GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

The Doppler Effect and Digital Video Broadcasting

Seminar: Digital Video Broadcasting SS2007
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Abstract

This report explains the Doppler Effect and shows, that DVD-T is only good enough to handle mobile devices with a single antenna in the lower frequency range. This is caused by the fact, that in band V the Doppler frequency shift makes a stable service nearly impossible. An alternative solution to DVB-T is the downwards compatible DVB-H standard. DVB-H is targeted at to mobile devices. Low power consumption, more stable handshake and of course a much greater robustness to Doppler frequency shifts are the main advantages of DVB-H.

Contents

1 Introduction

It is well know that fast cars produce different sounds depending on their velocity relative to the observer. They will produce high frequency sounds, if the approach the observer and low frequency sound, if they drive away.

The faster the movement, the more perceivable is the phenomenon. Thus this effect has to be dependent on the velocity relative to the observer. The sound waves of the car propagate in the form of spherical waves in all directions in space with an isotropic speed of about 333m/s. As long as the relative velocity remains constant, no deviation of the frequency shift is observed.

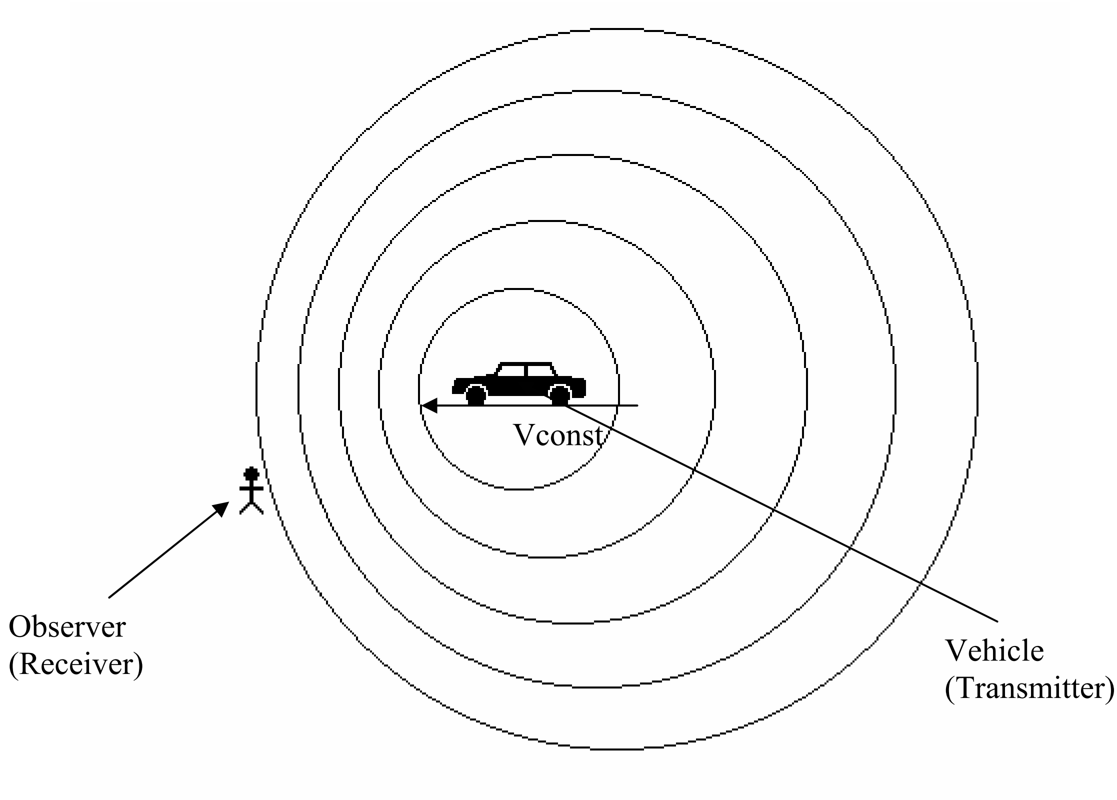

Figure 1: Illustration of Doppler frequency shift

The frequency compression and dilation is demonstrated in figure 1. The observer hears a tone which is higher than the one the car produced. This characteristic is called Doppler Effect.

2. Basics

2.1 Doppler Effect

The Doppler Effect is a frequency shift, which occurs, when source and observer move relative to each other. The Doppler Effect is named after the Austrian mathematician and physicist Christian Doppler. Doppler first published the effect 1842 for light waves in the monograph [1] but the effect was scientifically proven by Christoph Buys-Ballot [2] with sound waves three years later.

The Doppler Effect exists not only with sound waves, but also with light waves and electromagnetic waves in general. Because of the relatively "slow" speed of the sound waves ($vs/vc=10^{-6}$) it is much easier to observe the Doppler frequency shift with sound than with light waves. In practise the Doppler Effect is wisely used today, too. For example, in Medicine you can find out the speed and direction of the blood flow in blood vessels with Doppler Sonography. By means of the frequency shift a direct conclusion of the velocity of the blood flow can be drawn. The well-known radar speed checks of the police work similarly. In Astronomy the red and blue shift of electromagnetic radiation led to more precise statements about the possible dimension of our universe.

The formula for the Doppler frequency shift is [3]:

$$\Delta f = v \cdot \frac{f}{c} \cdot \cos \Phi$$

Δf	= Doppler frequency shift
v	= velocity of the observer/ receiver
f	= carrier frequency of transmitter
c	= speed of light
Φ	= angle between motion direction and signal incoming direction

Regarding the formula given above, the Doppler frequency shift depends directly on the velocity of the receiver v as well as on the single carrier frequency f divided be the speed of light c. The cosine of the angle beween the motion direction and signal incoming direction constitutes an additional factor.

As a consequence, there are three possibilities for the relative velocities (under the condition of a fixed transmitter). Firstly, if the mobile receiver moves directly towards the transmitter, the frequency will be stretched. As a second option, the receiver moves away from the transmitter, resulting in a frequency compression. The last possibility is a receiver, which is circularly moving around the transmitter. The angle Φ becomes 90° and the cosine equals zero.

As a consequence, the Doppler frequency shift becomes zero as well (see figure 2.). It seems as if the receiver does not move at all [3].

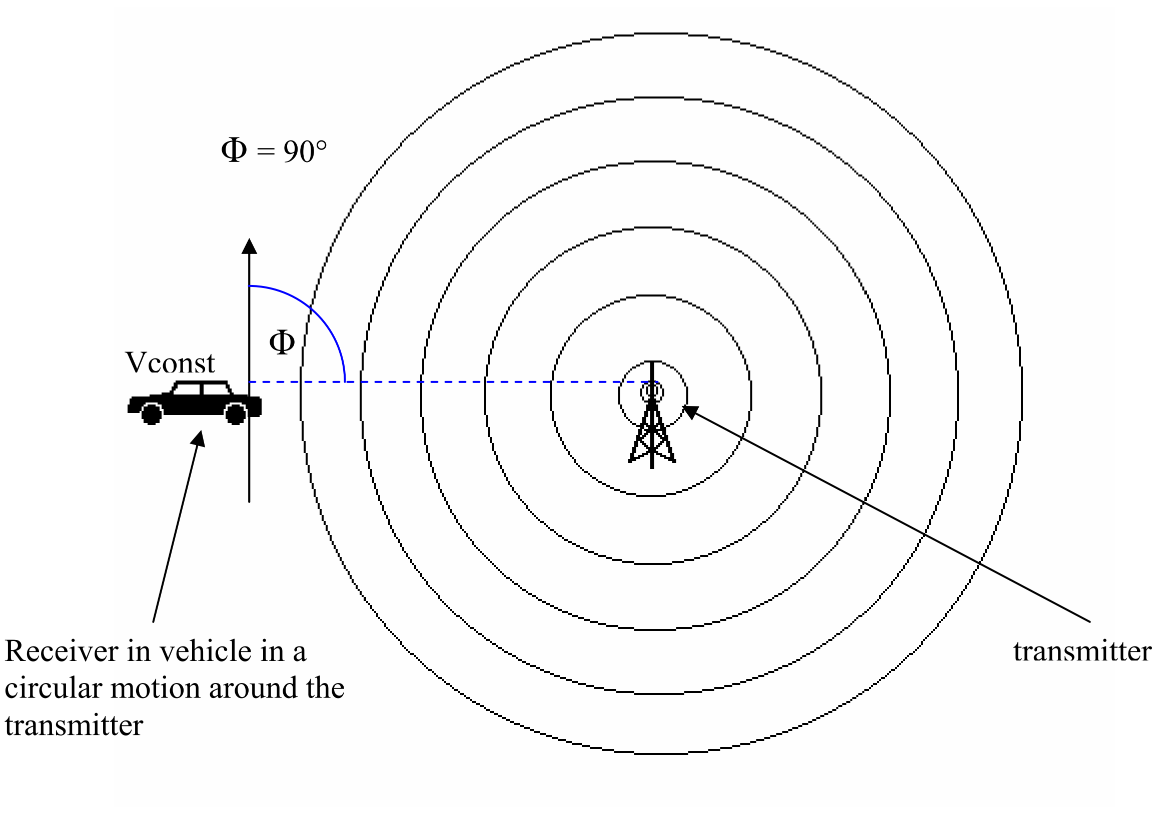

Figure 2: receiver in a circular motion around the transmitter

It is easy to see that this case is very improbable: Nevertheless it has to be mentioned because of other resulting problems in mobile data transmission at DVB-T and DVB-H. Even if the receiver is in a circular motion around the transmitter and thus the Doppler frequency shift equals zero (as in the example above), we can receive suddenly occurring side effects from walls or other obstacles. In a city (with many reflectors for electromagnetic waves) problems during the receiving are very probable.

Due to the fact that DVB-T and DVB-H use electromagnetic waves as transmission medium, problems with the Doppler frequency shift will most probably arise.

2.2 Digital Video Broadcasting

Digital Video Broadcasting is a standardised [5] method to transferring digital content over the old analog infrastructure. Since the World Cup in Germany used in some test applications, too. Besides the usual features like digital TV, radio and teletext DVB-(S/C/T/H) offers multi channel sound and further interactive contents as in the Multimedia Home Platform (short MHP) and the Electronic Program Guide (short EPG).

Current standards are:

- **DVB-S** (Satellite) over geostationary satellites
- **DVB-C** (Cable) over tv cable
- **DVB-T** (Terrestrial) European consortium standard [5] for the broadcast transmission of digital terrestrial television.
- **DVB-H** (Handheld) based on DVB-T,with better mobility and low-currend

- And many other (**DVB-IPI** (Internet Protocol Infrastructure), **DVB-RC** (Return Channel (over DVB-S/C/T)), **DVB-SH** etc.)

All the traditional analog transmission techniques will sooner or later be replaced by digital systems. Digital transmitters exist in Germany since 1996 on DVB-S ("Digitales Fernsehen 1" - DF1). Shortly afterwards the digital TV (like Premiere) reached the cable television via DVB-C. DVB-T shall completely replace the traditional analog television until the year.

The new DVB-T technology uses the old analog frequencies (like UHF and VHF). The MPEG2 or as well as H.264/AVC compression algorithm is used to reduce the data stream. Thus one analog television channel can hold up to four new digital television channels at the same time. One channel needs only 4Mbps now. Thanks to a digital error correction algorithm there is always a picture with good quality. There is no picture, if the transmission quality is not good enough. So-called "ghost pictures" (echoes on house walls) like the analog television are history now. The disadvantage of this is, that many households are thus refused access to the network, but could in principle just receive pictures in a mediocre quality.

In Europe the DVB-Organisation [5] works on the standardisation.

2.3 DVB-T Details

The carrier bandwidth is specified to 8MHz on DVB-T. Later this specification was revised and in principle every bandwith is possible (6MHz in America, 7MHz in Australia, 8MHz in Europe). DVB-T uses a multiple carrier system for the transmission. Both the phase and the amplitude states are modulated. Furthermore a multiplexing of the data streams will be done over COFDM (Coded Orthogonal Frequency Division Multiplex), thus there are many data streams in neighbouring frequencies [4].

Three carrier modulations are provided by DVB-T [6]:

- **QPSK** (Phase-shift keying) for robust data transfer and mobile receiving with low datarate
- **16-QAM** (Quadrature amplitude modulation) at medium data rate for portable receiving
- **64-QAM** for high data rates, yet with higher sensibility and therefore no mobile receiving.

As in DVB-T several programs will be emitted on the same frequency by different broadcasting stations, overlapping and multi path scattering problems are unavoidable. This transmission form is called Single Frequency Network (short SFN). All transmitters will synchronised over the Global Positioning System (GPS). The guard interval enhances the robustness against overlapping and multi path scattering problems, but has negative effects on the available data rate.

DVB-T comes with an Forward Error Correction algorithm, therefore bit errors can be corrected. DVB-T with COFDM has two single carrier modes 2k and 8k, that means the distance between the carriers [4][6].

4 Problems with Doppler Effects

Three usage categories are distinguished in receiving via DVB:

- **Stationary:** receiving via fixed antenna
- **Portable:** receiving outside or inside of buildings with very little movement possible
- **Mobile:** The receiver is in motion (train, bus or car)

DVB-C and DVB-S are unsuitable for mobile receiving. DVB-C necessitates a cable (thus not really mobile) and DVB-S uses a special (and expensive) antenna with a direct line of sight to the satellite. For mobile data transfer in a train or car DVB-S and DVB-C not applicable. DVB-T seems to be practical for mobility use, but this is not correct. Apart from multipath scattering and echoes, the biggest problem so far is the Doppler frequency shift. The faster the movement is, the bigger the Doppler frequency shift [1]. With higher frequencies we have a bigger Doppler frequency shift, too.

The following calculation example ought to clarify this:

Parameters are:

Carrier Frequency f=858MHz (the last channel in Band V UHF, with 8MHz bandwidth), the receiver speed is set to v=50km/h

$$v = 50\frac{km}{h} = \frac{50}{3{,}6}\frac{m}{s} = 13{,}889\frac{m}{s} \quad \text{and} \quad \Phi=0$$

$$\Delta f = 13{,}889 \cdot \frac{858 \cdot 10^6}{300 \cdot 10^6} \cdot 1 = 39{,}773 Hz$$

Taking into account the occurrence of transmission errors from circa 25Hz on [8] (at DVB-T 8k-Mode, 64-QAM), receiving is no longer possible in this range. This is surely an extreme example, because on band III (see figure 3.) UHF a higher mobility is definitely reachable due to the lower frequencies.

Frequency overview

very high frequency (VHF)			ultrahigh frequency (UHF)		
Band	**Frequencies (MHZ)**	**standards**	**Band**	**Frequencies (MHZ)**	**standards**
Band I	47 - 68	PAL-B TV	**Band IV**	470 - 622	PAL-G TV, DVB-T
Band II	87,5 - 108	FM Radio	**Band V**	622 - 854	PAL-G TV, DVB-T
Band III	174 - 230	PAL-B TV, DVB-T, DAB	**L-Band**	1452 - 1492	T-DAB

Figure 3: Frequency overview from VHF and UHF

However this example is not unrealistic, due to the fact that exactly these parameters (at DVB-T 8k-Mode, 64-QAM) will be standard in Germany.

Furthermore reflections of the electromagnetic waves at house walls (also Doppler Effects) are problematic. Rice Fading [9] is the production of Doppler echoes via reflection of the electromagnetic waves at house walls. Here we still have a direct line of sight to the transmitter (see figure 4.).

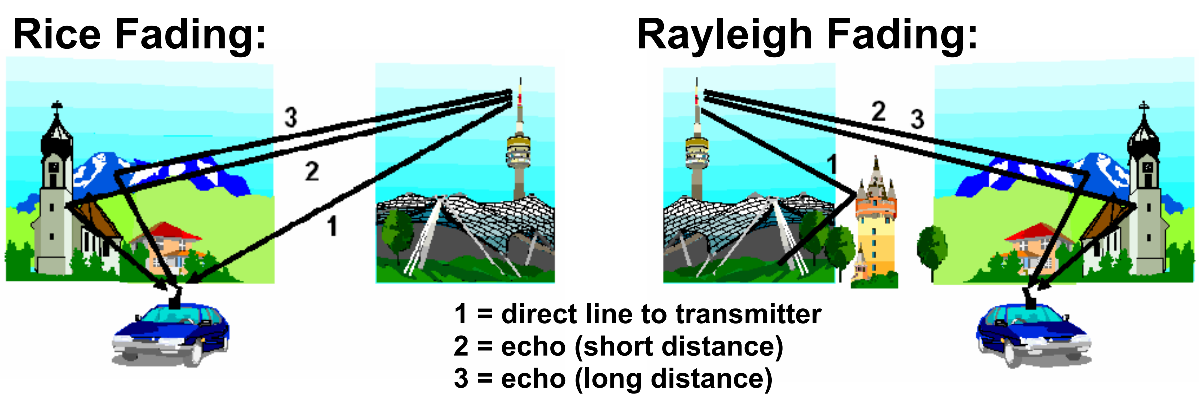

Figure 4: Rice Fading and Rayleigh Fading [6]

Rayleigh Fading [10] does not include a direct line of sight but only reflections contribute to the receiving (figure 4.). These effects are difficult to compensate.

Using the 2k- mode the mobility is drastically increased (with more than 400km/h stable receiving, see figure 5.). This implies with more complex "Coded Orthogonal Frequency Division Multiplexing" (COFDM) carrier modes we get more problems with the Doppler Effect.

"Possible" Reference Receiver Guard interval = 1/4			2k		Speed at Fd_{3dB} [km/h]		4k		Speed at Fd_{3dB} [km/h]		8k		Speed at Fd_{3dB} [km/h]	
Modulation	Code rate	Bit rate [Mbit/s]	C/N_{min} [dB]	Fd_{3dB} [Hz]	474 MHz	698 MHz	C/N_{min} [dB]	Fd_{3dB} [Hz]	474 MHz	698 MHz	C/N_{min} [dB]	Fd_{3dB} [Hz]	474 MHz	698 MHz
QPSK	1/2	4,98	8,5	520	1185	805	8,5	260	592	402	8,5	130	296	201
QPSK	2/3	6,64	11,5	520	1185	805	11,5	260	592	402	11,5	130	296	201
16-QAM	1/2	9,95	14,5	480	1094	743	14,5	240	547	371	14,5	120	273	186
16-QAM	2/3	13,27	17,5	480	1094	743	17,5	240	547	371	17,5	120	273	186

Figure 5: DVB speed test overview [11].

With more complex carrier modulations we get more problems with the Doppler Effect, as well [3] (shown in figure 5).

5 Solutions

Nevertheless there are methods to enhance the robustness against the Doppler frequency shifts.

The simplest solution is to use only the 2k-mode carrier modulation. The disadvantage is the not very effective use of the bandwidth (only one TV channel is possible, data rate: 5.805882 Mbit/s [according to 4]). The 2k-mode has low useable data rate and is therefore expensive.

A second solution is to use more than one antenna for receiving. This method is called diversity receiving. The receiver calculates the average value from all antennas for a more reliable signal. The subsequent table shows a field test in Berlin [8] with DVB-T 8k-mode, 16QAM, FEC 2/3 and Guard interval 1/8, which has been conducted with (single) and without diversity receiving :

Frequency Carrier	**V_{max}(Single) in km/h**	**V_{max}(Diversity) in km/h**
658MHz	80-85	135-140
787MHz	65-75	115-120

Figure 6: Enhancement of mobility with diversity receiving (according to [8])

The table shows a clear improvement of mobility with diversity receiving. This option however has only limited use. On the one hand the diversity receiver is more expensive than an ordinary one (single) and on the other hand mobile devices (like handhelds) are too small to integrate more than one antenna. Moreover, multiple antennas need more energy, and mobility is useless as soon as the battery does not have enough power. Therefore another solution had to be found for smaller devices.

DVB-H provides the answer to this problem. DVB-H uses a time-slicing technique, which reduces the power consumption by about 90 percent [12].

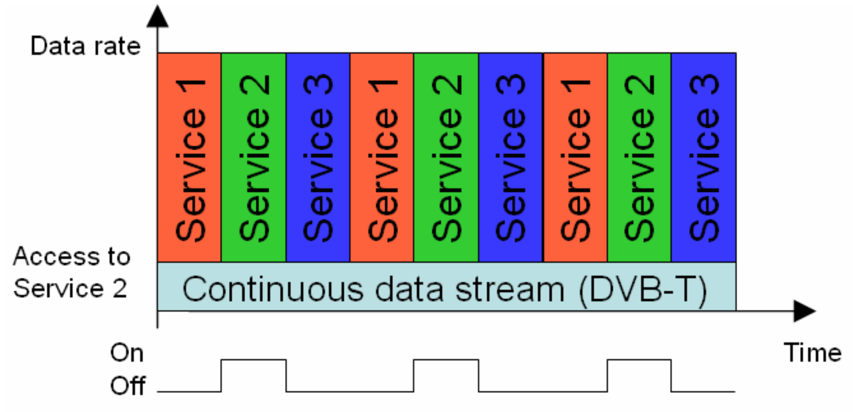

Figure 7: time-slicing in DVB-H with DVB-T data stream

The time-slicing based upon the strategy that the receiving device switches to offline mode, as soon as a different carrier has its time slice. If the right carrier with relevant data has its turn, the receiver will switch back to the online mode. Beside the improved power consumption, the handover process is improved, too. The pauses between the particular bursts give the Front-End-Tuner enough time to localise the strongest signal [8]. The consequence of this is a higher mobility. It is also possible to include a normal DVB-T stream inside of a DVB-H data stream (see figure 7.).

A further 4k mode was implemented in addition to the 2k and 8k modes. The 4k mode is a good trade off between robustness against Doppler frequency shifts and loss in data rate (see figure 5.). There is no balanced mode between good data rate and adequate robustness against the Doppler Effect on DVB-T (2K QPSK: > 400 km/h tolerable but 8k 64 QAM: < 50 km/h).

A new error correction algorithm, special for the mobility enhancement was integrated too. The „Multi Protocol Encapsulation Forward Error Correction“(short MPE-FEC) enhances the robustness against Doppler frequency shifts from 25Hz (without correction on DVB-T) up to 80Hz on DVB-H. Using the above formula an unproblematic receiving at 50km/h should be possible with DVB-H. And this unproblematic receiving could be extended to nearly 100km/h [7] (more about MPE-FEC [13]).

6 Conclusion

DVB-T with diversity receiving is a good solution. The mobility is increased enough. Today it is the best solution for cars. Handhelds are too small to integrate more than one antenna. The power consumption is to height for handhelds.

DVB-H is more efficient in handover and power consumption. A significantly increased mobility is guaranteed both due to longer battery duration and a greater robustness to the Doppler Effect (by the use of the new 4k-Mode and MPE-FEC). The downward compatibility DVB-H does not compete with the previous DVB-T standard [5].

With DVB-H it seems as if the problems with the Doppler frequency shift are solved as well as in any way possible. There will be (nearly) no limits to mobility in future applications.

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