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Title: On Early Stopping Rules for Turbo Decoding
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1. Introduction

Early stopping strategies have long been proposed to reduce operational complexity of turbo decoders [1, 2]. It is further shown in [3] that, in the high data rate LTE system, early stopping on the finer level of per code block segment can lead to 25% or more decoder hardware reduction with no or negligible performance losses. In addition, there is still further 20% or more average run-time complexity/power saving.

The proposal of introducing additional CRC attachments to multiple code block segments has been discussed from a diverse range of angles in 3GPP [4—10]. In particular, the question of whether alternative early stopping rules [11] suffice for the LTE applications was raised.

In the following, a high-level summary of the excellent NASA Jet Propulsion Lab (JPL) survey paper on alternative stopping rules [11] is presented. The implications to the LTE system are then analyzed. In conclusion, we agree with the final choice made at JPL: the CRC-based stopping rule is the simplest and reliable [12].

2. Analysis

The 2000 JPL paper [11] provides a comprehensive survey of early stopping methods for turbo decoding. Numerical results are supplied for methods based on CRC, hard-decision metrics and soft-decision metrics. There are two types of error events associated with early stopping rules:

- Miss prob (erroneous segment declared as correct) [11, Figure 11—13]

When an erroneous segment is declared as correct, the RX would continue to decode the rest of the segments in the same TB, which results in certain complexity waste. In this area, the alternative stopping rules are comparable to better (depending on parameters) than 16-bit CRC. However, this miss prob is less of a problem for LTE for two reasons. First, since the miss prob = 5×10^{-5} is around/below the error floors of the LTE turbo codes, it does not necessary add to the segment error rates. Secondly, the error performance of the TB is not affected since it is still protected by a 24-bit CRC.

The JPL team further commented [11, page 11] the CRC stopping rule could terminate the decoding prematurely when it is applied to outputs of the first few decoding iterations. This scientific observation can be easily remedied by an engineering solution. From the numerical results supplied in [3], it can be found the prob of correct decoding a segment of $K=6144$ and $r=0.8$ with less than 3 iterations is zero. Hence, the CRC stopping rule should not be applied for the first two iterations for reduce both complexity and chances of premature termination.

- False NACK prob (correct segment declared as erroneous) [11, page 15—16]

The JPL team has rated CRC best with zero false NACK prob. The false NACK prob could be more troublesome for our LTE application. If one of the segments is declared incorrect, it is desirable to abort the rest of the segments. But if such declaration is unreliable, a dilemma arises.

- If one continues to decode all segments and check the TB-level CRC, it is then possible to come back to re-decode segments that were declared erroneous. But one then loses all complexity savings.
- If one simply aborts the decoding of the rest of the TB, the retransmission rates are then unnecessarily increased. (Note the JPL plots are all for BLER<3%. The focus for LTE applications is mostly for BLER>3%.)

In all, adopting a stopping rule involves a five dimensional tradeoff: bandwidth overhead, checking complexity, turbo decoder complexity saving, miss prob and false NACK prob.

- For bandwidth overheads, alternative stopping rules is advantageous than the CRC based approach by 1%. For checking complexity, alternative stopping rules are more complicated to significantly more so [11, Section 3] than CRC checking. For instance, hard-decision rules require more memory and soft-decision rules require more computation and possibly SNR dependent thresholds. These concerns are, in fact, minor when compare to the tradeoff of the next three dimensions.
- The real problem seems to be the tradeoff amongst turbo decoding complexity saving, miss prob and false NACK prob. It can be found [11, Figures 3—6] none of the alternative stopping rules gives as large saving as CRC checking. Worse yet, the more reliable the alternative solutions are made (in terms of miss and false NACK prob), the less saving they give. As discuss in the above, ensuring the reliability of the alternatives result in loss of turbo decoding complexity savings. At the extreme, all turbo decoding complexity saving is lost.

Admittedly, this is a complicated problem. However, as the pioneer in advanced communication technologies with extensive research capacity, JPL has shined the way once again. The early stopping mechanism for their most recent capacity-approaching optical communication system is based on CRC checking [12, Section VII].

3. Conclusion

It is proposed to introduce additional CRC attachments to multiple code block segments to enable reliable application of early stopping rules.

References

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