Simulations and Measurements of a Receiver Diversity System for DRM+

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ABSTRACT
To enhance the system performance of a DRM+, Digital Radio Mondiale system in VHF Band II, several receiver diversity techniques have been evaluated. In this paper simulation and measurement results of different receiver diversity and combining techniques are presented. In preparation for the field trial, evaluations of the antenna setup and correlation between the two receiving antennas have been conducted. The hardware setup of a two antenna diversity receiver and the results of a measurement campaign of the receiver diversity system for DRM+ in urban areas in the city of Hannover will be presented. The results show a significant enhancement of the system performance with receiver diversity.

Keywords
Digital Radio Mondiale; DRM+; Receiver Diversity; MIMO; Digital Broadcasting; Field Trial; OFDM; Maximum Ratio Combining; Selection Combining

1. 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 existing FM frequency raster and offers the chance for 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.

Several field trials for the evaluation of the system performance have been conducted at the University of Hannover, which served as input for the ITU standardization.

Table 1: DRM+ System parameters

Subcarrier modulation	4-/16-QAM
Signal bandwidth	96 kHz
Subcarrier spread	444.444 Hz
Number of subcarriers	216
Symbol duration	2.25 ms
Guard interval duration	0.25 ms
Transmission frame duration	100 ms
Bit Interlever	100 ms
Cell Interleaver	600 ms

To enhance the 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 to recover the data. Antenna diversity techniques can overcome this flat fading by introducing additional diversity to the channel. Different field trials with transmitter diversity techniques and Single Frequency Networks have been conducted at the University of Hannover and showed good results ([3] and [4]) with a slowly moving receiver.

Receiver 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 receiver and transmitter diversity techniques is given in [5]. [6] shows the results of diversity reception of the Digital Audio Broadcasting system. This paper evaluates the usage of receiver diversity techniques for the DRM+ system. First the properties of the DRM+ system are introduced. Different receiver diversity techniques and simulation results of the system performance in channels based on the transversal filter method are presented. The hardware setup and measurement results of a field trial with a DRM+ system with a Selection Combining (SC) as well as a Maximum Ration Combining (MRC) receiver diversity setup are presented.

2. DRM+ SYSTEM PARAMETER
The DRM+ system uses Coded Orthogonal Frequency Division Multiplex (COFDM) modulation with different Quadrature Amplitude Modulation (QAM) schemes as subcarrier modulation. The additional use of different code rates re-

sults in data rates from 37 to 186 kbps. A signal with a low data rate is more robust and has lower SNR requirements. Table 1 shows the system parameters of the DRM+ system.

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).

3. RECEIVER DIVERSITY TECHNIQUES

The following combing methods have been evaluated in terms of diversity gain and performance costs.

Switched Combining (SWC): If one reception branch falls below a given SNR threshold the receiver switches to the other branch. This has the advantage that only one branch has to be decoded at all. However, as other synchronisation processes as frequency and frame synchronisation are done with values gathered from the previous frames, switching on a frame basis is not possible without doing this synchronisation also in the the second branch.

Selection Combining (SC): The SNR of both branches is estimated and the branch with better SNR is decoded. In theory two branches have to be decoded up to the time synchronisation as the SNR estimation is done via the time correlation/synchronisation as decribed in [7]. The statement about frequency and frame synchronisation from SWC is also valid here, so synchronisation up to a frame level has to be performed.

Maximum Ratio Combining (MRC): The gain of each branch is made proportional to the RMS signal level and inversely proportional to the mean square noise level in that branch. For this combining method the exact knowledge of the channel response of each branch is necessary. Two decoding stages up to channel estimation have to be implemented. To reduce the computational complexity and power consumption of the MRC scheme, different methods are given for example in [8].

Equal Gain Combining (EGC): Two signals are combined with equal gain. This offers a very simple implementation with good performance when used in conjunction with differential detection. As DRM+ uses QAM, phases have to be corrected before the combining. This also needs two decoding stages up to the channel estimation.

3.1 Simulations

Simulations have been conducted in different channels and different velocities with a 16-QAM at a code rate of 0.5. The channels were implemented as tapped delay filters with the properties of the 'urban' and 'rural' channel given in [1] with a velocity of 10, 60 and 150 km/h. The threshold for SWC has been set to an SNR of 12 dB, as this has shown the best results in further simulations that have been conducted.

Figure 1 shows the results of a very slow urban channel at a receiver velocity of 10 km/h. As the slow speed of the receiver results in slow and flat fading and the cell interleaver can only work properly up to a duration of 600 ms this

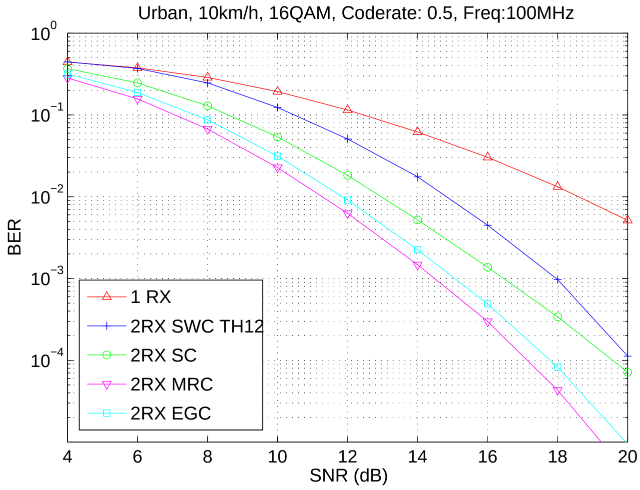

Figure 1: Simulation results for a very slow urban channel

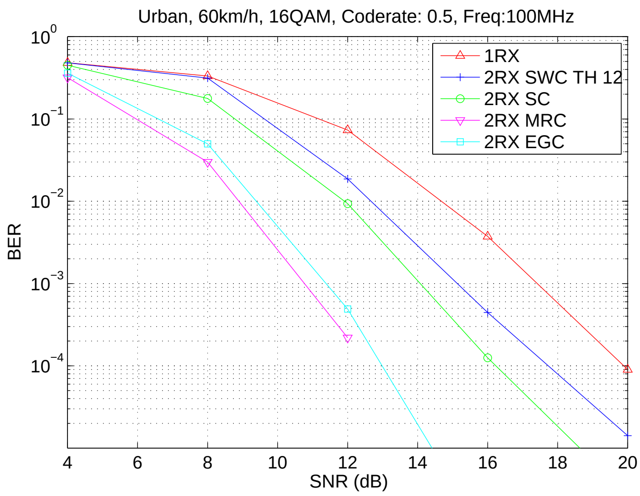

Figure 2: Simulation results for an urban channel

results in high error rates. Receiver diversity enhances the performance up to 8 dB with MRC, slightly less with EGC, SC performs somewhere in between and SWC has a gain of around 4 dB.

Higher receiver velocities result in better performance, as the interleaver can work properly. The results can be seen in Figure 2. The diversity gain in this performance simulation in an urban channel at a velocity of 60 km/h for MRC is also $\approx$ 8 dB, EGC slightly less, SC around 3 dB and SWC results in a gain of only $\approx$ 2 dB.

Figure 3 shows the simulation results for the rural channel. At a receiver velocity of 150 km/h the gain by application of SC and SWC is very low. As an effect of the high velocity, the channel variation within one frame is significant. The evaluation of the switching or selection parameter is done only once in a frame. Theoretically it could be done more often, resulting in a higher diversity gain for SC and SWC at high velocities, but the implementation effort of the channel

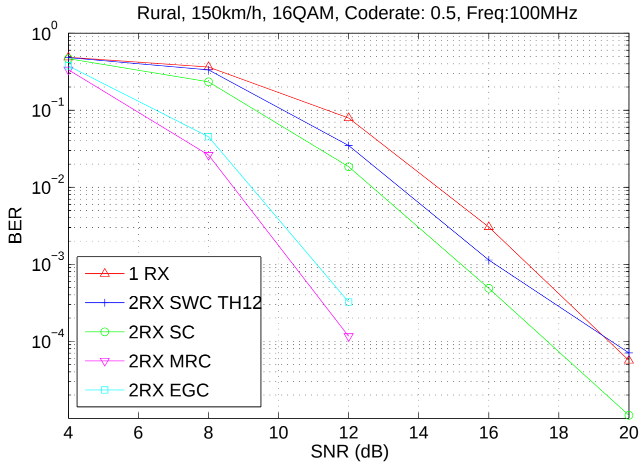

Figure 3: Simulation results for a rural channel

estimation will be very high, as this is based on a frame level. The gain of MRC is again around 8 dB, EGC slightly less.

As SC performs better than SWC and the implementation effort is comparable due to the recursive frequency and frame synchronisation, it has been used for the measurements. The same for MRC, which performs better than EGC and therefore has been chosen for the measurements.

3.2 Measurements

To setup the trial, the space diversity antenna installation has been evaluated. For receiver diversity with horizontal distributed antennas the correlation between the antennas in a Rayleigh fading environment, with the scatterers uniformly distributed around the receiver can be approximated by [9]:

$$\rho(d) = J_0(\frac{2\pi d}{\lambda}) \quad (1)$$

with the Bessel function of the first kind and zero order J_0, the distance d between the antennas ans the wavelength λ. For restricted angles of arrival the correlation for a given spacing is increasing. In [9] a distance of 0.5 λ is given as a reasonable compromise. A more detailed analysis about the effects between closely spaced antennas, is given in [10]. For smaller distances than 0.5 λ the coupling effects between the antennas are becoming significant. On the one hand this reduces the correlation between the antennas, on the other hand it can reduce the efficiency up to a level higher than the diversity gain.

For the measurement two vertically polarized magnetic antennas were mounted on a van at a distance of 1.5 m ($\approx$ 0.5 λ). As stated before, the combining was done with Selection Combining (SC) and Maximum Ratio Combining (MRC).

A prototype measurement receiver was developed, the frontend is shown in Figure 4. It sends IQ-data from both antennas via USB to the software receiver. For the measurements the IQ data was stored and the decoding for the different modes was done offline. The receiver records all kind of reception parameters, see details in [11]. For this trial the

Figure 4: Diversity DRM+ receiver prototype

mean errors of the cyclic redundancy check (CRC) of the FAC (fast access channel), the mean audio errors and the Bit Error Rate (BER) were analyzed.

The measurements with DRM+ and receiver diversity were conducted at four urban locations in the city of Hannover. The transmitter was located on the roof of the university building at a height of 70 m above ground. An ERP (Effective Radiated Power) of 3 W was transmitted vertically at 95.2 MHz. The locations were chosen to be at the edge of the coverage area in order to have some errors to compare the reception modes. Additionally the possibility of driving very slowly ($\approx$ 10 km/h) without too much problems with other traffic was given at this locations. At this slow velocities flat fading can occur.

Table 2: Measurement results

Location/ Mode	Mean BER [$\cdot 10^{-4}$]	FAC CRC mean error rate [$\cdot 10^{-4}$]	Mean audio error rate [$\cdot 10^{-4}$]
Urban area ('Bahnhof')			
Antenna A	584	1399	2587
Antenna B	2502	4683	7670
SC	259	1161	2549
MRC	217	993	2434
Urban area ('Linden Sued')			
Antenna A	676	2331	4975
Antenna B	608	1879	4434
SC	399	1665	3537
MRC	274	1034	1963
Urban area ('Ihmezentrum')			
Antenna A	227	1059	2538
Antenna B	173	378	746
SC	91	489	999
MRC	83	360	635
Suburban area ('Bult')			
Antenna A	420	1559	3316
Antenna B	936	3028	5639
SC	376	1405	2852
MRC	283	1435	2841

Most of the locations are 'urban', which are 5-6 floored buildings in Hannover. Only 'Bult' is 'suburban' with one family houses. Each route had a length of around 3 minutes. For the measurements a robust 4-QAM modulation with protection level 1 (data rate: 49.7 kbps) was chosen.

Table 2 shows the measurement results. As expected, in most of the results an enhancement of the reception quality can be seen with SC and even more with MRC compared to the one antenna receiver modes. Exceptions are the FAC CRC error rate and Audio error rate at 'Ihmezentrum' which is slightly higher in the SC mode than with only antenna B and the FAC CRC error rate at Bult, which is slightly higher with MRC than with SC. The differences between BER, Audio errors and FAC errors are caused by the different length of the evaluated CRCs and bit sequences. It showed that flat fading could be diminished with the diversity techniques which showed a significant enhancement of reception quality.

4. CONCLUSIONS

In this paper simulations and measurements of a receiver diversity system for DRM+ were presented.

Simulations show that a significant diversity gain can be achieved with receiver diversity. Different combining methods were compared, the best results could be achieved with Maximum Ratio Combining. Another promising method, that needs less computing time is Selection Combining.

The measurement results show that reception could be enhanced in most urban and suburban locations with receiver diversity. Maximum Ratio Combining provides better results at all locations. With Selection Combining in three out of four locations the reception quality could be enhanced.

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