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An Adaptive Type-II hybrid ARQ/FEC Protocol suitable for GSM

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Abstract: **To combat errors in data transmission in mobile radio systems usually forward error correction (FEC) and automatic repeat request (ARQ) schemes are combined to hybrid type-I ARQ protocols without using disturbed packets. In poor radio conditions type-I ARQ schemes produce a low throughput with a high delay jitter. Due to these unforeseeable channel delays type-I ARQ protocols are critical to use in cases where timing conditions have to be fulfilled as in speech and e.g. FAX-T30 transmission[3].**

Type-II hybrid ARQ (HARQ) protocols combine disturbed and retransmitted packets using FEC methods and limit the mean transmission delay by increasing the throughput. A type-II hybrid ARQ with punctured convolutional codes suitable for GSM data traffic and performance was compared to the recommended Radio Link Protocol (type-I).

A new type-II hybrid ARQ protocol is proposed which makes use of the state information given by the equalization process to estimate the amount and best location of the redundancy to be retransmitted.

I. Introduction

To combat the high error rates due to low signal to noise ratios which can be found on the radio interface in mobile communication systems, special error control procedures have to be provided.

Depending on the time restrictions of the supported application, by means of timing transparency two different types of services can be provided: transparent and non-transparent bearer services.

A transparent bearer service offers a constant delay, however, the transmission quality depends on the quality of the radio link. This can be reached with pure error detecting and error correcting channel codes. In detection only systems, a check sequences is added to a transmission message. If the receiver detects the presence of errors, the message will be discarded. In FEC (Forward Error Correcting) systems, the receiver will attempt to locate and correct the errors. If the decoding process fails or errors were not detected an erroneous code word is delivered to the user.

The non-transparent bearer service yields a very low remaining error rate by retransmission of unsuccessfully transmitted data packets. Retransmission occurs until the code word is transmitted successfully. This has the effect that throughput and delay can vary over time. Such ARQ (Automatic Repeat reQuest) protocols are well known in wired networks, using different retransmission mechanisms depending on the round trip delay and error rates.

But pure ARQ protocols are not useful in mobile environment due to the high bit error rates. In mobile environment hybrid FEC/ARQ mechanisms are used. These mechanisms supply ARQ protocols with forward error correction capability to reduce the frequency of retransmission. The remaining errors of the FEC mechanism are detected by a followed up ARQ scheme. As a result, a proper hybrid ARQ scheme provides higher reliability than an FEC system and higher throughput than ARQ systems alone.

Hybrid ARQ schemes are classified into type-I and type-II schemes.

Type-I hybrid ARQ/FEC systems use two codes, one for error detection (CRC) and one for error correction (FEC). If a received code word is erroneous, the receiver tries to correct the errors using the FEC code. If no remaining error is detected, the code word is delivered to the user. Otherwise the receiver requests a retransmission of the code word without storing the message. Since the performance of the type-I hybrid system depends mainly on the error correction capability of the forward error correcting code, FEC has to be adapted to the channel error rate.

Type-II hybrid ARQ/FEC systems use the same two codes as type-I. In opposition to the type-I, unsuccessfully received messages are stored within the receiver and will be combined with requested

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retransmissions via FEC mechanisms. This yields high throughput and low delay characteristics.

Additionally,
truncated type-II hybrid ARQ/FEC can be used in a semi-transparent bearer service to allow high throughput in combination with a limited delay. This can be reached by limiting the number of retransmissions to a certain degree.

Two main coding concepts can be used for type-II systems: code combining of block codes and rate-compatible punctured convolutional codes.

II. The Radio Link Protocol (Type-I)

The Radio Link Protocol (RLP) [1] used in the non-transparent service is based on a hybrid ARQ/FEC protocol applied to the 22.8 kbit/s radio link resulting in a user-bitrate of 9.6 kbit/s.

The ARQ-Part of RLP is based on the ISO HDLC[1] protocol.

Several enhancements were introduced to improve bandwidth efficiency. Because of the GSM time frame structure all RLP Frames have a fixed length of 240 bit (= 16 bit Header + 200 bit Information + 24 bit Frame Checking Sequence) and therefore no bit-stuffing is necessary.

Since point-to-point connections are served only, no address field is used. One bit is used to indicate whether the frame is a command or a response (C/R). RLP allows both, the reject (REJ) and the selective reject (SREJ) mechanism.

For channel coding, a punctured convolutional code with rate 1/2 is used.

Convolutional coders are designed to combat random independent errors produced by a memoryless channel. Mobile radio channels suffer from multipath fading which results in channels with memory. Therefore, if convolutional coding is used, interleaving is necessary to reach the memoryless property of the channel.

III. The Radio Link Protocol (Type-II) using RCC-family and fixed frame length

For a type-II hybrid ARQ/FEC protocol applied to GSM a convolutional coder was chosen with rate 1/2 and 9 bit memory[9]. The RCC-family was developed according to an article from Kallel[8]. The block length of the encoded message was set to a fixed length of 456 bit adapted to the number of information bits in a TDMA normal burst (114 bit).

[1] High-Level-Data-Link-Control

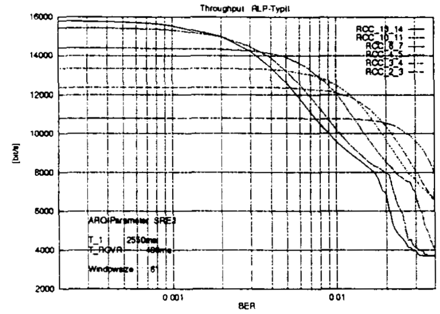

Figure 1: Throughput with different RCC-Codes with fixed packet length

Header and payload were encoded separately, both protected using a CRC. In opposition to the payload, the header is protected with a half rate convolutional coder to increase the success probability of the header transmission. The correct identification of packets is necessary even in case of erroneous payload to allow the recombination of different packet versions at the receiver. Additionally the high success probability of the header transmission protects the transmission of ARQ commands (such as SREJ) and allows retransmissions at the first possible time.

The Header includes the original RLP header and a puncture code identifier (2 bit). This allows the usage of 4 different puncture matrices. An extension bit allows signalling extended coding structures.

Depending on the rate of punctation a maximum rate can be chosen with:

$$10800\,\frac{bit}{s} \leq v_{max} \leq 15800\,\frac{bit}{s}$$

A. Simulation Results

For the simulation of the protocol a simulation tool (written in C++) was developed containing:

- CNCL [2] a basic simulation module library (random number generation, statistical evaluation, ...) which allows event driven simulation
- GSM modules for source and channel coding
- propagation and channel modules for indoor and outdoor environment

Rayleigh fading channel and ideal frequency hopping was assumed. Heavy load was assumed for one direction only, similar to fax or file transfer.

[2] CNCL can be obtained by anonymous ftp to ftp.dfv.rwth-aachen.de:pub/CNCL)

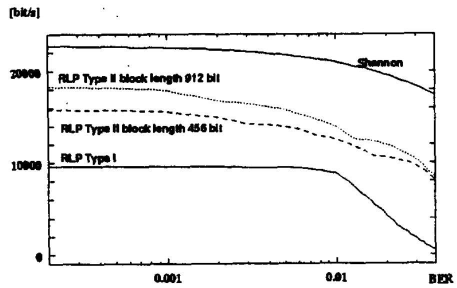

Figure 2: Throughput of Type-I RLP and adaptive fixed packet length type-II RLP

Throughput behaviour of RLP-type-II with fixed length are shown in figures 1 and 2.

Figure 1 shows the throughput behaviour of RLP-type-II for different puncturing rates (from 13/14 up to 2/3). To reach the envelope of the throughput in Fig.1 the puncturing rates are chosen depending on the current channel state.

Figure 2 shows the throughput behaviour of the adaptive type-II RLP with two different block lengths (456 and 912 bit) in comparison with the type-I RLP and Shannon's limit (memoryless channel).

IV. The Radio Link Protocol (Type-II) using variable frame length and burst level error detection

The amount and structure of retransmitted data in all previously described mechanisms are defined in advance. After an unsuccessful transmission, the receiver requests a protocol dependent retransmission packet. If the frame length of retransmitted frame is the same as the length of the first transmission this reduces the possible throughput for the benefit of a low transmission delays. If only small peaces of redundancy are transmitted this yields to a high delay for the benefit of a high throughput in cases where the amount of framing header is neglectable.

A great advantage would be the use of the state information of the channel to estimate the amount of the retransmitted redundancy. Additionally convolutional codes have a limited constraint length. Therefore it is necessary to determine the best location of the redundancy which should be transmitted.

To allow a variable packet length, the 20 bit header has a seperate 16 bit CRC and is encoded seperately with a convolutional code. To ensure the transmission of the header, a trailer at the end of each packet contains a copy of the corresponding header. Header and trailer of two succeeding packets are encoded with a convolutional code to one normal burst consisting of 114 bits.

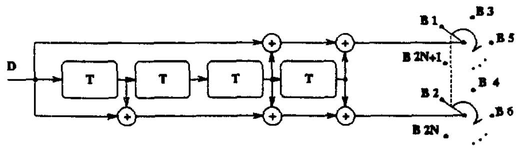

Figure 3: Interleaving of Encoded Bits

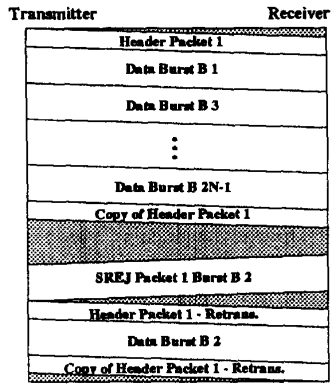

Figure 4: Transmission Scheme

To reach independent errors for the convolutional coder, a variable interleaving depth, depending on the packet length, was introduced for the data bursts. Therefore encoded bits are interleaved cyclic to the number of bursts. An coding example with a uncoded data length of $N \cdot 114$ bit is shown in figures 3 and 4.

Within a GSM system the state information of the channel is estimated by the equalization process. This side information is given in soft decision values sd which are normally used from the forward error decoding algorithm. They can be derived from the bit error rate p for the maximum likelihood decision.

$$sd := -\log\left(\frac{p}{1-p}\right) \quad \text{or} \quad p := \frac{e^{-sd}}{1+e^{-sd}}$$

This estimated bit error rates can be used to estimate the total capacity C_P of a packet).

$$C_P = \frac{1}{n}\sum_{k=1}^{n} 1 + p_k \cdot \log_2(p_k) + (1-p_k) \cdot \log_2(1-p_k)$$

The total estimated packet capacity is used to fix the amount of data which has to be retransmitted.

If the decoding of the first transmission was unsuccessful, the algorithm has to mark the bursts

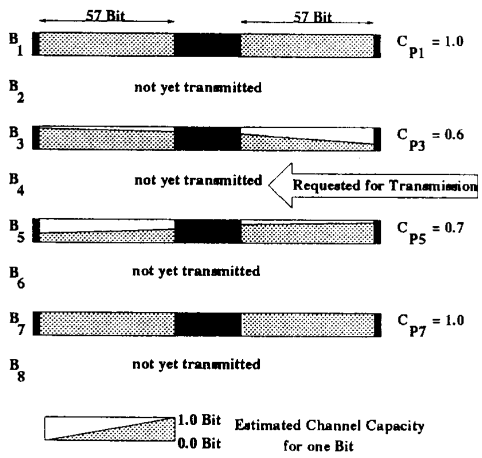

Figure 5: The Estimated Burst Capacity C_{Pi}

which have to be retransmitted using the estimated burst capacity C_{Pi} of all bursts of the packet.

The following table shows some simulation results in a channel with Rayleigh fading, shadowing and cochannel interference of 10dB (BER $\approx 4.5\%$). A mobile station velocity of 3.6 m/s and ideal frequency hopping was assumed. The table shows, that a user data rate of 19.2 kbit/s could be provided on a GSM full rate traffic channel (9.6 kbit/s on HR).

Protocol	Throughput (kbit/s)	
	CIR = 10 dB	CIR $\to \infty$
RLP-REJ	1.0	10.0
RLP-SREJ	2.2	10.0
RLP-Type II fixed length	6.0	15.8
RLP-Type II burst level	14.4	21.4

V. References

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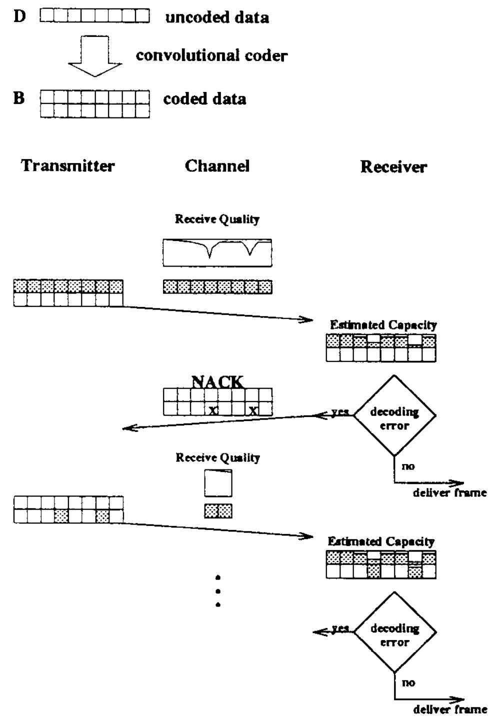

Figure 6: Request for retransmission mechanism

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