Evaluation of the Channel Properties for a DRM+ System and Field Tests in the VHF-Band III (174-230 MHz)

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***Abstract* - In this paper we present an evaluation of the channel properties for a DRM+ system in the frequency Band from 174-230 MHz (VHF-Band III). Simulations of the system performance at different frequencies and with different receiver velocities are shown. Other aspects that have an effect on the system performance at higher frequencies are analysed. Additionally, measurements in the VHF-Band II and III are presented to analyse and compare the performance in the real-world. The theoretical work show that reception is possible up to receiver velocities of around 200 km/h in Band III. The measurements show similar results for Band II and III.**

Keywords - Digital Radio Mondiale; mobile reception; Doppler spread; digital broadcasting; channel properties

I. INTRODUCTION

DRM+ (Digital Radio Mondiale, Mode E) is an extension of the long, medium and shortwave DRM standard up to Band III. It has been approved in the ETSI (European Telecommunications Standards Institute) DRM standard [1] for frequencies up to 174 MHz. Field trials with DRM+ were conducted in Hannover and Kaiserslautern [2] in Band II and in Paris in Band I. In Germany and other countries the VHF-Band II (87,5-108 MHz) is fully occupied with FM-radio, which will not be swiched off in the next years. At the same time, in Band III, which allocates the frequencies from 174 to 230 MHz, there is a lot of free spectrum intended for audio broadcast, therefore evaluations about the use of DRM+ in Band III were started. In Band III DRM+ can coexist with the multiplex radio system DAB (Digital Audio Broadcast), offering local radios a cheap and flexible possibility to digitalize their signals, which is hardly possible with DAB due to its multiplexed structure.

In this paper Section II gives a short introduction to the DRM+ system parameter. Evaluations of the channel properties, simulations of the effects of mobile reception for different receiver velocities at different frequencies are presented in Section III and Section IV gives a comparision of measurement results in Band II and III. Section V gives a conclusion of the possibilities and limitations of the DRM+ system in the VHF-Band III from 174-230 MHz.

Table I
DRM+ SYSTEM PARAMETER

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 dureation	100 ms

II. DRM+ SYSTEM PARAMETER

The DRM+ system uses Orthogonal Frequency Division Multiplex (OFDM) modulation with different Quadrature Amplitude Modulation (QAM) constellations as subcarrier modulation. The additional use of different code rates result in data rates from 40 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 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 cellinterleaving over 6 transmission frames (600 ms).

In the simulations and the measurements 16-QAM subcarrier modulation with a code rate of $R_0 = 0.5$ (protection level 2) resulting in a bit rate of 149 kbps was used.

III. CHANNEL PROPERTIES

The following section gives an overview of the channel properties at different frequencies and receiver velocities and how they can effect the reception.

A. Intercarrier interference

A receiver in motion causes Doppler shifts of the OFDM carriers. If this is combined with multipath propagation,

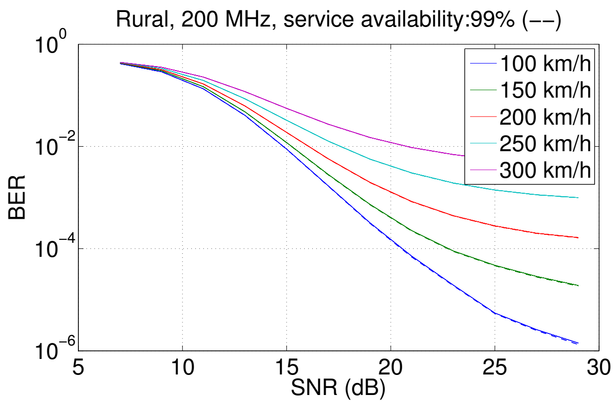

Figure 1. Performance in Band III

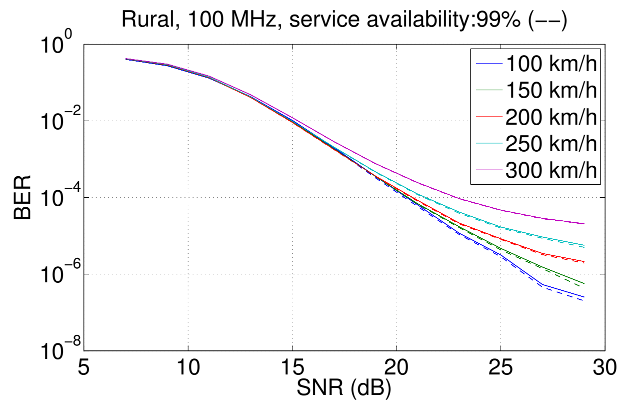

Figure 2. Performance in Band II

paths from different directions can cause frequency dependent Doppler shifts, which results in Intercarrier Interference (ICI). This interference can be handled as additional near-Gaussian noise [3]. In [4], upper bounds of the normalized interference power for a classical (Jakes) channel model depending on the maximum Dopplershifts (f_d) and the symbol duration (T_s) are given as

$$P_{ICI} \leq \frac{1}{12}(2\pi f_d T_s)^2. \quad (1)$$

The Doppler shift increases with increasing carrier frequencies f_0 and receiver velocities v as $f_d = f_0 \cdot \frac{v}{c} \cdot cos(\alpha)$, with the speed of light c and the angle between the direction of arrival and the direction of motion α. To analyse the performance of the system at different frequencies and receiver velocities, simulations were conducted with a rural channel, implemented as a tapped delay filter as described in [5]. The complex output signal $r(t)$ is generated from the following equation:

$$r(t) = \sum_{k=1}^{N_T} G_k(t) m(t - \tau_k). \quad (2)$$

With the complex input signal $m(t)$, the relative path delays τ_k and the the path process $G_k(t)$. $|G_k(t)|$ follows a Rayleigh distribution, the phase follows a uniform distribution, every path is characterized by a Doppler spectrum and a certain attenuation. The simulations were conducted with a 'rural' channel, which is defined in [1]. The effect of ICI power was added as an additional noise relative to the signal amplitude, in a function of the receiver velocity.

Additionally to the averaged Bit Error Rate (BER), the BER with a service availability of 99 % was plotted. In [6] a 'good' mobile reception is defined as having a coverage of 99 % of the locations. The simualtion was conducted with 100 channel calls, every call loads a random set of path processes, which stands for a different set of multipath components, which can be seen as different locations. An approximation of the 99 % coverage probability can be calculated as the average of the (in this case) 99 simulation calls, having the lowest bitrate. With every call 120 frames (12 sec. of data) containing a pseudo random bit sequence were filtered by the tapped delay filter, decoded and the BER was calculated. Figure 1 shows the simulation of the performance of a DRM+ system in Band III (200 MHz). For comparison Figure 2 shows the results for Band II (100 MHz). The BER for a coverage probability of 99 % is plotted together with the values for 100 % for receiver velocities from 100 to 300 km/h. In [7] a BER of 10^{-4} is given as a value where a proper reception is still possible in a DRM system. The simulation results show that at 100 MHz a signal to noise ratio (SNR) of 20 dB is necessary to reach this value at a velocity of 100 km/h. For 300 km/h a SNR of 22.5 dB is necessary. At 200 MHz and 100 km/h the necessary SNR stays the same as at 100 MHz. Stepping up the receiver velocity, the impact of the ICI increases faster. In Band III at 150 km/h a SNR of 22.5 dB is necessary, at 200 km/h the BER of 10^{-4} is hardly achived with around 30 dB. For higher velocities this scenario doesn't achive a bit error rate of 10^{-4}.

The coverage probability has no big effect on the system performance within the analysed velocities. At a frequency of 100 MHz and the lowest velocity small differences can be seen at high SNR values, at 200 MHz there are no differences between the full coverage and a coverage propability of 99 %. This shows that the coherence time of the channel at that frequencies is short enough (for 150 km/h ist is 0.072 sec. at 100 MHz and 0.036 sec. at 200 MHz) that the average over the simulation time stays nearly the same. The deep fades are short enough that the cell- and bitinterleaver can handle them. Simulations, carried out with low receiver velocities showed big differences between the full coverage and a certain coverage probability.

B. Flat fading

For low receiver velocities in Band II flat fading, resulting in signal dropouts occurs due to deep fades, lasting longer

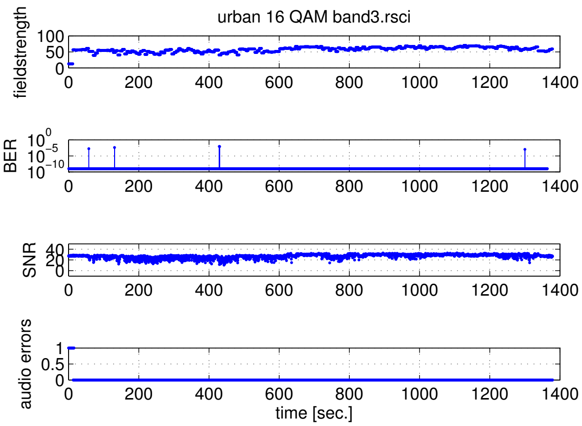

Figure 3. Measurement results in Band III

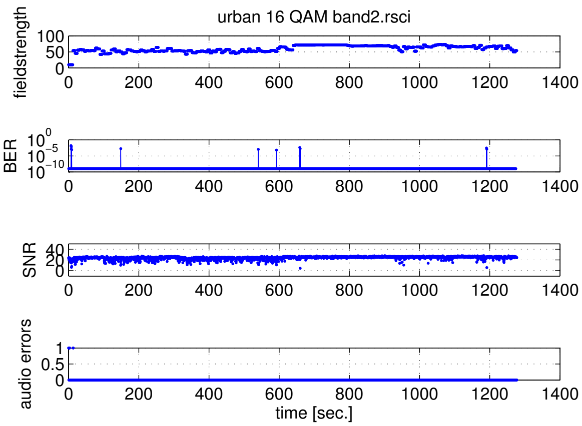

Figure 4. Measurement results in Band II

than the cell interleavers time. As a result, there is no chance to recover the signal by the following error correction. As a shorter wavelength results in a higher spatial resolution of the interference pattern in the air, the coherence time becomes smaler and there can be less dropouts due to flat fading.

C. The pilot grid

For channel estimation, DRM+ uses pilots, that are distributed diagonally over the frames. The pilots are inserted on every fourth subcarrier, every four symbols. As described in [8], the maximum Doppler frequency, a system can handle depends on the pilot grid in time direction. Considering the symbol duration of T_s=2,5 ms, in time direction the channel is measured every $4 * T_s$=10 ms, so the channel is sampled at a sampling frequency of 100 Hz. To satisfy the sampling theorem the maximum Doppler frequency f_d, which is the reciprocal of the channels coherence time, has to fullfill the condition: $f_d < 50$ Hz. At 100 MHz this value is achived at a velocity of 540 km/h, at 200 MHz at 270 km/h.

IV. Measurements in Band II and III

In winter/spring 2010, DRM+ measurements were conducted at 95.2 MHz (Band II) and 176.64 MHz (Band III) in the city of Hannover and its surroundings. The transmitter was located at the roof of the university building at a height of 70 m over the ground. Both in Band II and III an ERP (Effective Radiated Power) of 30 W was transmitted with directive yagi antennas with nearly the same radiation pattern, so that in the main beam the results of the coverage measurements are comparable. The transmission content was generated with a Fraunhofer Contentserver and consisted in an audio stream with a bit rate of 103.6 kbps and a pseudo random bit sequence with 45.4 kbps, to measure the Bit Error Rate (BER). The transmitter equipment consisted of a modulator from RFmondial, an amplifier from Nautel for Band II and a Thomson linear amplifier for Band III. The measurement included the field strength, which was recorded with an Rhode & Schwarz test receiver (ESVB), the audio status and BER of the receiver (RFmondial software receiver) and the Signal to Noise Ratio (SNR), calculated via the time correlation/syncronisation.

A. Measurements in an urban environment

To test the reception in an urban environment measurements were conducted in the inner city of Hannover. This area is located in the main beam of the transmission, so the results for Band II and III are comparable. The measurements were conducted at a velocity of around 15 km/h on the same route.

In Figure 3 and 4 the results are shown over the time. In the first row the field strength is plotted, the second row shows the BER, the third one shows the calculated SNR and the last one shows the status of the audio decoder (0: audio OK, 1: one or more audioframes corrupted). At both frequencies the reception was nearly the same. It worked down to a field strength of around 48 dBuV/m at an SNR of around 20 dB. Differences regarding flat fading of the channel can not be seen in the measurement results.

B. Measurements of the coverage limit

Additionally measurements of the coverage limit were conducted on a highway towards the transmitter in the main beam, passing rural area and some villages and the city of Hannover. In Figure 5 and 6 the measurement results are plotted.

The measurement in Band III was started at a distance of around 30 km from the transmitter, in Band II at a distance of around 20 km. While the reception in the open (flat) environment often was still good, errors came up, passing villages. In the open area reception at both frequencies worked down to a fieldstrength of around 43 dBuV/m.

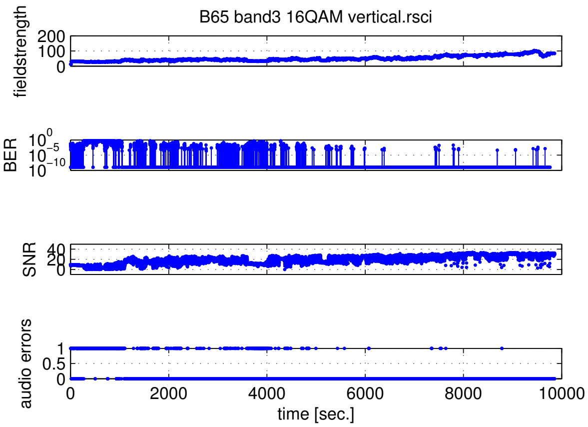

Figure 5. Measurement of the coverage limit in Band III

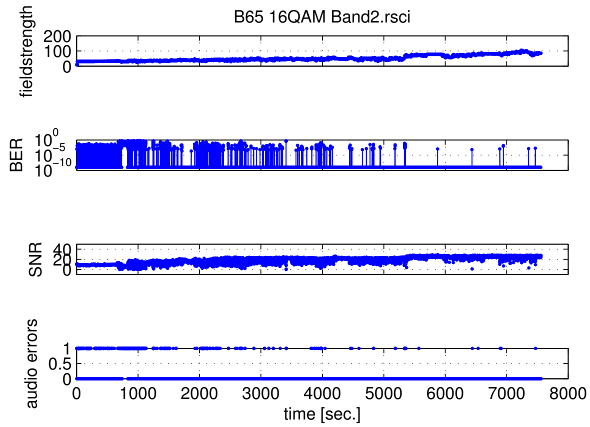

Figure 6. Measurement of the coverage limit in Band II

V. Conclusion

Evaluations of the channel properties of Band III for a DRM+ system show that the main problems using the system at higher frequencies are the intercarrier interference and the density of pilots needed for the channel estimation.

Simulations of the system performance, including the effects of ICI as noise in function of the receiver velocities, show no differences between Band II and III for a velocity of 100 km/h. At velocities up to 200 km/h the reception was effected by the ICI, but still reaches the bit error rate necessary for proper reception. In Band II reception was still possible at 300 km/h, in Band III with velocities higher than 200 km/h, the BER exceeds the value, necessary for proper reception. It should be pointed out that the simulations were conducted as a worst case scenario using upper bounds of the noise caused by ICI.

To fullfill the sampling theorem for the pilots that have to be sampled for the channel estimation, in Band III a Doppler shift corresponding to a receiver velocity of 270 km/h should not be exceeded.

Regarding flat fading, which appears at low receiver velocities in a multipath environment, the shorter wavelength in Band III can reduce the problem as the interference pattern has a higher spatial resolution. As a result, a receiver is passing the deep fades in a shorter time and the interleaver and error correction can work.

The measurements conducted in Band II and III, show no big differences.

A real speed test could not be made due to speed limits. As the ICI only becomes a problem when different carriers are effected by different Doppler shifts due to multipath propagation, this tests should be made in a region with obstacles in the countryside. The region of Hannover is in a quite flat area.

Acknowledgment

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