DIGITAL SOUND BROADCASTING TO MOBILE RECEIVERS

Bernard Le Floch, Roselyne Halbert-Lassalle, Damien Castelain
CCETT (Centre Commun d'Etudes de Télédiffusion et Télécommunications)
35512 Cesson Sévigné, France

ABSTRACT

Many European countries have shown an increasing interest in the development of a new audio broadcasting service with a view to providing an improved sound quality on portable and mobile receivers.

Digital techniques have progressed over the past few years in the areas of sound programme production and source bit rate reduction as well as in the field of channel coding and modulation. Within the framework of the DAB (Digital Audio Broadcasting) EUREKA 147 project, our research institute has designed a new broadcasting system, fully digital from studio to user.

This paper deals with a promising modulation and channel coding system, suitable for digital broadcasting through the particularly hostile urban radio channel.

A successful field demonstration has been organized under the auspices of the European Broadcasting Union during the WARC-ORB 88 in the town of Geneva, to validate these new concepts of digital sound broadcasting, combining spectrum and power efficiency.

1. INTRODUCTION

From the technical point of view, the development of such a new digital audio broadcasting system is related to a twofold problem :

- it requires the development of a sophisticated source coding system. It is generally admitted that, in this respect, a monophonic sound with a quality equivalent to that produced by compact disks can be reduced to 128 kbit/s or less.
- it also requires the design of a channel modulation and coding system that can be used by mobile receivers up to 1 GHz or more.

This article deals exclusively with this second problem.

For reception in a built-up area, the channel impulse response usually extends over a few microseconds, and in some cases as much as 10 µs or more. This being so, frequency-non-selectivity concerns only low bit-rate transmissions (a few tens of kbit/s) and can under no circumstances constitute a valid hypothesis for high-quality sound broadcasting.

Given the high selectivity of the channel, conventional equalization techniques are very difficult to implement. More sophisticated techniques, such as Viterbi equalization, do not apply because of the excessively high number of states required in the Viterbi decoder.

The methods generally adopted to resolve this type of problem are based on the use of M-orthogonal alphabets [1] [2] which increase the duration of symbols and allow for paths discrimination. Unfortunately intercorrelation constraints between the various alphabet sequences lead to a major increase in the bandwidth which is far from compensated by the increased number of bits transmitted per symbol. The spectral efficiency of this type of system is therefore totally incompatible with the broadcasting constraints.

The system described in this article, combining spectrum and power efficiency, is mainly based on the conjunction of the Orthogonal Frequency Division Multiplexing technique (already proposed for HF data transmission in an ionospheric channel or for transmissions through telephone networks [3] [4]), and a coding strategy associated with diversity in the frequency domain.

Section 2 gives a general overview of the urban mobile radio channel and its effects on data transmission. The general principles of the COFDM (Coded Orthogonal Frequency Division Multiplex) are explained in section 3. Section 4 gives a detailed representation of the signals and the decoding procedure. The performances of the system in the so-called selective Rayleigh channel are then presented in section 5. Section 6 describes the behaviour of the system when the conditions of temporal and frequential coherence of the channel are not fully met (very high speed reception and anormally extended channel delay spread). In section 7, the use of such a system in a broadcasting network is discussed. The realization aspects are finally presented in section 8.

0098 3063/89/0200 0493$01.00 © 1989 IEEE

Manuscript received June 9, 1989

2. DIGITAL TRANSMISSION IN THE URBAN RADIOMOBILE CHANNEL

The broadcasting channel used for transmission to mobile receivers in a built-up area is a particularly hostile transmission environment. Industrial interference, and mainly multipath propagation caused by natural obstacles, necessitate the implementation of sophisticated modulation devices in order to provide an excellent-quality transmission. One of the major difficulties results from the constant evolution of the channel characteristics as the receiver is moving.

Theoretical studies summarized in CCIR [5] reports established a twofold channel model :

- the first part estimates the value of the mean energy received in small areas (a few hundred wavelengths) ;
- the second part takes into account the combination of various paths originating from discrete reflections and received after scattering on objects (such as trees, other vehicles, etc...) that cannot be considered as mere reflective surfaces.

With regard to the first part of this model, results of experimental research in an urban environment showed that the distribution of mean energy passed from one small area to another follows a log-normal law with a mean value related to free-space propagation.

The second part of the model can be represented by the block diagram of figure 1 :

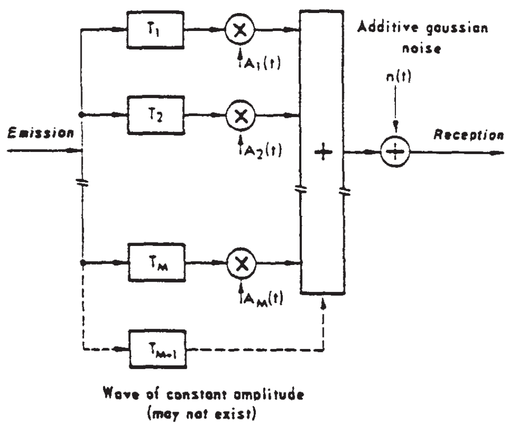

Figure 1

Outline of the transmission channel

The delays T_i originate from the various specular reflections, while the multiplying factors $A_i(t)$ are the consequence of local scattering. If the number of scattered sub-waves is large enough, it can be shown that the modulus of the term $A_i(t)$ follows a Rayleigh distribution. The power spectrum of $A_i(t)$ can be easily deduced from the distribution of the incidence of the sub-waves with respect to the direction of displacement of the vehicle. Assuming this distribution to be uniform and continuous over $[-\pi , \pi]$, the power spectrum of the process $A_i(t)$, translated to baseband and associated with each path, can be written :

$$\gamma A_i(\nu) = \frac{P_i}{\pi\sqrt{(\frac{v}{c}\cdot f_0)^2-\nu^2}} \quad \text{if } -\frac{v}{c}f_0<\nu<\frac{v}{c}f_0$$

In this expression, f_0 is the carrier frequency, v is the vehicle speed and c is the velocity of the light.

Moreover, it can be easily understood that the variations of the various Ai(t) are not correlated, because they arise from distinct origins.

Considering the problem of data transmission through this type of channel, a large number of authors [6] [7] [8] pointed out that classical modulation systems (eg 4-PSK or FSK) lead to an irreducible bit error rate, even for large signal-to-noise ratio, caused by two independent phenomena :

- Selectivity, due to the spread of the channel impulse response, will cause intersymbol interference, as soon as the data rate tends to increase.
- Time variation of the channel characteristics, as a result of the changing environment of the receiver, will cause degradation in the phase estimation of the receiver, as soon as the data rate tends to be too low, for a given vehicle speed and carrier frequency.

Even in the case where the channel is neither frequency-selective nor time-selective, the bit error rate as a function of the signal-to-noise ratio is known to decrease very slowly. More than 35 dB of E_b/N_0 is needed for a 4-DPSK modulation scheme, to achieve a 10^{-4} bit error rate (see section 6).

This makes evident the need of sophisticated modulation and channel coding schemes for data broadcasting through the mobile urban channel.

As it has already been said, frequency selectivity must be considered as an unavoidable phenomenon for high quality sound broadcasting. Moreover, the diversity provided by the use of wide-band transmission must be considered as an advantage if the communication system is designed to make use of multipaths rather than be restricted by their presence. Because of the spread of the channel response, it is highly unlikely that fading would simultaneously affect a frequency band covering a few megahertz.

The system described below exploits this property. In addition, it offers an excellent spectral efficiency, which is essential in sound broadcasting.

This being so, a certain number of sound programmes (e.g. 12 to 16) have to be multiplexed, forming a signal in which each basic data source will benefit from the "wide-band" character of the transmission.

3. GENERAL PRINCIPLES OF THE COFDM SYSTEM

Taking into account the above channel modelling, it is possible to represent the effects of the transmission by combining the channel frequency response and time variation (fig.2). This two-dimensional function characterizes the so-called "selective Rayleigh channel", and admits a decomposition in surfaces of different sizes :

- the small surfaces represent the frequency-time areas where the channel can be considered as locally invariant ;
- the large surfaces indicate the minimum separation for which two small surfaces are statistically independent.

Considering where the channel is invariant on the one hand and statistically independent on the other, this decomposition constitutes the basis of the channel modulation and coding method described in the following sections [9].

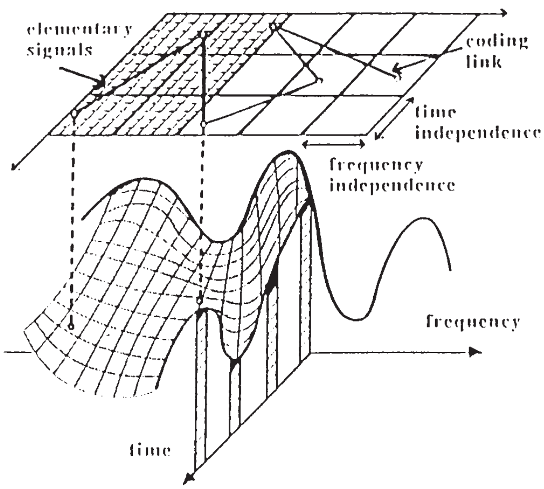

Figure 2

channel frequency response

3.1 OFDM modulation technique

The first principle consists in splitting the information to be transmitted into a large number N of modulated carriers with a low bit rate, in order to reduce the effect of the channel frequency selectivity. The OFDM technique permits the time-frequency domain to be split into small surfaces (fig. 2) with different dimension T_S and $1/T_S$ on the time and the frequency axes respectively.

The modulated OFDM signal can be expressed on an orthogonal base of elementary signals with complex coefficients, where each elementary signal is defined as one of the N emitted carriers during a symbol time T_S, and each coefficient, taking its value from a finite alphabet, represents the modulation applied to each elementary signal.

The main difference between conventional Frequency Division Multiplexing and this technique, is that the spectrum of the different carriers mutually overlap, giving therefore an optimum spectrum efficiency (asymptotically 2 bit/s/Hz for a 4-PSK modulation of each carrier). Nevertheless, the signal verifies orthogonality conditions, so that it is possible to extract the information modulating each carrier without suffering interference due to the presence of the other carriers. Morever, the modulation and the demodulation processes can be undertaken by means of Fast Fourier Transform algorithms.

Regarding the multiple paths of the transmission channel, the condition of perfect orthogonality between carriers is no longer maintained at the receiver input, due to residual intersymbol interference.

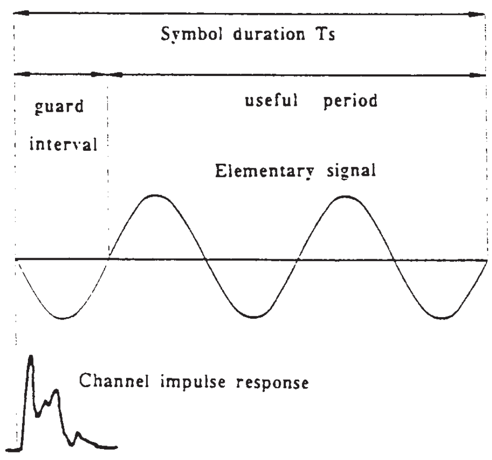

Figure 3

Use of a guard interval to suppress the intersymbol interference

An asymptotic solution to solve this problem would consist in increasing indefinitely the number of carriers and consequently the symbol duration. But this method is irrealistic taking into account the limitations dictated by the time coherence (see section 6) of the channel (Doppler effect). The retained solution comprises the addition of a safeguard interval before each useful symbol. If the safeguard interval duration is chosen sufficiently longer than the spread of the impulse response of the channel, the useful period of the signal remains free of intersymbol interference and the orthogonality remains perfect (fig. 3).

3.2 Coding scheme

Although the OFDM technique resolves the problem of transmission channel selectivity, it does not suppress fading. The amplitude of each carrier is usually affected by a Rayleigh law (or a Rice law when there is a direct path). This is why an efficient channel coding system is essential.

The second principle of the COFDM system consists on linking by a coding procedure, elementary signals (small squares) transmitted at distant locations of the time-frequency domain (fig.2). This is achieved by convolutional coding (associated to soft decision Viterbi decoding) in conjunction with frequency and time interleaving. The interleaving depth is relative to the dimensions of the large surfaces of the channel representation.

The diversity provided by interleaving plays a vital role in this system. The Viterbi decoder cannot function correctly unless successive samples presented at its input are affected by independent Rayleigh laws. In practice, the distortions to which these samples are subjected have a strong time/frequency correlation. When the receiver is not moving, the diversity in the frequency domain is sufficient to ensure that the system functions correctly. Due to the spread of the channel response (a few microseconds), flat fadings over a few megahertz are very unlikely. From this point of view, the existence of multipaths is a form of diversity and should be considered as an advantage.

4. SIGNALS REPRESENTATION AND DECODING PROCESS

The elementary modulation symbol transmitted during the time interval $T_S = t_S + \Delta$ is given by :

$$x(t) = \sum_{k=o}^{N-1} \mathrm{Re}\left(C_k e^{2i\pi f_k t}\right) \qquad t \in \left[0, T_s\right]$$

with $f_k = f_0 + k/t_S$

where the equation parameters are the following :

t_S : useful symbol duration, on which the demodulation will be processed.

Δ : guard interval duration.

f_0 : transmitting frequency.

N : number of carriers of the multiplex.

C_k : complex element of the modulation alphabet.

The emitted signal is constituted by the juxtaposition in time of the elementary symbols defined above.

The transmitted message fixes the values of the modulation elements C_k, belonging to an alphabet that specifies the type of modulation.

For example, the alphabet corresponding to a 4-PSK modulation is the following :

$$\{ 1+i, 1-i, -1+i, -1-i \}$$

On the assumption that the guard interval is longer than the channel impulse response, and that the channel varies slowly as compared to the symbol duration (invariance of the channel on small surfaces), the elementary symbol received in the time interval free of intersymbol interference, can be expressed by :

$$y(t) = \sum_{k=o}^{N-1} \mathrm{Re}\left(H_k C_k e^{2i\pi f_k t}\right)$$

where $H_k = \rho_k e^{i\varphi_k}$ is the channel response at the frequency f_k. The signal is translated in baseband by means of a local oscillator at the frequency $f_o + 1/2\,T$ where $T = t_S/N$. The corresponding complex signal thus obtained and sampled at the rate 1/T can be written :

$$z(nT) = (-1)^n . \sum_{k=o}^{N-1} H_k C_k . e^{2i\pi\frac{nk}{N}} \qquad (n = 0 \text{ to } N-1)$$

It appears that the set $\{ H_k C_k : k = \{0,\ldots, N-1\} \}$ is the Discrete Fourier Transform of the set :

$$\{ (-1)^n z(nT)/N : n = \{0,\ldots, N-1\} \}.$$

In fact, the FFT realizes in the discrete-time domain, the equivalent of a bank of N filters, each of them being matched to a given carrier of the multiplex.

The representation of the equivalent receiver using correlation is given in figure 4. The conditions of orthogonality mentioned above clearly appear in the fact that, at the input of the integrator of the row l, the carriers f_k ($k \neq l$) exhibit an integer number of periods $|k - l|$ during the integration time.

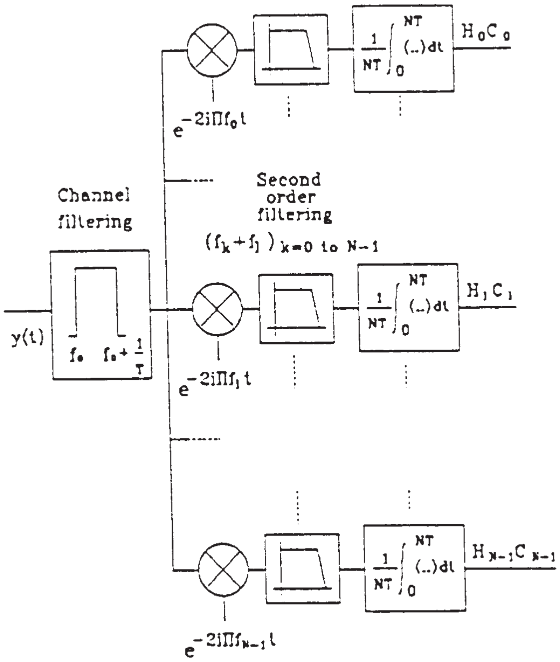

Figure 4

Theoretically equivalent receiver using a bank of N correlators

In absence of noise, the emitted symbols can be recognized without error, without taking into account the problem of H_k estimation that will be examined later. The phenomena of residual bit error rate due to the frequency selectivity have disappeared. Nevertheless, the decrease of the bit error rate as a function of the ratio Eb/No is extremely low in a Rayleigh channel. As previously said, this property justifies the use of an efficient channel coding system.

By introducing the temporal dimension (index j) and the noise, the Fourier Transform process returns the samples :

$$Y_{j,k} = H_{j,k} C_{j,k} + N_{j,k},$$

where $N_{j,k}$ is a complex gaussian noise, each component of which having a variance $\sigma^2_{j,k}$.

The *a posteriori* maximum likelihood criterion consists in maximizing with respect to the elements $\{C_{j,k}\}$ linked by the convolutional coding, the expression :

$$\sum_j \sum_k \| Y_{j,k} - H_{j,k} C_{j,k} \|^2 / 2\sigma^2_{j,k}$$

As far as the modulation and demodulation processes of each carrier are concerned, a 4-PSK modulation has been considered at the present time. In the first step of the study, other modulations with a larger number of states (8-PSK, 16-QAM,...) have been discarded, taking into account their reduced power efficiency. Considering the coherent demodulation a 4-PSK-COFDM signal using a convolutional code of rate 1/2, and free distance 10, simulation results point out that a bit error rate of 10^{-3} can be achieved for a mean value of the Eb/No ratio equal to 5 dB in a selective Rayleigh channel. It means that the instantaneous value of this ratio can highly decrease leading to a particularly difficult implementation of the coherent demodulation.

The differential demodulation is an alternative solution of which the essential interest resides in the very great simplicity of its implementation and its absence of inertia after a deep fade. The price to be paid is obviously a degradation in performance which nevertheless remains acceptable and which is in reality minimal if account is taken of the practical limitations of coherent demodulation.

As far as the estimation of the channel frequency response is concerned, differential demodulation consists in using at the time j a simplified estimator of the channel deduced from the time j-1 :

$$H_{j,k} \approx Y_{j-1,k} / C_{j-1,k}$$

Considering a precoding at the emission following the law,

$$a_{j,k} + i b_{j,k} = (1+i)\, C_{j,k} / C_{j-1,k}, \qquad a_{j,k} = \pm 1,\ b_{j,k} = \pm 1$$

where $a_{j,k}$ and $b_{j,k}$ constitute the outputs of the convolutional coder, it appears that the corresponding weightings to be used at the level of the Viterbi decoder are :

$$\mathrm{Re}\left(\frac{Y_{j,k}\, Y^*_{j-1,k}}{(1-i)\,\sigma^2_{j,k}}\right) \text{ and } \mathrm{Im}\left(\frac{Y_{j,k}\, Y^*_{j-1,k}}{(1-i)\,\sigma^2_{j,k}}\right)$$

Moreover, these formula indicate that if the signal is affected by a narrow-band interferer, the term $\sigma^2_{j,k}$ in the weightings has the effect of "deleting" the corresponding carriers in the same way as a fading of the same carriers. Taking into account that the spectral analysis of the noise is particularly simple with a COFDM system, this property makes this system extremely attractive for channels which are highly disturbed by noise or industrial interference.

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase® Smarter legal research.