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Evaluations and Measurements of a Single Frequency Network with DRM+

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Abstract - This paper presents the first DRM+ (Digital Radio Mondiale, Mode E) Single Frequency Network (SFN) in the air. A field trial has been conducted to evaluate the performance in different environments. Due to it's relatively small bandwidth, flat fading in the overlapping area can become a problem. Different solutions to overcome this problem are evaluated in this paper. Adding different delays to transmitters side-by-side is a solution to overcome the flat fading. In the field trial the error rates in the overlapping area in a two TX setup with delay were significantly smaller than without delay, the probability of deep fades was becoming smaller. This paper provides parameters for applying a Single Frequency Network with DRM+.

Keywords - Digital Radio Mondiale; DRM+ ; Single Frequency Network; SFN; digital broadcasting; COFDM; field trial

I. INTRODUCTION

DRM+ is an extension of the long, medium and shortwave DRM standard up to the upper VHF band. It has been approved in the ETSI (European Telecommunications Standards Institute) DRM standard [1] and added to the ITU recommended Digital Radio standards above 30 MHz [2] in 2011.

As a digital COFDM radio system, DRM+ is capable of transmitting in a Single Frequency Network (SFN) with several transmitters working on the same frequency. Due to a guard interval added after every symbol, differences in time of arrival from the different transmitters are not resulting in Intersymbol Interference (ISI) as long as they are within the guard interval duration. Attenuation of carriers due to the time delay often can be compensated by the SFN gain. This offers the possibility of covering a big area with several transmitters on only one frequency which saves bandwidth and simplifies frequency planning significantly. It also enhances the reception quality in areas with obstacles as buildings, hills or mountains. Other uses for SFN are gap filling transmitters and coverage extenders. First studies and simulations about using a DRM+ SFN are described in [3] and [4].

This principle is already highly used in other digital broadcasting systems as DVB-T or DAB. Principles on SFN planning for DAB and DVB-T are given in [5] and [6].

Recent studies about Single Frequency Networks for Broadcasting systems focus on planning optimization as in [7] or taking advantage of hierarchical modulation as in [8].

As the DRM+ signal bandwidth of 96 kHz, in contrast to DVB-T (7-8 MHz) and DAB (\approx 1.5 MHz) is quite small, flat fading in the overlapping area can degrade the reception quality. Adding a delay at one transmitter station was proposed

TABLE I DRM+ System parameters

Subcarrier modulation	4-/16-QAM	
Signal bandwith	96 kHz	
Subcarrier spread	444.444 Hz	
Number of subcarriers	213	
Symbol duration	2.25 ms	
Guard interval duration	0.25 ms	
Transmission frame duration	100 ms	
Bitinterlever	100 ms	
Cellinterleaver	600 ms	

in [9] to solve this problem. This setup can also be seen as a special case of transmitter delay diversity which was evaluated in [10] with very distant transmitters and as a result, quite uncorrelated signal pathes.

This paper starts with a description of the DRM+ system parameters, followed by an evaluation of the fading behaviour for a two- and a three-transmitter setup in the overlapping area. The system setup and the measuring results that were obtained in the measuring campaign are presented afterwards. A field strength prediction was made to plan the measurements and find good locations. Measurements have been conducted in the overlapping area in different surroundings to analyze and compare the performance of an one antenna system and a two-transmitter SFN setup with the same power and different delays.

II. DRM+ System Parameters

The DRM+ system uses Coded Orthogonal Frequency-Division Multiplex (COFDM) modulation with different Quadrature Amplitude Modulation (4-/16-QAM) constellations as subcarrier modulation. The additional use of different code rates results in data rates from 37 to 186 kbps with up to 4 audio streams or data channels. A signal with a low data rate is more robust and needs a lower signal level for proper reception. Table I shows the system parameters in an overview.

The Symbol duration is 2.25 ms followed by a guard interval of 0.25 ms. This guard interval duration allows a theoretical distance between the transmitters of 75 km.

To improve the robustness of the bit stream against burst errors, bit interleaving and multilevel coding are carried out over one transmission frame (100 ms) and cell interleaving over 6 transmission frames (600 ms).



Fig. 1. A 'Single Frequency Network' of two transmitters

III. PROPAGATION CONDITIONS IN A SFN

In an ideally synchronized two TX-SFN as seen in Figure 1, the vertical polarized E-field as the interference of signal $E_1(r_1)$ arriving from TX1 and $E_2(r_2)$ arriving from TX2 can be derived from the well known wave equation for one carrier at frequency $f_0 + \Delta f$ at reception point r:

$$E(r,t) = \hat{E}(r)e^{j2\pi(f_0 + \Delta f)(t + \frac{r}{c_o})}$$
(1)

With $E_{12}(r_1, r_2, t) = E_1 + E_2$ and assuming constant levels within one symbol duration the mean sum power level is given by [9]:

$$|E_{12}|^2 \sim \hat{E}_1(r_1)^2 + \hat{E}_2(r_2)^2$$

$$+ 2\hat{E}_1(r_1)\hat{E}_2(r_2)\cos\left(2\pi \frac{(f_0 + \Delta f)}{c_0}(r_2 - r_1)\right)$$
(2)

The power level of the interference of all carriers within the OFDM bandwidth B is then given to:

$$P_{12} = \int_{-\frac{B}{2}}^{+\frac{B}{2}} |E_{12}|^2 d\Delta f \tag{3}$$

which leads to the following equation:

$$\frac{P_{12}}{B} \sim \hat{E}_1(r_1)^2 + \hat{E}_2(r_2)^2 + \\
+ 2\hat{E}_1(r_1)\hat{E}_2(r_2)\cos\left(2\pi\frac{f_0}{c_0}(r_2 - r_1)\right) \cdot \\
\cdot si\left(\pi\frac{B}{c_0}(r_2 - r_1)\right)$$
(4)

In Figure 2 the sum power level is plotted together with the power level of the single transmitters, assuming free space loss $(|\hat{E}(r)|^2 \sim 1/r^2)$. The DRM+ signal bandwidth of 96 kHz, $f_0 = 100 \ MHz$ and a distance of 10 km between the transmitters was used for the calculation. TX1 is located at 0 m, TX2 at 10000 m. It shows clearly that additive interference as well as deep fades up to -40 dB can occur between the two transmitters, where the power level from both transmitters are similar and the signals from both transmitters are arriving simultaneously. Adding a delay at TX1, the region of simultaneous arrival of the signals is shifted to the delayed TX where the power level of both transmitters are not equal anymore and as a result the fading is not as distinctive as shown in Figure 3 for delays of 15 μs and 30 μs .

Adding a third transmitter, the sum power level can be calculated as:







Fig. 3. Sum power level with different delays added to TX1

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$$\frac{P_{123}}{B} \sim \hat{E}_{1}(r_{1})^{2} + \hat{E}_{2}(r_{2})^{2} + \hat{E}_{3}(r_{2})^{2} + 2\hat{E}_{1}(r_{1})\hat{E}_{2}(r_{2})\cos\left(2\pi\frac{f_{0}}{c_{0}}(r_{2} - r_{1})\right) \cdot si\left(\pi\frac{B}{c_{0}}(r_{2} - r_{1})\right) + 2\hat{E}_{2}(r_{2})\hat{E}_{3}(r_{3})\cos\left(2\pi\frac{f_{0}}{c_{0}}(r_{3} - r_{2})\right) \cdot si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{2})\right) + 2\hat{E}_{1}(r_{1})\hat{E}_{3}(r_{3})\cos\left(2\pi\frac{f_{0}}{c_{0}}(r_{3} - r_{1})\right) \cdot si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{1})\right) + si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{1}\right)\right) + si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{1}\right) + si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{1}\right)\right) + si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{1}\right)\right) + si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{1}\right) + si\left(\pi\frac{B}{c_{0}}(r_{3} - r_{1}\right)\right) + si\left(\pi\frac{B}{c_{0}}(r_{1} - r_{1}\right)$$

Figure 4 shows the sum power level of a three transmitter setup with a distance of 10 km between each TX without any delay added. The TX are located at [0,0] (TX1), [10000,0] (TX2) and [5000, $\sqrt{3}/2 \cdot 10000$] (TX3). From red to green the power level decreases. The dark blue moiré pattern between the three transmitters shows fades of more than 6 dB compared to the mean power level.

In Figure 5 the sum-power-level of the three TX setup with a delay of 15 μs added to TX1 and 30 μs added to TX2 is shown. The deep fades are no longer present due to the added delay.







Fig. 5. Sum power level in a 3 TX SFN with different a delay of 15 μs added to TX1 and 30 μs added to TX2

Further evaluations with different delays show that with smaller delays, the areas of the fading pattern increases. Higher delays are also not recommended, because the delays have to be substracted from the guard interval resulting in less robustness against multipath propagation and restricting the maximum distance between the transmitters.

Tests made with more transmitters have shown that the delay between two TX side-by-side should to be higher than 15 μs . A descriptive interpretation of this value is that the coherency bandwidth, which is the reciprocal of the delay spread [11] for 15 μs is approx. 66 kHz. Within the signal bandwidth of 96 kHz in the frequency response there is at least one maximum and one minimum.

Another possibility to prevent the flat fading can be using different power levels at the transmitters or using directional antennas.

The applied single-ray model simplifies the situation, as in a real setup, multipath propagation is taking place. But as multipath propagation is adding additional delay spread



Fig. 6. Field strength prediction and measuring routes and environments (Map data (c) OpenStreetMap and contributors, CC-BY-SA, http://www.openstreetmap.org)

and the pathes from both transmitters are quite uncorrelated due to the distant locations, the regularity of the fading will be destroyed and less fading due to the interference can be expected. To get an impression of what can happen in the worst cast in the overlapping area, the single-ray model gives a good overview.

IV. FIELD TEST

A. Hardware Setup

For the test, two synchronized transmitters had to be developed. This was realized with a FPGA based 'Realtime Board'. The 'Realtime Board' is synchronized via GPS and the FPGA is driven by a stable 10 MHz clock which offers hard real-time stability and a constant delay of the signals. One transmitter (TX1) was located at the University of Hanover (height: 70 m above ground), the other one (TX2) at the headquarters of the Trade Fair Hanover (height: 100 m above ground) at a distance of 9.2 km from the university. The transmission frequency was 95.2 MHz. For the measurements a robust 4-QAM modulation with protection level 1 (49.7 kbps) was chosen.

Some test measurements were conducted to look for reasonable places and a proper power level. To get some errors to compare, the transmitter power was set to 1 W at each transmitter in the SFN mode and 2 W in the single transmitter mode.

B. Field strength prediction and measurement locations overview

A field strength prediction was calculated with the free radio propagation simulation program 'Radio Mobile'. 'Radio Mobile' is based on the ITS (Longley-Rice) propagation model. The program uses topographic data (SRTM data from the Space Shuttle Radar Terrain Mapping Mission), but no Morphology (buildings, woods, etc.).



Fig. 7. Heigh velocity measurement with a delay $(31 \ \mu s)$ added to TX1

The prediction was conducted with 1 W power at each transmitter. In the map in Figure 6 the different measurement locations are marked. One route on a city highway ('B3') to make tests with height speed (\approx 100 km/h). Two routes in urban area in the overlapping area were choosen ('Bult' and 'Ricklingen'). Here the trial was conducted with low speed (\approx 10 km/h) to analyze especially the flat fading. Additionally one route outside the overlapping are in a mixed surrounding (city highway/urban) was measured ('Limmer') with velocities of 50-70 km/h.

C. Height velocity measurements

As the route to the north-east (B3) lies in the overlapping area, the reception with and without delay was measured here. Figure 7 shows the results with a delay of 6 samples (31 μ s) added to TX1. The reception parameters field strength, bit error rate (BER), signal-to-noise ratio (SNR), the mean FAC (Fast Access Channel) error rate, the mean SDC (Service Description Channel) error rate and the mean audio error rate are plotted over the time in seconds.

In Figure 8 the same route in the other direction is plotted without delay. As the B3 lies mostly in the overlapping area, as expected the standard deviation and the errors increase without added delay. An overview of the measurement results is given in Table II.

D. Low velocity urban measurements

Measurements on two different routes have been conducted in urban areas with low speed. Both places are located within the overlapping area, thus the SFN mode was tested with and without delay to test the effect of fading in the overlapping area. The measurements were conducted, driving slowly (≈ 10 km/h) by car, the results are shown in Table II.

The results in 'Bult' show a good enhancement of reception quality for the SFN mode with a delay of 6 samples compared to the one transmitter modes. Besides the BER and audio error



Fig. 8. Heigh velocity measurement without delay

TABLE II Measurement results

Location/	Median	Standard	Mean	Mean	
Mode	field	deviation	BER	audio	
	strength	of the field		error	
	$[dB\mu V/m]$	strength [dB]		rate	
City heighway ('B3'), heigh velocity test in overlapping area					
with delay	36.9	3.7	0.0043	0.073	
no delay	36.5	3.9	0.0057	0.126	
Urban area ('Bult'), low velocity test in overlapping area					
TX1 only	40.3	5.7	0.0063	0.103	
TX2 only	39.5	4.8	0.0017	0.057	
SFN delay	40.1	3.4	0.0002	0.029	
SFN no delay	37.9	4.9	0.0025	0.059	
Urban area ('Ricklingen'), low velocity test in overlapping area					
TX1 only	35.3	4.9	0.021	0.233	
TX2 only	42.9	5.4	0.0005	0.224	
SFN delay	40.9	4.3	$5 \cdot 10^{-6}$	0.011	
SFN no delay	38.6	4.9	0.004	0.072	
Mixed surrounding ('Limmer'), outsite overlapping area					
TX1 only	34.26	7.9	0.0023	0.056	
TX2 only	37.15	9.0	0.0077	0.14	
SFN delay	36.5	8.2	0.0004	0.007	

rate, also the standard deviation decreases significantly. The last measurement was conducted in the SFN mode without adding delay. Here the reception quality decreases compared to the SFN mode with delay. The standard deviation is higher, which indicates more flat fading.

At the measurement location 'Ricklingen' some more power of TX2 arrived, since the antenna at the university is quite directional and the location is not located in the main beam. Nevertheless the SFN setup with delay enhances the reception quality significantly as summarized in Table II. Due to the difference in the median field strength of over 7 dB in the



Fig. 9. Cumulative distribution function in 'Bult'

single transmitter modes, the SFN modes result in a lower median field strength than with only TX2. However the SFN mode with delay still enhances the reception quality. With no delay added in the SFN mode, the standard deviation is getting higher, reception quality is getting worse here compared to the SFN mode with delay.

E. Measurements in mixed surrounding

On the route in 'Limmer' measurements have been conducted with only TX1 and only TX2 and in the SFN mode with delay. The results in Table II show clearly the enhancement of reception in the SFN mode. Although the median reception field strength was not equal from both transmitters, the bit error rate (BER) and audio error rate decrease with both transmitters switched on at half power. Due to the different median field strength the standard deviation of the SFN mode is in between the ones with one transmitter. However the second transmitter could fill deep fades which occur in the propagation path from one side.

Additional details on the measurement results are given in [12].

F. Cumulative distribution function

As the median field strength levels from each transmitter at the location 'Bult' are almost equal, a cumulative distribution function (CDF) of the field strength levels was calculated as seen in Figure 9. This shows clearly that while the CDF of the SFN without delay is even worse than the CDF of the single transmitter modes, the CDF of the SFN with delay shows a lower probability of deep fades.

V. CONCLUSION

In this paper the first DRM+ SFN setup in the air was presented. Comparing the reception of the SFN with the results of an one transmitter setup with equal power in different environments, the SFN enhanced the reception performance significantly. Results show that due to the small bandwidth of the DRM+ system, care has to be taken in the planning to avoid flat fading in the overlapping area when transmitting with the same power from each TX. Adding a different delay to transmitters lying side-by-side is one solution to overcome the flat fading. A delay > 15 μs showed good results in the calculations. In the field trial conducted with two TX, the reception performance in the SFN could be enhanced, adding a delay of 31 μs to one of the transmitters, the probability of deep fades became smaller.

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