Performance Evaluation of a DAB system with Space-Time Block Coding.

Irma Uriarte, Ángel G. Andrade, Guillermo Galaviz.
Facultad de Ingeniería-México, Universidad Autónoma de Baja California, Blvd. Benito Juárez, S/N Mexicali, B.C. 21280, Phone: (686) 5664270 ext:1408 e-mail: [irma.ur, angel.andrade, ggalaviz]@uabc.mx

Abstract

This paper evaluates the performance of space-time coding techniques applied to a Digital Audio Broadcasting (DAB) System. The proposed scheme uses two transmitter antennas and one receiver antenna. This work investigates the way space and time diversity can decrease the distortion due to multipath fading and interference from other users and improve bit error rate. Numeric results show that space-time codes are a good way to improve the performance of a system DAB and the quality of additional information services.

1. Introduction

The past decade has been noted by remarkable changes and developments in the field of radio broadcasting. The need for fast conversion to digital radio broadcasting has been recognized and a lot of research has been done to develop schemes that can best satisfy the requirements. Digital Audio Broadcasting is referred to in various ways including DAB, DRB (Digital Radio Broadcasting) and DSB (Digital Satellite Broadcasting). Some new systems include the Eureka-147 (satellite based delivery in the frequency band from 30 MHz to 3 GHz), CD Radio (satellite based delivery in the S band from 2.31 to 2.36 GHz) and the Voice of America/Jet Propulsion Lab (VOA/JPL) system (another satellite based delivery system poised to operate in the S band at around 2.3 GHz). These “new-band” systems have the advantage that they can standardize their own allocation bandwidth and offer a lot of flexibility [1].

The DAB system requires high-rate transmission for multimedia and data services. However, due to spectral limitations, it is impractical or sometimes very expensive to increase bandwidth. Also, the transmitted signal undergoes severe distortion due to multipath fading and interference from other users. To combat the adverse effects of the radio signal propagation environment, several diversity techniques have been developed [2], [3]. These techniques offer increased protection against the channel-induced distortion by providing multiple versions of the transmitted signal to the receiver [4], [5].

Many different diversity (temporal, frequency, polarization, code, spatial) techniques have been utilized to get significant performance improvements by neutralizing effects of fading in wireless communication channels. During the past few years there has been a growing interest to combine the benefits of forward error control coding and antenna diversity.

Diversity transmission using Alamouti’s Space-Time Block Coding (STBC) scheme has been proposed in several wireless standards. The STBC schemes are focused on merging antenna diversity with appropriate channel coding in order to achieve both coding and antenna diversity gains. One of the first design criteria for such codes was derived in [6]. Such systems employ multiple antennas, or antenna arrays, at both the transmitter and the receiver to enable spatial and temporal multiplexing of data and, thus, increased data rates. Traditionally, multiple antennas have been used at the receiver to provide spatial diversity and mitigate the effects of signal fading due to multipath propagation in the channel. However, recent developments in information theory have shown that by using multiple transmit and receive antennas, signal fading can in fact be turned into an advantage. With multiple antennas at both the transmitter and the receiver, spatially distributed channels can be supported simultaneously in the same frequency band, and by transmitting data in parallel through these channels the data rate can be increased. However, the main impetus on research in the space-time coding area...
was done in [7], [8] where powerful and bandwidth efficient space-time trellis codes (Tarokh-STTC) were proposed. More recently, space-time block codes based differential space-time block code (DSTBC) modulation scheme was proposed in [9]. The decoding of the DSTBC modulation scheme is more efficient than before schemes, especially for large constellations, since it allows a decoupled linear detection, with which it detects each information symbol separately.

Most previous work in space-time coded systems has been evaluated in cellular systems. For example, a performance criterion for single-user space-time code construction was given in [10]. In this paper, multiuser detection for space-time coded multiple-access systems is considered. Spatial diversity has been proposed for support of very high rate data users within DAB systems [11]. In this work, the authors applied a layered space-time architecture to a DAB system. The MIMO-DAB system with a number of transmitting and receiving antennas increases the transmission rate efficiently with low multiplication operations. They proposed a training sequence and evaluated the channel estimation performance based on semi-blind processing using time-domain windowing. Also, they showed that the MIMO-DAB system with multi-antennas can achieve high-rate transmission for multimedia broadcasting and the performance of the MIMO-DAB system is impaired by imperfect channel information.

In [12], the authors analyze the reception of Terrestrial Digital Audio Broadcasting (T-DAB) signals at L-Band in mobile channels, where multipath fading, Doppler spread and noise effects degrade the received signal. The results presented in this paper contribute to a detailed characterization of the DAB signal degradation and the required CNR threshold values in mobile channels. An efficient coded scheme for transmitting digital audio over the existing FM channel, by multiplexing it with the baseband FM signal, is described in [13].

The investigated scheme opens up the possibility of achieving CD quality audio over FM-SCA by enabling high bit rate transmission using MPEG-1 layer 3 and MPEG-AAC audio coding for the digital audio. The system uses OFDM in conjunction with 8PSK/16PSK to modulate the digital bitstream and fit it in the 44 kHz (54 to 98 kHz) band available in the FM baseband.

The goal of this investigation is to evaluate the performance of a Space-Time Block code in a DAB system under a multipath environment. We use the Alamouti STBC due some of the attractive features:

first, it achieves full spatial diversity at full transmission rate for multiple transmitters and one or more receivers and at any signal constellation. Second, it does not require channel state information (CSI) at the transmitter. On the other hand, the STBC has a simple decoding scheme based on linear processing [6]. Also, the STBC has been adopted in several wireless standards such as WCDMA and Wireless LAN systems [14].

We organized the remainder of this paper as follows. As the preliminary, in the next section, we explain briefly the Alamouti’s Space-Time Block Coding used in this paper. In Section 3 and 4, we describe the configuration and operations of the model system. Computer simulation is presented in Section 5, numerical results are presented in section 6 and this paper is concluded in Section 7.

2. Alamouti’s STBC

In this section, we explain the Alamouti’s STBC scheme [6]. The Alamouti’s STBC with $M = 2$ transmitters, is the only scheme which can provide data transmission at full rate and with full diversity at any signal constellations. Without loss of generality, we shall restrict our attention to this type of STBC. At the transmitter of Alamouti’s STBC, input signal $s(t) : \{ t \in \mathbb{Z} \}$ is divided into two groups as $s_1(t)$ and $s_2(t)$. Both signals are sent through two transmit antennas at different time. At time $t$, 1st antenna (Tx1) transmits $s_1(t)$ while 2nd antenna (Tx2) transmits $s_2(t)$. In time $t+T_s$, Tx1 transmits $s_1^*(t+T_s)$ while Tx2 transmits $s_2^*(t)$. The transmit signal at Tx1 and Tx2 antennas will be summarized as follows. Note that $s(t)$ is the signal transmitted from antenna $i \in \{1, 2\}$, at time $t$.

\begin{align}
\begin{aligned}
x_1(t) &= s(t), & x_2(t+T_s) &= s_1^*(t+T_s) \\
x_2(t) &= s(t+T_s), & x_2(t+T_s) &= s_2^*(t)
\end{aligned}
\end{align}

(1)

(2)

where $x^*$ is the conjugate of $x$.

The channel transfer function $(h_1, h_2)$ is modeled as follows:

\[
H(t) = \sum_{\ell=0}^{\ell=4} H_{\ell} \delta(t - IT_s)
\]

(3)

where;
and $h_{ji}$ is complex number expressing the channel between $j$-th receive antenna and $i$-th transmit antenna and, $\delta$ is the Dirac delta function, $\tau$ is the discrete time sequences of propagation delay. $H^\prime$ is the channel state information of the preceding wave, while for $l \in \{1, \ldots, L - 1\}$, $H^\prime_l$ is $l$-th delayed channel information which causes ISI. Here, $L$ and $T_0$ are the length of the channel and symbol data duration, respectively.

After passing through the Frequency Selective Fading (FSF) channel, the received signal by $j$-th receiver antenna at time $t$ and $t + T_0$ are given as follows:

$$r_j(t) = \sum_{i=1}^{L} \left[ h_{ji} x_i(t - iT_0) + h_{ji} x_i(t - iT_0) \right] + n_j(t)$$  \hspace{1cm} (5)

$$r_j(t + T_0) = \sum_{i=0}^{L-1} \left[ h_{ji} x_i(t - (l-1)T_0) + h_{ji} x_i(t - (l-1)T_0) \right] + n_j(t + T_0)$$  \hspace{1cm} (6)

Here, $n_j(t)$ and $n_j(t + T_0)$ denote the complex additive white Gaussian noise (AWGN) with zero mean and variance $\sigma^2$ in each real dimension. This method shows a significant performance improvement in the flat fading channel. However, it cannot work well in the presence of multipath signal arriving with the longer delay than $T_0$, which causes the ISI. In [15], the authors present a strategy to improve the STBC transmission in a FSF channel.

3. System Model

Considering the general formulation of the STBC explained in section 2, in this section we present the system model used to evaluate the performance of a DAB system.

For simplicity, this paper only considers a system with two transmit and one receive antenna as shown in Figure 1. Initially, the transmitter sends a code unitary matrix $G_2$:

$$G_2 = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix}$$  \hspace{1cm} (7)

which is known at both the transmitter and the receiver. $x_1^*$, $x_2^*$ are the complex conjugates of $x_1$ and $x_2$, respectively.

Then, the matrix $G_2$ is transmitted over two different channels $h_1$ and $h_2$.

Therefore, we can write:

$$h_k = h_1(T = 1) = h_2(T = 2)$$  \hspace{1cm} (8)

$$h_k = h_1(T = 1) = h_2(T = 2)$$  \hspace{1cm} (9)

Independent noise samples are added at the receiver in each time slot and hence the receiver signals can be expressed by:

$$y_1 = h_1 x_1 + h_2 x_2 + n_1$$  \hspace{1cm} (10)

$$y_2 = -h_1 x_1 + h_2 x_2 + n_2$$  \hspace{1cm} (11)

Where $y_1$ is the first received signal and $y_2$ is the second. The first signal $y_1$ consists of the transmitted signals $x_1$ and $x_2$, and $y_2$ of their conjugates. To determine the transmitted symbols, signals $x_1$ and $x_2$ are extracted from $y_1$, $y_2$.

![Figure 1. Basic representation of STBC](image)

4.- Space-Time Block Code used in Digital Audio Broadcasting.

Digital Audio Broadcasting projects already exist in Europe and Unites States. They were developed based on the country’s needs and requirements. The European Community proposed its own standard called
Eureka-147. It requires the availability of new radio spectrum. The system provides more efficient use of the spectrum and promises CD audio quality. On the other hand, United States is working on a digital radio project called IBOC (in-band, on-channel), which uses the existing spectrum for analog radio (AM and FM bands) and is designed to coexist with the analog systems. In most cases, an IBOC DAB system will work with the existing antenna and transmitter, because it uses the same frequency bands that analog radio stations use. Some system characteristics are shown in Table 1.

Table 1. Basic characteristics of the Eureka 147 and IBOC Digital Audio Broadcast systems

<table>
<thead>
<tr>
<th>System</th>
<th>Audio Coding</th>
<th>Modulation</th>
<th>Channel Coding</th>
<th>Error Correction</th>
<th>Multiple Access</th>
<th>Interference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eureka</td>
<td>16 kbps</td>
<td>16 kbps</td>
<td>32 kbps</td>
<td>16 kbps</td>
<td>16 kbps</td>
<td>16 kbps</td>
</tr>
<tr>
<td>IBOC</td>
<td>32 kbps</td>
<td>32 kbps</td>
<td>64 kbps</td>
<td>32 kbps</td>
<td>32 kbps</td>
<td>32 kbps</td>
</tr>
</tbody>
</table>

To reduce the error probability and increase the bit rate, in this work we propose to carry out the performance evaluation of the Eureka-147 DAB system using the Alamouti Space-time block code. The basic model of the Eureka-147 DAB system is shown in Figure 2.

Figure 2. Eureka-147 system Block Diagram

5.- Computer Simulation.

We investigate the performance of the proposed scheme in figure 2 through computer simulations. The simulation conditions are shown in Table 1. Here, we consider the case of BPSK, QPSK and QAM modulation transmission. Moreover, for a higher order modulation scheme, it can be applied in the proposed scheme without any modifications. In our simulation the transmitter is equipped with M = 2 transmit antennas and uses the Alamouti's STBC to encode the data symbols. The receiver is equipped with N = {1, 2} antennas, as shown in Figure 1 and 3 respectively. The transmit power from each transmit antenna is set equal to 1/2 to normalize the total power to 1. The channel is assumed to be both AWGN and Rayleigh channel with the maximum delay of L−1, and with uniform power delay profile. The delay profile adopted here may not be realistic in actual environment, but it is suitable to investigate the ability of the proposed scheme in suppressing the interferences. The channel between each transmit antenna i-th and receive antenna j-th is assumed to be i.i.d and quasi-static Rayleigh fading. The quasi-static property means that the channel remains constant over a certain time, called frame period, and changes independently. The path gains are modeled as independent, complex, zero mean, circularly symmetric Gaussian random variables with unit variance. Furthermore, some additional assumptions are made to facilitate the analysis. First, the receiver has knowledge of the propagation coefficients. Second, the receiver is perfectly synchronized with the transmitter. Noise in each receive antenna is assumed spatially and temporally uncorrelated, and is generated using the same process as channel coefficients.

Figure 3.- Representation of G2 using two receivers.

The input bit stream is divided into b, bit long blocks, forming $B_{in}$ ($B = 2^{ln}$) source symbols. The STBC encoder works as a finite state machine with N states: it takes the current $b_t$ bit long source symbol, $bx$ ($b_t \in \{0, 1, \ldots, B − 1\}$) at discrete time $t$ ($t = 0, 1, 2, 3, \ldots$), and governed by this input and the current state, $S_i$ ($S_i$,
\( E \{0, 1, \ldots, N - 1\} \), it moves to the next state, \( S_{n+1} \). During this state transition, the encoder outputs \( K \) Bary channel symbol indices, one for each transmit antenna. We denote by \( i_k(S, b) \) the channel symbol index for transmit antenna \( k \), generated during the state transition from \( S \), when the current input source symbol is \( b \).

6. Numerical results

The Eureka-147 system was tested part-by-part to ensure that all the components were performing as expected. The core components that were tested first included the audio encoder-decoder, convolutional forward error correction, and space-time coder. Once these components were shown to be working, a basic model without coding, interleaving, equalization or fading was tested to confirm validity against theoretical results. The basic system consists of a 3 Mbps random data source, an AWGN channel is assumed initially. The system roll-off factor is fixed at 0.5 for all system configurations, because that is the most representative value for a practical communication system. We consider a mobile communication channel where base station is equipped with two transmitting antennas and the mobile receiver is equipped with one antenna. Figure 4 shows the results of basic performance of a G2 code for different modulating schemes (QPSK, 8PSK and QDPSK) according to the number of antennas (2 Tx or 1 Tx and 1 Rx). The generated symbols are introduced to the space-time coder, it makes a time and space mapping using (7). As is expected, coding gain of approximately 11 dB can be observed at the BER of \( 10^{-4} \) for both G2 QPSK (2 Tx, 1 Rx) and QDPSK (1Tx, 1 Rx) cases in general. Figure 4 is well in concert with theoretical expectations. As the Eb/No ratio decreases, BER performance drops slightly but not significantly. While 8-PSK can provide higher bandwidth efficiency than QPSK, it is not nearly as reliable as QPSK since it shows more degradation than QPSK case for the same G2 coding.

Figure 5 shows the performance results for the DAB system with a STBC G2, for \( K=2 \) transmit antennas and \( N = 2 \) receive antennas. We are considering four different modulation schemes, BPSK, QPSK, 8PSK, and 16PSK. We use the Bit Error rate (BER) as the measure of performance. In order to consider practical channel conditions, we simulate the system under a Rayleigh fading channel. It can be observed that the STBC indeed provides different spatial diversity advantages since the steepness of the bit error rate curves is different. The simulation result shows that the performance improvement is more pronounced at higher Eb/No. Also in figure 5 the performance of equivalent systems without STBC is shown. These results reveal the significant gains that can be achieved with space-time coding in DAB systems, even with only two transmitter antennas. For example, at 0.001 BER, there is more than 6 dB gain in employing the two-antenna space-time code, against a system that does not employ transmitter antenna diversity. Comparing this figure with Figure 4, we see that, at a BER of 0.001, there is more than 10 dB Eb/No gain over the two antennas system without STBC. It is clear from these results that space-time coding can offer significant Eb/No improvement in multiuser channels.

Figure 4. Eureka-147 Performance considering AWGN channel

Figure 5. Eureka-147 performance under G2 system

As indicated in table 1, Eureka-147 uses QDPSK modulation for the transmission. To carry out the results in figure 6, we use fading channel and QDPSK modulation. This digital radio system uses also a convolutional forward-error-correction (FEC) channel
coding to provide strong protection against bit-errors. The code rate used during the simulation was 1/2 and we simulated 1024 bits blocks. We can see in figure 6 that for 10 db the system got BER=10^5. However, if we only use DQPSK and a FEC, the system got a BER=10^3.

![Figure 6. Eureka-147 performance with DQPSK modulation and G2 code](image)

7. Conclusions

In this paper, we have presented a performance evaluation of the Eureka-147 DAB systems that use multiple transmit and receive antennas. Multiple transmit antennas are used for the purpose of increasing the data rate, while space-time coding and multiple receive antennas are employed to improve the performance in fading multipath channels by introducing signal diversity. We can see that using Alamouti’s space-time block code is possible to improve the information quality for a signal to noise ratio.

References