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1 Scope

This document aims to describe the most common techniques for error control at the Layer 2 based on Automatic Repeat reQuest (ARQ) techniques used in combination with Forward Error Correction (FEC) coding. ARQ has been suggested for the NRT services of UMTS, see [1], and in the form of Link Adaptation also for LCD services.

2 Introduction

2.1 Error control in the Link Layer

By means of the data link protocol the Layer 2 (Link Layer) of the OSI model provides

- channel integrity,
- error control,
- flow control, and
- link sequencing

to its lower layer, namely Layer 1 (Physical Layer) [2]. The data link protocol provides managing and controlling of the data exchange done at the Layer 1 level.

Error control is an essential feature of the data link protocol. The most common techniques for error control are based on the following two functions [3]:

- Error detection: the receiver is able to detect errors in the incoming sequence. A block-code, for example a Cyclic Redundancy Check (CRC), is normally used for this purpose.
- Automatic Repeat reQuest (ARQ): when an error is detected in the incoming sequence, the receiver requests to the source that additional symbols are to be transmitted.

There are different approaches to deal with the retransmission of non error-free received incoming sequences. In the next section, the common ARQ retransmission schemes are listed.

2.2 ARQ retransmission schemes

Combining error detection and ARQ into the data link protocol for error control purposes, results in the conversion of an unreliable Layer 1 data link into a reliable one. A very basic ARQ scheme includes only error detecting and retransmission capabilities. If a packet is found to have errors after decoding, this packet is discarded and a retransmission is requested to the source. The source then retransmits an exact copy of that packet. This process may be repeated indefinitely, but normally an upper bound in the number of retransmissions is set. If errors still persist after the maximum number of allowed retransmissions is reached, the layers above Layer 2 will have to decide how the situation is to be handled.

For the retransmission procedures using ARQ, the three most popular schemes are

- Stop-and-wait ARQ,
- Go-back-N continuous ARQ, and
- Selective-repeat continuous ARQ.

From those schemes, the selective-repeat continuous ARQ is the most effective, but also the most complex to implement. These procedures are sufficiently well known and will not be explained in detail here. For further information, refer to [3].

In the following, this paper will concentrate on coding schemes at Layer 1 level that are used in conjunction with ARQ retransmission schemes. It is assumed that an outer block-code for detecting residual decoding errors is available. The retransmission unit is considered to be a RLC-PDU in order to align the literature terminology with the ETSI one.

3 Coding strategies in combination with ARQ

As stated in the last section, in a very basic ARQ scheme, a RLC-PDU including only error detection and retransmission capabilities is sent. If errors are detected, the RLC-PDU is discarded. A request for that same RLC-PDU is then made to the transmitter through a return channel. This simple scheme can be further improved by using Multiple Copy Decoding (MCD) techniques, that allow the decoder to combine the received copies of a RLC-PDU prior to decoding, see [4].

Mobile radio environements are characterised by non stationary channels that are responsible for varying bit error rates. In order to reduce the damaging effect of these bit error rates in the data transfer, Forward Error Correcting (FEC) coding schemes have been proposed [5] and are widely used. In FEC schemes, part of the contents of the transmitted RLC-PDUs is redundant. Thanks to this redundancy, errors caused by the channel can be to an extend corrected at the receiver. A compromise between the ratio of user and redundant bits, and the correcting capabilities of the code has to be found, since high reliability of the user data at any time would result in an unacceptable overhead. Thus, not all errors will be always corrected by the FEC code and residual errors remain after its decoding.

FEC coding can be used to improve the efficiency of the ARQ retransmission schemes. The methods resulting of the combination of FEC and ARQ are called hybrid ARQ methods. Since the environements where UMTS is expected to be deployed are hostile, i.e. low Eb/No and high bit error rates have to be taken into account, on the following, only hybrid ARQ schemes will be further discussed. FEC using punctured and repetition convolutional coding has proven to be particularly efficient, see [6] and [7], and makes possible Adaptive Forward Error Correction (AFEC) mechanisms that are explained in the following sections.

Section 3.1 deals with type I hybrid ARQ, while sections 3.2 and 3.3 treat type II hybrid ARQ and type III hybrid ARQ, respectively.

3.1 Type I hybrid ARQ

The Type I hybrid ARQ is an Adaptive Coding Rate (ACR) method [8]. The main idea behind ACR ARQ methods is to vary the coding rate for error correction according to system constraints such as the signal-to-noise ratio in the given environement.

With ACR ARQ, whenever a data RLC-PDU is received with an uncorrectable error pattern, that RLC-PDU is discarded and a request for retransmission is sent back through a return channel to the transmitter. The transmitter then sends the original RLC-PDU again [8]. No MCD takes place at the receiver.

In the type I hybrid ARQ method, each RLC-PDU is self contained and has a constant rate of Forward Error Correction (FEC) coding. If an error in the incoming RLC-PDU is detected, then an identical copy of that which was originally transmitted is sent again. The RLC-PDU containing errors is discarded: there is no combining of earlier and later versions of the RLC-PDU, each is stand alone. The RLC-PDU can contain the RLC-PDU sequence number and consequently the receiver can identify which RLC-PDU it has received and, through sequence errors, which RLC-PDUs should be retransmitted. The chosen coding rate may depend on the environement. Coding rates of 1/3 to 2/3 are typical. For simulation results, see [9].

The type I hybrid ARQ has potentially lower signalling overheads than type II hybrid ARQ and type III hybrid ARQ. The physical layer, which only need FEC decoding (and possibly CRC checking also), is also simpler. However, because of the fixed FEC/CRC overhead throughput may be lower than for type II hybrid ARQ, see section 3.2 .

Since wireless channels are hostile, some more refined algorithms have been developed to adapt the code rate for the first transmission and the subsequent retransmission to the channel conditions, see [10],[11]. Those will not be treated in detail here.

3.2 Type II hybrid ARQ

The type II hybrid ARQ belongs to the Adaptive Incremental Redundancy (AIR) ARQ schemes. In AIR ARQ schemes, a RLC-PDU that needs to be retransmitted is not discarded, but is combined with some incremental redundancy bits provided by the transmitter for subsequent decoding.

A type II hybrid ARQ proposed in [12] uses a rate 1/2 invertible code and alternatively sends coded blocks containing information and parity sequences, which are either detected to be correct or combined for FEC decoding.

Other more elaborated methods try to avoid sending alternate code and parity transmission by just sending parity blocks to build up a code which is finally powerful enough to decode the message. Thus, none of the already transmitted code bits are thrown away but are used to improve FEC decoding. To this avail, in [13], rate compatible punctured convolutional codes (RCPC Codes) with Viterbi decoding for successive parity transmission is treated, and in [14] rate compatible punctured turbo-codes (RCPTC) are introduced. The principle of the proposed AIR ARQ scheme is not to repeat information or parity bits if the transmission is unsuccessful as in previous type II hybrid ARQ schemes, but to transmit additional code bits of a lower rate code until the code is powerful enough to enable decoding. The most appealing feature of RCPTCs is the possibility to adaptively change the code rate without having to transmit the whole encoded block. Rather, the transmission of an additional piece of information which makes up for the difference in code rate is necessary. This feature can be exploited when RCPTCs are combined with ARQ type II protocols. Clearly, RCPTCs facilitate the migration from fixed Error Correction Coding (ECC) to flexible ECC strategies which are adaptable to time varying requirements in packet data anticipated in UTRA. Furthermore, Turbo-Codes are introduced in the standardization documents of the UTRA layer 1 [15,16].

There are a number of other methods that are characterised as type II ARQ and these can be quite different in detail, see [17]. In principle, however, the first time a RLC-PDU is sent it has a high code rate (typically 7/8, 8/10 or even 1) and consequently few parity bits. If the CRC fails then additional information relating to the RLC-PDU can be transmitted. The second transmission predominantly contains additional parity bits that, when combined with the first version of the RLC-PDU, lower the FEC code rate to, in the region of, 1/3 or 1/2. Some schemes support further transmissions which further increase the code rate. If, after all versions of the RLC-PDU have been transmitted and combined, the CRC still fails, then the first version can be retransmitted and replaces that originally sent in the combination. Alternatively, combining between the first transmission and the successive retransmissions of a version can be performed prior to decoding. This procedure could be continued indefinitely but in practice an upper limit must be placed on the number of retransmissions that are made.

Type II hybrid ARQ requires that when RLC-PDU are transferred their identities are signaled externally to the RLC-PDU. This is because several versions of the RLC-PDU may need to be combined in the physical layer before it can be decoded and any identifier contained within the RLC-PDU detected. In addition, the physical layer is more complex because it must be capable of temporarily storing RLC-PDU versions prior to combining.

The advantages of type II hybrid ARQ, relative to type I hybrid ARQ, is that if the interference distribution across the cell is such that a significant fraction of RLC-PDUs will be received correctly even with the low initial code rate then a higher throughput can be achieved. Further, since repeat transmissions can be soft combined there is an increase in the probability of correctly decoding the RLC-PDU.

3.3 Type III hybrid ARQ

Like type II hybrid ARQ, type III hybrid ARQ also belongs to the AIR ARQ schemes. As explained in 3.2., this means that retransmissions concerning one RLC-PDU are not discarded but kept at the receiver for combination with additional information before decoding.

The main drawback of the methods proposed for type II hybrid ARQ is that additional incremental code bits sent for a RLC-PDU received with errors are in general not self decodable. In situations where the transmitted RLC-PDU can be severely damaged, for example, due to interference, it is desirable to have a scheme where any additional information sent is self decodable. In [18], a new class of punctured convolutional codes that are complementary, and thus called Complementary Punctured Convolutional (CPC) codes, is presented. CPC codes are self decodable, so that the decoder does not have to rely on previously received sequences for the same data RLC-PDU for decoding.

Type III hybrid ARQ can be seen as somewhat of a compromise between type I hybrid ARQ and type II hybrid ARQ. Different versions of a RLC-PDU are created, the first one with a coding level that would typically be used for type I hybrid ARQ. Different puncture bits are used in each version. If transmission of the first fails then the second version is sent. This may be correctly received in which case there is no more to do. If it is not then a new version can be formed removing both sets of puncture bits and this may or may not be correctly decoded. Transmission of further versions or repeat transmissions of the already transmitted versions may be made and combined.

Compared to type II hybrid ARQ, type III hybrid ARQ, may be more complex to implement, since the incoming RLC-PDUs and all the resulting combinations with previous transmissions may need to be decoded, whereas in type II hybrid ARQ, only the first received RLC-PDU and the successive combinations may need to be decoded [19].

Type III places similar requirements on the signalling protocol for external RLC-PDU identification and on the physical layer as type II hybrid ARQ. It does not, however, offer obvious throughput gains relative to type I hybrid ARQ save those that arise from the combining of consecutive transmissions offering a better decoding probability than repeat transmissions with type I hybrid ARQ, which may still be significant.

4 Conclusion

Different schemes of ARQ in combination with FEC have been described. Which of the proposed hybrid ARQ schemes or combination of them, best suits the specific requirements of UMTS has not been studied enough.

Simulations for UMTS services and environements have to be carried out. In [9] a comparison between ARQ hybrid type I and ARQ hybrid type II for the TDD mode of UMTS is presented.

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