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Mobile reception of DVB-T signals - first test results

Introduction

Recently the Commercial module (CM) of DVB identified a growing interests in mobile applications of DVB-T. Therefore, the Steering Board asked the Technical Module (TM) to investigate the potential of the DVB-T transmission standard for mobile reception. This report summarizes the main results of theoretical analyses, of laboratory tests and of first field trials, which were carried out by the ACTS project VALIDATE, by the German project MINT and by Deutsche Telekom. Detailed information on this work can be found in documents TM-1907, TM-1900 and TM-1909 respectively.

The DVB-T system has originally been designed for fixed roof-top and static portable reception, but not for mobile reception. Since the channel cannot be assumed to be completely stationary, due to the movement of the reflecting objects around the receiving antenna, in particular for portable receivers, slowly varying channel frequency responses are possible and have to be tracked. Dense pilot cells are therefore included in the DVB-T signal to make the receiver able to correctly demodulate the signal also in such slowly varying channels. Although the purpose of these scattered pilots were to make it possible for the receiver to track *slow* channel variations associated with portable reception, there are theoretical reasons to believe that *also the faster channel variations associated with mobile reception can be tracked*, assuming appropriate signal processing in the receiver. The degree to which mobile reception is possible depends at least on the following factors:

- The ability of the receiver to track channel time variation and provide a correct channel estimate. This is fundamentally limited by the density of the pilot cells in the DVB-T signal. For 2k mode the theoretical maximum Doppler frequencies $[-f_d, + f_d]$ in this respect are f_d = 446-541 Hz. For instance, at carrier frequency f_c = 626 MHz (UHF channel 40) it corresponds to a maximum speed of about V_{max} = 770-930 km/h (see the formula at last bullet). For 8k mode the maximum Doppler shift values are exactly 4 times lower, i.e. f_d = 112-135 Hz (maximum speed of about V_{max} = 190-230 km/h at f_c = 626 MHz). These theoretical limits are dependent on FFT size and guard interval but not on modulation and code rate. Current implementations are far from these theoretical limits due to the use of very simple interpolation filters. However, by employing a 2-dimentional interpolation filters (in time and frequency) much higher performance might be achieved.

- The ability of the receiver to handle the Gaussian noise like distortion which is created in a process called *FFT leakage*, caused by the non-orthogonality of the DVB-T sub-carriers introduced by the mobile channel, i.e. different Doppler shifts in sub-carriers. This ability is directly related to the required C/N for the DVB-T mode in question, but also significantly dependent on receiver implementation.

- The ability of the receiver to correctly estimate a reliability measure for each received data cell. In a channel with only time variations and Gaussian noise this is rather straight forward. However, when the receiver has to consider also frequency selective interference (such as e.g. analogue TV), current implementations are unable to calculate a correct reliability measure in fast time varying channels. Alternative methods are under investigation.

- The ability of the receiver to correctly synchronize in time and frequency in a mobile channel.

- The extent to which sufficient field strength is provided along the way the mobile is moving. Compared to DAB this is more difficult with DVB-T since there is no time interleaving to ”average” the stochastic micro-scale (from wave-length to wave-length) field strength variations (fast fading). DVB-T, on the other hand, has about five times wider bandwidth than DAB, which to a limited extent compensates for the absence of time interleaving. With appropriate network planning and/or receiver implementation sufficient field-strength can however always be provided. The associated extra cost for this (in network and/or receiver implementation) remains however to be estimated. For macro-scale field-strength variations (shadow fading) there is no principle difference between DAB and DVB-T. However, it should be noted that in the case of shadowing post processing techniques (both for DAB and DVB-T) such as error concealment are possible and promise a great improvement of subjective quality. It remains to be seen whether in addition error concealment can compensate the lack of time interleaving in DVB-T receivers.

- The actual RF frequency used. Maximum speed is proportional to the inverse of the RF frequency. Speed (v) as a function of RF carrier frequency (f_c) and maximum Doppler frequency (f_d) is given by the formula: $V_{max} = c \times f_d/f_c$, where c is the speed of light.

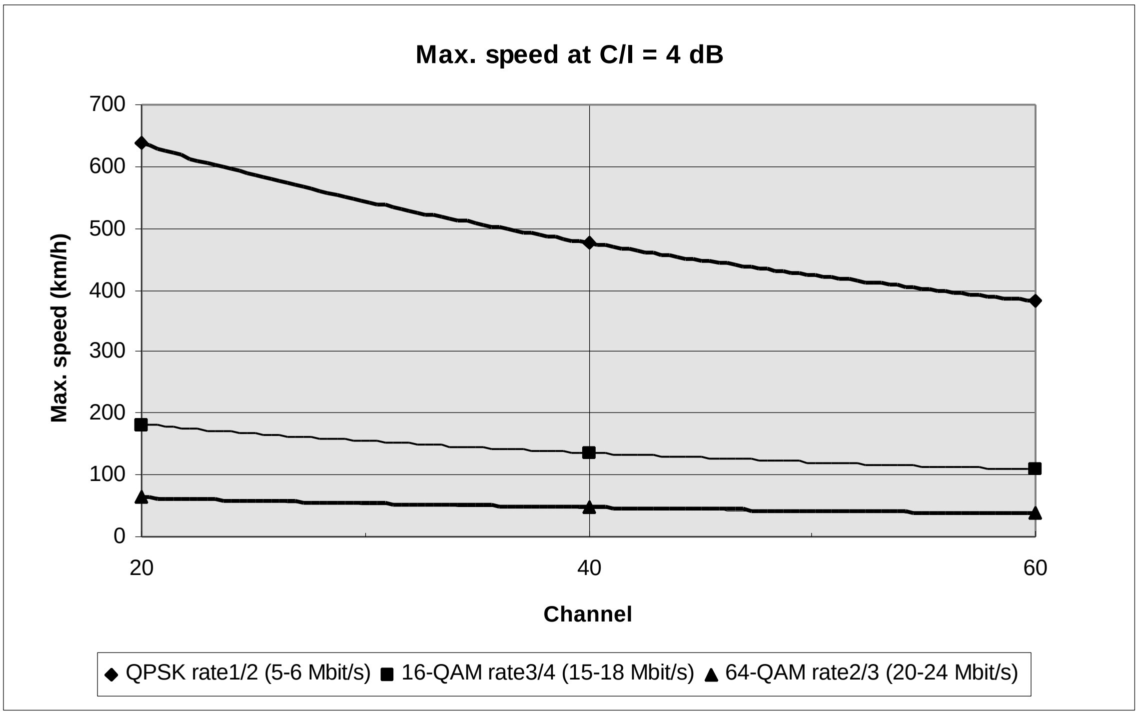
Warning: The DVB-T modems that have been tested are not optimized for mobile reception. The measured performance of the respective modems does therefore not in any way represent the performance limits inherent in the DVB-T system. One of the DVB-T modems under development in VALIDATE will however be optimized for mobile reception.

Laboratory tests with time varying echoes

Laboratory tests are carried out with a channel simulator which is able to test the modem with different channel models (echoes of varying levels and delay).
To simulate mobile reception the echoes are shifted (up and down) in frequency until a certain level of degradation in C/N performance (in these tests 4 dB). The frequency shift corresponds to the maximum Doppler frequency for the modem. From the maximum Doppler frequency the maximum speed at various frequencies can be calculated.

It is clear that the performance of the modem under test will depend very much on the channel model used, i.e. number and level of echoes. At present only a limited number of results are available. Annex-1 gives details of the different tested models and the corresponding performance for the dTTb and DMV modems.

To indicate the level of performance achieved with modems presently available the figure below shows graphs for maximum speed at frequencies from channel 20 to 60, at 3 different constellations and code rates, for the 2k mode. The channel model used has 4 paths (3 echoes) and a total C/I of 4 dB. It has to be remarked that this can be taken as an example only.



Field tests results

Based on the laboratory test results first field trails for mobile reception have been carried out with the DMV modem at two places in Germany.
In the area of Cologne where channel 40 was used mobile reception has been tested on the city roads and also on motor ways around Cologne. In general, in German towns there is a speed limit of 50 km/h. The test shows that the reception of a 16-QAM signal in such environment is independent of speed. Only the reception power (depending on field strength) in very dense urban areas of the town was a restriction for mobile reception.
In further tests, reception within a fast driving car has been investigated. These tests have been carried out on motor ways with no speed limit in the vicinity of Cologne. QPSK at a code rate 1/2 was used for these tests. Depending on the traffic situation during the tests the maximum speed of the car was 140 km/h. Also in this case the DVB-T reception was very robust.
Mobile reception using QPSK at a code rate 2/3 has been also tested in Berlin. The route included city roads and the local highway near the airport Tempelhof. This road followed a direct radial path from the transmitter. So there was the maximum possible Doppler shift. At this place the car could go up to 100 km/h. No interruptions of the DVB reception was noted there. At the end of the test route (in the middle of the town approximately 18 km from the transmitter) where the area was dense urban, reception was less stable due to the shadows of the buildings.

Conclusions

Already with existing DVB-T modems, not optimized for mobile reception, initial theoretical investigations, laboratory tests as well as field trials suggest that *at least under some conditions* mobile reception at relatively high speed is possible.

Based on the results obtained so far, the following can be concluded:

- DVB-T with QPSK has a similar performance as DAB

- DVB-T with 16-QAM is suitable for mobile reception at moderate speeds (=< 100 km/h)
- Doppler performance is not the main problem, even at 16-QAM. The main limitation occurs from field strength.
- Missing time interleaving in DVB-T is not regarded as a major drawback due to partial compensation by better frequency diversity. At low speeds time interleaving is even a disadvantage.
- Synchronisation in DVB-T is very robust, re-synchronisation is even faster than in DAB.

More work, theoretical as well as laboratory and field tests with more optimized modems, is needed before more precise relations between the factors*: maximum speed, RF frequency, DVB-T mode, coverage, network and receiver implementation*, can be given. Tests with a modem optimized for mobile reception are planned within VALIDATE during 1997.

Annex 1

Tests with the dTTb demonstrator

The system has been tested in the presence of single and multiple echoes affected by Doppler frequency shifts. The channel response is therefore characterized by notches shifting in the frequency domain at constant rate, producing amplitude and phase variations on the OFDM constellations. The total received power remains constant, while in mobile reception the power can fluctuate rapidly.
The tests identified the maximum Doppler shift f_d (peak-to-peak) acceptable by the system, for a noise margin loss ΔC/N =4 dB (reference: C/N on the relevant channel with f_d=0 Hz). Since the curves of ΔC/N versus f_d are very steep, the choice ΔC/N=4 dB is not crucial for the results of the tests. Two echo configurations have been tested, with echoes within the guard interval:

- Single echo; delay 0.9Δ; Doppler: 0 (main path), 2f_d ; echo attenuation: 0 or 3 or 5 or 10 dB
- 4 paths; delays: t=0 (main path), Δ/4, Δ/3, 2Δ/3; Doppler: +f_d, -f_d , +f_d, -f_d; attenuation of each echo with respect to the main path of 0, 8.77 dB (corresponding to a total C/I=4 dB) or 14.77 dB (corresponding to a total C/I=10 dB)

Table 1 shows the main results of the tests achieved with the dTTb demonstrator. Comparable results with the DMV 2K modem are reported.

Table 1 Maximum Doppler shift f_d for a noise margin loss DC/N=4 dB

		f_d [Hz]						
modulation		single echo				multiple echoes		
and code rate	mode	C/I=0	C/I=3	C/I=5	C/I=10	C/I=0	C/I=8.8 (total: 4)	C/I=14.8 (total 10)
QPSK 1/2 (Δ=1/8)	2k	150	160	>210	>210	115 (320*)	280	>425
	8k	24	50	75	>210	27	70	>425
16-QAM 3/4 (Δ=1/32)	2k	23(**)	58	88	165	37 (120*)	80	155
	8k	5	15	21	40	10	19	45
64-QAM 2/3	2k (Δ=1/4)	14	19	33	95	15 (120*)	28	100
	8k (Δ=1/8)	4	8	10	23	4	8.5	21

Note (*): computer simulation results from CCETT
Note (**):t=0.8D was used, since the system could not operate at t=0.9D even with fd=0

The performances with a single echo and with multiple echoes are comparable and, as expected, the 2k configuration is about four times faster than the 8k configuration, because of its shorter symbol duration. The maximum acceptable Doppler shift depends heavily on the echo amplitudes.
In the presence of 0 dB echoes, the 64-QAM 2/3 8k mode can follow only slow channel variations (few Hertz), while the QPSK 1/2 2k mode can track Doppler shift higher than 100 Hz, typical of mobile reception.
It should be noted that the simulation results predict Doppler tracking capabilities for the DVB-T system which are 4 to 6 times higher than the measured results. This is due to the difference of the algorithms implemented in the dTTb system, that must be able to handle also other channel distortions (e.g. narrow band interference) which are not considered in the simulations. Further studies are ongoing to identify optimized receiver algorithms.

Tests with the DMV modem

To investigate mobile reception, the performance in the presence of single and multiple echoes in time variant channels has been tested. This allows a first assessment of mobile reception. For these measurements a 2k-FFT Signal with a guard time $\Delta=1/8$ of the symbol length T_U was used. The transmission frequency was 626 MHz (UHF channel 40). Three modes of the DVB-T specification were chosen for the test: QPSK with code rate 1/2, 16-QAM modulation with code rate 3/4 and 64-QAM with code rate 2/3.

To simulate multipath propagation a hardware channel simulator was used. This device is able to generate several paths with varying delay and with Doppler frequencies ranging from 0 Hz to a maximum of 243 Hz. Taking into account the operation of the automatic frequency control (AFC) in the receiver this corresponds to Doppler frequencies in the range $[-f_d, +f_d]$, where $f_d=121.5$ Hz which is equivalent to a speed of 210 km/h (in case of channel 40).

If QPSK with a code rate of 1/2 is used the performance loss in the presence of single echoes is less than 3 dB. The multiple echo performance depends on the type of profile and also on the error protection rate. Nevertheless, QPSK, as the most robust modulation, does mainly work. Also the 16 QAM mode shows very good test results; the performance loss for 16-QAM code rate 3/4 is less than 4 dB at the highest Doppler frequency.