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Title: Support of Hybrid ARQ Type II/III in the Physical Layer

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Introduction

The benefits from employing Hybrid Automatic Repeat Request (HARQ) Type II/III compared to HARQ Type I were realized by 3GPP TSG RAN WG1 and RAN WG2. It was decided to support the operation of HARQ Type II/III in further development of the RLC protocol by RAN WG2. Work on the physical layer aspects of HARQ Type II/III has started in RAN WG1.

This document discusses the operation of HARQ Type II/III from the viewpoint of the physical layer.

Overview on Hybrid ARQ schemes

See Ref. [1] for a detailed discussion of HARQ schemes from the point of view of the higher layers. Only a brief summary is given here.

The term "HARQ Type II/III" refers to automatic repeat request protocols with incremental redundancy between retransmissions. The basic assumption is that the bit error rate of the radio channel is strongly time-variant. This results in different forward error correction (FEC) requirements for PDUs (payload data units) which are sent at different times.

With HARQ Type I, FEC has to be dimensioned for a relatively bad channel for avoiding a high number of retransmission. In particular, the probability of correct decoding for individual retransmissions is the same as for initial transmission which might be very low.

The HARQ Type II/III protocol takes the time-varying nature of the radio propagation channel into account. It first transmits the PDUs with little or no redundancy. If this unprotected transmission fails (CRC check failure), a retransmission occurs. This retransmission is not a copy of the first transmission. Instead, additional redundancy is sent (i.e. data which extends the code block of the first transmission to a lower code rate). At the receiver, the data of the first and the second transmission are combined to a coded block with lower code rate and, therefore, higher coding gain. The concatenated block is processed by a channel decoder (e.g. Viterbi decoder or turbo decoder). If the CRC check still fails, either a further extension to the redundancy (i.e. a third encoded version of the PDU) can be transmitted, or one of the already received coded versions can be repeated and maximum ratio combined with the previous transmission. Only the options of 2 or 3 redundancy versions are considered for the UTRA implementation.

For HARQ Type II/III, the PDU number must be transmitted separately from the PDU data to allow combining of retransmissions of the PDU. This numbering information is send in a separate Transport Channel. This can either be transmitted in a separate physical channel (e.g. the FACH for TDD mode), or it is transmitted in the same physical channel as the data part, but with better Quality of Service.

Since the HARQ operation is managed by the retransmission protocol of the RLC located in the RNC, all ARQ-schemes are applicable both for TDD and also for FDD with soft handover. However, both for the HARQ Type I and Type II/III, which combine the advantages of forward error correction (FEC) and Automatic Repeat Request (ARQ), some support from the physical layer is needed:

While for HARQ Type I, the physical layer functions CRC generation, Channel Coding, Channel Decoding, and CRC check are required, for HARQ Type II/III in addition the functions Redundancy Selection, Buffering and Combining must be supported by layer 1.

Impacts of Hybrid ARQ Type II/III on the Physical Layer

Hybrid ARQ Type II/III at the transmitting side

On the transmitting side HARQ type II/III needs only marginal support from the physical layer:

- The same channel coders (Convolution Coding or Turbo Coding) as for HARQ Type I operation are used.
- No buffering in the physical layer is needed. For retransmission, the same RLC PDU is sent through the MAC. This PDU is then coded as for the first transmission, but a different redundancy (a set of bits) is selected in the subsequent "Redundancy Selection" by puncturing. This puncturing is different from the normal rate matching, since a predefined bit mask is used for puncturing.
- The physical layer does not need any information about the PDU numbering. Only the redundancy selection, which is done at RLC layer, has to be passed as a parameter together with the PDU to the physical layer.

Hybrid ARQ Type II/III at the receiving side

On the receiving side the physical layer has to provide the following functions for HARQ Type II/III:

- Buffering in the physical layer is needed. For retransmission a different set of redundancy information is used. All received versions of the PDU have to be combined before channel decoding is applied. For this reason, a buffer for erroneously detected PDUs has to be implemented in the physical layer.
- The physical layer needs some information about the PDUs it receives. Therefore the PDU numbering and the redundancy version for each PDU are transmitted separately from the data. The higher layers can signal this information to the physical layer.
- After combining, the same channel decoder (Convolution Decoding or Turbo Decoding) as for HARQ Type I operation is used.

Additional functionality for Hybrid ARQ type II/III in the physical layer

Redundancy Selection

Redundancy selection is required on the transmitting side. Two different coding rates, 1/2 and 1/3, are basically supported for HARQ Type II/III operation. The transmitted redundancy information is selected from this base rate by puncturing. For the UTRA system, it is intended to transmit blocks with the same size for each (re)transmission. This results in coding rates 1 for the first transmission and 1/2 for the second transmission. For the third transmission, alternatively new redundancy to reach coding rate 1/3 can be transmitted, or one of the previous transmissions is repeated, resulting in coding rate 1/2.

The added functionality in the physical layer is the generation of the selected redundancy by puncturing of the coded data. The following rates are proposed for the inclusion into the standard:

Coding Rate	First redundancy version	Second redundancy version	Third redundancy version
1/2	1	1/2	-
1/3	1	1/2	1/3

The redundancy level of a certain PDU is indicated to the physical layer by means of the higher layer (RLC).

Buffering and Combining

In the receiver, before channel decoding the combining of different versions, which are retrieved from a buffer, must be supported for HARQ type II/III. The term "combining" refers to a merge of all available different redundancy versions of one PDU to a single data block which is then given as an input to the channel decoder.

The combining of the first two or three versions in case of a rate 1/2 or 1/3 code, respectively, is done by simple concatenation. In this case combining just means a multiplexing of bits from the different redundancy versions to one bit stream with the correct order for the channel decoder.

If additional redundancy is required, a retransmission of already sent versions will be performed. If a certain redundancy version of one PDU is retransmitted, i.e. it is already contained in the buffer at the receiver but has to be transmitted again, maximum ratio combining of the newly received copy and of the buffered copy has to be performed.

Buffering in the physical layer for Hybrid ARQ Type II/III is necessary to combine retransmitted PDUs with the data from previous transmissions. This buffering is associated with the PDU numbers and the redundancy versions. The entries are deleted from the buffer upon successful decoding (CRC check) or after the expiry of a predefined time period. There is no explicit buffer control by higher layers.

The buffering has to work on soft decision values of the channel coded data (after despreading and de-multiplexing of TrCHs). The required quantisation accuracy is 4 bit to enable a sufficient accuracy.

The buffer size depends on the maximum data rate which has to be supported. For a low cost mobile, which supports a data rate of 64 kbits/s, a buffer size of about 32..64 kByte will be sufficient, if it is assumed that at maximum the data of one second transmission time has to be kept. For high-end mobiles with a possible data rate of up to 2 Mbit/s a buffer size of about 1 MByte should be provided. The exact values depend on the design of the RLC protocol and should be checked with RAN WG2. If the buffer in the physical layer is full, a status information should be signalled to the higher layers, indicating which PDUs could not be kept in memory.

The buffer is controlled by the physical layer. The physical layer is informed about the PDU number and redundancy version of each received PDU. This information is used to control the buffer. The following table summarises those basic events which trigger a certain operation of the buffer.

	Event	**Operation for buffer**
1	Receiving of a new PDU (first transmission)	· If CRC check is successful, discard PDU data. · If CRC check fails, save PDU data associated with PDU number, redundancy version
2	Receiving of a retransmission of a PDU with new redundancy	· Output buffered versions of the PDU for combining and channel decoding. · If CRC check of combined data is successful, discard all redundancy versions of this PDU. · If CRC check of combined data fails, save new redundancy version and keep buffered versions.
3	Receiving of a retransmission of a PDU with repeated redundancy	· Output buffered version of the received redundancy level of the PDU for maximum ratio combing. · Output all other buffered versions of the PDU for combining and channel decoding. · If CRC check of combined data is good, discard all redundancy versions of this PDU. · If CRC check of combined data is bad, save maximum ratio combined data of the received redundancy version.

Introduction of Hybrid ARQ Type II/III in the current multiplexing scheme

The functionality needed in the physical layer for hybrid ARQ II/III is strongly correlated with channel (de)coding as already stated in [2]. However, to use the existing channel (de)coding box which is provided by the modular multiplexing scheme depicted in [5] and [6], it is advantageous to add the required functionality as a separate box in that scheme.

Although for hybrid ARQ type II/III the required Redundancy Selection on the transmitting side can be considered as a certain variant of rate matching, the generic puncturing scheme is not applicable since only predefined bits have to be punctured. Furthermore, the Redundancy Selection has to be performed before 1st interleaving.

Therefore we propose to incorporate a new box named ‘Redundancy Selection’ directly after the channel coding box of the multiplexing scheme on the transmitting side as depicted in the figure 1 on the left side. On the receiving side, additional functionality for ‘Buffering/Combining’ is required before applying the channel decoder.

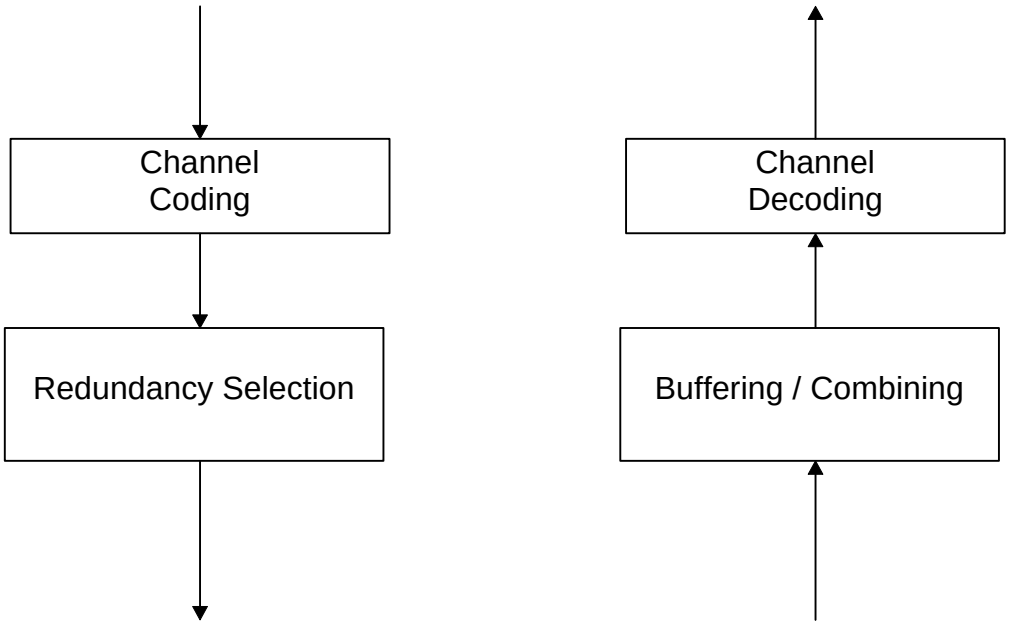

*Figure **Error! Unknown switch argument.**: Introduction of Hybrid ARQ Type II/III in the multiplexing scheme for the transmitting (left) and receiving side (right)*

Conclusion

In this paper it is shown that the incorporation of Hybrid ARQ type II/III, which yields better performance in comparison to hybrid ARQ type I, into the physical layer is simple and straightforward.

The multiplexing scheme on the transmitting side only has to be extended with one additional box "Redundancy Selection", which is transparent if Hybrid ARQ Type II/III is not used. A buffer is required on the receiving side to combine the different redundancy versions.

We propose to approve this feature in the 3GPP-standardisation both for FDD and TDD.

A detailed text proposal is available as a separate Tdoc [7].

References

[1] 3GPP TSG RAN WG1 Tdoc R1-99178: 'ARQ error control techniques', Source: SIEMENS AG
[2] 3GPP TSG RAN WG1 Tdoc R1-99296: 'Support of Hybrid ARQ Type II/III in the physical Layer', Source: SIEMENS AG
[3] 3GPP TSG RAN WG1 Tdoc R1-99195: 'Liaison statement to TSG RAN WG 1 on Random Access and Hybrid ARQ Type II/III', source: TSG RAN WG2
[4] 3GPP TSG RAN WG1 Tdoc R1-99313: 'Liaison Statement on Hybrid ARQ Type II/III', Source: TSG RAN WG1
[5] 3GPP TSG RAN WG1 TS S1.12 V1.0.1: 'Multiplexing and channel coding (FDD)', Source: editor
[6] 3GPP TSG RAN WG1 TS S1.22 V1.0.0: 'Multiplexing and channel coding (TDD)', Source: editor
[7] 3GPP TSG RAN WG1 Tdoc R1-99356: 'Text proposal for Support of Hybrid ARQ Type II/III in the physical Layer', Source: SIEMENS AG