Application of Iterative Decoding Systems (UTTCM) to 4G-LTE Mobile Radio Communication Network

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November 6, 2021

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***Abstract*—The mobile communications market has grown at an unprecedented rate and cellular phones have been adopted much faster than any other equipment. At the same time, current systems meet many needs, depending on whether mobility, speed, cost and quality are promoted and ensured ... To meet the ever-increasing demands of consumers. These large capacity demands can only be met by high efficiency and very good optimization of mobile network infrastructures, while taking into account the constraints that are power, bandwidth and limited complexity. The concern to transmit at high rates while being confined to a defined bandwidth has led some researchers to consider the application of iterative channel codes to high spectral efficiency modulations. In order to recover the transmitted data correctly and efficiently. In our paper, we are mainly interested in simulation analysis to improve the performance of 4G-LTE mobile radio transmission, through the use of iterative coding technique, which is efficient and less complex, named UTTCM through three models of channels (EPA, EVA, ETU).**

Keywords—UTTCM, LTE, TC, OFDM, Models Channels

I. Introduction

LTE is a project led by the standardisation organisation 3GPP to draft the fourth generation technical standards for mobile telephony. It enables very high speed data transfer, with greater range, more calls per cell, and lower latency. However, the increase in throughput requirements is hampered by the availability of spectral resources but also by the nature of the channels themselves [1]. Indeed, communications occur in increasingly limited frequency bands due to the high number of standards. In addition, wireless communications occur through the propagation of an electromagnetic wave in space; however, the channel is generally of the multi-path type, because of the presence of obstacles (buildings, trees, cars, etc.). In reception, the received signal is then composed of a combination of signals coming from different directions making the channel frequency selective and whose influence increases with the transmission rate. To meet the constraints with limited bands and power, multi-carrier algorithms of the OFDM (Orthogonal Frequency Division Multiplex) type, are among the main candidates for the race for spectral efficiency. Their combination is particularly suitable and makes it possible to envisage an increase in speed while maintaining a reasonable reception complexity. Indeed, multi-carrier techniques [2] make it possible to use the radio resource in an ideal way and to comply with strict spectral constraints by distributing the power in an appropriate manner. In addition, combined with coding, they ensure robustness by exploiting a time-frequency diversity. The progress of channel-coding techniques, in particular with the appearance of turbo principles in Berrou's article [3], makes it possible to approach the theoretical terminals planned by Shannon.

The growing momentum of a large number of 4G-LTE network users, service diversification and the ever-growing use of the latest multimedia applications, which immediately led to the congestion of the frequency spectrum. Unfortunately, it is a very limited resource. Therefore, any approach to the design and optimization of communication systems must not only lead to a compromise between spectral efficiency, but also to the resistance of these systems against transmission errors. However, the variable nature of the channel with the presence of deep "fadings" and the ever-increasing demand for frequency spectrum remains a major obstacle to the increase in transmitted flows. A fundamental solution to the problem of radio-mobile channel (LTE) performance was the idea of maximizing the bandwidth useful rate ratio, that is, the spectral efficiency of transmissions. To do this, it seems natural to couple numerical modulations at a large number of points with powerful error-correcting codes of high efficiency such as turbos codes.

This new code family (Turbos codes) is the work of Berrou and Glavieux and Thitimajshima in 1993 [3]. They brought the greatest advance in coding since the work of Ungerboeck which had introduced the Coded Modulations (Trellis-Coded

Modulation) in 1982. They exploit all the potential of the concatenated code schemes proposed by Forney in 1966. We can indeed see the turbo-codes as a refinement of a concatenated coding structure with the implementation of an iterative decoding with flexible output. This flexible output will determine the symbols issued from a MAP rule (maximum a posteriori). As we can reduce the complexity of decoding while maintaining the same performance of this code as described in [3,5, 6].

As a result, the practical advantage of localized iterative decoding is that powerful codes can now be decoded with reasonable complexity [7], which is why much of the research is focused on evaluating the performance of iterative decoding for the future of LTE network systems [8]. Proakis considered in [9] that The turbo-code is an evolution of convolutive coding technology used in all previous standards with impressive performance in terms of capacity in nearby channels. The turbos-codes are currently used in channel coding to the 4G-LTE network, and they are embedded in the standards (3GPP-LTE). The main objective of this work is to improve the performance of the 4G-LTE network, using a new iterative coding technique, which is efficient and less complex, called UTTCM [10, 11] instead of classic turbo-code (TC) coding.

II. UTTCM Encoder Design

The UTTCM encoder is a coder created from the concatenation of two strictly equivalent TCM encoders separated by an interleaver, each with a rate m/(m+1), which is used to generate two encodings of the same information, i.e., they have the same generator polynomials. So their trellis diagram is common. The whole point is actually the insertion of an interleave between the input of the first encoder and the input of the second encoder. For a spectral efficiency of *m* bps, at the entry of the Mappeur it finds 2^{m+2} bits, m bits systematic with a parity bit extracted by the 1st encoder and a parity bit deinterlaced extracted by the 2nd encoder, this leads to the use of a constellation 2^{m+2} point, as shown in the following figure.

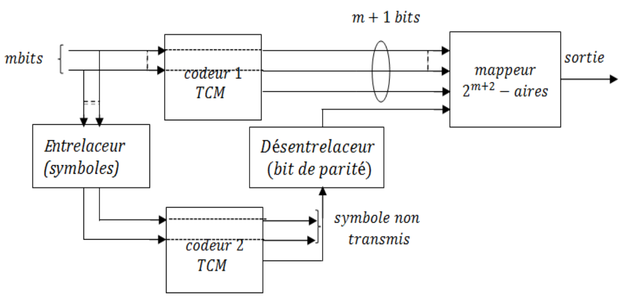


Fig. 1 UTTCM encoder for *m* input bits.

To make signal sequences more resistant to noise, they must be very different from each other [12], in other words, the Euclidean distance between the different signals taken in their space must be as great as possible. Fig. 1 shows the UTTCM encoder with m bits input and m+2 bits output. The TCM coders that are used in this work are 4 and 8 state coders and for gray mapping and Ungerboeck Gray with the following generator polynomials:

TABLE I. Best 4 and 8 State TCM Coders For Gray Mapping And Ungerboeck Gray

Numbers of states	*m*	*h₀*	*h₁*	*h₂*	*h₃*	*h₄*	Mapping
4	2	07	03	07	/	/	G
		07	03	06	/	/	UG
	4	07	03	05	03	05	G
		07	03	05	03	04	UG
8	2	13	05	10	/	/	G
		13	11	04	/	/	UG
	4	13	05	11	05	11	G
		13	11	05	11	04	UG

For a spectral efficiency of 2 *bits/s/Hz*, the rate of each encoder is 2/3 of 8 states and constellation of 16-QAM, using the mapping Gray (G) and Ungerboeck-Gray (UG) with the generator polynomials defined above, The free distance of the set UTTCM is $d_f = \sqrt{3.6}$, Fig. 2 defines the constellation of 16-QAM for mapping G and UG.

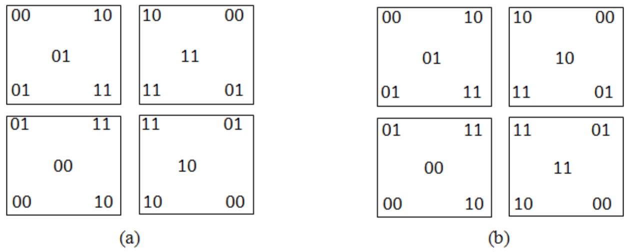


Fig. 2 Constellation 16-QAM ((a) : mapping-Gray et (b) : mapping Ungerboeck-Gray).

For a spectral efficiency of 4 *bits/s/Hz*, the rate of each encoder is 4/5 for 8 states and constellation of 64-QAM, using the mapping-Gray (G) and Ungerboeck-Gray (UG) with the generator polynomials defined above, The free distance of the set UTTCM is $d_f = \sqrt{0.86}$, Fig. 3 defines the 64-QAM constellation for G mapping and UG mapping.

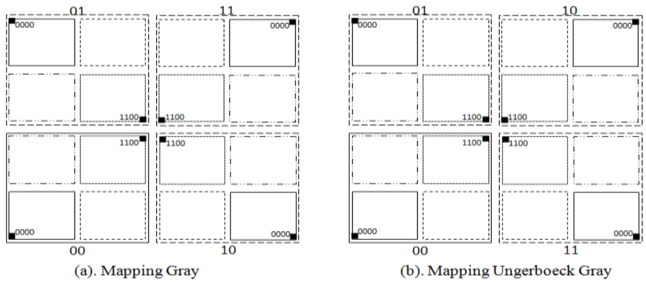


Fig. 3 Constellation 64-QAM ((a) : mapping Gray (b) : mapping Ungerboeck Gray).

III. Iterative Structure Of The UTTCM Turbo-Decoder

The general operation of a turbo-decoder is based on the looping of two decoders identical to the one we have just seen. One is used to decode the parity bits provided by the first coder while the other uses those provided by the second.

The UTTCM decoder shown in Fig. 4, proposed in [13] is a serial concatenation of two decoders based on the *MAP* posterior maximum decoding algorithm.

Each constituent decoder must calculate, at each step *k*, the probability.

$$Pr\{d_k = i \mid \underline{y}\}\ (i \in \{0, \dots, 2^m - 1\})$$

$$Pr\{d_k = i \mid \underline{y}\} = const \sum_{M}\sum_{M'} \gamma_i(y_k, M', M).\alpha_{k-1}(M').\beta_k(M) \quad (1)$$

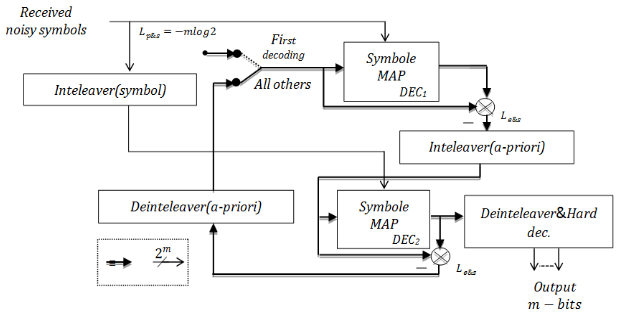


Fig. 4 Structure of Decoder UTTCM.

Where d_k is a group of m information bits from step k, $\alpha_{k-1}(M')$ is the forward variable, $\beta_k(M)$ is the backward variable and $\gamma_i(y_k, M', M)$ is the branch transition probability of the constituent trellis of the encoder given by:

$$\gamma_i(y_k, M', M) = P(y_k | d_k = i, S_k = M, S_{k-1} = M') \times q(d_k = i | S_k = M, S_{k-1} = M').Pr\{S_k = M | S_{k-1} = M'\}. \quad (2)$$

S_k is the state in step k, of the constitutive treillis of the coder and the constant (const) to (1) can be eliminated by normalizing the sum (1), over the set i to the unit.

According to the decoding process following Fig. 4, the probability given in (1) can be represented, in the logarithmic domain, by the sum of two terms: the component a priori L_a (d_k = i), and the component (extrinsic and systematic) $L_{e\&s}$ (d_k = i) given by:

$$L_a(d_k = i) = log\ Pr\{d_k = i\} \quad (3)$$

$$L_{e\&s}(d_k = i) = log\ Pr\{d_k = i \mid y\} - L_a(d_k = i) \quad (4)$$

In the decoder of the TCM, the iterative decoding process is as follows: the term (extrinsic and systematic) ($L_{e\&s}$) generated at the output of the constituent decoder DEC_1 (respectively DEC_2) will be considered as a priori term (L_a) of the constituent decoder DEC_2 (respectively DEC_1), except for the first decoding step, where the constituent DEC_1 decoder sees at its entry the (parity and systematic) term ($L_{p\&s}$); Thus, at this stage, the a priori information is adjusted to:

$$Pr\{d_k = i\} = \left(\frac{1}{2}\right)^m \quad (5)$$

The 2^m combinations of the symbol d_k are equally likely. All the thin paths in Fig. 4 are the output of the channel, the thick paths represent a group of values of 2^m of the logarithms of the probabilities.

IV. Testing And Implementation Of UTTCM Encoder In AWGN Channel

Figure 5 shows the simulation results of 2 bps of digital transmission with an UTTCM channel encoding of 6 iterations in an AWGN channel. Mappeur uses 16-QAM with Gray and Ungerboeck Gray mapping.

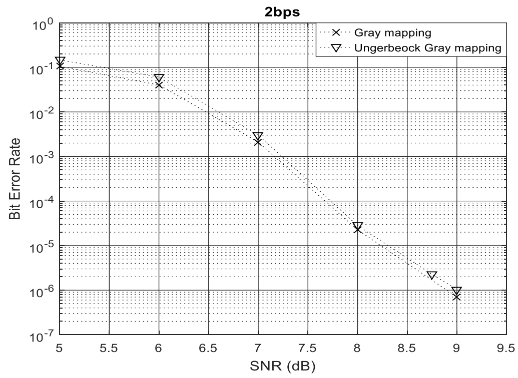


Fig. 5 Comparison between G and UG mapping with UTTCM channel encoding for 16-QAM.

Fig. 6 illustrates the simulation results of 4 bps of digital transmission with UTTCM channel encoding of 6 decoding iterations in an AWGN channel for 64-QAM modulation with two mapping techniques Gray and Ungerboeck Gray.

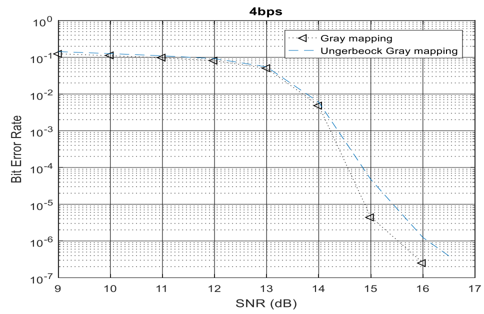


Fig. 6 Comparison between G and UG mapping with UTTCM channel encoding for 64-QAM.

From the two figures (Fig.5 and Fig. 6) it can be seen that the Gray mapping gives a better result per contribution to the Ungerboeck Gray mapping.

V. Typical 4G-LTE Channel Models

Following the 3GPP standards in [14], the LTE system has been adopted on three models of propagation channels essential for simulation and testing, these models are defined as Extended Pedestrian A (EPA), Extended Vehicular A (EVA) [15] and Extended Typical Urban (ETU) [16]. The table 2 shows the maximum Doppler offsets for each model to represent the low, medium and high moving conditions [17, 18, 19].

TABLE II. Channel Model Papameters (Delay, Power) Preset In LTE.

Tap N°	EPA Channel		EVA Channel		ETU Channel	
	τ (ns)	SMR (dB)	τ (ns)	SMR (dB)	τ (ns)	SMR (dB)
1	0	0.0	0	0.0	0	-1.0
2	30	-1.0	30	-1.5	50	-1.0
3	70	-2.0	150	-1.4	120	-1.0
4	90	-3.0	310	-3.6	200	0.0
5	110	-8.0	370	-0.6	230	0.0
6	190	-17.2	710	-9.1	500	0.0
7	410	-20.8	1090	-7.0	1600	-3.0
8			1730	-12.0	2300	-5.0
9			2510	-16.9	5000	-7.0

VI. Results And Discussion

The structure of the transmission chain of the proposed LTE network radio interface is shown in Fig. 7. The physical layer of LTE technology is an efficient way to send data and control signals between the base station and the mobile user. LTE uses many advanced technologies, including orthogonal Frequency Division Multiplexing (OFDM). In an uplink, it uses Single Carrier Frequency Division Multiple Accès (SC-FDMA), while on the downlink, it uses Orthogonal Frequency Division Multiple Access (OFDMA).

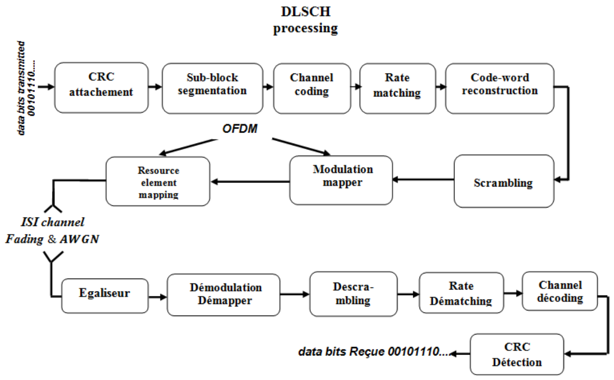


Fig. 7 LTE Physical Layer Specifications

In the transmitter part, the data coming from the upper layers are encapsulated in the form of frames called [20, 21, 22] "transport block" before their passage in the radio link and their transmission, the duration of which is characterized by the TTI (Transmission Time Interval). The transport block size (TBS) depends on the number of physical resource blocks (PRB) and the modulation and coding scheme adopted. The transmitter starts with the resource data which is grouped together in the form of transport blocks. In each TTI, a transport block will be transferred first to the encoding part of the channel which consists of two cyclic redundancy check (CRC) encoders and error correcting code.

A. *Parameters used*

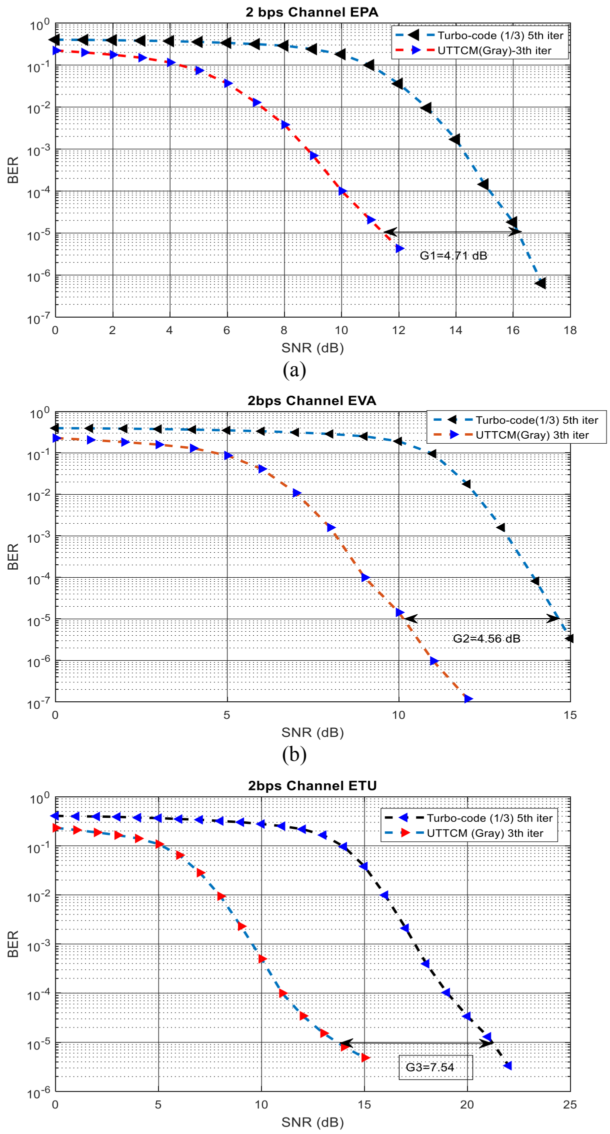
The parameters used during the simulation are given in table 3:

TABLE III. Parameters Used In The Simulation

Parameters	Values
size of frame transmitted	3869
FFT size	1024
No of resource blocks	50
No of Transmit and received antennas	1*1
Cell ID	17
Cyclic prefix	Normal
Duplex mode	TDD (Time Division Duplex)
Downlink channel	PDSCH (Physical downlink shared channel)
Channel bandwidth	10 MHz
Channel model	EVA / EPA/ETU
Doppler shift	EVA =222.22 / EPA =5.55/ETU =5.55
Modulation	QPSK,16QAM,64QAM
Equalization mode	Zero-forcing

B. *UTTCM encoder performance on LTE system*

From the results of the simulations shown in Fig.8, in the three fading channels (EPA, EVA, ETU) it is found that for the same spectral efficiency ρ = 2 bps, the UTTCM encoder has a good performance compared to the classic turbo-encodercode during downlink transmission of LTE system and although the complexity of UTTCM encoder decoding is very low compared to turbo-code decoding.



(a) (b) (c)

Fig. 8 LTE Physical Layer Specifications

The measured gain of the encoding between the UTTCM encoder curve and the Turbo-code curve, for a BER = 10^{-5}. In the EPA channel, the gain is G1 = 4.71, for the EVA channel it is G2 = 4.56 and finally for the ETU this gain is G3 = 7.54. The LTE system with UTTCM channel encoding has better performances than an LTE system with standard Turbo-code encoding on all simulation channel (EPA, EVA, ETU).

VII. Conclusions

At the physical layer level, the LTE system makes it possible to use the propagation channel with great flexibility. The flexibility of the configuration offers many advantages (scalability according to the capabilities of the mobile receiver, adaptation to the environment ....). The potential of the LTE system techniques has been evaluated in order to meet the constraints of spectral efficiency, robustness or compatibility with simple and economical receivers, in different scenario.

In this paper, the work carried out focuses on the analysis and simulation for the optimization and improvement of the performance of LTE systems against transmission errors in typical channels (EPA, EVA, ETU). The results of the simulations show that the UTTCM encoding technique provides a significant gain in terms of performance quality with a lower degree of complexity, compared to the classic turbo-code encoding.

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