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# PERFORMANCE EVALUATION OF HYBRID ARQ SCHEMES OF 3GPP LTE OFDMA SYSTEM

Kian Chung Beh, Angela Doufexi, Simon Armour  
Centre for Communication Research, University of Bristol, Woodland Road, Bristol, BS8 1UB, U.K

## ABSTRACT

Expectations and requirements for future wireless communication systems continue to grow and evolve. Thus, recently, the Third Generation Partnership Project (3GPP) has considered the Long Term Evolution (LTE) of 3G – also known as Super 3G – to ensure its competitiveness in the future. It is generally assumed that the downlink of the new air interface would be OFDMA based and that some form of Hybrid ARQ (HARQ) might be employed. This paper aims to evaluate the performance of various HARQ schemes over the OFDMA downlink of the currently proposed 3GPP LTE specification. Schemes are compared in terms of throughput and PER in the context their differing memory requirements for implementation. Simulation results show that Type II Incremental Redundancy offers the best throughput performance but at the cost of higher memory requirement. However, when the schemes are enhanced with subcarrier and constellation rearrangement techniques, the performance gap between the different HARQ types is reduced significantly.

*Keywords* – 3GPP LTE, OFDMA, Hybrid ARQ, Incremental Redundancy, Chase Combining

## I. INTRODUCTION

3GPP LTE is assumed to be an all-IP packet based system targeting provision of 100Mbps in the downlink and 50Mbps in the uplink. An improvement of two to four times the spectral efficiency (bits/s/Hz) of 3GPP Release 5 (HSDPA) is also expected. The new standard aims to reduce delays, improve spectrum flexibility and reduce cost for operators and end users [1]. To fulfil these targets, new enabling technologies need to be integrated into the current 3G radio network architectures. It is generally assumed that the downlink of the new air interface would be OFDMA based, while single carrier FDMA (SC-FDMA) will be employed in the uplink. OFDMA (in combination with Dynamic Sub-Carrier Allocation) has been previously investigated for next generation cellular systems in [2].

Hybrid ARQ is essentially a combination of Forward Error Correction (FEC) with Automatic Retransmission reQuest, in an optimal manner. Hybrid ARQ schemes are commonly used to provide a reliable communication over noisy wireless channels. HARQ is able to compensate for link adaptation errors and provide a finer granularity of coding rate thus giving a better throughput performance. The simplest method is called Hybrid ARQ Type-I. When a packet is found to be in error, usually through the use of Cyclic Redundancy Check (CRC), a retransmission request will be sent to the transmitter and the erroneous packet will be discarded. The transmitter will then retransmit the same packet until the packet is

successfully decoded at the receiver or a maximum retransmission limit is reached. In the case where the erroneous packets are stored in a buffer and the corresponding soft values at bit level are combined according to the weights of received signal to noise ratio, this method is known as Hybrid ARQ Type I with Packet Combining or Chase Combining. Hybrid ARQ Type-II is also known as Full Incremental Redundancy (IR) and this technique gradually decreases coding rate in each retransmission by sending additional redundancy bits. These bits will then be combined with the previously received packets which were stored at the buffer of the receiver to form more powerful error correction codes. Hybrid ARQ Type III is known as Partial IR. This method decreases coding rate by sending additional redundancy bits while maintaining self-decodability in each retransmission. The retransmitted packet can be chase combined with the previous packets to increase the diversity gain. Incremental Redundancy techniques often make use of Rate Compatible Punctured Convolutional Codes (RCPC) or Rate Compatible Punctured Turbo Codes (RCPT). These codes respect the rate compatibility criterion which requires that the puncturing matrices are chosen in such a way that the coded bits of higher puncturing rates belong to the coded bits of lower puncturing rates.

In section II, the system and channel models are presented. Enhanced Hybrid ARQ techniques are given in Section III. Simulation results are presented and discussed in Section IV. Section V concludes the paper.

## II. SYSTEM AND CHANNEL MODEL

New access technology under consideration for LTE downlink is OFDMA. OFDMA is a multiple access scheme based on OFDM where data is transmitted to different users on different subcarriers. It is a very attractive choice for the LTE as it is suitable for high data rate transmission in wideband wireless systems due to its spectral efficiency and good immunity to multipath fading. Different sets of parameters for the downlink transmission scheme are given in [3]. The key parameters of the LTE OFDMA downlink system assumed in this paper are given in Table 1.

Figure 1 shows the proposed system model of LTE OFDMA system which employs Hybrid ARQ. It is assumed that the use of a Cyclic Redundancy Check (CRC) enables perfect error detection at the receiver. The feedback channel is further assumed to be error free. Turbo decoding employs the Log-MAP (Maximum a Posteriori) algorithm and the maximum number of decoding iterations is limited to 8. The turbo inner interleaver is pseudorandom.

Table 1: Parameters for LTE OFDMA downlink

|  |       |                            |
|--|-------|----------------------------|
| Transmission BW                                      |       | 10 MHz                     |
| Sub-frame duration                                   |       | 0.5ms                      |
| Sub-carrier spacing                                  |       | 15kHz                      |
| Sampling frequency                                   |       | 15.36MHz<br>(4x3.84MHz)    |
| FFT size   |       | 1024                       |
| Number of occupied sub-carriers                      |       | 601                        |
| Number of OFDM symbols per sub frame (Short/Long CP) |       | 7/6                        |
| CP length (μs/samples)                               | Short | (4.69/72)x6<br>(5.21/80)x1 |
|  | Long  | (16.67/256)                |

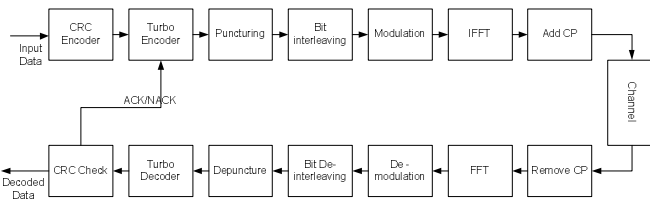


Figure 1: System Model for LTE OFDMA

RCPT codes [4] can be obtained by puncturing the parity bits of a rate 1/3 mother turbo code which employs a PCCC (Parallel Concatenated Convolutional code) scheme with two RSC (Recursive Systematic Convolutional) encoders of rate 1/2. A puncturing period of 6 is used in this simulation to form code rates of 3/4 and 1/2.

The simulation employs the 3GPP Spatial Channel Model Extension (SCME) as specified in [5] [6]. This is the channel model commonly used by the European WINNER project for evaluation of candidate techniques. SCME defines three environments (Suburban Macro, Urban Macro, and Urban Micro) where the default scenario used in the results presented below is Urban Macro. SCME provides a reduced-variability tapped delay-line model [7] for calibration and comparison simulations and this model will be used in this paper. A new channel impulse response is used at each new packet transmission. However channels remain invariant over the retransmissions – no temporal diversity is achieved by retransmission.

For Chase Combining, packets are combined at bit level by direct addition of the demodulation of soft bits. Demodulation of soft bit is equivalent to values of Log Likelihood Ratio (LLR) given as:

$$LLR(b) = \log \frac{P_r \{b = 1|r\}}{P_r \{b = 0|r\}} \quad (1)$$

Summation of LLR values at bit levels is mathematically equivalent to performing Maximal Ratio Combining (MRC) at symbol level before calculating the LLR. Chase Combining at

bit level enables the use of enhanced hybrid ARQ schemes as will be described in section III.

The maximum number of retransmissions is limited to 4, with initial coding rate of 1/2 or 3/4. As specified in [3], three data modulation schemes are supported. These are QPSK, 16QAM and 64QAM. Six Modulation and Coding Schemes (MCS) levels are considered in this paper, as shown in Table 2.

Table 2: Modulation and Coding Schemes

| MCS | Modulation | Coding Rate |
|-----|------------|-------------|
| 1   | QPSK       | 1/2         |
| 2   | QPSK       | 3/4         |
| 3   | 16QAM      | 1/2         |
| 4   | 16QAM      | 3/4         |
| 5   | 64QAM      | 1/2         |
| 6   | 64QAM      | 3/4         |

### III. ENHANCED HYBRID ARQ SCHEMES

For the M-QAM constellation, a serial data bit stream is serial-parallel converted into two (in-phase (I) and quadrature (Q)) bit streams. These two components are then mapped to form complex symbols using Gray encoding. For 16-QAM, every four bits ( $I_1Q_1I_2Q_2$ ) defines a constellation symbol which is then transmitted over the communication channel.

It is well known that unequal error protection exists among the four bits which form a 16-QAM symbol. Among these four bits, the probability of error for a most significant bit (MSB) is considerably less than a least significant bit (LSB). For example, for the first bit of a 16 QAM symbol to be demodulated erroneously, it requires three times more perturbation in the real (or imaginary) part than the third bit of the 16 QAM symbol. In short, the MSBs have three times more reliability than LSBs to induce a bit error. Therefore, in order to compensate for this problem, bits can be rearranged in such a manner that less protected bits will be given more protection in the retransmissions.

Table 3: Constellation rearrangement for 16QAM [8]

| Constellation version parameter b | Output bit sequence | Operation                         |
|-----------------------------------|---------------------|-----------------------------------|
| 0                                 | $I_1Q_1I_2Q_2$      | None                              |
| 1                                 | $I_2Q_2I_1Q_1$      | Swapping MSBs with LSBs           |
| 2                                 | $I_1Q_1I_2Q_2$      | Inversion of LSBs' logical values |
| 3                                 | $I_2Q_2I_1Q_1$      | Both Swapping and inversion       |

Table 3 define the operations applied to the bits before constellation mapping. These rearrangement techniques average the error probability of each bit over the retransmissions. Maximum benefit from constellation rearrangement can be achieved with four retransmissions, each with different constellation mapping. In addition, constellation rearrangement does not require additional User Equipment (UE) buffer but only trivial operations to rearrange the output bit sequence to achieve a different constellation mapping. 64-QAM has a similar characteristic of unequal error protection as

in 16-QAM. Similar rearrangement techniques can be applied in the case of 64-QAM to achieve maximum benefit with four retransmissions.

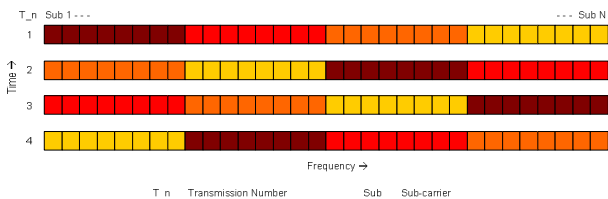


Figure 2: Subcarrier Rearrangement

In a frequency selective channel, each OFDM subcarrier suffers different distortion and thus different received signal quality. Fading in between pairs of subcarriers will be uncorrelated provided they are separated wider than channel coherence bandwidth in the frequency domain. Therefore, frequency diversity can be achieved by assigning code bits to different subcarriers in retransmissions by shifting the code bits with an appropriate step – larger than the channel coherent bandwidth.

In this paper, a subcarrier rearrangement scheme [9] is employed as shown in Figure 2. In the first retransmission, the subcarriers are shifted by half of the useful data subcarriers, which correspond to half of the system bandwidth, 5MHz in this case. The shift in the frequency domain will be large enough to fully utilize the inherent frequency diversity effect. In the following retransmission, subcarriers are shifted by 3/4 and 1/4 of useful data carriers, relative to the first transmitted packet. The merit of this scheme is that no additional buffer is required, but only simple shifting operations are needed in the retransmission.

These two techniques can be combined to obtain both ‘constellation’ and frequency diversity. Code bits are modulated using different constellation mapping and then assigned to subcarriers which are shifted by a reasonably large step in frequency domain to further achieve frequency diversity in retransmissions. However, when QPSK is used as the modulation scheme, the constellation rearrangement technique cannot be applied and therefore only frequency diversity can be achieved through subcarrier rearrangement. Performance of these enhanced hybrid ARQ schemes will be evaluated in the following section.

#### IV. SIMULATION RESULTS

Different Hybrid ARQ schemes are simulated for the LTE OFDMA system as described in section II. In order to evaluate the performance comparison of different schemes, two metrics are considered: packet error rate (PER) and throughput performance.

Throughput is defined as the expected number of correctly received information bits per channel use. Throughput is measured in terms of bits per second and given as:

$$Throughput = \frac{R(1 - PER)}{N} \quad (2)$$

where R is the transmitted bit rate, PER is residual packet error rate after maximum number of retransmissions and N is average number of transmissions.

#### A. PER Performance

Figures 3-5 present the PER performance of various Hybrid ARQ schemes for different MCS levels, with a packet size of 54 bytes. It can be clearly seen that Full IR outperforms other Hybrid ARQ schemes in term of reliability, especially for high MCS. For low initial coding rate such as 1/2, both Full IR and Partial IR have identical performance. Both IR techniques outperform Chase Combining due to the high decoding gain obtained over the retransmissions.

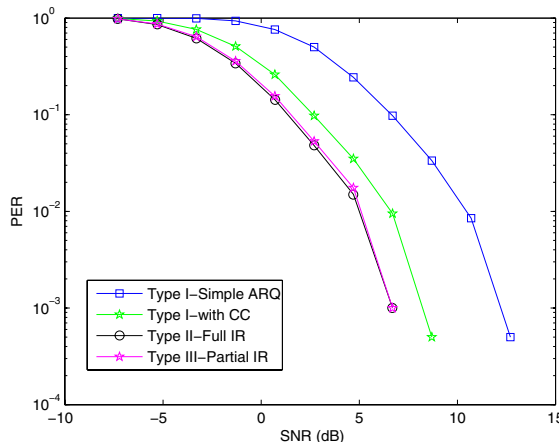


Figure 3: PER Performance comparison for MCS1

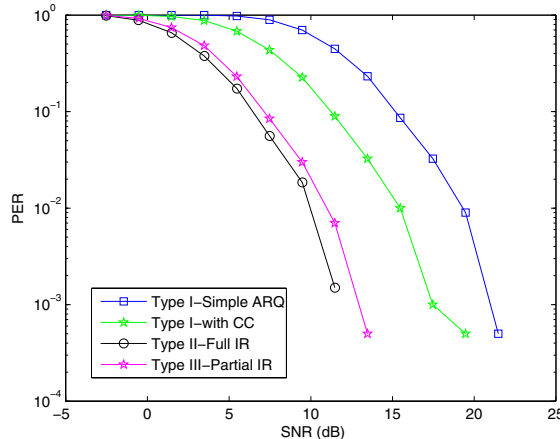


Figure 4: PER Performance comparison for MCS4

For high coding rate (3/4), Partial IR require six retransmission to transmit all the redundancy bits and to reduce the effective coding rate down to 1/3 mother coding rate. On the contrary, Full IR can reduce the coding more rapidly as more redundancy bits are sent instead of systematic bit. For lower coding rate (1/2), Full IR no longer has decoding gain over Partial IR since both methods reduced the coding rate down to 1/3 mother code with just one retransmission.

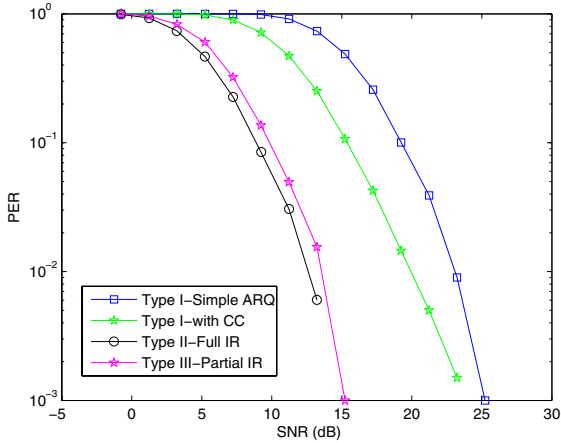


Figure 5: PER Performance comparison for MCS6

Full IR offers maximum decoding gain among all schemes but at the expense of highest soft combining buffer requirements. Chase Combining on the other hand is easier to implement and requires lower memory. It offers better performance than Type I Simple ARQ, which has the worst performance, but with no additional memory and the least complexity.

**B. Throughput Performance**

The throughput performance of the Hybrid ARQ schemes is given in Figures 6-8. Full IR achieves the best throughput performance, especially for high MCS. Partial IR offers the second highest throughput with less memory requirements. Chase Combining has relatively poor throughput performance. However, as will be shown in the next section, this scheme will benefit more from the frequency and constellation diversity enhancements.

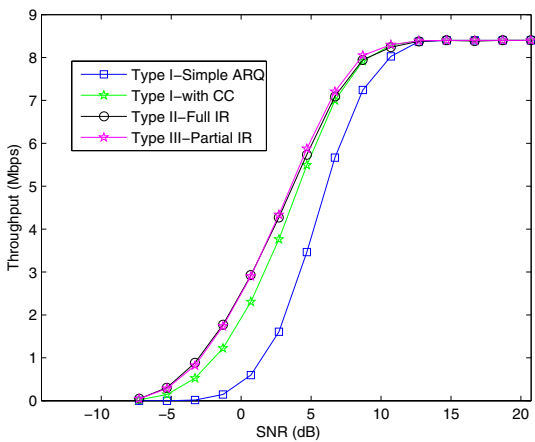


Figure 6: Throughput performance comparison for MCS1

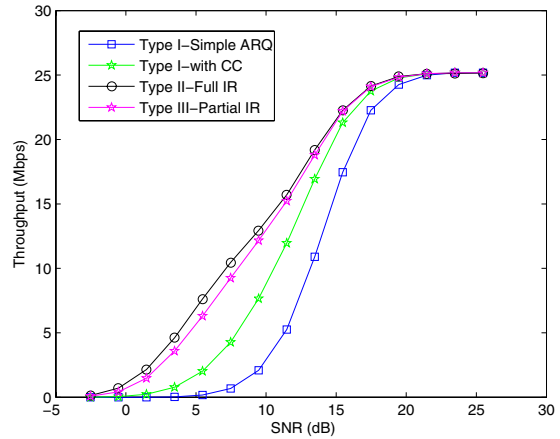


Figure 7: Throughput performance comparison for MCS4

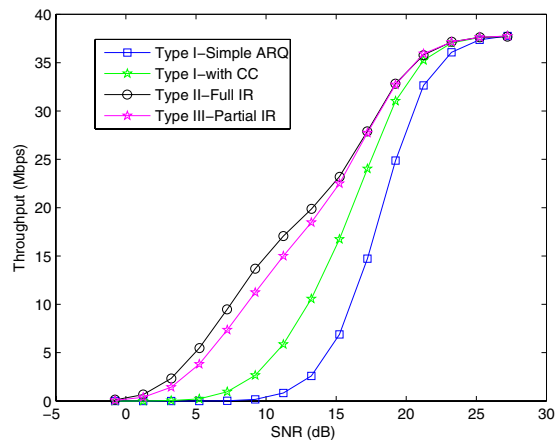


Figure 8: Throughput performance comparison for MCS6

**C. Performance for Enhanced Hybrid ARQ Schemes**

Firstly, the performance of enhanced Hybrid ARQ schemes for Chase Combining is investigated. As can be observed from Figure 9, the retransmission technique based on the combination of both subcarrier rearrangement and constellation rearrangement outperforms the conventional Chase Combining by approximately 5dB at PER of 1%. The scheme that utilizes subcarrier rearrangement performs slightly better than the scheme that utilizes constellation rearrangement and both schemes outperform the conventional Chase Combining by approximately 2-3 dB. From Figure 10, it can be seen that all schemes obtain highest throughput gains in poor channel SNR and the performance gain diminishes when the channel SNR improves.

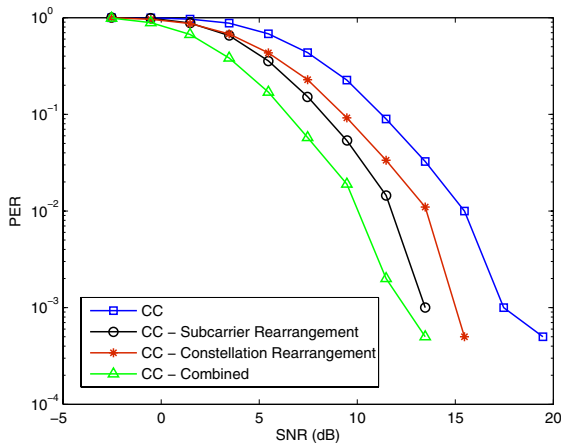


Figure 9: PER Performance for different retransmission techniques for Chase Combining. (MCS4)

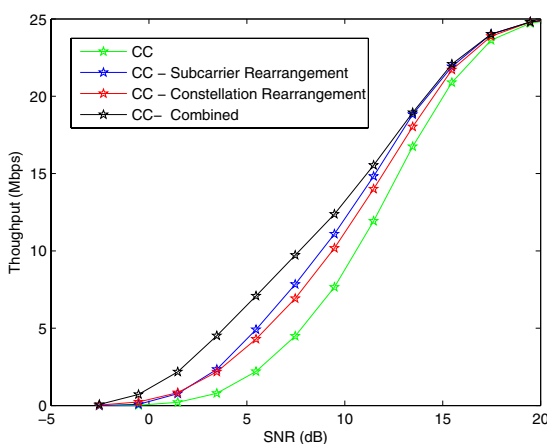


Figure 10: Throughput Performance for different retransmission techniques for Chase Combining. (MCS4)

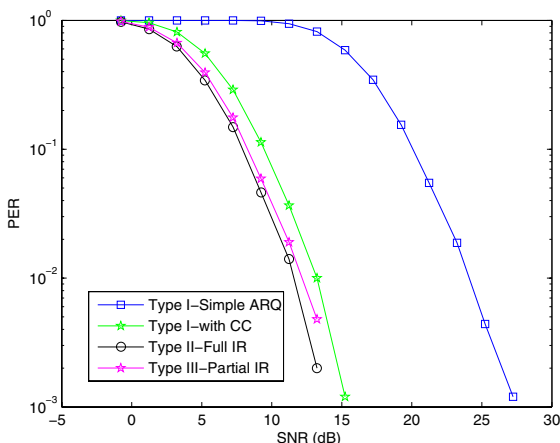


Figure 11: PER Performance comparison for MCS6 for enhanced Hybrid ARQ schemes

Figure 11 shows the PER performance of all enhanced Hybrid ARQ schemes. It can be seen that the performance gap between Full IR, Partial and Chase Combining has been reduced to less than 2dB even for the highest MCS.

## V. CONCLUSIONS

In this paper, the performance of different Hybrid ARQ techniques has been evaluated for an LTE OFDMA system. Simulation results have shown that Full IR offers the best throughput performance for high modulation schemes but at the cost of higher memory requirement. If the cost of the system in term of memory requirement is considered, Chase Combining is favoured instead as it provides comparable performance at lower cost especially for lower modulation schemes. Partial IR provides a good trade off between these two techniques.

Retransmission techniques which adopt frequency diversity and constellation diversity provide an enhancement to existing Hybrid ARQ schemes and offer better throughput performance for various modulations and coding rates. The subcarrier rearrangement technique is unique to an OFDMA system and when this technique is coupled with constellation rearrangement, it is able to give a significant improvement for existing Hybrid ARQ schemes, especially for the case of Chase Combining.

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