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The text gives an overview on these parameters before describing the work of the DRM System Evaluation Group and how it contributes in building up a knowledge database helping the broadcaster to operate digital DRM transmissions successfully.

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Key words: digital radio, DRM

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DIGITAL RADIO MONDIALE
FIELD TRIALS AND THEIR IMPACT ON SYSTEM DESIGN AND OPERATION

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ABSTRACT

This paper introduces the new digital radio system Digital Radio Mondiale (http://www.drm.org) from an operational point of view. The system offers a range of new transmission parameters that put the broadcaster into the position of adapting the digital output signal to the specific channel conditions (and impairments) observed on the transmission channel.

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INTRODUCTION

Digital Radio Mondiale

The year 2001 marks the beginning of a phase of more intensive testing of the Digital Radio Mondiale (DRM) system. Primarily designed for audio broadcasting on frequencies below 30 MHz, this multicarrier system provides a considerably improved audio quality with respect to conventional AM radio.

Furthermore, it offers a range of useful features such as alternative frequency switching, programme labels, text messages and the possibility to be operated on a single frequency network.

One of the attractive characteristics from a broadcaster's point of view is the possibility to adapt the robustness of the transmitted digital signal to the channel conditions encountered on individual circuits. This allows a network operator to ensure that the best possible signal reaches the listener, regardless of whether a frequency in the long-wave, medium-wave or short-wave bands is used. It also makes it possible to react to changing propagation conditions in a flexible way.

The latter can be achieved through appropriate observation of the transmission channel. The experience of the DRM System Evaluation group, which is currently carrying out an extensive series of field trials, helps to define a crucial set of channel parameters that need to be taken into account.

Analogue Versus Digital Transmissions

The frequency bands allocated for radio broadcasting below 30 MHz are of an extremely variable nature. Not only are the different frequency bands subject to different propagation mechanisms, it is also obvious to any short-wave listener that even the same frequency can show different propagation characteristics from one day to another.

In the world of analogue amplitude modulation, the broadcaster has a very limited choice in adapting its output signal to the current propagation condition. A high level of radiated power and a skilful choice of the transmission frequency are the main tools at the broadcaster's disposition, aiming at providing sufficiently high signal strength inside the target area. Audio impairments introduced by multipath and interference are problems that a broadcaster can try to reduce, but will rarely eliminate.

The nature of digital radio implies that an audio programme can either be heard in the best possible quality – or not at all. The transition between satisfying and unacceptable reception is quite abrupt and can usually be associated with a threshold of certain propagation characteristics (signal-to-noise ratio, Doppler spread, Delay spread…).

In contrast to AM radio, DRM offers the possibility to adapt a considerable number of transmission parameters to the transmission channel, the most important of which are described in the following sections. The choice of the correct parameter values for a given propagation situation serves one major goal: to set the system operating thresholds to the lowest necessary level while achieving the highest possible audio quality.

Consequently, by observing the characteristics of the transmission channel, the broadcaster should be in the position to choose an appropriate set of transmission parameters which in turn determine the operational thresholds of the system.

CHANNEL IMPAIRMENTS AND THE DRM TOOLBOX

The DRM system offers a toolbox of various transmission parameters that help the broadcaster to adapt the digital transmission signal to the channel conditions observed on the served circuit.

The transmission path can suffer from

- Low signal strength
- Interference (co-channel and adjacent channel AM stations, man-made-noise)
- Multipath (due to multiple reflections of the radio signal at the ionosphere)
- Fading (due to moving reflection layers in the ionosphere)

Each of these channel impairments can be countered by appropriately setting the system parameters described below.

Low Signal Strength And Interference

The DRM system provides two means of dealing with low signal strength and interference conditions: choosing an appropriate *constellation* as well as choosing an appropriate *code rate* for the Main Service Channel (MSC). The latter carries the main payload, i.e. digital audio in most cases.

The constellation can be chosen to be 64-QAM (each MSC carrier is modulated using one of 64 possible combinations of amplitude and phase) or 16-QAM (16 possible amplitude/phase combinations, implying that the receiver is less likely to misjudge which amplitude and phase was originally transmitted). Choosing the more robust 16-QAM constellation reduces the useful bit rate by approximately 1/3 (16 constellation points code 4 bits in contrast to 64 constellation points coding 6 bits). This is compensated by the fact that the lowest acceptable signal-to-noise ratio (SNR) level can be lowered by about 5 dB.

The code rate provides an even finer instrument to tune the transmission signal. It determines how many redundant bits are added to the stream of data bits.

The receiver uses these redundant bits to identify and (up to a certain error rate) correct bit errors in the received bit stream. The code rate can be varied between 0.50 (strongest code, every second bit is redundant) and 0.78 (weakest code, two redundant bits for every seven data bits).

Both the code rate and the constellation determine the lowest acceptable SNR as well as the useful data rate. The broadcaster will find that different combinations of code rate and constellation yield similar useful data rates. The choice on which combinations are the most appropriate depend on the nature of the individual transmission channel. It will be based on experience gained during the DRM field trials as well as during regular day-to-day operation.

Multipath And Fading

Multipath and fading on HF frequencies are introduced by the reflective properties of moving ionospheric layers. More specifically, multipath effects can be identified by the fact that multiple versions of the original radio signal (signal paths) arrive at the reception site at slightly different times (the relative delay ranging from a 1/10 ms to about 6-10 ms). The quantitative description of multipath is the Delay spread.

The fact that the different reflections vary over time in intensity and phase causes self-interference, where the individual signals superpose each other either constructively and destructively. The temporal variation of this effect (fading) is quantified by the Doppler spread which can attain values of a few Hz in a significant number of broadcast circuits.

The DRM system tool which adapts the output to the Doppler and Delay spread levels observed on the individual circuits is the *robustness mode*. The broadcaster can choose between three (possibly four) different robustness modes, each of which offering a different level of robustness in terms of maximum Doppler and Delay spread.

The maximum level of manageable spread depends on several signal characteristics, but most importantly two principle parameters of the OFDM (multicarrier) symbol.

- The *guard interval* determines the maximum delay between the earliest and the latest signal path of significant energy.
- The carrier spacing determines the maximum allowable Doppler spread. A useful rule of thumb defines 5% of carrier spacing as the maximum (single-sided) Doppler spread.

The following Table 1 provides an overview on the four robustness modes under consideration at the time of writing of this paper. Since the specification is currently (beginning of May 2001) still open to amendments, it is not possible to say whether all considered modes will end up in the standard.

Mode	Guard interval	Carrier spacing	Robustness	Capacity
A	2.6 ms	41.6 Hz	Low	High
B	5.3 ms	46.9 Hz	Middle	Middle
C	5.3 ms	69.2 Hz	High	Low
D	7.3 ms	107.1 Hz	Very high	Very low

Table 1 -Robustness modes under consideration

The modes are named in order of increasing robustness and decreasing capacity: Mode A as the least robust mode (smallest guard interval and lowest carrier spacing) provides the highest capacity, while Mode D is designed to cope with extreme channel conditions (highest robustness with respect to Doppler and Delay spread). This increase in robustness does come with a price: The resulting capacity of mode D is comparatively low.

As a result, mode A is most likely to be used on long-wave, medium-wave and very benign short-wave channels. Mode B is designed to be the default mode for short-wave transmissions. Mode C should be the fallback mode for difficult short-wave transmission channels (broadcasting over very long distances), whereas Mode D would come into use for extremely difficult transmissions situations (one example being tropical near-vertical incidence short-wave broadcasts during night-time).

Thus, every mode could be used for short-wave transmissions. The choice of which mode to use will be based on the broadcaster's experience, combined with the field test results provided by the DRM System Evaluation Group.

MEASURING THE RECEPTION QUALITY

Digital Audio Quality

The prime application of DRM is the transport of digital audio data. In contrast to AM quality assessments which rely on subjective evaluation methods (SIO and SINPO), the digital audio quality can be assessed automatically, without human intervention.

The digital audio content is transmitted in blocks of equal duration, called *audio frames*. The receiver can check whether they are error-free or not and thus generate a *corruption flag*.

As an example, the currently (May 2001) tested audio encoder (AAC+SBR, Advanced audio coding enhanced with Spectral Band Replication) produces one audio frame every 40 ms. Consequently, the receiver is in the position of assessing every 40 ms whether an audio frame was correctly received.

From this flow of corruption flags a number of interesting measurements can be deduced that provide information on the digital audio quality:

- The number of error-free audio frames per minute
- The longest sequence of erroneous audio frames (i.e., the longest audio loss) observed during a minute
- The number of audio losses with a duration exceeding 1 second – observed during one minute.

The advantage of this minute-by-minute observation is that the amount of collected data becomes more manageable. On order to compress the data even further, it is possible to summarise the data on an hourly, daily, monthly or even yearly basis.

Information On The Transmission Channel

For the purpose of planning future transmissions, it is useful to complement the assessment of the digital audio quality by measurements of the transmission channel itself, notably

- the minimum, median and maximum wanted signal strength at the receiver input
- the minimum, median and maximum unwanted signal strength at the receiver input
- the noise level
- the fading rate (fades per minute)
- the Doppler and Delay spread

By recording this data over the same time interval as the digital audio quality, useful deductions can be drawn in order to get a clear view of the circumstances under which a DRM transmission can be received in a satisfying way.

THE DRM FIELD TESTS

Since November 1999, the DRM System Evaluation Group has been carrying out field tests, testing different aspects of the system.

Short-Term Point-To-Point Tests

Initially, during the year 2000, the group concentrated on testing potential system features, feeding the results back to the group responsible for the technical specification (the DRM Coding and Modulation Group). Tests included point-to-point transmissions over distances of up to 8000 km as well as tropical NVIS receptions in Ecuador. These tests were usually carried out over several days, with one-hour-long transmissions from transmitters in Canada, Portugal, Germany, Norway, Ecuador and the UK to a receiver in Germany, the Netherlands, Finland, Cyprus, Bonaire, Ecuador and the UK.

The test sequence included alternating analogue and digital audio segments, the latter being transmitted using different robustness modes and constellations. This allowed the demonstration of the difference in sound quality between analogue and digital transmissions under similar channel conditions. Furthermore, it helped the group to build up its experience regarding the performance of various combinations of robustness modes and constellations.

In addition to the mixture of DRM and AM segments, the test sequence contained a specifically designed channel sounding signal (basically a 2-PSK modulated repetitive bit sequence) which allowed to estimate the channel impulse response during periods of one minute duration. In the course of one reception hour, four of these recordings were made, thus making it possible to calculate the *scattering function* of the channel every 15 minutes. The latter gives an insight into the distribution of the signal energy in time (due to multipath) and frequency (due to fading) and is essential in order to assess the OFDM damage caused by Doppler and Delay spread.

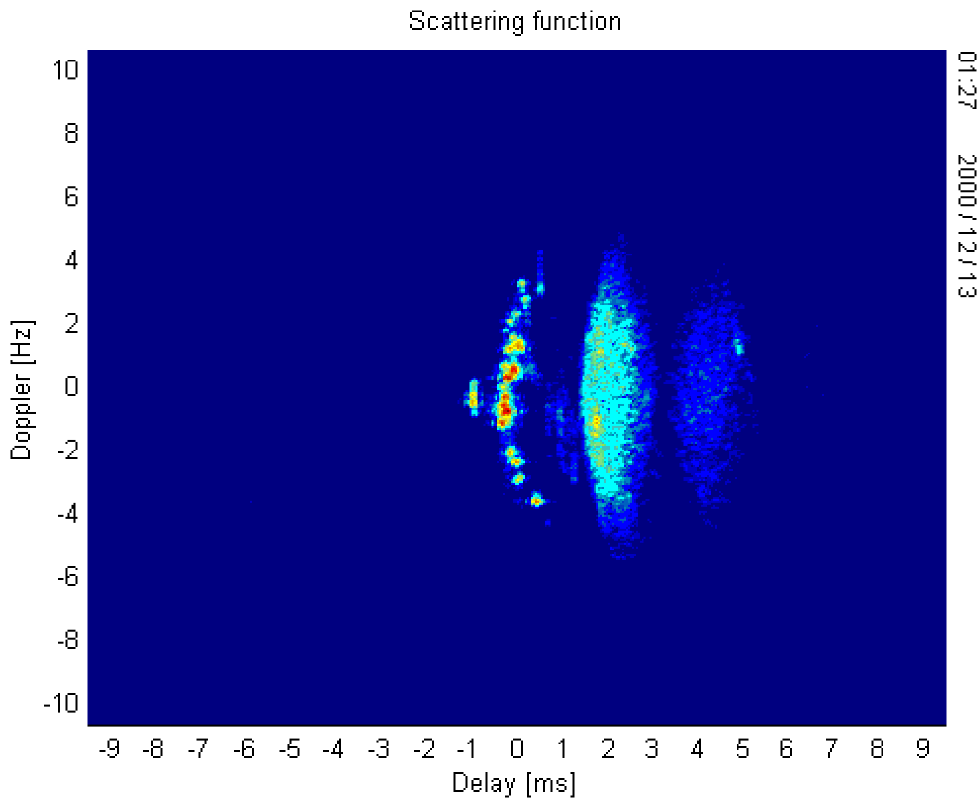

Figure 1 – NVIS scattering function. The colours depict a range of 40 dB.

Figure 1 shows an example of such a scattering function, recorded at night-time during an NVIS transmission over 460 km in Ecuador (between Pifo and Loja). It represents one of the more challenging channels for a DRM signal and helped to choose the appropriate design parameters (amongst them the guard interval and the carrier spacing) for the very robust mode D (see Table 1).

The *delay spectrum* (or multipath intensity profile) can be calculated from the scattering function and illustrates the multipath nature of the channel. For illustration, Figure 2 shows the delay spectrum of another (more benign) NVIS transmission recorded 16 km from the Ecuadorian transmission site. It reveals five distinguishable reflections (the first peak represents the ground wave) with a respective delay of 1.5 ms – suggesting that the signal is reflected approx. 225 km above ground. Furthermore, the graph helps to determine the relative power of the individual reflections – thus making it easy to reproduce the channel in the laboratory for the purpose of testing prototype receivers.

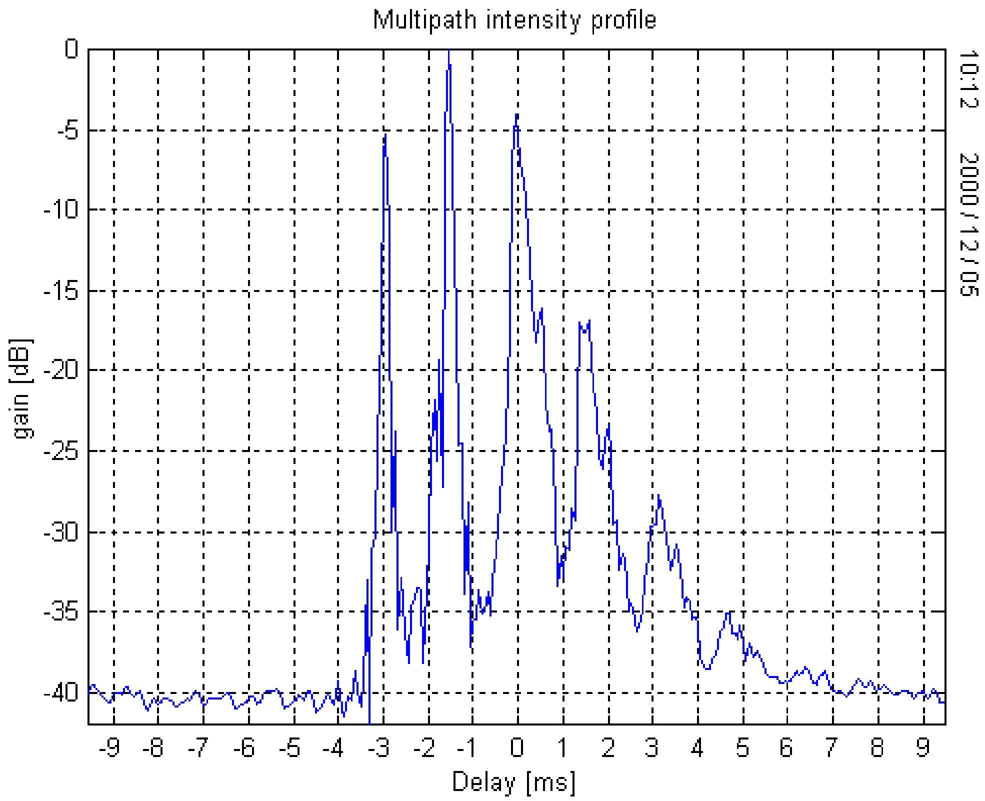

Figure 2 - Delay Spectrum of a benign NVIS reception in Ecuador

Long-Term Tests

In April 2001, a phase of long-term tests started, aiming at gathering information about the reliability of digital transmissions. For this purpose, a network of remote digital receivers was set up (initially in London, Hilversum, Cologne and Ottawa), receiving daily transmissions from Rampisham (UK), Sines (Portugal), Juelich (Germany) and Bonaire (Netherlands Antilles).

The test signal consists mainly of digital audio, broadcast over a duration of typically one hour, using a specific combination of code rate, constellation and robustness mode.

The exact transmission parameters change cyclically on a daily basis and are specified in a monthly schedule. For instance, the schedule of the first month (April 2001) consisted of two different test signals: Mode B at code rate 0.6 with alternating constellations (1st day 64-QAM, 2nd day 16-QAM, 3rd day 64-QAM,…).

For each reception day, the remote receivers produce a data file containing the recorded data in compressed form. The file is sent to a central data analysis site via email and automatically processed by feeding its content into a database (see Figure 3).

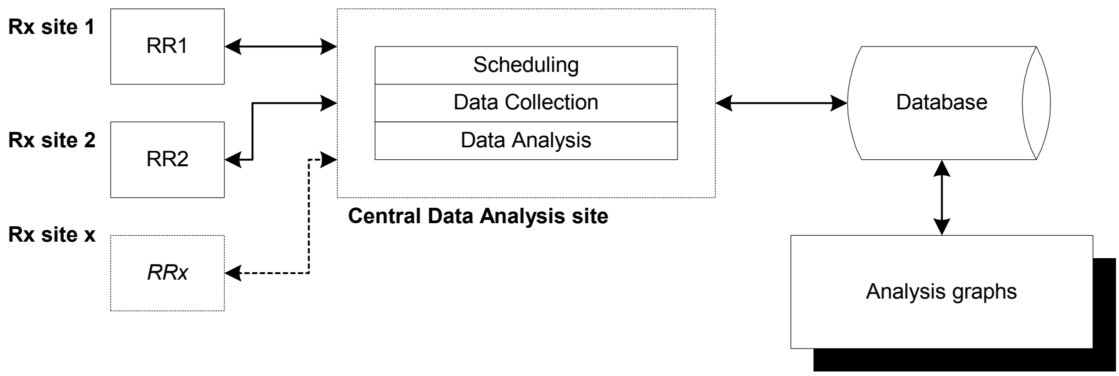

Figure 3 - Data flow between remote receivers and central data analysis site

A typical analysis graph is shown in Figure 4.

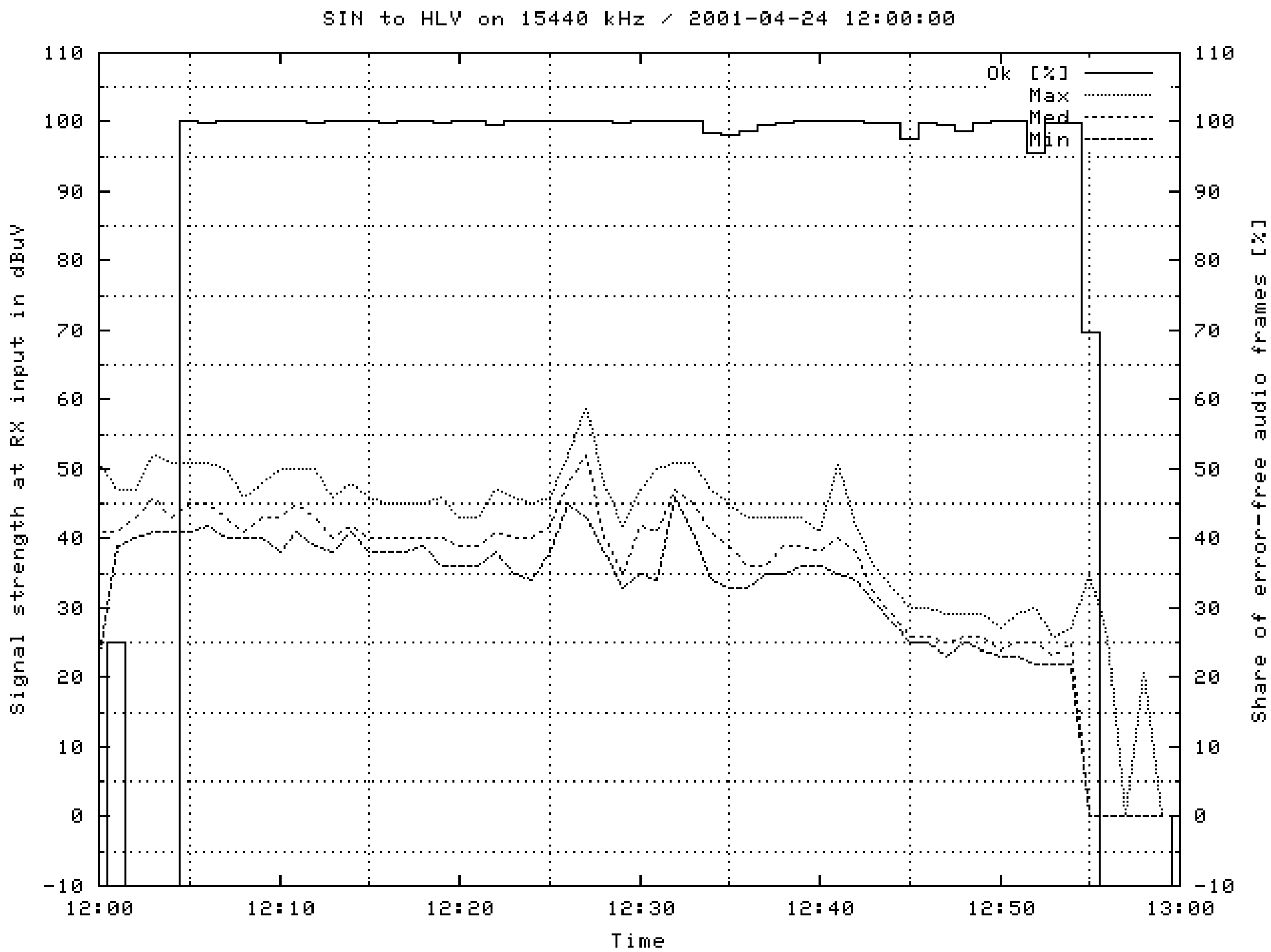

Figure 4 - Example of graph showing the evolution of signal strength and audio quality. Transmission from Sines (Portugal) to Hilversum (NL).

Future Tests

In addition to the tests mentioned in earlier, the DRM System Evaluation group plans tests covering the following topics:

- Single Frequency Network
- Alternative Frequency Switching
- Mobile Reception
- Simulcast
- Point-to-point transmissions over distances of up to 23000 km

CONCLUSION

This article introduced the Digital Radio Mondiale System from the point of view of the DRM System Evaluation Group.

After briefly describing the key features of DRM, it pointed out the importance of choosing the appropriate digital transmission parameters for a given channel. These parameters determine the level of certain channel characteristics (the maximum Doppler and Delay spread as well as the lowest signal-to-noise ratio) that should not be overstepped to achieve high service reliability while offering the best possible audio quality.

The system offers a number of tools (constellation, code rate, robustness mode) that increase the robustness of the digital signal with respect to channel impairments (low signal strength, interference, multipath and fading). The correct use of these tools usually means to find the right trade-off between sound quality and robustness.

The digital sound quality can be measured by analysing the error statistics on an audio frame basis. This method is used to assess the reception quality during the DRM short-term and long-term tests which help to build up the required knowledge database necessary to carry out DRM transmissions successfully.

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