Evaluations and Measurements of a Transmitter Delay Diversity System for DRM+

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Abstract - **In this paper the hardware setup and a field trial of a transmitter delay diversity (DD) system for DRM+ (Digital Radio Mondiale, Mode E) in 'urban' areas in the city of Hannover are presented. DD should help against destructive interferences resulting in signal dropouts, especially for slow receiver velocities. A closer look is taken on the spatial correlation of the channel paths and their influence on the system performance. Raytracing calculations with different transmitter heights and distances have been conducted to evaluate the correlation in different transmitter setups. Additionally the possibilities of using polarization diversity are evaluated.**

Keywords - Digital Radio Mondiale; DRM+; Transmit Delay Diversity ; Polarization Diversity ; Digital Broadcasting; Field Trial; Spatial Correlation, Raytracing, OFDM

I. Introduction

DRM+ (Digital Radio Mondiale, Mode E) is an extension of the long, medium and shortwave DRM standard for 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. With a bandwidth of 96 kHz, the OFDM based DRM+ system fits into the FM frequency raster and offers the chance to a successive digitalization of the FM-radio band. Especially for local radio stations, the system can be a possibility to digitize their signals, as in contrast to the DAB multiplex system, it offers a flexible frequency planning with an individual coverage area. As especially local radios are often licensed with low power and using low antenna facilities, techniques to enhance the reception quality can be interesting for a better coverage area.

To enhance system performance, the DRM+ channel coding offers the possibility to take advantage of the channel diversity. Especially with slow receiver velocities, destructive interference can produce channel attenuation over the whole signal bandwidth for a time period which exceeds the ability of the interleaver and the Viterbi decoder to recover the data.

Different diversity techniques are already used to enhance the performance in many OFDM based systems as IEEE 802.11, DAB or DVB-T. An overview of different spatial transmitter diversity techniques is given in [3]. As a diversity system without the necessity of applying changes to the receiver, the transmit delay diversity system was proposed for DRM+ in [4]. A comparison between the well known Alamouti transmit diversity scheme [5] and (cyclic) delay diversity (C)DD is given in [6]. It could be shown that the Alamouti scheme is leading to significant performance gains. For (C)DD, the gains are slightly smaller. On the other hand, the Almouti scheme is very sensitive against fast fading and changes have to be applied to the receivers, which are not part of the standard.

Therefore a transmitter delay diversity system was set up to evaluate the promising results in a real environment. As the performance enhancement is highly dependent on the correlation between the transmission paths, the wavelength in the VHF Band II is quite big and space is mostly a problem at antenna facilities, further evaluations on the spatial correlation and antenna distances at different antenna heights have been conducted.

In this paper, the channel coding properties of the DRM+ system and the DD setup are introduced. Simulations of the system performance in channels with different spatial correlations based on the transversal filter method are presented. Different transmitter setups (heights and distances and polarization diversity) are being evaluated by raytracing calculations and the hardware transmitter setup and measurement results of a field trial with a DRM+ DD system are presented.

TABLE I
DRM+ System parameters

Subcarrier modulation	4-/16-QAM
Signal bandwidth	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
Bit Interlever	100 ms
Cell Interleaver	600 ms

II. DRM+ system parameter

The DRM+ system uses Coded Orthogonal Frequency Division Multiplex (COFDM) modulation with different Quadrature Amplitude Modulation (QAM) constellations as subcarrier modulation. The additional use of different code rates result in data rates from 37 to 186 kbps with up to 4 program services. 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.

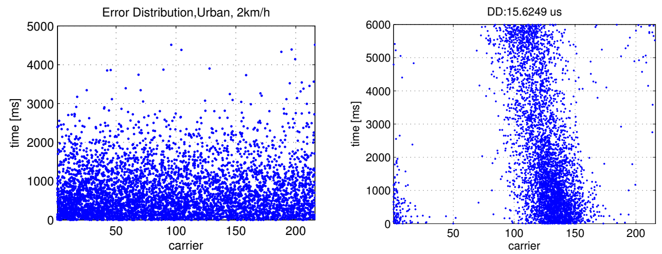

Fig. 1. Distribution of bit errors (blue dots) in an uncoded system in an urban channel simulation with slow receiver velocity (left: without DD, right: with DD)

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

In the measurements 4-QAM subcarrier modulation with a code rate of $R_0 = 0.33$ was used.

III. Transmitter Delay Diversity

A common experience listening to FM radio in the car and stopping at a traffic light is hearing it degenerating into static, while the signal is reacquired if the vehicle moves a fraction of a meter out of the destructive interference, which is caused by multipath propagation. A possibility to overcome this problem is the introduction of additional diversity to the channel. As DRM+ is a broadcasting system, transmitter diversity applications have the advantage that two (or more) antennas have to be installed only once at the transmitter. The cost and size of the receivers does not increase.

A transmit diversity scheme using space-time-block coding was proposed by Alamouti [5]. This system is optimal in the sense that it provides the same diversity gain as a two RX antenna system with maximum ratio combining (MRC). On the other hand, it has the drawback to increase the necessary amount of pilots for channel estimation by a factor of two. Furthermore, it is quite sensitive against fast fading scenario [6]. And in the receiver the Alamouti decoder has to be implemented, which is not part of the approved DRM standard. For this reasons a simpler transmitter delay diversity (DD) system was set up. In this DD system a second (or more) antenna transmits the same OFDM signal with a small time delay δ. The signals are weighted according to the number of TX branches in a way that the overall power level stays the same.

At the receiver the signal can be seen as a superposition of both signals with an increased delay spread. As the introduced delay reduces the size of the effective guard interval, it should be chosen sufficiently small. In the field trial a delay of 15.625 us and 31.25 us was used, as this could implemented easy by delaying one signal branch by 3 or 6 samples at the sample rate of 192 kHz. The corresponding coherence bandwidth is 64 kHz/32 kHz. With this flat fading can be prevented as the frequency response at least has one maximum and one minimum at the signal bandwidth of 96 kHz.

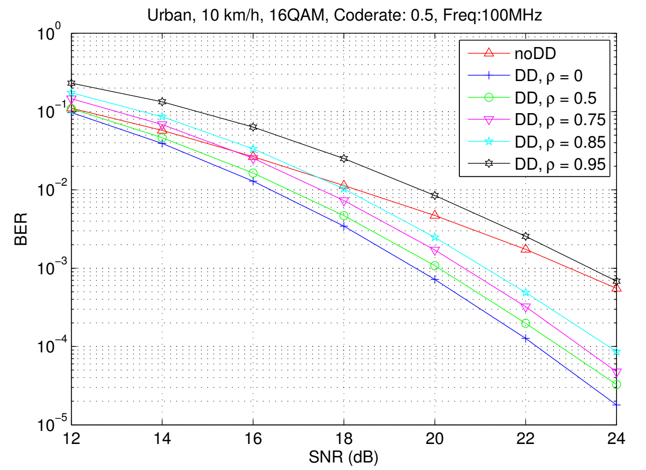

Fig. 2. Simulation of the performance in an 'urban' channel with different correlated paths

An additional approach to avoid the reduction of the guard interval is cyclic delay diversity (CDD). Here a cyclic delay of the OFDM symbol is applied before appending the guard interval [6]. However, as the DRM+ guard interval is 250 μs and a delay of 15.625 μs is enough to get a frequency selective channel, this approach was not evaluated.

Figure 1 shows the disribution of the bit errors in an uncoded system over the time and carriers. On the left the signal was filtered by a tab delay line filter, representing an 'urban' channel at a slow receiver velocity at a center frequency of 100 MHz. The channel parameters are given in [1]. The bit errors are distributed over all carriers and, due to the slow velocity, over a long time. The error correction won't be able to correct the bit errors. On the right a DD system was simulated with the same channel parameters and a delay of 15.625 μs. The errors appear over the whole time but only affect part of the carriers. With an appropriate interleaving and error correction the signal can be decoded properly.

IV. System performance simulations

Simulations of a DRM+ system with (cyclic) transmitter delay diversity are presented in [6] and [4]. They show a diversity gain between 3 and 6 dB for an urban channel at different velocities, but only with fully decorrelated transmission paths. However, in a transmitter diversity setup with an elevated transmitter the antenna distance has to be considerably greater than in a receiver diversity setup to get uncorrelated transmission paths [7]. Therefore simulations with a delay diversity setup with correlated paths were conducted.

The channel was implemented as a tapped delay filter with the properties of the 'urban' channel given in [1] with a velocity of 10 km/h. Simulations were conducted with a correlation coefficient ρ of 0, 0.5, 0.75, 0.85 and 0.95. Additionally the results of a one transmitter setup are shown in Figure 2.

Up to ρ = 0.85 Figure 2 shows small degradations in the diversity gain with increasing correlation. For higher corella-

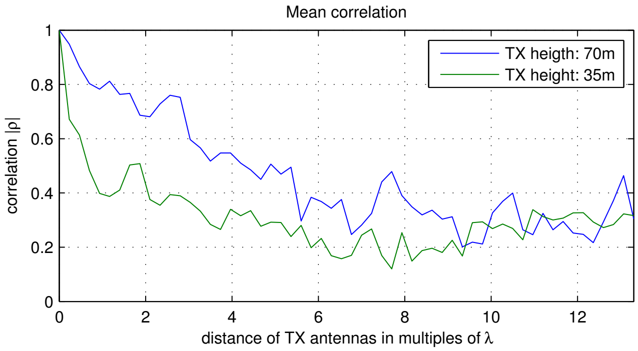

Fig. 3. Mean correlation between the RX signals from 2 vertical polarized TX antennas with different distances

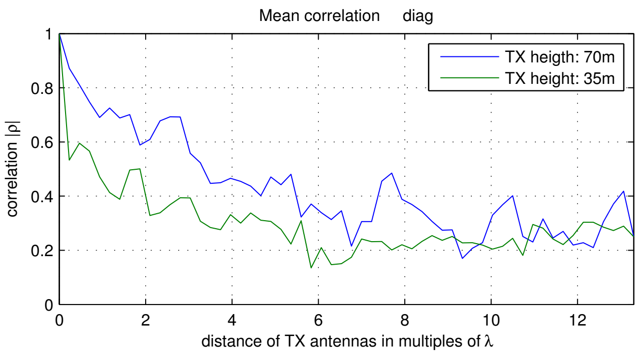

Fig. 4. Mean correlation between the RX signals from 2 diagonal ($\pm 45°$ slanted) TX antennas with different distances

tion a significant degradation in system performance can be seen.

V. Raytracing calculations

As the correlation coefficient in a broadcast situation with an elevated transmitter is highly dependent on the scatterers in the receivers surrounding [8], it's not possible to calculate the exact correlation between the two signal paths. Therefore a city model was created with 'Wireless InSite' to get an idea of the parameters. Also as the possibilities of the realworld transmit antenna setup were quite restricted, further raytracing calculations were conducted to analyze the behavior of the system with different TX antenna distances and heights. The model of the city was created of around 4000 x 800 m. Two routes of 58 transmitters each were installed at one end at a height of 35 m and 70 m over ground. The houses in the TX surrounding have heights between 30 and 42 m so the lower transmitter route (35 m) is located at around the height of the roofs to provoke reflections near the transmitters. This low antenna setup shall represent the situation of many local radio stations using the given infrastructure of rooftops to setup the TX antenna. The other setup is adapted to the situation in the field trial with an antenna elevation of 70 m over ground. The distance between the transmitters was 0.7 m, so transmitter distances up to 40.6 m (corresponding to 13.5 λ at 100 MHz) have been evaluated. Four receiver routes were installed at a distance of 3500 - 4000 m from the TX at a height of 2 m

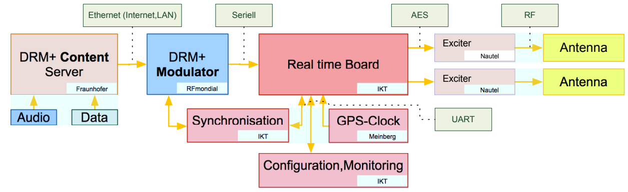

Fig. 5. Block diagram of the transmitters hardware setup

over ground. The RX routes consisted of 200 - 300 single receivers, with a distance of 2 m. The height of the buildings in the surrounding of the RX is 10 - 50 m, so there was little LOS propagation, lots of reflections occured in the surrounding of the receivers.

The complex RX power was calculated as the summation of the complex impulse response. In order to evaluate the correlation coefficient, the complex power at a receiver route, transmitting for example from the first transmitting antenna (x_i) is combined to the complex power at the same receiver route arriving from the second transmitting antenna (y_i).The correlation coefficient for the n reception points is then calculated as:

$$\rho(x, y) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad (1)$$

with $\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ and $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$.

This was then repeated for the other TX antennas at rising distances from the first antenna.

Figure 3 shows the mean correlation between the vertically polarized TX antennas versus the distance between the TX antennas at different heights of the TX antennas. As expected, the correlation is much lower with lower TX antennas as reflections already took place near to the transmitter. At the TX height of 70 m a correlation lower than 0.8 was achieved with a distance of 2 λ.

As the space at a transmitter tower is often limited, polarization diversity, as often used in mobile communication [9], was evaluated. A setup with a diagonal polarization diversity antenna setup was tested with two antennas $\pm 45°$ slanted. Figure 4 shows that in this setup the correlation is significantly lower, especially for the 70 m height TX setups up to a distance of 2 λ. A correlation coefficient below 0.8 can be achieved at a distance of 1 λ for the 70 m setup. Another advantage of this setup is that it offers comparable reception quality for vertical and horizontal RX antennas.

A polarization diversity setup with vertical/horizontal polarized antennas also showed good decorrelation. However the cross polar discrimination (XPD) was very high in this setup with vertical RX antennas so the performance enhancement is quite low. Another possibility could be using circular polarization as evaluated in [10].

VI. Transmitter Hardware Setup

The main challenge for the hardware setup was the exact synchronization of the two transmitters. As the setup should also work for a Single Frequency Network (SFN) test, the

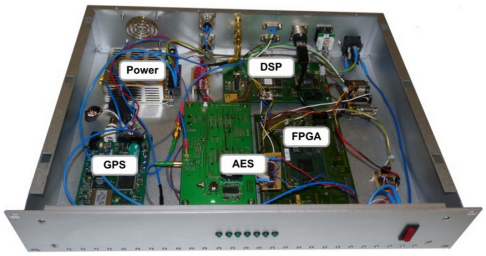

Fig. 6. The hardware setup of the DRM+ diversity transmitter

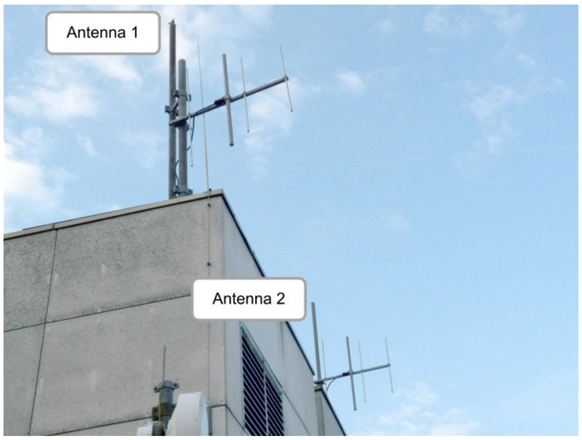

Fig. 7. Transmit antennas

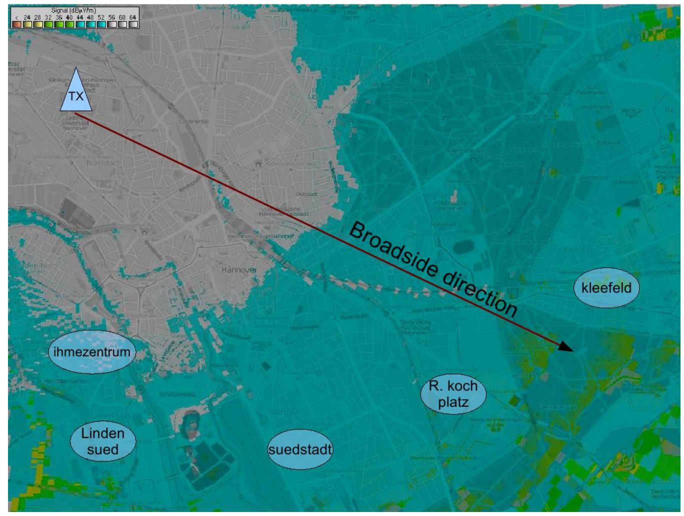

Fig. 8. Measurement locations (mapdata (c) OpenStreetMap and contributors, CC-BY-SA, http://www.openstreetmap.org)

synchronization also has to work when the transmitters are at different locations.

Figure 5 shows the transmitter setup. The program relevant data like audio, text messages, pictures etc. are encoded by the content server. The prepared data stream is sent via LAN or Internet to the DRM+ modulator. The modulator adds the channel coding and modulation to the data stream. For the synchronization of the two baseband signals for DD, a FPGA based 'Realtime Board' was developed. As it should also work in a Single Frequency Network with distant transmitters, the 'Realtime Board' is synchronized via GPS and the FPGA is driven by a stable 10 MHz clock which offers the possibility to synchronize the two transmitters and to add a constant delay to the signals.

VII. Measurements

The measurements with DRM+ in the DD mode were conducted in 2010 in the city of Hannover. The transmitter was located on the roof of the university building at a height of 70 m over the ground. An ERP (Effective Radiated Power) of 30 W (2x15 W in case of DD) was transmitted at 95.2 MHz. The two vertically polarized yagi antennas were mounted at a distance d of 8 m (2.5 λ) as this was the maximum available space on the roof. Compared to the calculations in section V and IV this distance should already provide enough decorrelation to enhance the reception quality.

Measurements have been conducted at five locations at different distances from the transmitter and angles to the antennas broadside direction at a receiver velocity of around 10 km/h. Depending on the angle between the broadside direction of the antennas and the direction of the measurement location α, the effective antenna distance varies as $d_{eff} = d \cdot cos(\alpha)$. Figure 8 shows the locations together with a field strength prediction calculated with the freeware program 'Radiomobile'. Most of the locations are 'urban', which are 5-6 floored buildings in Hannover. Only 'R. Koch-Platz' is 'suburban' with one family houses. Each route had a length of approximately 5 minutes.

For comparison the transmitter setup was switched between one transmitter (nondiv), two transmitters with a delay of 3 samples (15.625 μs, DD3) and two transmitters with a delay of 6 samples (31.25 μs, DD6).

A. Measurement equipment and parameters

The magnetic monopole reception antenna was mounted on a van at a height of 2 m. As HF-Frontend a Rhode & Schwarz test receiver (ESVB) was used, providing filtering at the IF output (300 kHz). The IF output was connected to an Universal Software Periferial (USRP, Ettus Research LLC), which provided A/D conversion and resampling. The DRM+ signal was then decoded by the software receiver (RFmondial). The IQ data was recorded and the power spectrum density (PSD) was analyzed offline on it's standard deviation. The receiver records all kind of reception parameters, see details in [11]. Here, the mean FAC (fast access channel) CRC and the mean audio errors (when available) were analyzed.

B. Measurement results

Table II shows the results of the measurements. In the second column the standard deviation of the PSD is given. Additionally the FAC CRC error rate and, if measured, the audio error rate are given to compare the reception quality.

The results show, that the standard deviation decreases in the DD-mode at every measurement location, which indicates, that fading is decreasing. In most of the 'urban' measurement

TABLE II
MEASUREMENT RESULTS

Location/Mode	Std. PSD	FAC CRC	Audio
'Urban' ('Ihmezentrum'), 2 km from TX, $d_{eff} = 4\ m$			
nondiv	5.64000	0.00588	x
div DD3	5.03000	0.02313	x
div DD6	4.78000	0.00441	x
'Urban' ('Linden Sued'), 3 km from TX, $d_{eff} = 4\ m$			
nondiv	6.00170	0.02690	0.07440
div DD3	5.49	0.01220	0.02950
div DD6	5.48580	0.00540	0.01775
'Urban' ('Suedstadt'), 4 km from TX, $d_{eff} = 7\ m$			
nondiv	5.47000	0.01610	0.04800
div DD3	4.76000	0.00240	0.00890
div DD6	5.22000	0.00189	0.00760
'Urban' ('Kleefeld'), 6 km from TX, $d_{eff} = 7.8\ m$			
nondiv	5.63000	0.00120	0.00481
div DD3	5.22000	0.00213	0.00273
div DD6	5.18000	0.00152	0.00485
'Suburban' ('R. Koch-Pl.'), 4.5 km from TX, $d_{eff} = 7.8\ m$			
nondiv	5.26000	0.00407	x
div DD3	4.02000	0.07560	x
div DD6	4.90000	0.01650	x

locations the reception was getting better with DD. Exceptions are the FAC-CRC DD3-Ihmezentrum and Kleefeld and the audio errors of DD6-Kleefeld, which are sligthly increasing compared to the one-TX setup. The 'suburban' measurement at 'R. Koch Platz' is worse with DD compared to the single transmitter case. An explanation for this can be the lower buildings in this area, resulting in less multipath propagation than higher buildings. This is supported by the lower standard deviation in this case.

The angle to the broadside direction and therefore the effective distance between the antennas doesn't seem to have an influence on the measurement results.

VIII. CONCLUSIONS

In this paper a DRM+ system setup and field trial with transmitter delay diversity was presented and analyzed. Further studies have been conducted regarding the spatial correlation between two transmission paths for different transmitter setups (heights, distances and polarizations) and it's impact on system performance.

Simulations show the dependency of the diversity gain on the spatial correlation of the channel paths. A significant diversity gain could be achieved up to a correlation coefficient of 0.85.

Raytracing calculations of two transmitter setups with different distances between the TX antennas have been conducted. The low transmitter setup, as it could be used by small local radio stations using the rooftop to install the antenna, shows a very fast decrease of the correlation, offering an anhancement of the performance at distances of less than a wavelength between the transmit antennas.

The higher transmitter setup, as used in the field trial shows that a correlation coefficient lower than 0.8 can be achieved with antenna distances of 2 λ with two vertical TX antennas. Lower correlation could be achieved in both cases with additional polarization diversity.

The measurement results show that reception could be enhanced in most 'urban' locations with our DD setup. In some cases reception quality slightly decreases, specially in the 'suburban' environment with lower standard deviation.

ACKNOWLEDGMENTS

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