Field Tests and Comparison of the Channel Properties for the DRM+ System in the VHF-Bands II (87.5 MHz-108.0 MHz) and III (174-230 MHz)

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Abstract - **This paper presents a comparison of the channel properties for the DRM+ (Digital Radio Mondiale, Mode E) radio system in the frequency Bands II and III for mobile reception. The impact of different transmitting frequencies and receiver velocities is analyzed by simulations of the system performance with different channel profiles. A closer view is taken on the upper bounds of receiver velocities as this is the main problem for proper reception at higher frequencies. Additionally, measurements of the DRM+ system in the VHF-Bands II and III are presented to analyze 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 in a worst case scenario. The measurements show comparable results for Band II and III.**

Keywords* - *Digital Radio Mondiale; DRM+ ; mobile reception; Doppler spread; digital broadcasting; channel properties; COFDM

I. Introduction

DRM+ is an extension of the long, medium and short-wave DRM standard up to the upper VHF band. Field trials with DRM+ were conducted in Hannover [1] and Kaiserslautern [2] in Band II and in Paris in Band I. It has been approved in the ETSI (European Telecommunications Standards Institute) DRM standard [3] for frequencies up to 174 MHz. In Germany and other countries the VHF-Band II (87,5-108 MHz) is fully occupied by FM-radio, which will not be switched 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 digitize their signals, which is hardly possible with DAB due to its multiplexed structure [4].

Section II in this paper gives a short introduction to the DRM+ system parameters. 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 comparison 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 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

II. DRM+ system parameters

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 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.

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

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

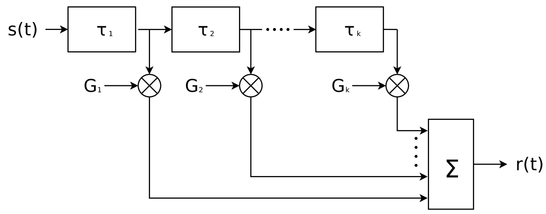

Figure 1. Tapped delay filter

A. Channel properties

To analyze 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] and shown in Figure 1. The complex output signal $r(t)$ is generated as shown in Equation 1.

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

With the complex input signal $m(t)$, the relative path delays τ_k and 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. In case that all waves are arriving from all directions at the receiving antenna with approximately the same power the real Doppler spectrum can be approximated by the Jakes spectrum:

$$P_d(f) = \frac{A}{\sqrt{1 - (\frac{f}{f_d})^2}} \quad \text{for} \quad |f| \leq f_d \quad (2)$$

For propagation paths with large delay times for example the 'Single Frequency Network' used in Section III-D, the Gaussian spectra are used. They are defined with the help of the Gaussian function:

$$G(f, A, f_1, f_2) = A e^{-\frac{(f-f_1)^2}{2f_2^2}} \quad (3)$$

The spectra denoted by 'Gauss1' and 'Gauss2' consist of a single Gaussian function and are defined as [3]:

Table II
CHANNEL PROFILE 'RURAL'

Path Nr.	Delay in μs	Powerlevel in dB	Doppler-spectrum
1	0	-4	JAKES
2	0.3	-8	JAKES
3	0.5	0	JAKES
4	0.9	-5	JAKES
5	1.2	-16	JAKES
6	1.9	-18	JAKES
7	2.1	-14	JAKES
8	2.5	-20	JAKES
9	3.0	-25	JAKES

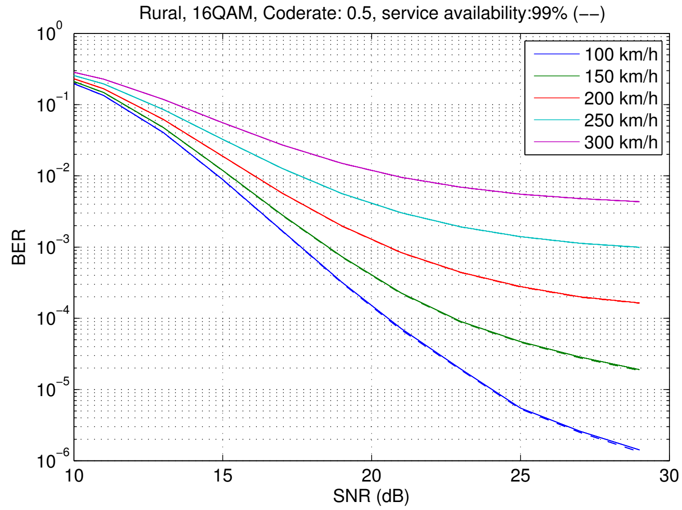

Figure 2. Performance in Band III

$$P_d(f) = G(f, A, \pm 0.7 f_d, 0.1 f_d) \quad (4)$$

where the '+' sign is valid for 'Gauss1' and the '-' sign for 'Gauss2'

Table II shows the properties of the tapped delay filter for a 'rural' channel. A set of other channels is given in the DRM ETSI Standard [3].

B. Inter-Carrier-Interference

A moving receiver causes Doppler shifts of the OFDM carriers. If this is combined with multipath propagation, paths from different directions can cause frequency dependent Doppler shifts, which results in Inter-Carrier-Interference (ICI). This interference can be handled as additional near-Gaussian noise [6]. In [7] upper bounds of the normalized interference power for a classical (Jakes) channel model depending on the maximum Doppler shifts (f_d) and the symbol duration (T_s) are given as

$$P_{ICI} \leq \frac{1}{12}(2\pi f_d T_s)^2. \quad (5)$$

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.

The effect of ICI power was added as an additional noise relative to the signal amplitude in function of the receiver velocity for an angle $\alpha = 0$ as the worst caste scenario when the receiver is moving directly towards or away from the transmitter on a radial route.

Additionally to the averaged Bit Error Rate (BER) the BER with a service availability of 99 % was plotted. In [8] a 'good' mobile reception is defined as having a coverage of 99 % of the locations. The simulation was conducted with 100 channel calls. Every call loads a random set of

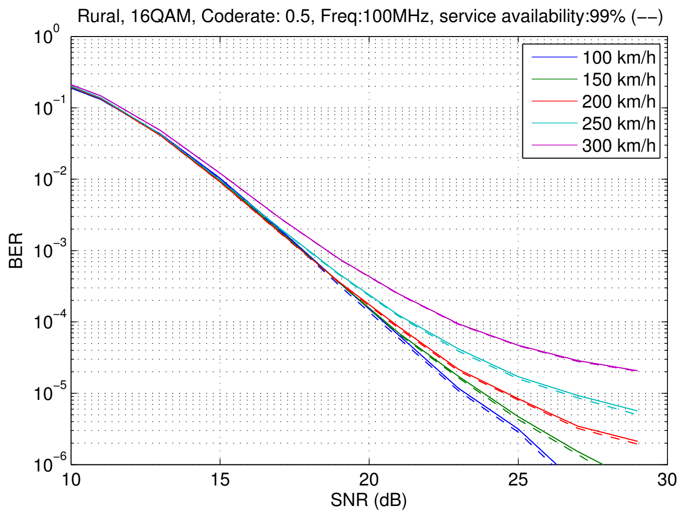

Figure 3. Performance in Band II

path processes, which stands for a different set of multipath components, that 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 BER. 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.

C. ICI in a 'rural' channel

Simulations were conducted with a 'rural' channel profile for receiver velocities from 100 - 300 km/h. It's parameters are given in Table II.

Figure 2 shows the simulation of the performance of a DRM+ system in Band III (200 MHz). For comparison Figure 3 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 [9] 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 achieved with around 30 dB. At 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 analyzed 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 probability of 99 %. This shows that the coherence time of the channel at these frequencies is short enough (for 150 km/h it 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 as shown in Section III-E showed more differences between the full coverage and a certain coverage probability.

Table III
CHANNEL PROFILE 'SFN'

Path Nr.	Delay in μs	Powerlevel in dB	Doppler-spectrum
1	0	0	JAKES
2	100	-13	GAUSS1
3	220	-18	GAUSS2
4	290	-22	GAUSS1
5	385	-26	GAUSS2
6	480	-31	GAUSS1
7	600	-32	GAUSS2

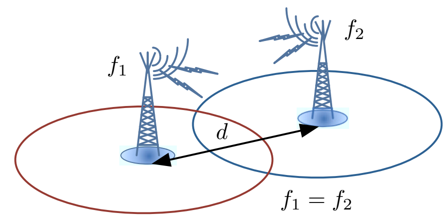

Figure 4. A 'Single Frequency Network' of two transmitters

D. ICI in a 'Single Frequency Network' channel

A special case of propagation occurs in a 'Single Frequency Network' (SFN) as shown in Figure 4. It represents a network of transmitters sharing the same radio frequency to achieve a large area coverage. As shown in Table III the delays are in the range of several hundreds micro seconds representing signals arriving from the different transmitter stations in the overlapping area.

Simulation were conducted with a 'Single Frequency Network' (SFN) channel profile for receiver velocities from 50 - 200 km/h. Figure 5 shows the worst case performance of a 'Single Frequency Network' at a frequency of 200 MHz. It can be seen that for a receiver velocity of 150 km/h a slightly higher SNR is needed as for 100 km/h to get a bit error rate below 10^{-4}. For 200 km/h it is still possible to get a proper reception, but more field strength is needed.

E. Slow and flat fading

For low receiver velocities in Band II slow fading over the whole signal bandwidth can lead to deep fades, lasting

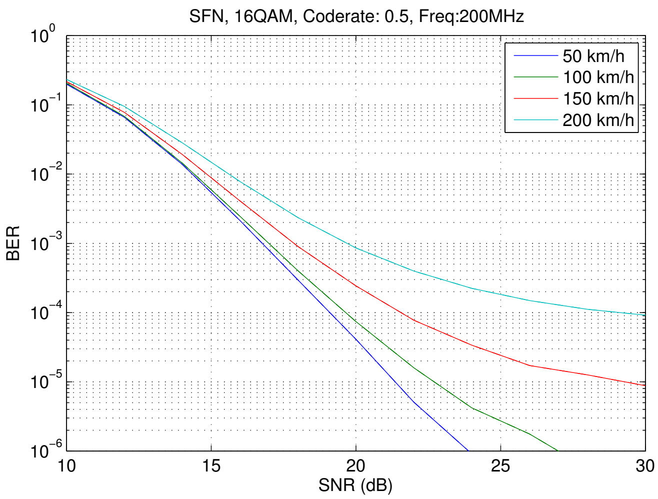

Figure 5. Performance in a 'Single Frequency Network' in Band III

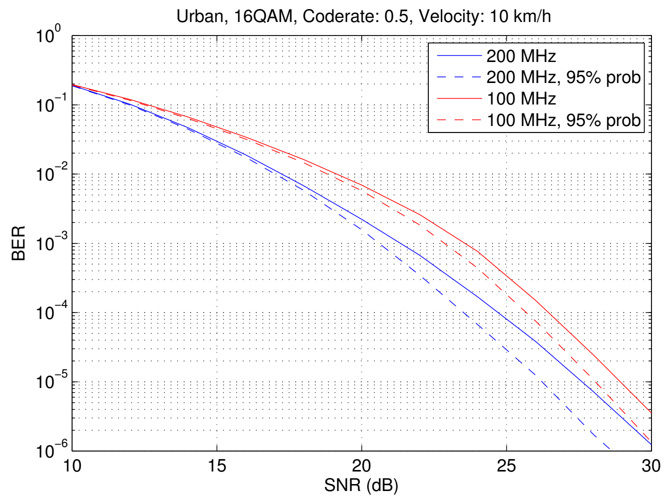

Figure 6. Comparison of the performance in a slow and flat fading environment

longer than the cell interleavers time (600 ms). This can result in signal dropouts as 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 smaller, which results in less dropouts due to slow fading.

Figure 6 shows a comparison of the system performance with a slowly moving receiver at 10 km/h for frequencies of 100 and 200 MHz. The performance is enhanced by the higher frequency. Additionally an error probability of 95 %, calculated as described in Section III-B, is plotted. The differences between full 'coverage' and a coverage probability of 95 % in this slow channel exceed the differences in the fast channel clearly, especially for the lower frequency. The reason for this are the higher spatial resolution of the interference patterns of the field strength in the air. Moving through this interference patterns, the resulting signal dropouts are shorter with higher frequencies, the interleaver and error correction can work.

F. The pilot grid

For channel estimation DRM+ uses pilots, that are distributed diagonally over the frames [10]. As shown in Figure 7 the pilots are inserted on every fourth subcarrier and every four symbols. As described in [11], 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 resulting in 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 fulfill the condition: $f_d < 50$ Hz. At 100 MHz this value is achieved at a velocity of 540 km/h, at 200 MHz at 270 km/h.

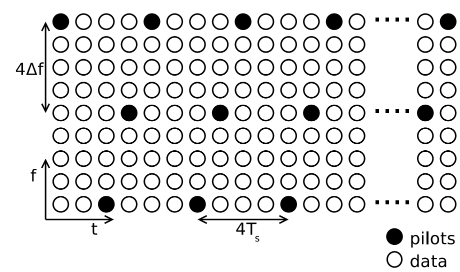

Figure 7. Pilot grid

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 Content Server and consisted of 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 measurements 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/synchronization.

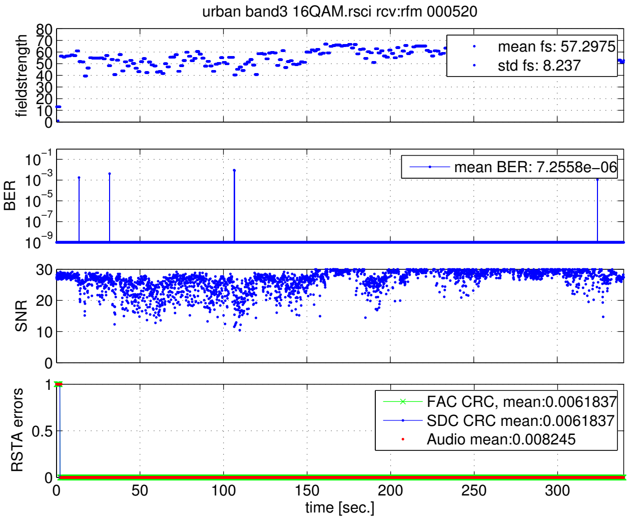

Figure 8. Measurement results in Band III

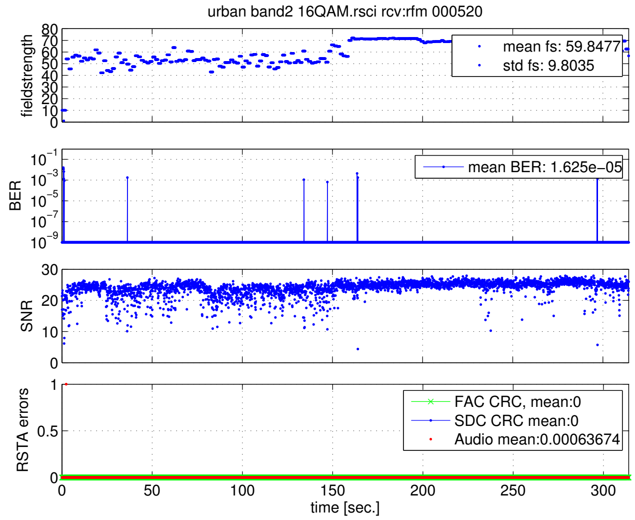

Figure 9. Measurement results in Band II

A. *Measurements in an urban environment*

To test the reception in an urban environment measurements were conducted in the inner city of Hannover. As this area is located in the main beam of the transmission 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 Figures 8 and 9, the results are shown over the time. In the first row the field strength is plotted. Additionally the mean field strength (mean fs) and the standard deviation of the field strength (std fs) are inserted in the Figures. This shows that the field strength in Band II is slightly higher than in Band III, the standard deviation is a bit lower in Band III which can be caused by differences in slow and flat fading. The second row shows the BER, which is slightly lower in Band III than in Band II. The third one shows the calculated SNR which is higher in Band III. As at the time of the measurement in Band III only block 12A (around 223 MHz) is used for DAB in the region of Hannover, this could be caused by less interferences. In Band II interferences from other FM transmitters can effect the reception and degrade the SNR. The last row shows the status of the Cyclic Redundancy Check (CRC) of the Fast Access Channel (FAC), the CRC of the Service Description Channel (SDC) and the audio decoder errors (0: errorfree, 1: one or more CRC/audio frames corrupted). Here some more errors show up in Band III. On the whole at both frequencies the reception was nearly the same.

B. *Measurements of the coverage limit*

Additional measurements of the coverage limit were conducted on a highway leaving the city in the main beam and passing rural area and some villages. In the maps in Figure 10 and 11 the audio status is plotted.

While the reception in the open (flat) environment is still good, errors came up passing villages. Compared to Band III, in Band II some more errors occurred while leaving the city of Hannover and in the village before Sehnde. Here due to a four-lane road velocities up to 100 km/h could be driven. This could be caused again by higher interferences with FM in Band II.

V. Conclusion

Evaluations of the channel properties in Band III for a DRM+ system show that the main problems using the system at higher frequencies are the Inter-Carrier-Interference and the density of pilots needed for the channel estimation.

Simulations of the systems performance in a ’rural’ channel, 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 suffice 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 in the evaluated worst case scenario.

The simulations of a ’Single Frequency Network’ at a frequency of 200 MHz show a similar result. Reception is possible up to receiver velocities of 200 km/h.

To fulfill 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 slow and flat fading, which appear 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

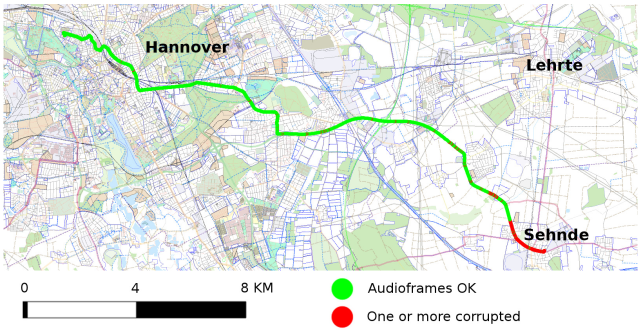

Figure 10. Audio status in Band III (mapdata (c) OpenStreetMap and contributors, CC-BY-SA, http://www.openstreetmap.org)

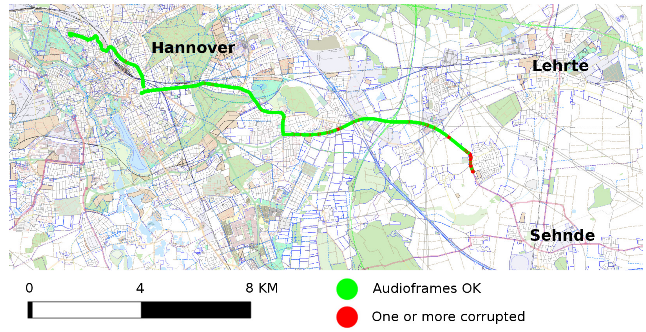

Figure 11. Audio status in Band II (mapdata (c) OpenStreetMap and contributors, CC-BY-SA, http://www.openstreetmap.org)

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. While measuring the coverage limit, less errors were recorded in Band III, which can be caused by less interferences in Band III in Hannover.

A real speed test could not be conducted 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 a quite flat area.

ACKNOWLEDGMENT

The authors would like to thank the NLM (State Media Authority Lower Saxony), RFmondial, Thomson, Nautel, BNetzA (Federal Network Agency), the DRM Consortium, Fraunhofer IIS and others for their support and good advice.

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