Link Adaptation Improvements for Long Term Evolution by employing Newly designed LDPC codes: A Survey

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Abstract: This paper presents an overview of Link Adaptation Improvements for Long Term Evolution by employing LDPC codes. It has been shown from this study that encoding eliminates the effect of independent losses at different receivers, while achieving a reduction in the rate of packet loss, due to the redundancy introduced by the FEC encoder.

Keywords: LTE, FEC, LDPC codes

I. INTRODUCTION

Forward error correction (FEC) is an error control method used to improve or replace other reliability methods. Generally FEC provides the ability to overcome losses and corruptions at multiple receivers, without the retransmission of lost data. In multicast protocols the use of FEC has very strong motivations.

The channel coding scheme for forward error correction, on which the code rate adaptation is based, was the subject of extensive study during the standardization of LTE. The work therefore continues with a review of the key theoretical aspects of the types of channel coding studied for LTE: convolutional codes, turbo codes with iterative decoding, and a brief introduction of Low-Density Parity Check (LDPC) codes. The theory of channel coding has seen intense activity in recent decades, especially since the discovery of LDPC codes offering near-Shannon limit performance, and the development of iterative processing techniques in general. 3GPP was an early adopter of these advanced channel coding techniques, with the turbo code being standardized in the first version of the UMTS as early as 1999. Later releases of UMTS (in HSPA) added more advanced channel coding features with the introduction of link adaptation, including Hybrid Automatic Repeat request (HARQ), a combination of ARQ and channel coding which provides more robustness against fading; these schemes include incremental redundancy, whereby the code rate is progressively reduced by transmitting additional parity information with each retransmission. The encoding eliminates the effect of independent losses at different receivers, while achieving a reduction in the rate of packet loss, due to the redundancy introduced by the FEC encoder.

Particularly in MBMS, application layer FEC (AL-FEC) can address the problems, not addressed by physical layer FEC or by other error protection mechanisms in upper layers, to provide reliability and scalability against different packet loss rates. Raptor AL-FEC aims is, to provide protection against data losses and not against data corruptions. Consequently, 3GPP recommends the use of AL-FEC for MBMS, and more specifically, Raptor codes [1-3] have been selected because of their high performance in comparison with other AL-FEC schemes.

This work proposed to improve the system performance for LTE downlink and uplink by using differentiated link adaptation based on packet error occurrences of each user as feedback coupled with newly designed LDPC codes. The performance of the differentiated link adaptation was compared to the best performance that is
achievable using a fixed link adaptation margin. In this work the influence of several parameters on the link adaptation error characteristics, such as settings for SINR estimation, scheduling algorithms, and traffic patterns will be investigated.

It has been shown from the survey that there are error clusters, but that these are short and difficult to react to on time. A performance gain is only possible in the downlink for FTP traffic with a proportional fair in time and frequency (PPTF) scheduler which is the scenario with the largest variations with regards to both scheduling and traffic model.

In the LTE downlink, the User Equipments (UEs) measure the received Signal-to-Interference and Noise Ratio (SINR) and report to the base station. In the uplink, the UEs may transmit a known wideband channel-sounding reference signal from time to time, usually on a periodic basis.

A higher order modulation scheme such as 64QAM or 16QAM would allow more bits per modulation symbol allowing a higher data rate and bandwidth efficiency, while at the same time requiring better SINR at the receiver for error-free demodulation. Likewise a high code rate will reduce redundancy at the cost of lower error correction capability. Subsequently choosing the MCS that best matches the usual instantaneous channel conditions is essential. But it is almost impossible for the SINR estimations to correctly reflect the actual channel conditions at the time of transmission. There are numerous sources of errors. Initially, there can be errors when measuring the received channel quality by the UEs for the downlink and by the base stations for the uplink. Also, there are rounding errors when quantizing the SINR values. Lastly, there is predictable delay from the time the SINR measurement is taken until the actual transmission takes place, due to processing and transmission delays. Furthermore to this, the reporting period is usually much higher than once every transmission time interval (TTI) because of the overhead for measuring and reporting. Throughout this time the channel conditions may alter significantly and randomly due to fast fading and varying levels of interference making the SINR measurements outdated at the time they are being used. Therefore, the selected MCS can be too traditional or too ferocious for the usual channel conditions at the time of transmission resulting in waste of resources or too many errors, correspondingly. In either case the system throughput will fall under what is attainable with perfect channel information. It makes sense to trust that if the selected MCS for a certain UE is too conventional for the instantaneous channel conditions, the particular UE may show certain short term tendencies in its presentation such as periods of remarkably low error rates or unexpected error bursts. If such short term tendencies last long enough, it may be likely to adjust the SINR value therefore to enhance the throughput.

II. RELATED WORK

A preliminary study on the application of AL-FEC for LTE multicast streaming services provide in [5]. Apart from this initial investigation study that consists the basis for the present full study, other related works presented cover research on AL-FEC for MBMS download delivery method over the LTE mobile networks or for MBMS streaming services over earlier to LTE systems.

In [6], a file recovery scheme for the LTE MBMS download delivery method was presented. In this method authors proposed the limited sending of redundant packets, using AL-FEC, that is, Raptor codes, instead of using the retransmission-based error recovery scheme. Sending of exclusive redundant packets using AL-FEC process continues until all receivers recover the Error correction for multicast streaming over LTE network file.

An evaluation of MBMS download services presented in [7] in universal mobile telecommunications system (UMTS) mobile networks. In this work the optimal dimensioning of Raptor codes based on a probabilistic method was investigated, that models the multicast user distribution.

It is worth noting that both Refs [6] and [7] have been performed from the telecommunication cost perspective. In [8], authors investigated the benefits of FEC on user experience and radio resource consumption through system level simulator, reflects the trade-off between AL-FEC and physical layer FEC over MBMS download delivery services in UMTS system.

The authors in [9] proposed the usage of FEC protection in combination with point-to-point (PTP) and the PTM file repair schemes for the MBMS download delivery method over UMTS systems.

A novel scheme providing reliability for single-cell evolved MBMS download delivery method was discussed in [10], considering the application of Raptor FEC at application layer and hybrid automatic repeat request at link layer. The main objective of this analysis is to minimize the number of
retransmissions in hybrid automatic repeat request considering the properties of Raptor codes and satisfy the QoS requirement as well. The study in [11] included among others an investigation of Raptor codes as a method to provide application layer QoS in the MBMS streaming framework over third generation networks by adjusting the AL-FEC parameters to maximize the amount of satisfied users who participate in video stream reception. The work in [12] investigated different system design options for MBMS video streaming over mobile networks such as enhanced general packet radio service and UMTS. One of their main goals was to evaluate and to clarify the impact of AL-FEC application on the overall system performance. The authors in [13] introduced a method, where partly erased data can be utilized in the decoding process to enhance the performance of Raptor codes in multicast streaming applications over a predecessor of LTE mobile networks. In [14], the authors provided a power control analysis for the operations count at code rate 1/2. The transport blocks larger than one millisecond, the channel is almost static within a subframe particularly for a larger number of code blocks. However, with this allows for pipelining of code block decoding reducing decoding complexity. A drawback of frequency-first mapping is that time-diversity is not fully captured as code block transmissions can be localized within a subframe particularly for a larger number of code blocks. However, with short subframe duration of one millisecond, the channel is almost static within a subframe at low to medium speeds of interest. At higher UE speeds, we should expect some degradation of performance due to a lack of time-diversity with time-first mapping. However, the LTE system is to optimize performance at low to medium speeds. Therefore, frequency-first mapping offers a good tradeoff of reduced complexity with some performance loss at high UE speeds.

The early stopping strategies can be used to further reduce the operational complexity and also the power consumption of turbo decoders. A single acknowledgment (ACK) or negative acknowledgment (NACK) per transport block is provided for hybrid ARQ retransmissions. Therefore, in transmissions with multiple code blocks, the receivers will NACK the transmission as long as one of the code blocks is in error after the maximum number of iterations. If we can introduce a CRC per code block, the decoder can stop decoding after one

streaming delivery over HSDPA systems, including the impacts of the AL-FEC application to the transmission. Finally, in [15] an adaptive scheme over 3GPP video broadcast streaming services was presented. The authors proposed a joint optimization framework of video coding, AL-FEC, and physical layer rate selection to enhance the end user experience. It is obvious that the related works do not provide an in-depth analysis of the AL-FEC performance over multicast streaming services, but examine the application of AL-FEC in a limited context of the multicast transmission and consider a restricted range of aspects of mobile networks prior to LTE. Therefore, our persuasion is to fill the gap of the evaluation of AL-FEC over LTE multicast streaming services, providing a thorough performance analysis of the application of AL-FEC over MBMS streaming. The main focus in this work is to investigate the LDPC AL-FEC for LTE applications.

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The code block consists of set of data bits that are encoded together. The maximum code block size in LTE is limited to $Z = 6144$ bits. A transport block is a data block delivered by the MAC layer to the physical layer for transmission in a single subframe of one millisecond.

In multi-codeword MIMO transmission in LTE, up to a maximum of two transport blocks also referred to as codewords in MIMO context can be transmitted in a single subframe. The transport blocks larger than the maximum code block size need to be segmented into multiple code blocks. The maximum code block size is limited for reasons of turbo code internal interleaver size as well as decoding complexity.

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III. METHODOLOGY

The draw of LDPC codes is clear: performance almost up to the Shannon limit, with claims of up to eight times less complexity than turbo codes. LDPC codes had also recently been standardized as an option in IEEE 802.16-2005. The complexity angle is all-important in LTE. However, LDPC proposals put forward for LTE claimed less complexity benefits. In fact, it turns out that the complexity benefit is code-rate dependent, with roughly a factor-of-two reduction in the operations count at code rate 1/2. This comparison assumes that the LDPC code is decoded with the Layered Belief Propagation (LBP) decoder while the turbo code is decoded with a log- MAP decoder.

On operations count alone, LDPC would be the choice for LTE. However, at least two factors curbed enthusiasm for LDPC. LDPC decoders have less implementation complexity for memory and routing, which makes simple operation counts representative. A codeblock consists of a set of data bits that are encoded together. The maximum code block size in LTE is limited to $Z = 6144$ bits. A transport block is a data block delivered by the MAC layer to the physical layer for transmission in a single subframe of one millisecond.

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code block is in error, thus saving power that could have been wasted in decoding the rest of the code blocks. From a power saving perspective, a small 8-bit code blocks CRC, which gives a miss detection rate of 0.4%, will be sufficient. Note that even if miss detection occurs, the only negative impact is the receiver will proceed to decode the rest of the code blocks and waste the decoding power with 0.4% of probability. Here, we assume that transport block CRC of length 24 bits is available to catch miss detections from the code block CRC to ensure transport block integrity. However, when code block CRC is used for the early stopping of the iterative decoding, a high misdetection is undesirable. This is because if code block CRC declares a code block correct due to misdetection, the transport block CRC will fail, resulting in a transport block error event. If the decoder had continued until the maximum number of iterations, the code block might have been successfully decoded. Therefore, when used for early stopping, the CRC should be of sufficient length to limit the erroneous early stopping.

In multi-codeword MIMO transmission in LTE, two MIMO code words are transmitted, each of which can carry multiple code blocks. For each MIMO codeword or transport block, a CRC is computed based on all information bits in the transport block, that is based on all the Code blocks in the MIMO codeword. In the case when there is no code block CRC, the receiver has to wait until all the code blocks in the first codeword are decoded before it can cancel this codeword and proceed to decoding of code blocks in the second codeword.

In this section three CRC attachment methods for multiple code blocks shown in Figure 1, transport block (TB) is first segmented into C code block segments. In CRC attachment scheme A, a CRC is computed for and attached to each segment independently. In scheme B, CRC computation for the first \((C - 1)\) code block segments is different from that for the last one. For the first \((C - 1)\) segments, CRC is computed for and attached to each segment independently.

In attachment scheme B and scheme C, a TB-level CRC computed based on all information bits of that transport block is attached to the TB. The entire transport block along with the TB-level CRC is then segmented into multiple code block segments. A CRC is then computed for and attached to each segment independently.

In attachment scheme B and scheme C, a TB-level CRC attachment of \(L = 24\) bits is retained. The probability of misdetection of an erroneous TB is roughly

\[ P_m = 2^{-24} = 6 \times 10^{-8} \]
IV. CONCLUSION

This paper presented an overview of FEC role particularly LDPC codes in LTE-A. It has been shown from the paper that the maximum code block size is limited for reasons of turbo code internal interleaver size as well as decoding complexity. It has been concluded from the study that the code blocks are mapped to time-frequency resources in a frequency-first fashion for pipelining of code block decoding reducing.

V. REFERENCES