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A . Giefer

Research & Development
BRITISH BROADCASTING CORPORATION

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Abstract

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The tests explored the performance of the new DRM digital radio system under the extreme propagation conditions faced by many tropical broadcasters. The data revealed that the robustness of the prototype system with respect to Doppler and Delay spread needed to be increased. As a result, two extra OFDM modes were included into the system specification. The paper describes how these additional modes were deduced from the recorded channel data.

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DIGITAL RADIO MONDIALE:

FINDING THE RIGHT TRANSMISSION MODE

FOR TROPICAL BROADCASTING

Andy Giefer[1]

[1] BBC Research & Development
Kingswood Warren
Tadworth, Surrey KT20 6NP, UK
andyg@rd.bbc.co.uk

ABSTRACT

In December 2000, a series of field tests was carried out in Ecuador by the Digital Radio Mondiale (DRM) consortium. The tests explored the performance of the new DRM digital radio system under the extreme propagation conditions faced by many tropical broadcasters. The data revealed that the robustness of the prototype system with respect to Doppler and Delay spread needed to be increased. As a result, two extra OFDM modes were included into the system specification. The paper describes how these additional modes were deduced from the recorded channel data.

INTRODUCTION

In December 2000, a series of reception tests was carried out in Ecuador as part of the field test work undertaken by the System Evaluation group of the Digital Radio Mondiale (DRM) consortium. These tests were supported by the European Union under the IST-Radiate Project.

The aim of these tests was to explore the robustness of this new radio system under the extreme propagation conditions that tropical broadcasters have to deal with. Transmitting their signals at vertical angles, these broadcast organizations often cover an entire country from a single transmitter, using Near-Vertical Incidence Skywave (NVIS) propagation.

With NVIS propagation, the radio signal is transmitted at a low frequency (usually 2–5 MHz) and at an elevation of about 90º. The ionosphere reflects it, thus sending it back to the ground, where it bounces back sky-wards again and so forth. Naturally, with each reflection the radio wave loses a part of its energy which means that this process will not continue indefinitely.

As a result, the temporal evolution of the impulse response of such a short-wave channel reveals a high degree of Doppler and Delay spread which noticeably impairs the audio quality of standard analogue amplitude-modulated (AM) radio programmes.

The DRM System

With DRM a new digital radio system targeting frequencies below 30 MHz (long-wave, medium-wave and short-wave) has been developed over recent years. Recommended by the International Telecommunications Union (ITU) for world-wide radio broadcasting, it aims to cope with as many different propagation channels as possible, including NVIS channels. The system is based on Orthogonal Frequency Division Multiplex (OFDM) modulation and therefore shares many of its design principles with other multi-carrier systems such as Digital Audio Broadcasting (DAB) or Digital Video Broadcasting (DVB).

Two of the main design parameters for OFDM systems are the spacing between the individual carriers and the length of the guard interval. They dictate to a large extent whether the system is able to cope with a given amount of Doppler and delay spread. The DRM system incorporates four combinations of carrier spacing and guard interval, constituting the four so-called *robustness modes*. As the name implies, each of these modes offers a certain level of robustness to channel impairments, following the simple rule that increased robustness usually goes hand-in-hand with lower useful bit rates and hence a lower audio quality.

Owing to the challenging nature of NVIS channels, tropical broadcasts constitute a good test environment for the DRM prototype system as it existed in December 2000. The task of the field testers was to explore how suitable the robustness modes (as they were defined at the time) were when subject to these severe conditions.

DATA ACQUISITION

Transmission and Reception Sites

Transmissions were made using a Siemens class-A transmitter belonging to HCJB, Voice of the Andes whose transmission site is located at Pifo, in the vicinity of Ecuador's capital Quito. It was fed with a DRM RF signal which was broadcast using a lazy-H antenna.

Reception took place at three different sites, in Quito (16 km from Pifo), Guayaquil (280 km) and Loja (460 km), where the reception team recorded and analysed the transmissions during three consecutive days, respectively.

The Test Procedure

The tests were carried out as follows. The available transmission time was sub-divided into 1-hour long transmission slots. During each slot, the transmitter broadcast a 57-minute long pre-recorded test sequence containing four transmission blocks for each of the robustness modes, each of them sub-divided into two segments of digital audio, one AM segment, and a special (non-DRM compatible) channel sounding signal. Consequently, the channel sounding data was collected at intervals of about 15 minutes.

DRM Segments

The DRM segments were broadcast using a 64-QAM or 16-QAM (Quadrature Amplitude Modulation) constellation with a code rate of 0.6. The four robustness modes are summarised in Table 1. Note that at the time of testing, it was generally agreed that modes A and B should be part of the final system specification, whereas modes ROB and DEL were only provisionally implemented in the prototype system.

Table 1 Tested DRM Modes

Mode	**A**	**B**	**ROB**	**DEL**
Carrier spacing [Hz]	41 2/3	46 7/8	68 1/5	31 1/4
Guard interval [ms]	2 2/3	5 1/3	5 1/3	8
Useful symbol length [ms]	24	21 1/3	14 2/3	32

Channel Sounding

The channel sounding signal was generated by Deutsche Telekom T-Nova (now T-Systems). In essence, it is a 8000 baud BPSK (binary-phase-shift-keying) signal, shaped with a root-raised-cosine filter using a roll-off of 0.2. The BPSK modulator itself is fed with a 255-bit PN (pseudo-noise) sequence.

Note that the BPSK was slightly modified by slightly delaying the two base-band components I and Q with respect to each other. As a consequence, zero-crossings of the amplitude of the eventual RF signal can be avoided and therefore the amount of out-of-band radiation reduced (the latter is a particular problem of non-linear transmitters when operated at low amplitude levels).

The resulting signal periodically repeats every 31.875 ms, corresponding to a repetition rate of 31.3 Hz. Hence, the range of measurable delay is limited to +/-15 ms and the range of measurable Doppler frequencies to +/- 15Hz.

DATA ANALYSIS

Evaluation of the Digital Audio

During the reception, the received digital audio was analysed in real-time. This is in fact much easier than it is the case for analogue audio, since the analysis can be done more objectively. The audio content is transmitted as a series of audio frames of equal length (depending on the employed audio coding, this length varies between 20 ms and 80 ms).

Using a check-sum mechanism, the receiver is able to identify whether a received audio frame is error-free or corrupted. Based on this information, it is possible to measure the length of audio dropouts as well as the frequency of their occurrence (a singular erroneous audio frame is usually concealed, whereas longer sequences tend to be muted).

The ratio between uncorrupted and corrupted audio frames provides a good indication on how well the individual combinations of robustness mode, constellation and code rate worked.

Impulse Response and Scattering Function

The BPSK channel sounding signal was recorded by the prototype DRM receiver as IQ-baseband signal. Through means of correlation, it is possible to deduce the impulse response of the channel with a resolution of 62.5 µs. Fig. 1 shows the evolution of such an impulse response over the period of one minute.

Based on this temporal evolution of the impulse response, a scattering function can be calculated (using a 512-point FFT and Hanning windowing) according to [1]. Fig. 2 shows the corresponding scattering function to fig. 1. The data was recorded at 21:27 (01:27 UTC) local time on December 12th 2000 over a distance of 460 km

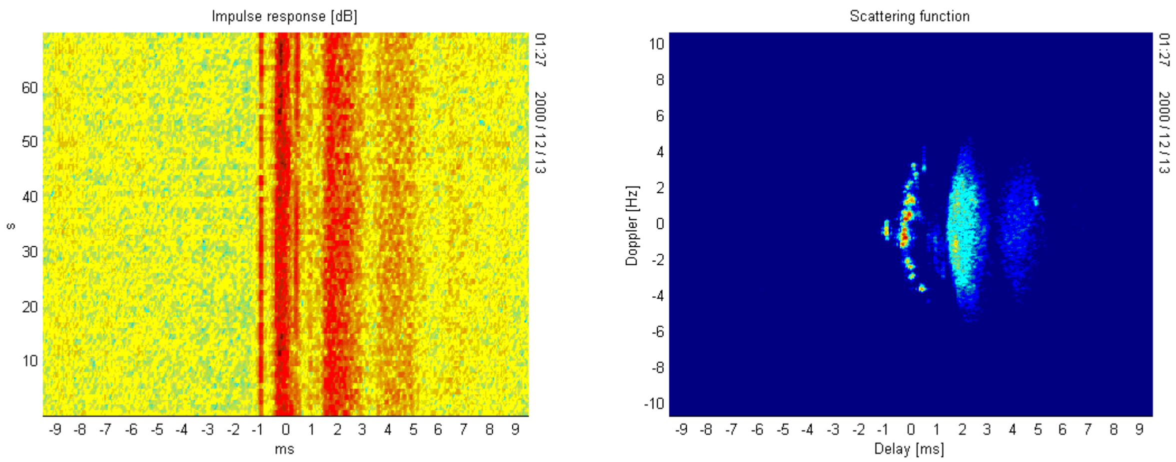


Figure 1 and Figure 2: Pifo to Loja on 6185 kHz

Analysing the OFDM Degradation

The specific effects of Doppler and delay spread on OFDM systems can be quantified by the inter-carrier-interference (ICI) and inter-symbol-interference (ISI). Whereas the Doppler spread focuses on the channel itself, the ICI highlights its effect on the multi-carrier signal. Similarly, the multipath-nature of the channel is reflected by both ICI and ISI.

The effect of combined ICI and ISI expresses itself as a seemingly decreased signal-to-noise ratio (SNR) at the receiver, even in the absence of noise. This degradation can be calculated by multiplying the scattering function $s(f,t)$ (which provides the distribution of the received signal energy in frequency and time) with a weighting function $w(f,t)$ and integrating the result. This function was first presented in [2]. Note that $w(f,t)$ is a function of both the OFDM carrier spacing and the guard interval. Fig. 3 and 4 show a contour plot and a 3-dimensional plot for the OFDM parameters of mode A.

Before multiplication, the weighting function can be offset in frequency and time with respect to the scattering function. This offset reflects the synchronisation state of the receiver. The more ideal the synchronisation is, the smaller is the ICI/ISI degradation.

Consequently, each of the recorded channel sounding segments was analysed as follows:

(1) Generate the matrix containing all channel responses recorded during one minute.

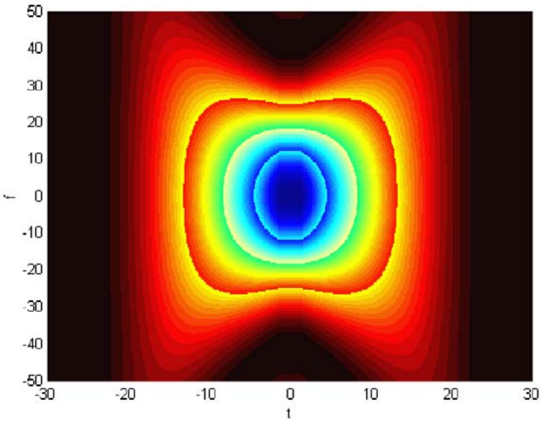
(2) Calculate the corresponding scattering function $s(f,t)$.

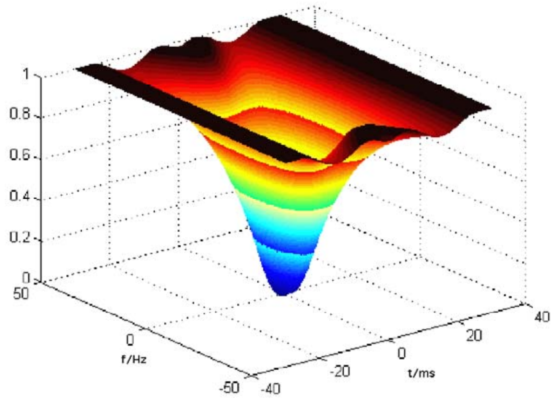
(3) In an iterative processes, find the time and frequency offsets Δf and Δt so that $d(\Delta f,\Delta t) = \int_t \int_f s(f,t) \cdot w(f+\Delta f, t+\Delta t) df\, dt$ yields its absolute minimum.

(4) The apparent maximum *SNR* under noise-free conditions is given by dividing the total signal energy by the minimum deterioration: $SNR(\Delta f,\Delta t) = \int_t \int_f s(f,t) df\, dt \,/\, d(\Delta f,\Delta t)$

As a result, each robustness mode (via its corresponding weighting function) could be analysed with respect to its suitability for the measured transmission channels (via their corresponding scattering functions).

In order to be able to differentiate between suitable and unsuitable robustness modes, an acceptable limit for the apparent SNR had to be defined. This limit was found by calculating the ICI/ISI deterioration of mode B when subject to the most challenging DRM channel model defined at the time of the analysis, channel model 5. The latter features two discrete paths of equal strength, with a relative path delay of 4 ms and a (two-sided) Doppler spread of 2 Hz on each path. The apparent SNR for mode B on channel 5 was found to be 28 dB. Consequently, robustness modes that showed an apparent SNR of less then 28 dB were considered to be not suitable for a given scattering function.





Figures 3 and 4: The weighting function

RESULTS AND CONCLUSIONS

The analysis of the OFDM degradation showed that robustness mode A was the least suitable mode to cope with NVIS channels (35% of mode A scattering functions were found to be unsuitable), followed by modes DEL (14% unsuitable), B (8%) and ROB (2%).

The low suitability of mode A can be explained by the relatively small guard interval of only 2.6 ms. The guard interval roughly defines the maximum allowable delay between the first and the last significant path of the channel impulse response. The multiple ionospheric reflections of the transmission signal produced significant paths with delays exceeding the guard interval, thus deteriorating the signal considerably. An insufficient digital audio performance of mode A confirmed the low suitability.

Mode DEL turned out to more suitable. Combining the fact that its guard interval is 8 ms long (the highest robustness to delay spread of all the modes then available) and that its resistance to Doppler spread is even weaker than for mode A, it can be deduced that Delay spread was indeed the dominant problem for mode A. Despite mode B's shorter guard interval (5.3 ms) with respect to mode ROB, only 8% of mode B measurements presented themselves as being severely impaired. This can be explained based on its higher robustness with respect to Doppler spread. Finally, ROB revealed itself to be the most suitable mode for NVIS. Using the same guard interval as mode B, it features an even higher robustness to Doppler spread.

However, a few channel recordings showed such high values for Doppler and delay spread, that even ROB was inappropriate to deal with these conditions and so it was felt that another robustness mode was required. Twelve candidates were considered and evaluated using the method described above (each candidate corresponding to a different weighting function) with the result that a new robustness mode was found that could have coped with all channel conditions encountered during the measurement campaign: It features a guard interval of 7 1/3 ms and a carrier spacing of 107 1/7 Hz, thus giving it more robustness than mode ROB with respect to both Doppler and delay spread.

Consequently, by keeping modes A and B as they were defined, renaming mode ROB to Mode C and the introduction of the new Mode D, the four DRM robustness modes that are now included in the DRM specification [3] were specified.

CURRENT TESTS

As soon as the final DRM specification (including all four robustness modes) was implemented into the first DRM prototype receivers (summer 2001), the DRM System Evaluation group started to carry out further trials. These tests are still on-going, but plans for 2002 include the possibility of repeating the NVIS tests in order to verify the results described in this paper

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