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Audio watermarking with high embedding capacity based on multiple access techniques

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ABSTRACT

This paper deals with a new digital audio watermarking scheme based on multiple access techniques. In digital communication, multiple access techniques allow several users transmissions by taking the same communication channel. The present work proposes to embed multiple sub-watermarks in the same channel that is the audio signal. Our main objective is to investigate embedding capacity (the amount of information that can be hidden) limitations of our proposed audio watermarking system. Three multiple access techniques have been employed in the new multi-watermarking system: DS-CDMA (Direct-Sequence Code Division Multiple Access), FHMA (Frequency Hopped Multiple Access) and FDMA (Frequency Division Multiple Access). Experimental results allow us to make the choice on the best multiple access technique, in the multi-watermarking system, which significantly permits the highest embedding capacity (a data embedding rate up to 6 kb/s) with almost no loss of data imperceptibility and with acceptable extraction fidelity (BER $\simeq 10^{-2}$) even in presence of disturbances.

1. Introduction

Audio watermarking is the process that embeds data called watermark into the host audio, in such a way that it is imperceptible but easily extracted by computer algorithms. Initially proposed to protect the copyright [1], nowadays it is dedicated to various non-security-oriented applications [2]. One interesting and non-security application is the transmission of meta data along with multimedia. The embedded watermark in this application is expected to have a high capacity and to be detected and decoded using a blind detection algorithm. While the robustness against intentional attacks is not required, a certain degree of robustness against common processing like MPEG compression may be desired.

Nevertheless, it is not possible to attain simultaneously high robustness against signal modifications and high data rate of the embedded watermark. Indeed, the two most important watermarking approaches proposed in the past decade [3,4], can be grouped into two categories: robust methods based on Spread Spectrum (SS) modulations [5–8] and high capacity techniques based on Quantization Index Modulation (QIM) [9–11].

Watermarking systems look very similar to a particular communication one, where the audio signal is considered as a noise whereas the watermark signal is considered as data to be recovered [12]. However, watermarking schemes present major differences with communication ones. The watermark signal is characterized by a low power compared to the audio signal, whose properties are very different to white gaussian noise. Hence, audio watermarking performances are very low bit rates (several hundred bits per second) and high error rates (typically 10^{-2}) [2,8], as opposed to the megabits per second provided by communication systems and their associated low error rates (10^{-6}) [13]. It is therefore clear that watermark capacity and robustness against distortions are the two key issues of such a system.

Currently, enhancing embedding capacity with marginal degradation in robustness is one of the most desired aspects of each watermarking scheme. Few algorithms have been proposed to deal with this issue. In [14], the authors propose a multiple audio watermarking algorithm applying CDMA. Two watermarks are embedded in the discrete wavelet transform coefficients of the audio signal and then they are extracted by using FastICA (Fast Independent Components Analysis) algorithm. In that work, however, neither the amount of embedded data under the inaudibility constraint nor the robustness of the watermarks has been discussed. Another work is presented in [15] which is based on amplitude modification; the capacity of watermark information is increased by embedding multiple data in the different levels of audio data independently. This system is robust but requires stereo-audio signal to embed the multiple watermarks. In [16], the authors propose to embed different watermarks in the Empirical Mode Decomposition (EMD) domain to increase the number of binary data

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inserted into the audio or speech signals. The major shortcoming of this work is the computation cost that makes the algorithm inadequate to real-time applications. Moreover, the embedding data rate in that scheme is limited to 800 b/s. In a previous work [17], we proposed a new watermarking system based on CDMA and ICA techniques that provides an embedding rate up to 60 kb/s, while ensuring a compromise between inaudibility and extraction reliability. This system is simple but it is very fragile to perturbations and requires specific two-channel audio signals to be watermarked.

Other audio watermarking schemes that ensure a convenient trade-off between robustness and capacity have been proposed in [18,19]. In [18], the authors propose a high embedding capacity watermarking algorithm that embed data by changing the magnitudes of the FFT spectrum. In [19], the capacity of information is increased by embedding data in the high frequency band of the wavelet decomposition in which the watermark is imperceptible.

In this paper, we propose a new approach for audio watermarking that exploits multiple access techniques to increase the capacity of embedded information. Indeed, the problem is viewed as the realization of a multi-user communication system, where the different users represent multiple sub-watermarks that simultaneously access the audio channel [20]. In this case, two main factors limit the embedding capacity: extraction fidelity and inaudibility constraint. The multiple access technique used, in the proposed multi-watermarking system, can have an impact on the watermarking performance. Therefore we discuss three multiple access techniques: DS-CDMA (Direct-Sequence Code Division Multiple Access), FHMA (Frequency Hopped Multiple Access) and FDMA (Frequency Division Multiple Access). In addition to the evaluation of the new watermarking system, according to many criteria, we show how improvement in inaudibility can be achieved by choosing adequate carrier frequencies in the FDMA-based watermarking system. Moreover, we show how FDMA technique is robust to disturbances, like MPEG compression.

The outline of the paper is the following. In the next section, we present a brief description of multiple access techniques in watermarking. In Section 3, we present the proposed high capacity watermarking system. Experimental and various test results discussed in Section 4, will evaluate the performances of different multiple access techniques in terms of inaudibility, detection reliability, embedding capacity and robustness. Finally a conclusion ends this paper.

2. Multiple access techniques in watermarking

Multiple Access techniques allow all users of a communication system to share the available bandwidth simultaneously [21]. By exploiting the analogy between digital communication and digital watermarking [12], we consider different users as various sub-watermarks embedded in the same audio channel. The principal issue of the new multi-watermarking system is to eliminate the effects of sub-watermarks interference which limit the capacity of embedded information and degrade the Bit Error Rate (BER). Furthermore, by increasing the number of sub-watermarks, the BER grows significantly and the embedded data will be more perceptible. For this reason, three multiple access techniques; DS-CDMA, FHMA and FDMA are used, in the new system, in order to evaluate their impact on the performance system according to their own characteristics.

2.1. Code Division Multiple Access

2.1.1. Direct Sequence-CDMA

Direct Sequence Code Division Multiple Access (DS-CDMA) is a method that can be used to multiplex different sub-watermarks by distinct codes. The original data signal is multiplied directly by the high chip rate spreading code. The codes properties can be characterized by an important factor that is the low values of cross-correlation between codes that reduces the Multiple Access Interference (MAI). The selection of the best spreading code, to differentiate the multiple sub-watermarks, plays an important role in the watermarking system. In this work, we use Walsh codes that consist of a set of orthogonal functions. This choice stems from a previous comparative study already made between various spreading codes, that has shown the superiority of Walsh codes in terms of ensuring the best compromise between inaudibility and detection fidelity [22].

2.1.2. Frequency Hopping Multiple Access

Frequency Hopping Multiple Access is another digital multiple access technique, in which the carrier frequency of each sub-watermark is rapidly changed according to the spreading code within the system's available bandwidth. The resulting signal is spread over a wide frequency range in a sequence of carrier frequencies randomly selected.[1] Moreover, it is sent with a chip rate R_c defined as [13]:

$$R_c = \max(R_h, R_s) \tag{1}$$

where R_h is the hop rate and R_s the symbol one.

Since frequency hopping does not cover the entire spread spectrum instantaneously, we are led to consider the rate at which the hops occur. In this context, we use FFH[2] codes that provide better performance, in terms of inaudibility and extraction fidelity, than SFH[3] codes [22]. By using FFH codes, there are several frequency hops per modulation data symbol and the chip rate is defined as [13]:

$$R_c = R_h = U R_s \tag{2}$$

where R_s is the symbol rate and U is the number of hops in each symbol.

2.2. Frequency Division Multiple Access

One of the simplest ways to minimize co-channel interference consists in employing sub-watermark signals whose spectra do not overlap. This multiple access mode called FDMA, commonly used in cellular systems [23], can be used in audio watermarking [24]. The available audio channel is sliced up into a number of frequency channels which are used by a single sub-watermark at a specific audio samples. If M-ary PSK is used for data embedding at the rate R, the data symbol duration is $T_s = \frac{\log_2(M)}{R}$ so that each sub-watermark's signal occupies bandwidth no smaller than [13]:

$$W = \frac{R}{\log_2(M)} \tag{3}$$

3. The high capacity audio watermarking system

3.1. Embedding process

The proposed multi-watermarking embedding scheme is presented in Fig. 1.

The original binary message m of length N is represented as an independent and identically distributed binary sequence. The time T_b used to insert one bit is related to the sampling frequency F_s of the audio signal by:

$$T_b = \frac{N_b}{F_s} \tag{4}$$

[1] This sequence is called Hopping Code.
[2] Fast Frequency Hop.
[3] Slow Frequency Hop.