A Review of Hybrid ARQ in 4G LTE

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ABSTRACT

Long Term Evaluation (LTE) technology is the most efficient mobile broadband technology for providing an excellent user experience. The 3rd Generation Partnership Project (3GPP), Release'8 LTE provides the next step of 3G technology. LTE offers cogent improvements over previous technologies like GSM/UMTS/HSPA. Lower latency, higher downlink & uplink speeds, and simpler network architecture are among, other new features that are provided. This paper presents a survey on hybrid ARQ (HARQ) types and mechanisms which is the core feature that provides robustness in LTE and Advance LTE networks.

Keyword: - *ARQ, HARQ, Chase Combing, Incremental Redundancy, LTE.*

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1. INTRODUCTION

4G is the upcoming technology of cellular wireless systems. Long term evolution is the latest advancement of the 3GPP standards. The LTE supports packet switched network alone unlike the hybrid of circuit and packet switched network of 3G. High data rates provided by LTE will enable new services and applications such as video conferencing, VoIP, high-speed cellular modem, or even a streaming multimedia.

As part of IMT Advanced, LTE is defined to meet the following requirements set by the ITU (International Telecommunication Union) [4]:

- A flexible degree of common functionalities to provide wide range of services and application in cost efficient way.
- High performance mobile devices with worldwide roaming capabilities.
- Backward service compatible with IMT and other networks also internetworking with other radio access systems.
- Peak data rate UL: 500 Mbps, DL: 1 Gbps.
- Bandwidth transmission should be wider than approximately 40 MHz in UL and 70 MHz in DL.
- UL: 15 bps/Hz, DL: 30 bps/Hz of Peak spectrum efficiency.
- Flexible Support of spectrum aggregation and scalable bandwidth.

2. LTE PROTOCOL STACK

System Architecture used here is called E-UTRAN (Evolved UMTS terrestrial radio access network) with the necessary control and user plane protocols. Figure 1 gives an insight of these protocol stacks. In the user plane they use protocols such as Packet Data Convergence Protocol, Radio Link Control, Medium Access Control, and Physical Layer protocols to transmit the data packets. The control plane stack also includes Radio Resource Control protocols and it sends only the control information necessary to transmit the data.

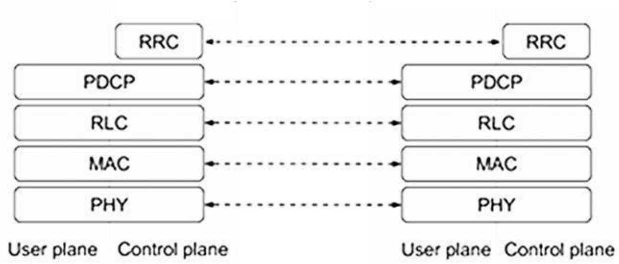

Figure 1: *LTE protocol stack in both User Equipment and evolved NodeB.*

In this paper, MAC protocol stack is considered, which provides various functionalities like hybrid-ARQ retransmissions, multiplexing and de-multiplexing of logical channels, scheduling uplink and downlink, power control, and random access mechanism. eNodeB provides scheduling functionality for both uplink and downlink. The hybrid-ARQ part is present in both transmitting and receiving ends of the MAC protocol. The MAC provides services to the RLC in the form of logical channels and sends PDUs to the physical channels.

3. ERROR MANAGEMENT

Interference and Noise leads to error in a wireless communication medium. These are bad enough during voice calls, but are even more deleterious to important information such as e-mails and web pages. There are various ways to overcome these problems [11].

A. Forward Error Correction:

Here, transmitted packet is expressed using a *code word* which is comparatively larger than the original packet. Extra bits added provide additional, redundant information that allow receiver to reacquire the original data sequence. Ratio of, number of data bits over the number of transmitted bits gives the coding rate. FEC or channel coding algorithms operate with a fixed coding rate. This coding rate can be acclimatized in wireless transmitter in two-ways, as shown in Figure 2. In First phase, the data bits are moved to a fixed rate coder. Here *turbo coding* algorithm is used with fixed $^1/_3$ coding rate. Second phase, is called as *rate matching*, where some of the coded bits are chosen for transmission, while the others are deserted during *puncturing*. The receiver has an archetype of the puncturing algorithm, so it can add dummy bits at the points where data was discarded. It sends the result to turbo decoder for error correction [1] [2]. Major disadvantage in FEC systems is that, the probability of decoding error is usually greater than the probability of an undetected error, so such systems are not reliable.

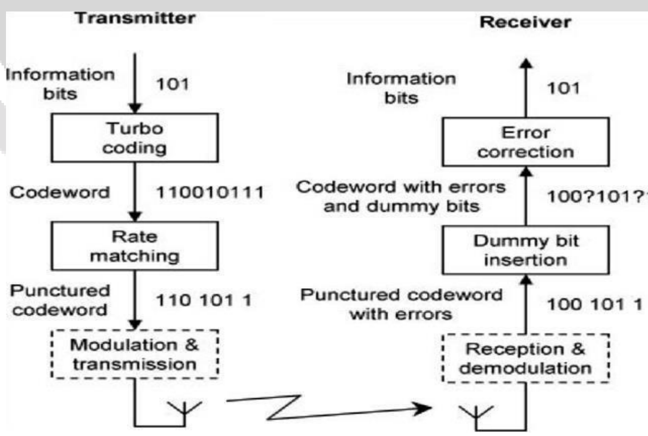

Figure 2: *Block diagram of a transmitter and receiver using FEC.*

B. Automatic Repeat request:

Error management in ARQ is as shown in Figure 3. Here, sender considers a block of data bits, computes and adds some extra bits that are known as a *cyclic redundancy check* (CRC) [3]. It affixes these two sets of data and transmits in the normal way.

The receiver detaches the two fields and uses data bits to cast up the expected CRC bits. If two values of CRC bits (expected and observed) are equal, then it implies that the information has been received correctly and sends ACK back to the sender. If the CRC bits are different, it means that an error has occurred and sends a NACK to request a retransmission [2].

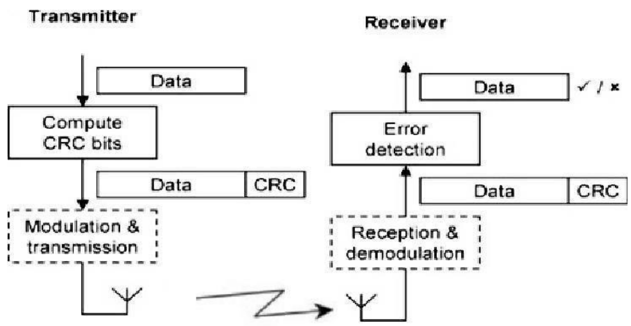

Figure 3: *Block diagram of a transmitter and receiver using ARQ.*

C. Hybrid ARQ:

HARQ is a technique which combine the important features of both FEC and ARQ error control, it is as shown in figure 4. In ARQ, extra bits are added to data using an error detecting CRC. Receiver detecting an erroneous data will request for a new message from the transmitter. In HARQ, the actual data is encrypted with a FEC code, and parity bits are sent upon request or immediately sent along with the message when erroneous data is detected. The FEC code is used to correct a known sub-part of all errors that may occur, while the ARQ method is chosen to correct errors that are uncorrectable. As a conclusion, HARQ performs better than normal ARQ in plummeted signal conditions [5].

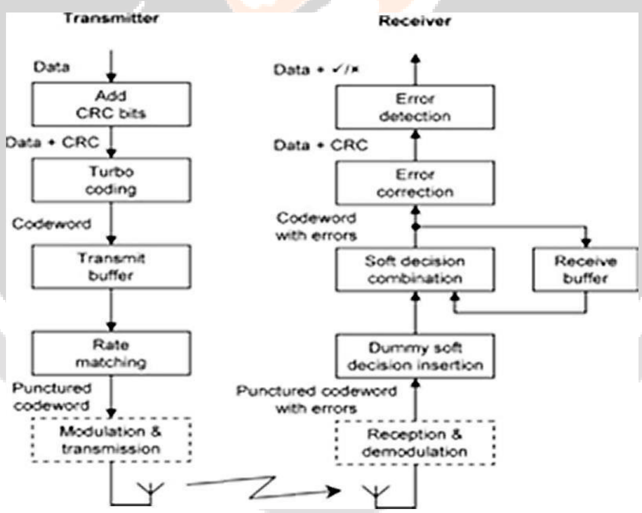

Figure 4: *Block diagram of a transmitter and receiver using HybridARQ.*

4. HARQ OPERATIONS AND TYPES

A. HARQ Schemes:

HARQ protocols can be classified as Synchronous or Asynchronous operations based on time domain flexibility, as well as Adaptive or Non Adaptive operations based on frequency domain flexibility (Surya Patar Munda, www.3gnets.in, p. 6).

1. *Synchronous or Asynchronous HARQ:*
   In Synchronous HARQ, retransmission processes occur at certain interval of time. So this operation does not require HARQ process number for packets retransmission and can operate with minimum signaling overhead.

   In asynchronous HARQ, retransmission processes can occur at any time, i.e. no timing constraints and may occur any time after decoding of ACK/NACK signaling. Therefore, explicit signaling like HARQ process number is required to transmit each retransmission packets, and provides more flexibility in scheduling. But due to explicit signaling, overhead in signaling increases.

2. *Adaptive or Non-Adaptive:*
   In adaptive HARQ, transmission parameters like code rate, number of resource allocation, and modulation order may change during retransmissions. We obtain more flexibility in scheduling by adding these attributes adaptively with varying channel condition. Thus, scheduling gain can be achieved easily in here. However, there is more single control overhead than non-adaptive HARQ since transmission parameters will be informed to receiver at every retransmissions.

   In non-adaptive HARQ, retransmission packet format is not changed or know to both communicating parties. Hence, no further signal control overhead is required but, difficult to achieve scheduling gain because of its fixed characteristics in packet formats.

B. HARQ Mechanisms:

1. HARQ Type1: It is the simplest version, if channel quality is good, all transmission errors should be rectified and receiver should be able to decode the data block correctly. If the channel quality is bad, not all transmission errors can be debugged, the data block will be discarded and receiver request for a retransmission. This type suffers from delay and capacity loss when channel quality is good [7].
2. HARQ Type2: The initial transmission contains enough data, FEC and ED (Error Detecting) bits to decrypt the data block correctly. Sender will prepare and transmit the next block of data as soon as the first transmission is received error-free. Suppose second transmission received results in erroneous data then sender resends the data block which will contain different set of data, FEC and ED bits. By combining both first and second transmissions information, error correction can be carried out. This type has no delay and capacity loss, because the code rate is decreased iteratively on successive retransmissions [7] [10].

4. SOFT COMBINING

In simple HARQ process, erroneous packets are discarded even though it may contain some useful information which are not tampered and are requested by receiver for retransmission. This problem is addressed by HARQ with soft combining (Dahlman et al., p. 120). In this technique, erroneously received packets are placed in buffer and are added with the retransmission packets to get a single, combined packet that is more reliable than its associates. At the receiver, decoding of error-correcting code takes on combined packet. If this decoding fails, a retransmission is requested.

In any Hybrid ARQ process, retransmission should contain same set of information bits as the initial transmission. However, it may contain different coded bits for each retransmission that represents same set of information bits. HARQ with soft combining is thus classified based on whether retransmitted bits are required to be same as initial transmission or not into **Incremental redundancy and Chase combining** [9].

A. Chase combining:

With Chase combining (CC) [6] as shown in figure 5, each retransmission contains same parity bits and information as the original transmission therefore, it is also called as repetition coding. At receiver all anterior packets are stored in buffer so that retransmitted packets are combined with earlier erroneous packets before they are fed to the decoder. The mechanism used to combine the packets at receiver side is called as Maximum Ratio Combining (MRC) technique. As this scheme do not transmit any new redundancy, CC increases only the accumulated received Eb/N0 (Energy bit on Spectral Noise density) and do not give any additional coding gain for each retransmission.

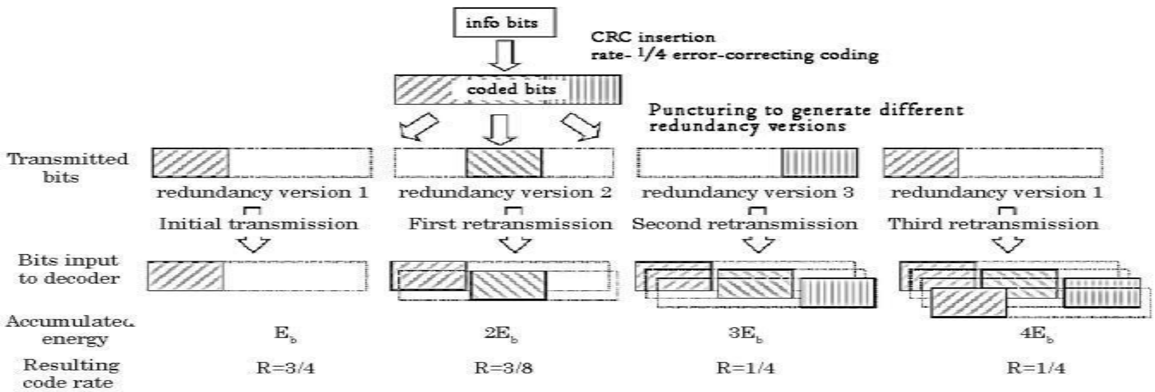

Figure 5: *Block diagram of Chase Combining.*

B. Incremental redundancy:

With Incremental Redundancy (IR) as shown in figure 6, each retransmission unlike in CC type contains multiple different set of code bits for same set of information bits. These sets contains different redundancy versions accomplished by different puncturing patterns and at different channel conditions these different sets are transmitted. As additional parity and redundant information bits are transmitted in each retransmission receiver combines this with previous transmission attempts of the same packet and resulting code rate thus is decreased. Furthermore, in general each retransmission may also contain different modulation scheme other than different coded bits. Hence, IR is seen to be the generalization of CC [6].

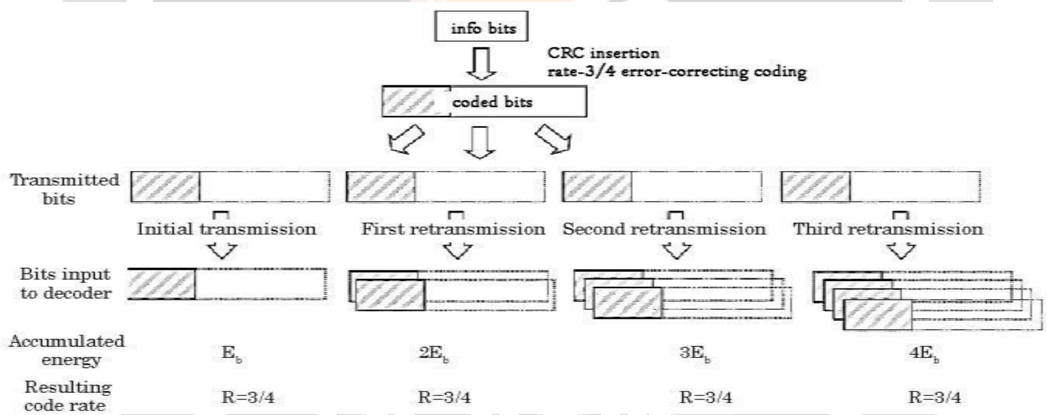

Figure 6: *Block diagram of Incremental Redundancy.*

5. HARQ PROCESS

HARQ uses a stop and wait protocol. Here sender stops and waits for ACK or NACK from receiver before transmitting next block or same block of data. Uplink transmission in LTE uses synchronous HARQ. This means that eNodeB knows exactly which RV (Redundant Version) and HARQ process the UE will transmit. The RV specifies which set of ED, FEC and Data bits are being sent. But scheduling flexibility in uplink is not so good compared to the downlink. Downlink transmission in LTE uses asynchronous HARQ. This means the eNodeB does not know what exactly is being transmitted, so the RV and HARQ process identifier must be sent along with the data.

There are exactly eight HARQ processes present in uplink, while the downlink can have up to eight. Uplink HARQ process is assigned to a specific sub frame. While with no fixed timing constraints, downlink HARQ processes can be transmitted in any order. In every eighth sub frame UE sends the same HARQ process [12].

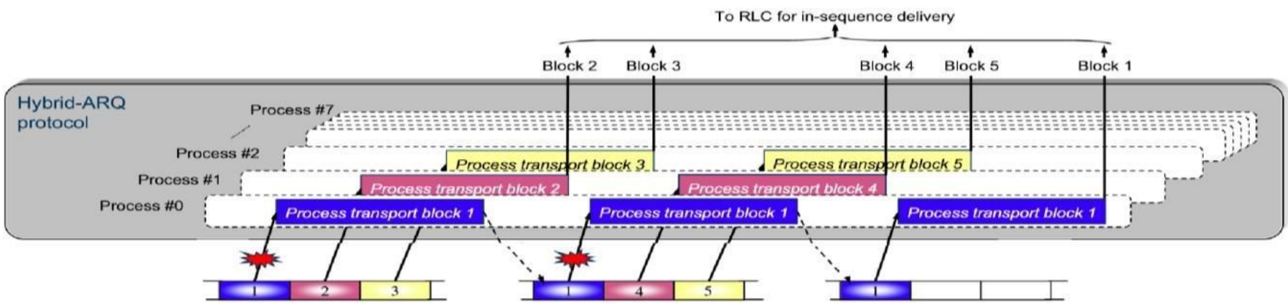

Figure 7: *Block diagram of HARQ Process.*

Using simultaneous multiple HARQ processes for each user, as shown in Figure 7, data from HARQ mechanism is delivered out-of-sequence. For example, before decoding block 1 which is erroneously received and requires retransmission, transport block 5 was successfully decoded. Therefore RLC protocol layer ensures in-sequence delivery of data. As said earlier, HARQ retransmissions are managed independently per component carrier, which results in out-ofsequence delivery which is similar to a component carrier.

CONCLUSIONS

In this paper, one of the main functionality of MAC in LTE protocol stack called the hybrid ARQ retransmission has been investigated. We have surveyed various schemes and mechanisms which are present in HARQ protocol. Overview of various packet combination techniques need to be enlightened in order to know the best transmission conditions for the protocol schemes. Especially when comparing the two schemes which are reviewed in this paper called Incremental Redundancy and Chase Combing, mobile speed plays a very important role. An extension to the presented work, implementation of CC-HARQ and IRHARQ in LTE-Sim is planned. Also various parameters governing this scheme is analyzed and presented in the future work.

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