Extending UTRAN Physical Layer with Coded Modulation Schemes

Attila Zsiros, Attila Fülöp and Gábor Jeney

***Abstract*—Our previous work was a [1] complete UMTS-UTRAN FDD physical layer implementation, which is highly compliant with ETSI standards. Standards specify to be used in UMTS devices only two channel coding methods: convolutional and turbo channel coding methods. In this paper we explain our goal to expand the existing simulation with alternative (TCM, TTCM and LDPC based) coded modulation techniques. Performance and complexity of these error correction coding schemes are studied in comparison with standard solutions.**

***Index Terms*—Channel coding, Code division multiaccess (CDMA), Coded modulation (CM), Trellis Coded Modulation (TCM), Turbo Trellis Coded Modulation (TTCM), Low Density Parity Check (LDPC), UMTS.**

I. Introduction

MOBILE communication systems are both power- and bandwidth-limited. Efficient exploitation of the available spectrum is therefore important, in order to accommodate ever-increasing traffic demands. Forward Error Correction (FEC) codes are powerful tools to improve spectrum efficiency of the system.

Our previous work [1] was to develop a flexible, easily configurable implementation of UTRAN (UMTS Terrestrial radio Access Network) physical layer. This simulation enables easy tuning of parameters and modification of network elements. Beyond this advantage, the main consideration is to support changeable elements, platform independent codes, efficient implementation and compliance with the standards.

The aim of this paper is to study joint coding and modulation schemes in our UTRAN physical layer simulation environment. The designing and implementation considerations presented here take two main concepts into account: modular realization and minimal difference from standards.

Current paper is organized as follows: Section II introduces the UTRAN physical layer structure and system model. The alternative FEC techniques are described in Section III. Insertion of alternative solutions in the existing physical layer structure is presented in the next section. Section V describes some simulation and measurement results. The last section concludes the paper and shows some plans for future work.

II. System overview

A. UTRAN signal processing chain

Although UMTS supports both the TDD and FDD duplex modes, only the frequency division duplex Wideband CDMA access is simulated in our environment. In this paper we study the uplink direction in UTRAN physical layer. Fig. 1 shows the main elements of signal processing functions involved in uplink simulation chain [2].

The information (i.e. bit streams in transport channels, TrCHs) arrives from MAC (Medium Access Control) layer. The information goes through several transformations which create an error resistant bit stream with service expected bit rate. ETSI technical specifications [2] specifies convolutional (both 1/2 and 1/3 code rate) and turbo coding that underlie comparison with alternative techniques. Structure, shown in Fig. 1, results in a link level simulator that has a connection with radio channel through spreading and modulation functions. Focus is on the spreading and modulation components of the simulator: insertion of our alternative coded modulation schemes means replacing these modules.

B. System model for spreading and modulation

In compliance with standards, we use antipodal signals instead of 0, 1 bits in spreading. Signal stream of the *n*-th physical channel is spread to the chip rate by channelization code c_n. Spreaded, real-valued contents of channels are mapped to real or

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imaginary part of complex-valued chip stream. This complex-valued signal is then scrambled by the complex-valued scrambling code *S*. One control channel (DPCCH) and up to six parallel data channels (DPDCHs) can be transmitted simultaneously.

Modulation component use root raised cosine (RRC) pulse shaping of scrambled complex-valued stream. Carrier frequency does not have to appear in the simulation due to the applied complex baseband equivalent (CBBE) model.

On the receiver side coherent rake receiver [3] means an applicable solution for restoring information sequence. Adjusting RRC filter, resolving paths and combining results to obtain information bits are based on the following formula:

$$\hat{d}_k[i] = \sum_{l=1}^{\hat{L}_k} \int_{-\infty}^{+\infty} \left(y(t) \cdot \hat{\alpha}^*_{kl} \cdot s^*{}_k(t - \hat{\tau}_{kl} - i\mathrm{T_s}) \right) dt \,. \quad (1)$$

Equation (1) uses the notation $\hat{d}_k[i]$ to describe the *k*-th user *i*-th continuous estimated symbol. $\mathrm{T_S}$ is the symbol time, $\hat{L}_k$ is the estimated number of paths, $y(t)$ is the received signal, $\hat{\alpha}_{kl}$ and $\hat{\tau}_{kl}$ the estimated attenuation and delays of *l*-th paths for user *k*. We use the complex conjugate of complex attenuation $\hat{\alpha}_{kl}$. Signature waveform s_k of *k*-th user expressed as

$$s_k(t) = RRC\,(t) * \left(C_n(t) \cdot S(t)\right). \quad (2)$$

The impulse response of RRC filter $RRC(t)$ is convolved with the impulse of complex conjugate code sequence. The code sequence is created as the product of *S* scrambling and C_n complex-valued channelization sequences. C_n is constructed by above mentioned c_n, mapping the real-valued sequence into real or imaginary part of complex sequence. The so-called scrambling code identifies the mobile equipment and c_n is for channel identification.

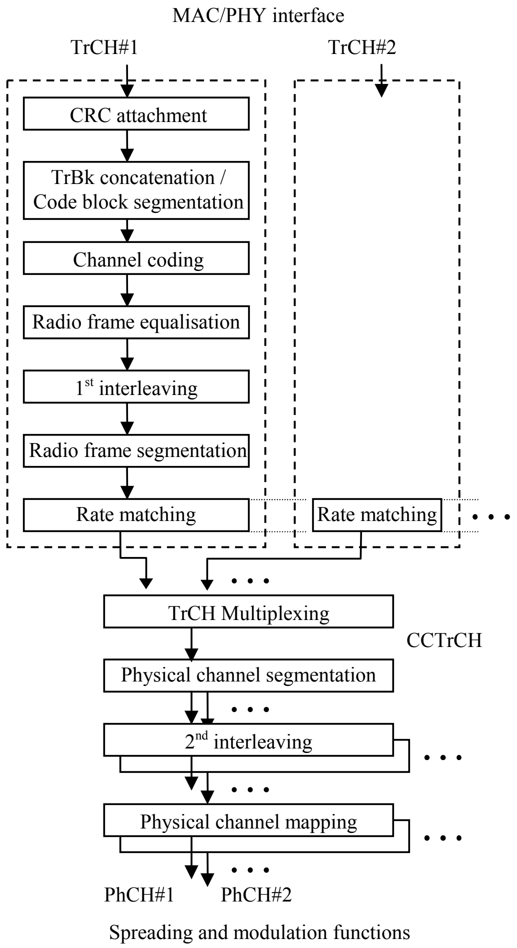

Fig. 1. UTRAN physical layer signal processing chain in uplink transmission.

III. Alternative Channel Coding and Modulation Schemes

Coded modulation is a bandwidth efficient scheme that combines the functions of coding and modulation. As mentioned earlier, UMTS standards include three FEC-based channel coding schemes: convolutional coding (with code rates 1/2 and 1/3) and turbo coding. Alternative FEC techniques are Trellis Coded Modulation (TCM), Turbo Trellis Coded Modulation (TTCM) and Low Density Parity Check (LDPC) based coded modulation.

TCM was introduced by Ungerböck in 1976 and optimum codes were obtained by using an exhaustive computer search [4].

The invention of turbo codes [5] in 1993 was a breakthrough in the history of error control coding. Research showed that, by

TABLE I
Ungerboeck TCM Codes for 8PSK

State	$H^0(D)^a$	$H^2(D)^a$	$H^2(D)^a$
8	11	02	04
32	45	16	34
64	103	30	66
128	277	54	122
256	435	72	130

[a]octal format is used for presenting the generator polynomials coefficients.

TABLE II
TCM Component Codes for TTCM for 8PSK

State	$H^0(D)^a$	$H^2(D)^a$	$H^2(D)^a$
4	07	02	04
8	11	02	04
8	11	06	04
16	23	02	10
16	23	14	06

[a]octal format is used for presenting the generator polynomials coefficients.

using turbo coding, a performance close to Shannon capacity can be achieved. Turbo Trellis Coded Modulation (TTCM) is another more recently proposed channel coding scheme that employs TCM schemes as its component codes. Besides, TTCM has a structure similar to turbo codes; therefore it has the advantages of turbo coding technique too [6].

Another powerful error correcting solution, the Low Density Parity Check (LDPC) scheme has a relatively low decoding complexity, while maintaining a performance comparable to turbo codes.

Ungerböck codes are optimal for transmission over AWGN channels. Efficiency improvements are achived by interleaving the 3-bit code words gained form TCM coder output. Symbol [4] or bit interleaved solutions [7] can increase performance, and enables upgrade the current simulation system. Interleaver design is important because it affects both performance and latency. Interleaver beside TCM coder is not included in current version of simulation environment, although it is advisable to be used in a fading channel.

Ungerböck codes [4] used in simulation for coding QPSK symbols to 8PSK shown are Table I. All two input bits of QPSK are coded in above cases, so set partitioning is not applied. Soft-decision based Viterbi decoder [8] is used at the receiver side finding the most likely signal path through the trellis (branches of the trellis are weighted according to Euclidean distance).

Standard turbo-type code designs employ a symmetrical structure using two identical generator polynomials. In Table II some component TCM codes for TTCM scheme are listed. These generator polynomials were obtained by Robertson and Wörz [9]. Decoder is based on modified MAP (maximum a posteriori) algorithm suitable for TTCM, detailed in [9]. Parity bits are provided alternatively by two identical component encoders linked by a symbol interleaver.

There has been a great interest in Low Density Parity Check (LDPC) codes recently because of results suggesting reliable transmission extremely close to the Shannon limit. LDPC codes are linear block codes with a very sparse parity check matrix (H). LDPC codes were first analyzed by R. Gallager [10] in 1962.

Gallager defined a set of (j, k) regular LDPC codes where j and k denote the column and the row weights of parity check matrix, respectively. In our test case these are j=5 and k=15.

IV. Modified System Structure

The standard UTRAN signal processing chain needed to be modified to be able to insert CM schemes. Focusing on dedicated data transmission Fig. 2 shows our functional module that contains CM coder on transmitter side. Signal processing chain (Fig. 1) forwards output bit streams on PhCHs. This new module is aligned between the physical channel mapping and spreading functions. Processing of channels occurs pair-wise; in case of an odd number of channels an additional channel filled with alternating (+1, −1) symbols is used.

The QPSK signal is created from two streams of PhCHs containing (+1, −1) antipodal symbols. LDPC based CM coding is fundamentally block coding [11]; code block forming is performed by a segmentation unit. CM coder operates with code rate 2:3 to generate input for 8PSK signal mapping. The complex 8PSK output is then mapped back to PhCHs, taking into account the mapping of channel data after spreading. [12] specifies that streams of DPDCHs after the spreading are summed and treated

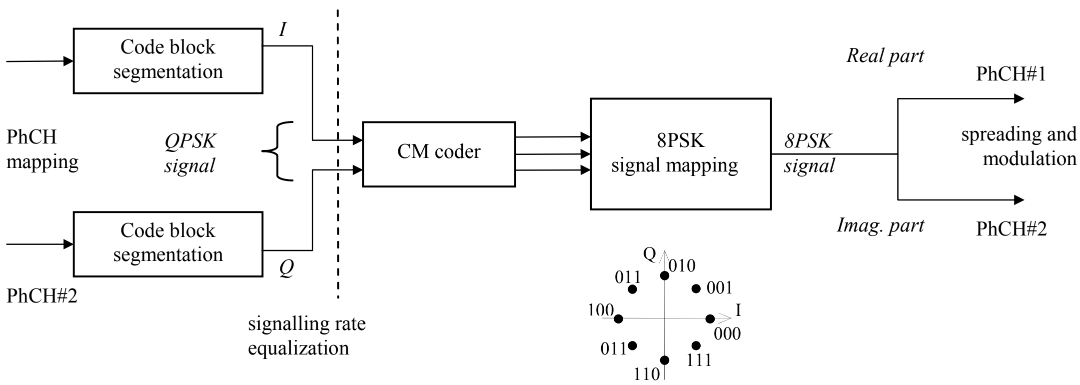

Fig. 2. Insertion of coded modulation (CM) schemes to UTRAN. CM coder aligns between PhCH mapping and spreading functional modules.

as complex-valued stream of chips. If after spreading the DPDCH is mapped into real value then the 8PSK symbol real part is put in this DPDCH. After spreading – according to [12] – mapping of channels into real and imaginary parts takes place by alternating channels. Taking into account the considerations mentioned before, it is always possible to choose two appropriate channels.

Complex valued spreaded signal is scrambled and RRC pulse shaped as in standard solution.

The relation between the number of physical data channels (DPDCHs), the spreading factor and the number of bits transmitted are shown in Table III. In addition to the mentioned dedicated channel(s), one more control channel, namely DPCCH exists (not including the optional High Speed DPCCH).

TABLE III
NUMBER OF BITS ON CCTRCH

Number of DPDCHs	Spreading Factor (SF)	Number of bits / radio frame
1	256	150
1	128	300
1	64	600
1	32	1200
1	16	2400
1	8	4800
1	4	9600
2	4	19200
3	4	28800
4	4	38400
5	4	48000
6	4	57600

TABLE IV
LINK LEVEL CHANNEL MODEL PARAMETER SUMMARY

3GPP2 Designator		Model A		Model B		Model C		Model F	
Power Delay Profile (PDP)		Modified Pedestrian A		Pedestrian B		Vehicular A		Single Path	
Nr. of Paths			5		6		6		1
Relative Path Power (dB)	Delay (ns)	0.0	0	0.0	0	0.0	0	0.0	0
		-6.51	0	-0.9	200	-1.0	310		
		-16.21	110	-4.9	800	-9.0	710		
		-25.71	190	-8.0	1200	-10.0	1090		
		-29.31	410	-7.8	2300	-15.0	1730		
				-23.9	3700	-20.0	2510		
Speed (km/h)			3		3, 30, 120		3, 30, 120		3

DPCCH is always transmitted using a channelization code with a spreading factor of 256. Signaling rate equalization is required to have same number of bits per block. Spreading code of DPCCH is always the OVSF (Orthogonal Variable Spreading Factor) consisting of only +1 symbols with a length of 256. Equalization can be carried out by repeating one symbol of the control channel $256/SF_{DPDCH}$ times, where SF_{DPDCH} is the spreading factor of the DPDCHs (marked on Table III). Then channelization of DPCCH is performed with length SF_{DPDCH}.

On receiver side rake receiver resolves 8PSK symbols as described in (1) and (2). The near 8PSK signals are decoded with soft input decoders providing QPSK symbols, i.e. 2 information bits per symbol.

The multipath channel model for simulation is characterized by [13]. Pedestrian and vehicular link level parameters are summarized in Table IV. Rayleigh fading is applied with time invariant delays in multipath propagation scenario.

V. SIMULATION RESULTS

Scope of our simulation covers only the single user link level case. The performance of UTRAN physical layer extended by CM schemes is measured by bit error rate (BER). Dedicated data transmission was simulated with SF=4 and 2 physical channels over AWGN and fading channels.

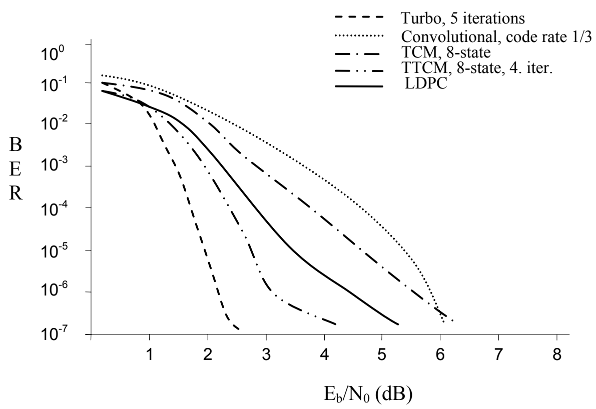

Fig. 3. Bit error rate (BER) of channel coding techniques on AWGN channel.

The number of transmitted bits depends on the spreading factor and the number of physical channels (Table III). The minimum value is 150, according to SF=256, all other values are the multiple of 150. So every bitstream after PhCH mapping can be divided into blocks with length 150. Considering these facts we have created for LDPC a parity check matrix with size 75×225 so the input blocks to the coder have the size 150 and the output blocks are 225 bits length.

TABLE V
EXECUTION TIMES OF CHANNEL CODING COMPONENTS

Component	Execution time (ms)	Comments
Convolutional encoder[a]	0.83	Block size = 504, Code rate = 1/3
Convolutional decoder[a]	250.10	Block size = 504, Code rate = 1/3
Turbo encoder[a]	7.90	Block size = 5114
Turbo decoder[a]	1514.30	Block size = 5114, 5 iterations
TCM encoder	0.52	Nr. of bits coded = 19200, 8-state
TCM decoder	118.00	Nr. of bits coded = 19200, 8-state
LDPC encoder	2.30	Nr. of bits coded = 19200, 10 iterations
LDPC decoder	776.00	Nr. of bits coded = 19200
TTCM encoder	9,35	Nr. of bits coded = 19200
TTCM decoder	1852.00	Nr. of bits coded = 19200, 8-state, 5 iterations

Execution time values are measured on Athlon XP 1.5 GHz processor under Linux operating system.
[a]values are presented in [1].

The bit error rate (BER) of channel coding techniques is shown in Fig. 3 measured on AWGN channel. Turbo and convolutional coding is applied on antipodal bit streams, CM schemes provides 8PSK signals.

Fig. 4 shows rake receiver performance combined with CM schemes. We used TCM coder with 8-state and generator polynomials coefficients presented in Table I. TTCM coder also utilizes this TCM coder as its component.

Although there is a possibility of disabling the original convolutional and turbo coding in the signal processing chain, it is more efficient to use the newly inserted and standard channel coding simultaneously. Some combined solution is depicted on Fig. 5. TCM used by rake receiver and convolutional coder is activated in signal processing chain. LDPC based CM worked with the more powerful turbo coding.

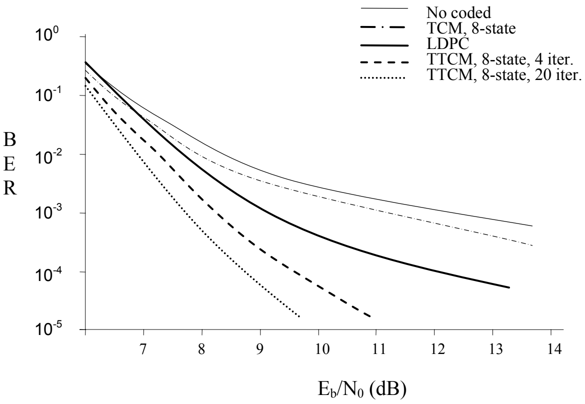

Fig. 4. Receiver performance on channel Model A (Table IV).

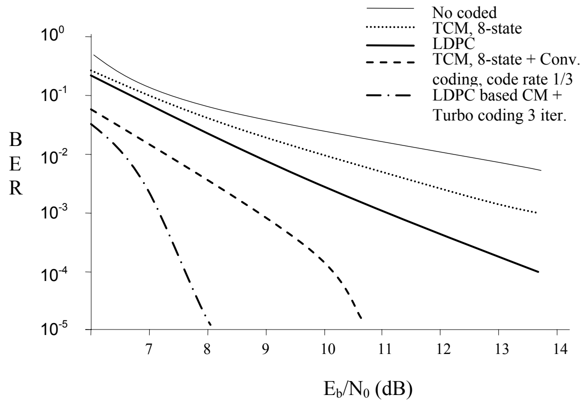

Fig. 5. Performance on channel Model B (Table IV).

Computational requirement of TCM coding is comparable with convolutional coding of standards, as shown in Table V. TTCM and turbo coding have also similar complexities. LDPC based CM provides a rather good BER and its complexity is lower than using TTCM.

Comparing the execution times in Table V with performance results on Fig. 4 shows that more processing power requiring results in better performance.

VI. Conclusion

Our goal was to improve our existing ISO/ANSI C platform independent implementation of UTRAN physical layer. Extending UTRAN physical layer with coded modulation scheme can increase performance of transmission. The complexity of system increases necessarily. As an adaptive system, which accommodates to the variable propagation scenarios, CM schemes might be effective.

We have tested the performance and the execution time of the coded modulation schemes. The TCM technique needed the least execution time but it had worse performance than the others. The LDPC based coded modulation has an average efficiency (in execution time) and performance compared to TCM and TTCM. TTCM has the best performance but it also needs a lot of processing power.

Some improvements of our solution are under development. Spectral efficiency of the system can be studied in multiuser case, but this is not supported now. The TCM technique in current simulation system can be upgraded with bit or symbol interleaved solutions mentioned in Section II. Throughput of the UTRAN system is measurable in an environment containing not only physical layer but higher (MAC, RLC, RRC) layers too; current physical layer implementation has the necessary interfaces to other layers of the UTRAN radio interface. Such complete UTRAN simulation system is under development in IST Phoenix project, in which our physical layer simulation software will also be applied.

In the near future physical layer will be implemented using DSP (Digital Signal Processor) architecture to develop a Software Radio System. Some components have already been tested on TI (Texas Instruments) TMS320C6711 DSP device successfully.

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