# Turbo-Coded Mobile Terrestrial Communication Systems in Urban and Suburban Areas for Wireless Multimedia Applications

F. Mehran

***Abstract*****—**With the rapid popularization of internet services, it is apparent that the next generation terrestrial communication systems must be capable of supporting various applications like voice, video, and data. This paper presents the performance evaluation of turbo-coded mobile terrestrial communication systems, which are capable of providing high quality services for delay sensitive (voice or video) and delay tolerant (text transmission) multimedia applications in urban and suburban areas. Different types of multimedia information require different service qualities, which are generally expressed in terms of a maximum acceptable bit-error-rate (BER) and maximum tolerable latency. The breakthrough discovery of turbo codes allows us to significantly reduce the probability of bit errors with feasible latency. In a turbo-coded system, a trade-off between latency and BER results from the choice of convolutional component codes, interleaver type and size, decoding algorithm, and the number of decoding iterations. This trade-off can be exploited for multimedia applications by using optimal and suboptimal performance parameter amalgamations to achieve different service qualities. The results are therefore proposing an adaptive framework for turbo-coded wireless multimedia communications which incorporate a set of performance parameters that achieve an appropriate set of service qualities, depending on the application's requirements.

***Keywords*****—**Mobile communications, Turbo codes, wireless multimedia communication systems.

## I. INTRODUCTION

IN wireless communication systems, the substantial bit-error-rate (BER) degradation is mostly due to the multipath fading. Frequency/Spatial diversity systems, equalizers, and Rake receivers are the most well-known techniques for suppressing fading effects; however, such advanced receivers might not sufficiently reduce the BER values. The remarkable forward error correction (FEC) capability of turbo codes [1] have obtaining a wide acceptance in many international standards such as the ETSI standard for digital video broadcasting (DVB) [2], the UMTS/3GPP standard for personal communications [3], and the Consultative Committee for Space Data Systems (CCSDS) standard for deep-space telemetry [4]. Moreover, the 3G TD-SCDMA, CDMA 2000, and WCDMA standards have all adopted turbo codes as one of their standard error-correcting codes [5]. Turbo codes are also employed in numerous Optical CDMA (OCDMA) networks [6]-[7], showing to yield substantial performance improvements compared with the uncoded networks.

In this paper, an adaptive coding strategy for the practical utilization of turbo codes in mobile terrestrial multimedia communication systems is discussed, and the numerical results on the BER performances and latencies in urban and suburban propagation environments are demonstrated through the simulations.

## II. TURBO-CODED MOBILE COMMUNICATION SYSTEMS

### A. Turbo Principles

Fig.1 shows the block diagram of the turbo coding system in wireless channel. The turbo encoder consists of two recursive systematic convolutional (RSC) codes known as component or constituent codes. The encoding operation can be viewed as the modulo-2 matrix multiplication of an information matrix with a generator matrix [6]. RSC encoder #1 encodes the input

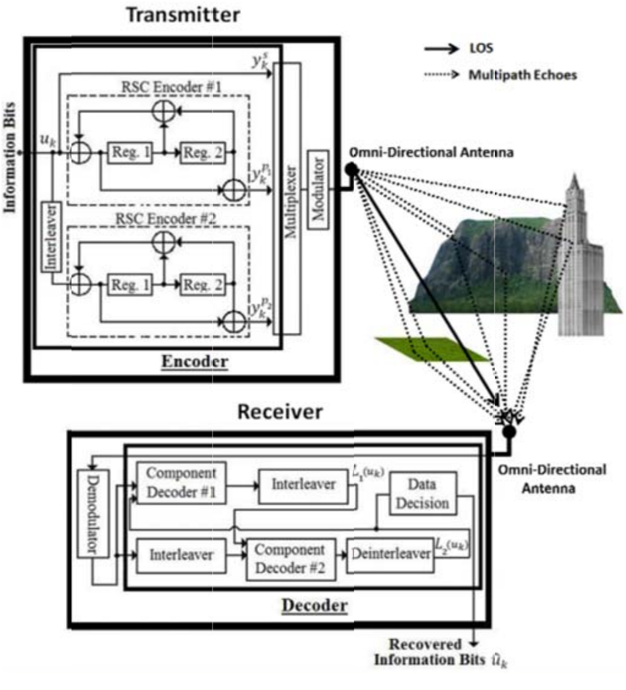

Fig.1. Turbo coding system in wireless channel.

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F. Mehran is with the Department of Electronic, Electrical, and Computer Engineering, University of Birmingham, Edgbaston, B15 2TT, UK, (E-mail: farhad.mehran@yahoo.com).

information bits directly, while RSC encoder #2 encodes the permuted version of the information bits (permuted in time by interleaver). The encoder outputs at time $k$ are composed of the systematic bit $y_k^s$ and parity bits $y_k^{p_1}$ and $y_k^{p_2}$ from the two component codes. As a result of this process, a large constraint length and randomized sequence is generated through the principles of concatenation and interleaving which help us to approach the Shannon's idea (i.e. error-free communications [8]). Due to the utilization of parallel concatenation in such turbo coding schemes, they are also termed parallel concatenated convolutional codes (PCCCs). The coded bit stream is modulated in a modulator, and afterward, the modulated signal is transmitted over the wireless channel.

The received signal is first processed in a demodulator for the detection. The demodulated signal is then decoded at the turbo decoder to estimate the transmitted information bits. Due to the presence of the interleaver, optimum maximum-likelihood (ML) decoding algorithms are very complex; however, implementation of the iterative decoding is quite feasible, where soft information is exchanged between component decoders. Actually, the term "turbo" stems from this iterative decoding with reference to the turbo engine principle. The core of the iterative decoding algorithm is the maximum a posteriori probability (MAP) decoding based on BCJR algorithm [9]. Each component decoder computes the *a posteriori* log-likelihood ratio (LLR) of the systematic bits known as the extrinsic information $L_{(u_k)}$. The extrinsic information refines the decoder outputs in each iteration. Based on the cross entropy (CE) between the distributions of estimated outputs of the component decoders at each iteration [10]-[11], or based on signature code of estimated outputs [12], the iterative process is stopped, and the data bit decision $\hat{u}_k$ is made according to the final decoder's output.

In many turbo-coded systems, it has been reported that at low BERs, the increase in transmit power leads to marginal reduction of BER values; for that reason, these errors are often called error floor or irreducible errors [8]. As one of the methods to avoid the BER floor of classic turbo codes, serial concatenated convolutional codes (SCCCs) were proposed by Benedetto *et al.* in 1996 [13]. SCCCs have been shown to outperform PCCCs in many cases [21]. The SCCC encoder consists of the cascade of RSC outer encoder, an interleaver, and an RSC inner encoder whose input codewords are the time-shifted version of the outer code's codewords. The SCCC decoding is based on the same algorithm as in PCCC, but with the slight difference in the decoder structure. Unlike PCCC, in the SCCC decoder, the outer decoder does not make use of a direct input from the demodulator [6]. The exhaustive discussions on SCCCs could be found in [21].

### B. Adaptive Turbo Coding for Multimedia Applications

The tremendous development in SCCCs has provided great opportunities for physical layer performance enhancements of various wireless communication systems. Due to the exhibition of error bursts during the multipath propagation in wireless channels, SCCCs are enabling technology for providing reliable communications. Two critical issues are often considered with respect to the design of SCCCs for multimedia applications: buffering delay and processing time. To provide better BER performance at moderate signal-to-noise ratios (SNRs) and eradicate the BER floor, the free distance of the code could be increased by increasing interleaver size; however, increasing the interleaver size leads to higher buffering delays which may not be desirable for some delay sensitive applications. Moreover, to provide high coding gain with low BER floor, the free distance could be increased by using a component code with a longer constraint length $L$; consequently, the decoding complexity and therefore the processing time increases exponentially [14]. Also, the steeper BER curve could be obtained by increasing the number of iterations in the decoding process at the expense of higher processing delay (it is worthful to mention that further iterations beyond a certain number offer only marginal additional coding gain which is not useful in practice). In addition, using original MAP decoding over suboptimal algorithms such as Log-MAP and Max-Log-MAP, results in better BER performance [15], while higher processing time is introduced at the decoder due to the considerable amount of computations.

To approach optimum quality-of-service (QoS) in terms of BER and latency requirements for multimedia applications, practical performance parameter combinations should be employed for SCCCs. For different types of multimedia information, different BERs and latencies are required. Voice or video applications accept higher error rates with low latency, while most data applications such as text transmission typically accept low BERs with high delay. Therefore, a new level of flexibility could be offered for multimedia applications by adopting SCCC's performance parameters so that we can use any of systems according to application requirements. The performance parameters of the designed SCCC systems are shown in Table I. Here, we used rate 1/2 component outer codes, and rate 2/3 inner codes (consisting of two component codes), resulting overall rate of 1/3.

TABLE I
TURBO CODING SCHEMES

| No. | Component Codes | Generator Polynomial Matrix | Interleaver (Type and Size) | Decoding Algorithm | Decoding Iterations |
|---|---|---|---|---|---|
| #1 | 4-state<br>(L=3) | outer code:<br>G(7,5)<br>inner code:<br>G(7,5,0) and<br>G(0,7,7) | Random<br>$N=2*200$ | Max-Log-MAP | It=4 |
| #2 | 4-state<br>(L=3) | outer code:<br>G(7,5)<br>inner code:<br>G(7,5,0) and<br>G(0,7,7) | Random<br>$N=2*1000$ | Log-MAP | It=6 |
| #3 | 8-state<br>(L=4) | outer code:<br>G(17,13)<br>inner code:<br>G(17,13,0)<br>and<br>G(0,17,17) | Random<br>$N=2*3000$ | Log-MAP | It=14 |

### C. Signaling Format

Generally, due to the difficulties as well as the cost and complexity incurred for the carrier phase recovery in coherent modulations, differential modulation techniques which do not require a coherent phase reference at the receiver are preferred for wireless applications [16]. Throughout this work, we have used differential binary-phase-shift-keying (DBPSK) signaling, as it is a commonly used method in many existing hardware platforms. DBPSK is a noncoherent form of BPSK which is easy and cheap to build, and therefore is widely used in wireless communication systems. In addition, it is more robust than coherent BPSK in high-Doppler and deep-faded environments [17].

### *D. Wireless Channels in Urban and Suburban Areas*

Wireless channel modeling is one of the most tantalizing components in the design of wireless communication systems. Generally, site-specific models are used to model the probability density function (PDF) of the channel impulse response for network planning and system deployment, while stochastic models are used more for the design and comparison of systems [8]. Stochastic models try to predict the PDF of the fieldstrength over a large area, instead of making correct prediction in one specific location.

The most well-known stochastic channel models are Rayleigh and Rician fading models, wherein *Rayleigh* and *Rician* distributions are used to describe the statistical time varying nature of the received signal's envelope when mobile moves characteristic of *urban* and *suburban* environments respectively [18]. When line-of-sight (LOS) is blocked by objects such as hills, mountains, trees or buildings, Rayleigh distribution is used to describe the PDF of received signal's amplitude. Meanwhile, when LOS exists, Rician distribution is used. In addition to the signal's amplitude, the spectral broadening of the received signal due to the mobility of the receiver could also be modeled based on statistical models. In [19], COST 207 channel models specify the Bi-Gaussian Doppler power spectral density (PSD) to be used for Doppler spectrum modeling of long echoes of the terrestrial propagations in urban areas [20].

## III. NUMERICAL RESULTS AND DISCUSSIONS

As we discussed previously, in urban environments where the LOS is blocked, Rayleigh PDF is used to describe the channel model if mobile moves characteristic of deep urban environment [18]. Fig. 2 shows curves of BER as a function of the energy per bit/noise power spectral density ($E_b/N_0$) for SCCC systems #1, #2, and #3 (discussed in the previous section) for mobile wireless communication system using DBPSK modulation in urban environment. The Doppler spectrum is modeled based on Bi-Gaussian PSD with the Doppler frequency of $f_d \ll 10Hz$ (assuming vehicle's speed is relatively low). Fig.3 also compares the resultant system latencies at $E_b/N_0 = 22\,dB$, where $\alpha$ is defined as a parameter that will vary depending on the processor's speed. In our investigation, the simulation model is implemented on a computer with moderate speed, resulting $\alpha = 500\,sec$s. As far as the time delay of turbo codes is the main bottleneck of their application for real-time voice and video communications, system #2 could be employed in this case which realizes sufficient error correction (i.e. $BER$=$1.64 \times 10^{-6}$ at $E_b/N_0 = 22\,dB$) with moderate latency; however, it should be noted that for hard real-time systems where late delivery cannot be tolerated, system #1 is an appropriate choice which provides very high speed service at the expense of degraded BER performance. For most data applications such as text transmission which can accept higher latency, the system #3 is a strong candidate because of its remarkable BER performance. It is worth to mention that for soft real-time applications in which we can relax the real-time constraints for providing better BER performance, system #3 could be used over system #2. Moreover, system #2 could be a better choice over system #3 for near real-time data transfer applications.

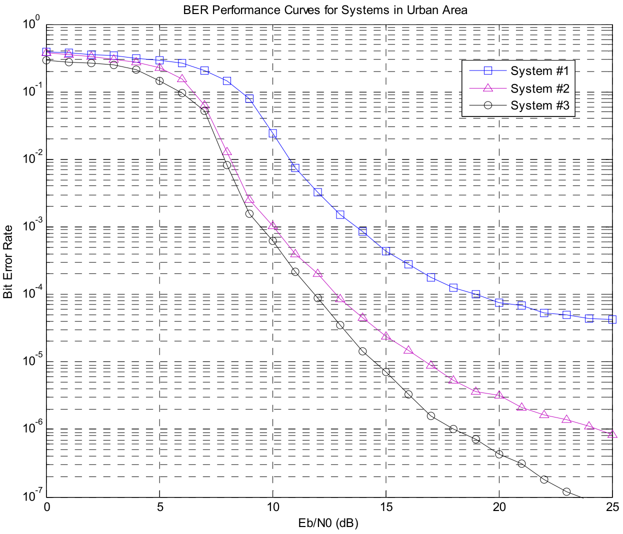

Fig. 2. Bit error probability versus energy per bit/noise power spectral density ($E_b/N_0$) for system #1, system #2, and system #3 with DBPSK, over Rayleigh-multipath fading channel with Bi-Gaussian Doppler PSD.

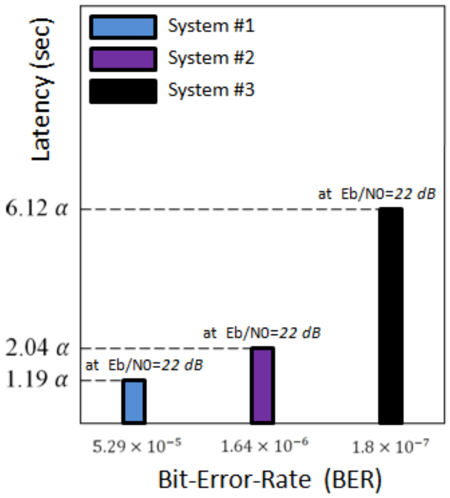

Fig. 3. Latency graphs associated with system #1, system #2, and system #3 in Rayleigh-multipath fading channel with Bi-Gaussian Doppler PSD at $E_b/N_0 = 22\,dB$.

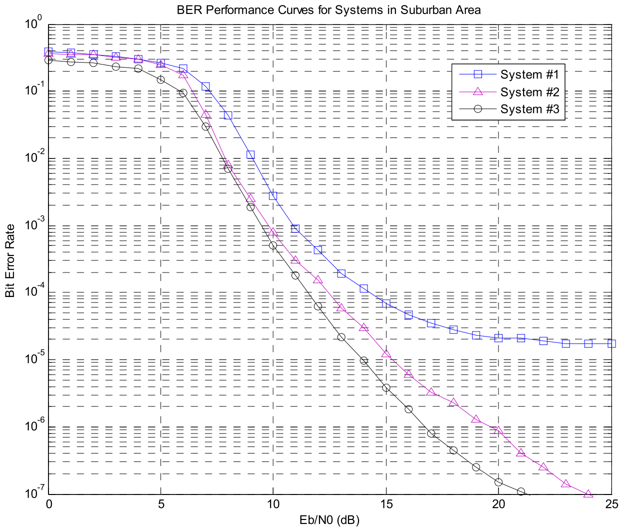

Fig. 4. Bit error probability versus energy per bit/noise power spectral density ($E_b/N_0$) for system #1, system #2, and system #3 with DBPSK, over Rician-multipath fading channel (*K* factor=*1*) with Bi-Gaussian Doppler PSD.

In Fig. 4, the performance of SCCC systems are simulated over Rician channel. Due to the presence of LOS in suburban areas, Rician PDF is used to statistical modeling of fading channel. In Rician fading, the ratio of the power in the LOS component to the power in the diffuse component is referred to as $K$ factor. The occurrence of deep fades is rare if strong LOS exists in propagation path (i.e. higher $K$ factor). In this simulation, we used $K$ factor=*1* (highly faded LOS) where Doppler shift of LOS component and the maximum shift of diffuse component are $f_{d,LOS} \ll 5\ Hz$ and $f_{d,diff} \ll 10\ Hz$ respectively. It is seen from the results that, as expected, even the existence of highly faded LOS in radio link provides substantial BER improvements. For instance for system #3 at $BER = 1.2 \times 10^{-7}$, we have up to $2dB$ improvement in power efficiency.

## IV. CONCLUSION

The challenging problems of turbo code's QoS for their practical utilization in mobile terrestrial multimedia communication systems have been tackled in this paper, and the numerical results on the BER performance and resultant latencies have been demonstrated through the simulations. The results can be interpreted generally as favoring the use of turbo codes in mobile terrestrial communication systems in urban and suburban areas. The results of this paper can be extended in a number of ways, including the utilization of interleavers with the better distance properties, and using the other serial concatenation schemes.

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**Farhad Mehran** (S'09) was born in Iran, in 1986. He received the MEng degree in Electronic and Communication systems engineering from the Department of Electronic, Electrical and Computer Engineering, University of Birmingham, Birmingham, U.K., in 2009.

From 2006 to 2007, he was working on DSP/FPGA projects at the *Microelectronic Research and Development Center of Iran*. In 2009, he was supervising training courses of BitGate data systems GmbH, and Solinet GmbH at the *Telecommunication Infrastructure Company (TIC) of Iran*. Meanwhile, he was also a director of "Pilot Flame Monitoring DSP Systems" project at the *HPC Technology Industries Co*. He is currently with *JDSU* agent in Iran, working on optical network testing systems. He is granted the JDSU TFSC in IP, Ethernet, MPLS, xDSL, ISDN, VoIP, and IPTV. His research interests include Channel Coding, Wireless and Optical CDMA systems, and Optical Communications.