46 dBm)
Lognormal Shadowing	8dB
Noise Figure	9 dB
Transmit Antenna Gain	14 dBi
Receive Antenna Gain	0 dBi
Maximum CIR	30 dB
Path-Loss	128.1+37.6log10(R), R in km
Penetration Loss	20dB
Scheduler	Proportional Fair
Channel Estimation	Ideal
ACK/NAK Channel	Perfect
Traffic Model	Full Buffer
MCS Table	29 Levels [4]
BLER Target for MCS Selection	10%
Effective SINR	Mutual Information Basis
Overhead	25%, LTE basis
MCS Feedback Interval	5msec
BLER for MCS Selction	10% (LTE based)
Number of HARQ Channel	8 (Maximum Buffer Size)
Number of RBs per Tx UE	10
Channel Model	TU
UE Speed	30km/h
# Useful Sub-Carriers per Symbol	600
FFT Size	1024
Receiver Type	LMMSE
Ratio of Information Bits, α	0.5

3.2. Link Level Performance

To implement a system level simulation, the link level curves in terms of SNR vs. BLER in AWGN is inevitable. The link level curves play an important role in mapping the effective SNR (calculated in system level simulation using mutual information based effective SNR mapping scheme [3]) into BLER (generated in link level simulation), so that whether the received packet is in error or not can be judged in system level evaluation.

In addition, adaptive modulation and coding (AMC) with modulation and coding scheme (MCS) levels is considered to properly capture the fading channel variation. The MCS format is defined in [5], with 29 MCS levels considering QPSK, 16QAM and 64QAM, and many various code rates. Two types of MCS each with 29 levels are prepared in G-HARQ simulation. Type-1 is used for the general mapping purpose, and only implemented under conditions as follows:

- Ordinary HARQ simulation as a baseline,
- G-HARQ simulation, but only when a regular packet transmission (without retransmission) is in request.
- Retransmit packet reception in G-HARQ simulation, as discussed in Figure 2.

- Failed initial packet reception in G-HARQ simulation if the retransmit packet is received in error, as discussed in Figure 3.

Type-2 is used for the G-HARQ mapping purpose, and only implemented under condition as follows:

- Failed initial packet reception in G-HARQ simulation if the retransmit packet is successfully received, as discussed in Figure 4.

Here, we provide BLER as a function of SNR for both types of MCS corresponding to baseline and G-HARQ. In the baseline (type-1 MCS), the BLER is generated on AWGN, without any specific assumptions, whereas in the G-HARQ (type-2 MCS), the BLER is dependent on the ratio α, and generated by assuming 50% information bits (α = 0.5) are pre-known with infinite LLR.

Figure 6 exemplifies the BLER as a function of SNR for both baseline and G-HARQ, with simulation assumptions of 16QAM, various code rates (0.332, 0.643), and α = 0.5. From the results, it can be observed that the SNR gain achieved by G-HARQ is around 3dB. This SNR gain is almost the same as the ordinary HARQ Chase combining which in general gives 3dB average SNR gain, but costing 100% channel resource.

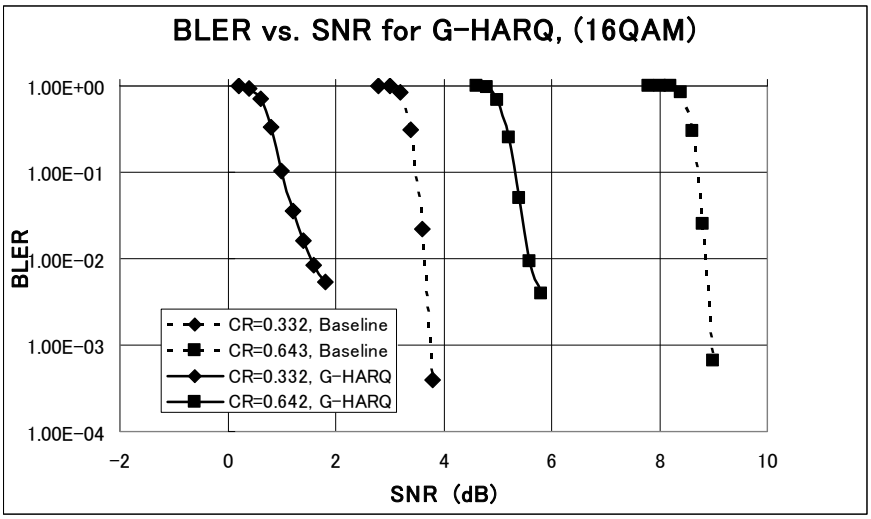

Figure 6: BLER vs. SNR with 16QAM and α = 0.5, compared between G-HARQ and baseline.

3.3. System Level Performance

In a full system level simulation implemented according to the LTE methodology [4], main metrics as simulation output are the BLER and user throughput, whereby user throughput vs. geometry and its relative CDF can be plotted.

Firstly, it is worthwhile showing the BLER of the retransmit packet (first energy combining shown in Figure 2) because it impacts G-HARQ coding gain. The purpose is to confirm how much BLER can be reduced by energy combining. Figure 7 shows the BLER for retransmit packet as a function of geometry, compared between G-HARQ and baseline schemes. It can be found that BLER of retransmit packet is much lower. On average, the BLER can be reduced from 77% to 20%.

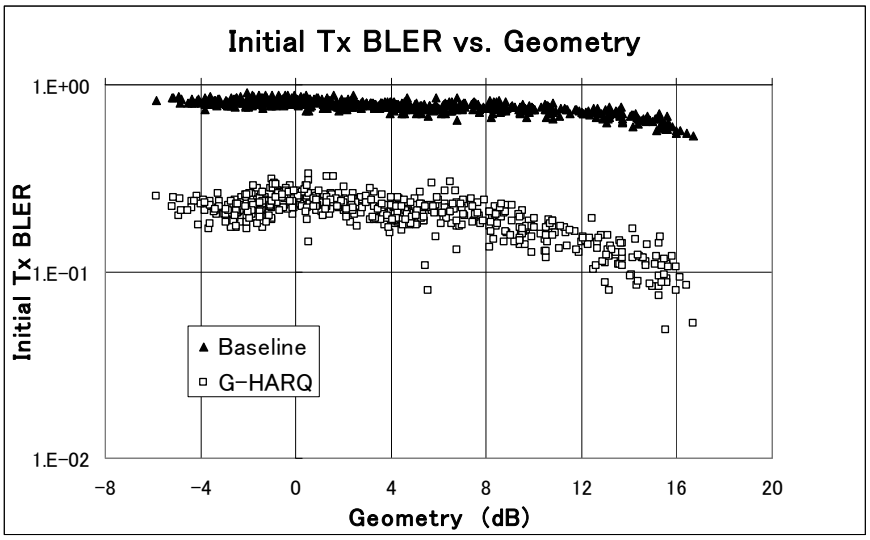

Figure 7: BLER for retransmit packet vs. geometry, compared between G-HARQ and baseline scheme.

Then, we demonstrate the throughput gain achieved by G-HARQ. Figure 8 shows the user throughput as a function of geometry, and Figure 9 shows its relative CDF of user throughput. It can be clearly observed that the G-HARQ achieves significant throughput gain as opposed to baseline (Chase combining based ordinary HARQ). In addition, we compute the average sector throughput and user coverage (5%tile CDF of user throughput from Figure 9), accordingly, which is summarized in Table 2. It can be seen that the gain on average in sector throughput is 15%, whereas the user coverage is not capable of being improved. Nevertheless, it is worthwhile noting that 15% sector throughput gain can be considered as a significant number, similar to the MIMO gain achieved from 2x2 antenna configuration as opposed to 1x2. MIMO gain can be easily confirmed in LTE calibration [4].

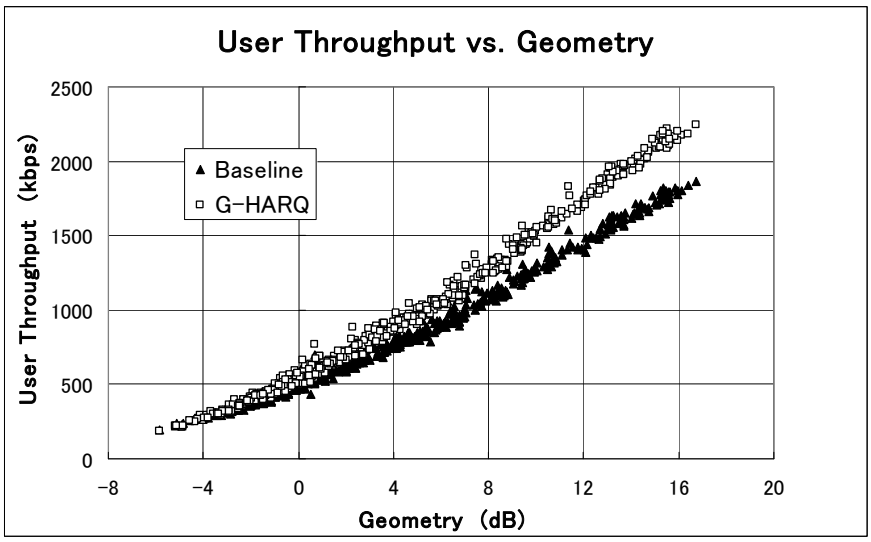

Figure 8: User throughput vs. geometry.

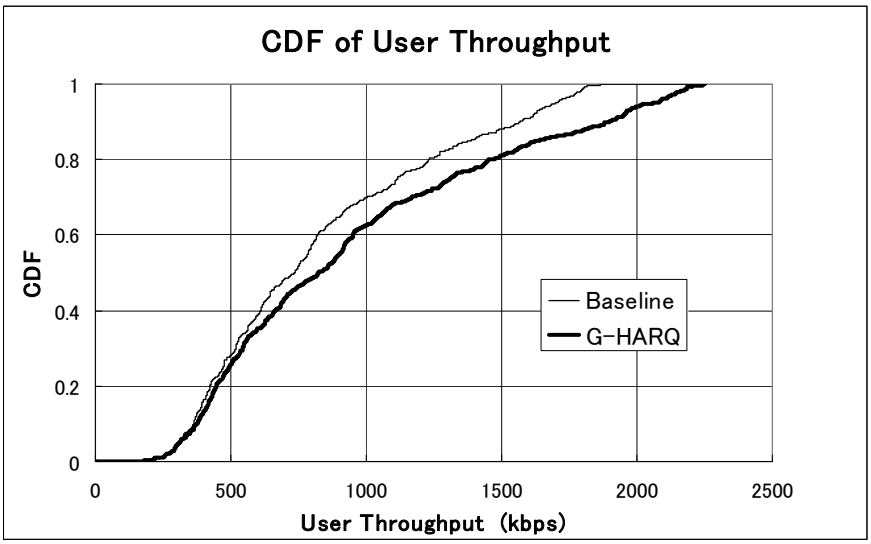

Figure 9: CDF of user throughput.

Table 2: Summary for throughput comparison.

	Sector Throughput	User Coverage (5%tile)
Baseline	0.829 Mbps	0.031 Mbps
Group-HARQ	0.954 Mbps	0.031 Mbps

4. Conclusions

In this paper, we have proposed a novel G-HARQ scheme by grouping the information bit portions from failed packet and the new information bit portion from new transmit packet, and then both portions are encoded by CRC and turbo code. In the reception, both bit portions are jointly decoded to obtain grouped coding gain. System level simulation demonstrated that grouping based HARQ achieves 15% sector throughput gain as opposed to ordinary Chase-combining HARQ at the UE speed of 30km/h, by slightly increasing transmit latency and only adding a single ACK/NAK bit.

Reference

[1] K. R. Narayanan and G. L. Stuber, “A novel ARQ technique using the turbo coding principle,” *IEEE Commun. Lett.*, vol. 1, pp. 49–51, Mar.1997.

[2] 3GPP TR 36.913 v8.0.0, Requirement for further advancements for E-UTRA, release-8, June 2008.

[3] IEEE C802.16m-07/080r3, IEEE 802.16 Broadband Wireless Access Working Group, August 28, 2007, http://ieee802.org/16.

[4] 3GPP TR 25.814 v7.0.0, Physical layer aspects for evolved UTRA, release-7, June 2006.

[5] 3GPP TSG-RAN1 #55, R1-084299, “DL System Level Performance Comparison between 2GHz and 3.5GHz for Advanced E-UTRA”, Prague, Czech Republic, November 10-14, 2008.