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ANALYSIS AND SIMULATION OF THE SIGNALS TRANSMISSION IN THE DVB-H/SH STANDARDS

ANALÝZA A MODELOVÁNÍ PŘENOSU SIGNÁLU VE STANDARDECH DVB-H/SH

DIZERTAČNÍ PRÁCE
DOCTORAL THESIS

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Abstract

This dissertation thesis deals with the analysis, simulation and measurement of the signal processing and transmission in DVB-H and DVB-SH standards. These standards are based on the assumption that signal reception is characterized by the transmission channels with echoes. These, so called fading channels, are mainly characterized by the path delays and path losses. Depending on the other, additional features (speed of the receiver, Doppler spectrum, etc.), it can be possible divided these channels onto three main groups: mobile, portable and fixed. Of course, signal transmission in different transmission channel models are affected differently. Therefore, it is needed found the optimal system parameters in both, DVB-H and DVB-SH standards, for the quality reception of the broadcasted mobile TV services, which is the main goal of this thesis. For this purpose, two appropriate applications (one for DVB-H and one for DVB-SH) with GUI were created in MATLAB, which enable simulated and analyzed the signal distortions in mobile, portable and fixed transmission scenarios. Moreover, these applications also contain a second application with GUI for the easy set and modification of the parameters of the used channel models. Therefore, it is possible to evaluate the effect of parameters of whole system and channel models on the achieved error rate (BER and MER) and quality of the transmission. In all mentioned transmission scenarios, the signal distortions (depending on the Carrier-to-Noise ratio) were obtained, evaluated and discussed in this dissertation thesis. Furthermore, in case of DVB-H, all obtained results from the simulations, were verified by the measuring. Differences between the obtained results (simulation and measuring) are also discussed.

This dissertation thesis can be divided into four main parts. The first part of this dissertation thesis, after the short introduction, deals with present state-of-the-art and literature survey in mobile broadcast DVB-H/SH standards. At the end of this part are clearly outlined the main aims of this dissertation thesis. Second part is focused on the brief description of the functional block diagram of transmitters in both, DVB-H/SH standards. Furthermore, there are briefly described the transmission fading channel models, which are commonly used for the modeling of the signal transmission. The brief description of program applications with flowcharts, appropriate for the simulation of the transmission in the DVB-H/SH standards, are presented and described in the third part of this thesis. Finally, the fourth and longest part of this thesis is focused on the evaluation and comparison of obtained results from the simulations and measurements.

Keywords

DVB-T, DVB-H, DVB-SH, fading transmission channels, mobile scenario, portable scenario, fixed scenario, Doppler’s shift, BER before and after Viterbi decoding, BER after turbo decoding, MER, number of iterations, constellation diagram.

Abstrakt

Tato disertační práce se zabývá analýzou, simulací a měřením zpracování a přenosu signálů digitální televize pro příjem mobilního TV vysílání ve standardech DVB-H a DVB-SH. Tyto standardy vycházejí z předpokladu, že příjem signálu je charakterizován modely přenosových kanálů s vícecestným šířením. Tyto, tzv. únikové kanály, jsou charakterizovány hlavně zpožděním a ziskem jednotlivých cest. V závislosti na dalších parametrech (rychlost přijímače, Dopplerovské spektrum), je možné rozdělit únikové kanály do třech hlavních skupin: mobilní, přenosné a fixní. Dá se předpokládat, že v různých modelech kanálů bude přenášený signál různě ovlivněn. Proto je potřebné najít optimální parametry systémů (DVB-H/SH) pro kvalitní příjem vysílaných služeb mobilní televize, což je hlavním cílem této disertační práci. Pro tento účel byly vytvořeny dvě vhodné aplikace (jedna pro DVB-H a jedna pro DVB-SH) s GUI v prostředí MATLAB, které umožňují simulovat a analyzovat míru zkreslení signálu v případě mobilních, přenosných a fixních scénářů přenosu. Navíc, tyto aplikace obsahují i druhý samostatný simulátor pro nastavení a modifikaci parametrů jednotlivých přenosových cest. Díky tomu je možné zhodnotit vliv parametrů celého systému a kanálových modelů na dosaženou chybovost (BER a MER) a kvalitu přenosu. Ve všech přenosových scénářích (v závislosti na poměru C/N) byly získané, vyhodnocené a diskutované zkreslení signálů. Navíc, u standardu DVB-H, všechny získané výsledky ze simulací byly ověřeny měřením. Rozdíly mezi dosaženými výsledky (simulace a měření) byly rovněž podrobeny diskuzi.

Tuto disertační práci je možné rozdělit do čtyř hlavních částí. První část disertační práce se zabývá rešerší současného vývoje v oblasti digitálního televizního vysílání na mobilní terminály ve standardech DVB-H/SH. Na konci této části jsou jasně popsány cíle této disertační práce. Druhá část práce je zaměřená na stručný popis blokového diagramu vysílačů v obou standardech DVB-H/SH. Dále jsou stručně popsány modely přenosových kanálů, které se používají pro modelování přenosu signálu. Stručný popis vytvořených aplikací, i s vývojovým diagramem, které jsou vhodné pro simulaci a analýzu přenosu v DVB-H/SH, jsou popsány v třetí části práce. Čtvrtá a nejdelší část této disertační práce se zabývá vyhodnocením získaných výsledků ze simulací a měření.

Klíčová slova

DVB-H, DVB-SH, únikové přenosové kanály, mobilní scénář, přenosný scénář, fixní scénář, Dopplerův posuv, BER před a po Viterbiho dekódování, BER po turbo dekódování, MER, počet iterací, konstelační diagram.

Declaration

I declare that I have elaborated my doctoral thesis on the theme of “Analysis and simulation of the signal transmission in the DVB-H/SH standards” independently, under the supervision of the doctoral thesis supervisor and with the use of technical literature and other sources of information which are all quoted in the thesis and detailed in the list of literature at the end of the thesis.

As the author of the doctoral thesis I furthermore declare that, concerning the creation of this doctoral thesis, I have not infringed any copyright. In particular, I have not unlawfully encroached on anyone’s personal copyright and I am fully aware of the consequences in the case of breaking Regulation § 11 and the following of the Copyright Act No 121/2000 Vol., including the possible consequences of criminal law resulted from Regulation § 152 of Criminal Act No 140/1961 Vol.

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List of Abbreviations

16APSK	16-state APSK
16QAM	16-state QAM
64QAM	64-state QAM
3GPP2	Third Generation Partnership Program 2
8PSK	8-state PSK
APSK	Amplitude Phase Shift Keying
ATV	Analog Television
AWGN	Additive White Gaussian Noise
BER	Bit Error Ratio
CENELEC	Centre for Electrotechnical Standards
CGC	Complementary Ground Component
COFDM	Coded Orthogonal Frequency Division Multiplexing
C/N	Carrier-to-Noise Ratio
D/A	Digital-to-Analog
DBPSK	Differential Binary Phase Shift Keying
DTT	Digital Terrestrial Television
DTV	Digital Television
DVB	Digital Video Broadcasting
DVB-C	DVB-Cable
DVB-H	DVB-Handheld
DVB-NGH	DVB-Next Generation Handheld
DVB-S	DVB-Satellite
DVB-T	DVB-Terrestrial
DVB-T2	2^{nd} Generation Digital Terrestrial Television Broadcasting
ETSI	European Telecommunication Standard Institute
FEC	Forward Error Correction
FER	Frame Error Ratio
FFT	Fast Fourier Transform
FIFO	First In First Out
GF	Galois Field

GI	Guard Interval
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HP	High Priority
HSPA	High Speed Packet Access
IFFT	Inverse FFT
IP	Internet Protocol
ISI	Intersymbol Interference
IU	Interleaving Unit
JTC	Joint Technical Committee
LOS	Line of Sight
LP	Low Priority
LTE	Long Term Evolution
MAC	Medium Access Control
MER	Modulation Error Ratio
MFER	MPE-FEC Error Ratio
MOTIVATE	Mobile Television and Innovative Receivers
MPE-FEC	Multiprotocol Encapsulation-FEC
MPEG	Motion Picture Experts Group
MR	Motorway Rural
MUX	Multiplex
OFDM	Orthogonal Frequency Division Multiplexing
PDP	Power Delay Profile
PF	Pilot Field
PL	Physical Layer
PRBS	Pseudo Random Binary Sequence
QAM	Quadrature Amplitude Modulation
QEF	Quasi Error Free
QPSK	Quadrature Phase Shift Keying
PI	Pedestrian Indoor
PO	Pedestrian Outdoor
RA6	Rural Area
RCF	Raised-Cosine Filter
RF	Radio Frequency
RRCF	Root-Raised-Cosine Filter

RS	Reed-Solomon
SFN	Single Frequency Network
SHF	Super High Frequency
SISO-MAP	Soft Input Soft Output Maximum A Posteriori
TDM	Time Division Multiplexing
TPS	Transmission Parameter Signaling
TS	Transport Stream
TU6	Typical Urban
UHF	Ultra High Frequency
VU	Vehicular Urban
WLAN	Wireless Local Area Network

List of Symbols

$A(e)$	output vector from inner bit interleaver e
$a_{e,w}$	bit number w of inner bit interleaver output stream e
$B(e)$	input vector to inner bit interleaver e
$b_{e,w}$	bit number w of inner bit interleaver input stream e
$c_{m,l,k}$	complex cell for frame m in OFDM symbol l at carrier k
C/N	RF signal (all carriers) to noise ratio required by the system (dB)
C_i	complex scrambling code sequence
E	demultiplexed bit stream number
f_c	centre frequency of the transmitted signal
G_1, G_2	convolutional code Generator polynomials
$g(x)$	RS (Reed-Solomon) code generator polynomial
$H(q)$	permutation function of the bit and symbol interleaver
$H(e)$	inner bit interleaver permutation
I	interleaving depth of the outer convolutional interleaver
$I_0,\ldots,I_5$	inner interleavers
j	branch index of the outer interleaver
k	carrier number index in each OFDM symbol
K	value of the level of the direct path in the Ricean channel model
K_{max}	carrier number of the largest active carriers in the OFDM signals
K_{min}	carrier number of the lower active carriers in the OFDM signals
l	OFDM symbol number index in an OFDM frame
L_{TOT}	total length of one PL slot
m	OFDM frame number index
M	convolutional interleaver branch depth for j=1, M=N/I
n	transport stream sync byte number
N	length of the error protected packet in bytes
N_{max}	total number of OFDM carriers
$p(x)$	RS code field generator polynomial
R_0	integer value of the converted binary sequence from the z_0
Rx	receiver

S/N	RF signal (payload carriers) to noise ratio required by the system (dB)
T	elementary Time period
t	check symbols (number of added symbols) in the RS encoder/decoder
Tx	transmitter
v	number of the sub-streams for the inner interleaving process
w_k	value of reference PRBS sequence applicable to carrier k
Y	output vector of the symbol interleaver
Y'	intermediate vector of inner symbol interleaver
y_q	bit number q of output from inner symbol interleaver
y'_q	bit number q of intermediate vector from inner symbol interleaver
z_0	actual value of the Gold sequence

Content

1 Introduction

At present, there is big interest in DTV (Digital Television). As we enter the twenty-first century, digital television is considered as an integral part of the new millennium. This is because the DTV can offer enormous amounts of information at very low cost to the infinity number of viewers. Furthermore, it can now be fully integrated into completely digital transmission networks [1].

Digital television system can provide more programs and possibilities than old and classical ATV (Analog Television). The reasons are several. One of them is that the information (video, audio, image, data) in digital form can be modified and treated in ways never possible with ATV. Stream in digital form is easy to store on computer or discs and play them over digital networks without significant signal degradation. Because the benefits of the digital systems were more then analog systems, in September 1993 was to sign the contract of understanding. Organization DVB (Digital Video Broadcasting) was based and became a full development work [1]-[4].

DVB [2]-[4] is the standard for digital broadcasting that was first adopted in Europe. The DVB standard also tells how to combine several services as radio and TV channels in a so called multiplex. This is important if we want to receive the signal from satellite, cable or terrestrial transmitters. The DVB standard also contains rules for how the signals are to be distributed trough three kinds of distribution media: DVB-S (Satellite), DVB-C (Cable) and DVB-T (Terrestrial). For bringing broadcast services to mobile handsets serves DVB-H (Handheld) and DVB-SH (Satellite to Handheld) standards.

The DVB-S system for digital satellite broadcasting was developed in 1993. It is a relatively straightforward system, using QPSK (Quadrature Phase Shift Keying) modulation. The specification described different tools for channel encoding/decoding and error protection, which were later used for other media systems. Nowadays, DVB-S is one of the most used standard for broadcasting of digital TV services, because its reception by satellite is easy (installation is very simple) and cheap [2]-[5].

The DVB-C system for digital cable networks was developed in 1994. It is focused on the use of different type of QAM (Quadrature Amplitude Modulation) modulations and for the European satellite and cable environment can, if needed, convey a complete satellite channel multiplex on a cable channel. Generally, in coax cable systems 64QAM modulation is used, while in optical fiber networks 256QAM modulation is generally used [2]-[4], [6].

The DVB-T system for digital terrestrial broadcasting was developed in 1997 and first, it is broadcast in the United Kingdom in 1998. The DVB-T system is more complex, because it is intended to cope with a different noise, for example ISI (Intersymbol Interference) and multipath reception. The DVB-T standard uses OFDM (Orthogonal Frequency Division Multiplexing) modulation. There are two modes: 2K carriers and QAM, 8K carriers and QAM [1]-[4], [7], [8].

The DVB-H (in this dissertation thesis also marked as a DVB-T/H) system can be precisely defined as a transmission system, built out of several DVB standards, aiming at efficient terrestrial broadcasting of digital multimedia data to handheld devices. The DVB organization formally adopted this standard in November 2004. The DVB-H system, compare to DVB-T, is more flexible and robust digital transmission system. The system also includes additional features, which will reduce battery power consumption (time slicing) of the handheld receivers and a 4K OFDM mode, together with other innovations [1]-[3], [9], [10], [13]-[17].

From March 2008, standard DVB-H is officially endorsed by the European Union as the "preferred technology for terrestrial mobile broadcasting". The Tab. 1.1 gives overview of the newest countries, where the DVB-H broadcasting was launched. In 2007, a study mission was formed to investigate the new options for a potential DVB-H2 successor to DVB-H, but the project was later shelved. In November 2009, the DVB group made a 'Call for Technologies' for a new system DVB-NGH (Next Generation Handheld) [91] to update and replace the DVB-H standard for digital broadcasting to mobile devices. The schedule was for submissions to be closed in February 2010, the new ETSI standard published in 2011, and rollout of the first DVB-NGH devices from 2013 [13].

The DVB-SH system is a physical layer standard for delivering IP based media content and data to handheld terminals such as mobile phones or PDAs, based on a hybrid satellite/terrestrial downlink and for example a GPRS (General Packet Radio Service) uplink. The DVB organization published this standard in February 2007. System DVB-SH was designed for frequencies below 3 GHz, supporting UHF (Ultra High Frequency), L-band or S-band. It complements and improves the existing DVB-H physical layer standard [11]-[13], [15], [16].

The Tab. 1.2 gives overview of the newest countries, where DVB-SH standard was launched. DVB-SH terminals are still in development by several manufactures and the first terminals are arrived to market nowadays. In Europe, the driving force for DVB-SH technology is the group Alcatel-Lucent. This company worked closely with NXP Semiconductors and they are developing a receiver module for UHF and the L-band. Of course, that will be extended to the S-band, based on the forthcoming DVB-SH standard [13].

This dissertation thesis deals with the simulation, measurement and analysis of signal processing and transmission in DVB-H/SH standards. In this work, it is determined the error rate of transmission, depending on system configurations and parameters of transmission communication channels.

In the next subchapter will be briefly described the state-of-the-art in the DVB-H/SH standards. The description also focused on the present research and innovations in area of both standards.

Tab. 1.1 Overview of today available DVB-H Services [18]

COUNTRY/PARTICIPATING COMPANY	FULL SERVICE LAUNCH	TRIAL SERVICE	DATE
Italy/Reti Radiotelevisive Digitali	Yes	No	2006
Albania/ DigitAlb	Yes	No	2006
Vietnam/ Vietnam Multimedia Corporeation	Yes	No	2006
Malaysia/U Mobile	No	Yes	2007
Ireland/O_2 Ireland	No	Yes	2007
Finland/Mobili-TV	Yes	No	2007
Finland/Mobili-TV	Yes	No	2007
France/Paris(CANAL+)	Yes	No	2008
Austria/Media Broad	Yes	No	2008
Switzerland/Swisscom	Yes	No	2008
China/Shanghai Media Group	Yes	No	2008
Netherlands/KPN	Yes	No	2008
Russian Federation/KENTAVR	No	Yes	2009
Iraq/Mobision	Yes	No	2009
Poland/INFO-TV-FM	Yes	No	2009
Slovakia/University of Zilina	No	Yes	from 2010 to 2012

Tab. 1.2 Overview of today available DVB-SH Services [19]

COUNTRY/PARTICIPATING COMPANY	FULL SERVICE LAUNCH	TRIAL SERVICE	DATE
USA/ICO	No	Yes	2008
France/SFR and Alcatel-Lucent	No	Yes	2009
Italy/3 Italia, RAI and Alcatel-Lucent	No	Yes	probably in 2011

1.1 STATE-OF-THE-ART IN DVB-H/SH STANDARDS

Digital broadcast systems have been deployed increasingly for various services, such as terrestrial digital and satellite TV and digital radio. The number of features, integrated in mobile phone terminals, has increased significantly over time. Today, mobile phones offer services far beyond speech telephony and lean toward becoming new multimedia terminals. This is the reason why digital TV services are offered on these devices. Access to TV and video services on a mobile phone is already possible via a UMTS (Universal Mobile Telecommunication System) connection, but this solution has a several disadvantages [12], [13].

A more efficient solution is to transfer the video data stream to the terminals via a classical broadcast network, such as a terrestrial television network. DVB-T standard is already in operation in many countries of the world. Therefore, his benefits also attracted the interest of the wireless mobile communication industry. The International DVB Project responded to this interest by specifying the new digital broadcast standard DVB-H, which is in fact a spin-off DVB-T, tailored to the needs of handheld receivers. It was later developed another standard, so called DVB-SH, allowing transmission of data stream via satellite path [9]-[13].

The state-of-the-art in the latest standards (DVB-H/SH) for the mobile, portable and fixed TV broadcasting is described below.

1.1.1 DVB-H

Nowadays, the research and development in DVB-H standard can be divided into several areas. These areas are closely related with the technical characteristics and innovations of the mentioned standard.

Comparing to digital terrestrial television, handheld television (mobile terminal) is much more difficult from technical points of view [17]. Mobile terminals have very small antenna size, comparing to standard television antennas. As a consequence is that the handheld mobile terminals need stronger signals than standard TV. On the other hand, it must be respected one important thing: the antenna should be covering the whole UHF DVB-H standard frequency band (470-862 MHz). Of course, there are several solutions to solve this problem. Very good and smart solutions are published in [20]-[24]. Recently, various types of antennas have been developed for DVB-H system, respecting other technologies (LTE, WLAN) and frequency bands (L-band, SHF). This area has been explored too and the main results are presented in [25] and [26].

Mobile reception can be expected everywhere, especially and mainly inside buildings and in vehicles [17]. This demands extraordinary robustness for transmission signal. Therefore, DVB-H system contains functional changes in the link and physical layers, while it is backward compatible with DVB-T standard. In case of the link layer, time slicing and MPE-FEC (Multiprotocol Encapsulation-Forward Error Correction) were added. With these extensions the signal for the mobile reception can be more powerful. The research in this area and innovations for FEC scheme of the signal for the mobile reception also continues today. More details and practical informations can be found in the [27]-[33].

One of the main characteristics of handheld receivers is that they do not use constant electrical power supply, but are powered by batteries of limited capacity. Of course, the limited power supply is an important area of handheld terminals. Therefore, the inclusion of specific provisions in the technology itself, so as to restrict the power consumption, of the devices is required [13]. On the link layer of DVB-H system configuration, time-slicing data transmission technique was implemented [10]. Time-Slicing enables a receiver to stay active only a small fraction of the time, while receiving bursts of a requested service. This is the most important feature of time-slicing technology. The innovation and improvement of this technology, which can reduced the power consumption by 90%, are continuing nowadays and the most important results are clearly described in [34]-[37].

With time-slicing technology is closely related the handover, known from the field of mobile technology and communication. The mobility of the users of mobile phones introduces requirement of cell handover. Handover refers to the process to change the frequency and receive data stream with the same content in another radio cell. To ensure a high quality of services, handovers should be seamless [13]. Seamless handover has no higher influence on the quality of TV picture. In general, time-slicing is optimizing handovers and has important role in the realization of the seamless handover [17]. The newest and actual results in this area are published in [39]-[41].

In the DVB-H standard a classical, so called, non-hierarchical modulations are used. However, a hierarchical modulation [11]-[12] is also adopted as an "alternative" modulation technique. If the hierarchical modulation is used, the DVB-T/H modulator has two transport stream inputs and two FEC blocks. One transport stream, with a low data, is fed into the HP (High Priority) path and provided with a large amount of error protection. In this case, typically, a QPSK modulation is used. A second transport stream, with a higher data rate, is supplied in parallel to the LP (Low Priority) path and is provided with less error protection. In this case, for the transmission a 16QAM modulation is used [42]. Possibilities and features of hierarchical modulation were experimentally tested and the results were evaluated in [42], [43] and [80].

How it was mentioned, for achieving a good signal quality at the mobile TV transmission in the mobile phones, on the transmitted signal must be applied a robust FEC. Broadcasted signal can be propagated directly, if the optical visibility between the transmitter and receiver is secured. Generally, there are many obstructions in communication environments, like houses, natural (e.g. hills) and industrial objects. This situation is typical especially for the mobile reception. Moreover, the mobile terminal is practically always on the move. Therefore, it is needed a robustness FEC and improved techniques for achieving a good signal quality. For testing of the mentioned and described situations existing several types of communication channel models, which can respect the signal transmission with and/or without Doppler's shift. How it is known, DVB-T standard allows the transmission of the signal in mobile (2K), and fixed (8K) mode [8]. Moreover, DVB-H standard enable transmission in portable (4K) mode [9]. Performance of the DVB-T transmission in mobile and fixed reception scenarios was sufficiently explored. Main results and conclusions were presented in [44]-[46]. On the other hand, the exploring of the DVB-H transmission in all possible reception scenarios is still continued.

1.1.2 DVB-SH

Standard DVB-SH complements and improves the existing DVB-H (physical layer) standard. This improving pushes the limits on the possibilities of DVB broadcasting to handheld terminals. The research and development in DVB-SH standard, as it is in case of DVB-H, can be divided into several areas.

In the last decade, several works dealt with the research and development in area of DVB-SH standard. The DVB-SH system allows mobile TV transmission in two principle modes: OFDM (for satellite and terrestrial mode) and TDM (for satellite mode). Therefore, it is very necessary in order to has sufficient information about the satellite/terrestrial signal propagation and its gain. Field measurements of a DVB-SH network with both, satellite and terrestrial transmitters, has been done and the obtained results were presented in [47].

Especially, TDM (Time Division Multiplexing) [11]-[13], [48] is one of the main innovations in DVB-SH system. In the TDM transmission mode [13], the data are broadcasted to mobile terminals on a direct path from a broadcast station via satellite. The TDM signal is partly derived from the DVB-S2 (2^{nd} Generation Digital Satellite Television Broadcasting) standard [48]. It allows optimizing transmission through satellite toward mobile terminals. Of course, according to the DVB-S/S2 characteristics, it is used on the direct path only. Moreover, the configuration of the DVB-SH standard allows a combination of TDM and OFDM modes, which is increasing the robustness of the transmission in relevant areas (mainly suburban). Of course, this solution may be of interest in power limited satellite systems [49].

In the recent years, the research in the area of TDM transmission is mainly focused on the developing of the appropriate satellite channel model for the analysis and simulation of the signal transmission. In case of TDM, a LMS (Land Mobile Satellite) [50] model is usually used. This model describes the narrowband propagation channel in three possible shadowed states: case of line of sight, moderate shadow and deep shadow. The main obtained results and their discussion were described in [51], [52]. Measuring of signal level and quality in the hybrid satellite/terrestrial channel model were already done and the results were presented in [53]-[56].

The S-Band is very demanding in terms of signal coverage. For achieving a good signal quality, it is required a dense terrestrial repeater network in urban areas [13]. The cost of this network can be reduced if the C/N (Carrier-to-Noise Ratio) ratio, required for stable reception, is low. This requirement in DVB-SH system is met by the high frequency band, in which it operates and it is compensated by a selection of tools that enhance the signal robustness. Therefore, it is necessary the correct and robust FEC of the transmitted mobile TV service. In DVB-SH standard, as a FEC encoder and decoder, the turbo code, concretely, the 3GPP2 (Third Generation Partnership Program 2) turbo encoder is used [11], [12]. The advantages and disadvantages and very brief implementation notes of this encoder were available in [12] and [83]. On the other hand, nowadays, the research is focused on the alternative and modified turbo schemes, which have many advantages (less complexity, simpler interleaver and decoding methods) in comparison with 3GPP2 turbo coder. The main alternative and perspective solutions (modifications of the original turbo encoder/decoder, which is preferred in DVB-SH standard) were presented in [57]-[60].

In the DVB-SH standard a classical, so called, non hierarchical modulations are used too. How it was in DVB-H system, a hierarchical modulation [11]-[12] is also adopted in DVB-SH, as an “alternative” modulation technique. Hierarchical modulation is particularly used to mitigate the cliff-off effect in DTV broadcasting, particularly mobile TV, by providing a lower quality fallback signal in case of weak conditions of the reception. It is allowing graceful degradation, instead of complete signal loss [61]. The principle of hierarchical modulation and its optimal implementation to the DVB-SH system is under study. The first obtained results and their evaluation from this study has been clearly presented and discussed in [61], [62].

For the achieving a good signal quality at the mobile, portable and fixed TV transmission in the mobile terminals, on the transmitted signal must be applied robust FEC, as it is in DVB-H standard. The suitable system configurations in both transmission modes (OFDM and TDM) are therefore very important. Of course, for the exploring of the DVB-SH transmission a special communication fading channels is used, that is in case of DVB-H. And again, the exploring of the DVB-SH transmission in all possible reception scenarios is still continued.

1.2 DISSERTATION AIMS

In the previous chapter the state-of-the-art of the DVB-H/SH standards was described. There were also presented the main areas of both standards, where the research activities are topical and still open.

How it was briefly described in the previous subchapters, the main innovations in both standards have been done in area of channel coding. In case of mobile TV transmission, the technique of FEC has an important role for the achieving of the error-free reception of the received signal. On the other hand, DVB-H and DVB-SH systems allow set of different settings to adapt the transmission parameters of current channel conditions and requirements. These settings have very big impact on the *BER* (Bit Error Ratio) on data stream before/after the transmission via channel, as well as characteristics of communication channel. Dependences of the *BER* on the various settings and different types of transmission channels with varying parameters, usually, can not be determined theoretically or mathematically.

The terrestrial propagation channel is considered to be frequency selective [69], [70], because of its respective coherence bandwidths. A frequency selective fading is classically characterized through a PDP (Power Delay Profile), which gives the relative time of arrival, the relative power and the type of spectrum (Ricean, Rayleigh, Gaussian) of each group of unresolved echoes (also called paths) [44], [45]. The real dependences of the transmitted signal on the transmission parameters in different channel transmission model were not adequately investigated yet. The critical and required *C*/*N* for achieved a QEF (Quasi Error Free) reception [3] was not clearly determined in different types of communication fading channels. Therefore, it is necessary to analyze the signal transmission in different fading channel models in DVB-H/SH standards, to establish the error rate of the transmission, which is the one of the main aim of this dissertation thesis.

The aims, which should be achieved in this dissertation work, are summarized in the following points:

- Exploring of the system configurations (on the level of physical layer) of the DVB-H/SH standards and their possibilities for the transmission of TV services.
- Exploring and analysis of different transmission channel models, which are respecting the features of all transmission scenarios (path delays, path losses, phase shift, movement of the receiver, Doppler's shift, etc.).
- Creation of appropriate program applications in MATLAB, which allow simulate and analyze the signal distortions at transmission in DVB-H/SH standards.
- Measurement of the transmission distortions in typical scenarios and channel models, according to the technical and laboratory possibilities.
- Evaluation and discussion of the obtained results from simulations and measurements and determination of critical *C*/*N* values for achieving a good signal quality in real transmission scenarios for DVB-H/SH standards.

2 Standard DVB-H

This chapter briefly describes the main innovations in the DVB-H standard and its functional block diagram. The description is focused on the link and the physical layer. The conceptual structure of DVB-H system will be described too.

The digitization of traditional broadcast systems has made significant progress in recent years. This development could be observed recently with respect to the standard for digital terrestrial television DVB-T, which is already in operation in many countries throughout the world. In many countries, the decision to select DVB-T, as the terrestrial television system, was based on the exceptional features of the DVB-T standard; among them the possibility to receive broadcast services also with mobile and portable devices and even in cars [2], [3], [13], [17].

In 2000, the EU-sponsored MOTIVATE (Mobile Television and Innovative Receivers) project concluded that mobile reception of DVB-T is possible, but it implies dedicated broadcast networks, as such mobile services are more demanding in robustness than broadcast networks, planned for fixed DVB-T reception. The work to define such a system within the DVB project is started in the year 2002. Of course, this work focused by defining a set of commercial requirements for a system supporting handheld devices (terminals) [63]. The technical work then lead to a system, called DVB-H. This standard was published as ETSI Standard EN 302 304 [9] in November 2004. The DVB-H system is defined based on the existing DVB-T standard for fixed and in-car reception of digital mobile TV services.

2.1 GENERAL OVERWIEV OF THE DVB-H SYSTEM

A full DVB-H system is a combination of elements of the physical and link layers, as well as service information. The main additional elements [9], [10], [13]-[17] in the link layer are:

- **Time slicing** in order to reduce the power consumption of the receiving terminal. It is also enable smooth and seamless frequency handover.
- **MPE-FEC** for an improvement in *C/N* performance and Doppler performance in mobile channels. It is also improve to the tolerance to impulse interference.

How it was described in 1.1.1, time slicing technology is an important innovation in area of power consumption. The concept of time slicing is to send data in bursts, using a significantly higher bitrates compared to the bitrates, required if the data was transmitted continuously. The front end of the receiver switches on only for the time interval, when the data burst of a selected service is on air. With this technology the power saving for the front end could be up to 90% [9], [10], [13].

In view of the particularly difficult reception conditions that may occur in the mobile environment, further error correction schemes are included. A scheme, known as MPE-FEC, provides additional error correction. This FEC scheme is applied on the transmitted data and after reception and demodulation, allows the errors to be detected and corrected [9], [10], [13].

The main additional elements [9], [10], [13]-[17] in the physical layer are:

- **DVB-H signaling in the TPS-bits** (Transmission Parameter Signaling) to enhance and speed up service discovery. A cell identifier is also carried in the TPS-bits to support quicker signal scan and frequency handover on mobile receivers.
- **4K mode** for trading off mobility and SFN (Single Frequency Network) cell size, allowing single antenna reception in medium SFN networks at very high speed. This mode also adding flexibility for the network design (compromise between the 2K and 8K modes).
- **In-Depth symbol interleaver** for the 2K and 4K OFDM modes to further improve the robustness in mobile environments and impulse noise conditions.

Originally, the TPS was first defined for the purposes of DVB-T. It was further extended for the DVB-H system requirements. The main purpose of the TPS in DVB-H system is to fasten receiver signal scan and synchronization procedure [10], [14].

The general transmission mode, used in the DVB-T, it can be 2K or 8K. The DVB-H includes a new mode: the 4K mode. This mode brings additional flexibility in network design by treading off mobile reception performance [10], [13].

The in-depth symbol interleaving is an additional feature of DVB-H system. For 2K and 4K modes, the in-depth interleaver increases the flexibility of the symbol interleaver. Thank to this flexibility, a 2K or 4K signal can be used the memory of the 8K symbol interleaver [10], [13].

2.1.1 MPE-FEC

The video and audio data in a DVB-H system is delivered using IP (Internet Protocol) datacasting. This implies that the data is encapsulated with IP headers and transmitted in the same way as it is over the Internet [16]. One the other hand, requires of data transmission (resistance to interference and multipath transmission) are much higher. Therefore, at the link layer of DVB-H systems, MPE-FEC is used for carrying data [13], [14], [16].

The syntax of the MPE was formally adopted for the DVB-H and the MAC (Medium Access Control) address fields, redefined for the purposes of real-time parameters of time-slicing signaling [14]. The input data stream is constructed on the MPE-FEC frames. The typical structure of this frame is presented in the Fig. 2.1.

A frame can be divided on two main parts. First one is the application data table, which contains the datagrams (useful data) and padding (when amount of data is less then the total capacity of the table). The second one is the RS (Reed-Solomon) data table with the parity bits. The datagrams and padding are always allocated in the left side of the frame, while parity bits (RS data) are allocated on the right side [13], [14].

Overall, MPE-FEC frame is a matrix, composed of 255 columns and from 256 up to 1024 rows (details are shown in Fig. 2.1). The maximum size of one frame could be 2 Mbits. Each position in the matrix holds an information byte [10], [13], [14].

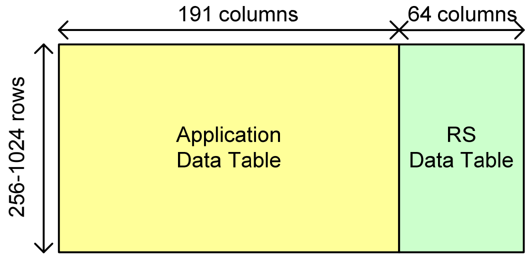


Fig. 2.1 The structure of MPE-FEC frame.

Tab. 2.1 Overview of the MPE-FEC Code Rates [13]

MPE-FEC Code Rate	Data Columns	RS Columns	Total Amount of Columns
1/2	64	64	128
2/3	128	64	192
3/4	191	64	255
5/6	190	38	228
7/8	189	27	216
1/1 (Uncoded)	255	0	255

The RS table is generally consists 64 columns. On each row, the content results from the application of the RS code to the corresponding row of the application data table [13] . One of the optional features of MPE-FEC is the puncturing. Thank for this a number of columns of the RS code are not actually transmitted to reduce the overhead that they introduce [10], [13], [14], [17]. All possible MPE-FEC code rates and dependences between the data and RS columns are clearly presented in Tab. 2.1.

How it was described, the datagrams are encapsulated column-wise to the frame, and the encoding (on physical layer) is done row-wise with RS code [14]. In general, for the real transmission the RS(191,64) variant (the MPE-FEC code rate is 3/4) is the most used. Therefore, in this dissertation thesis, this type of RS encoding will be used.

In this chapter, the brief description of the MPE-FEC scheme was described. This type of error protection is one of the most important innovations in DVB-H standard.

2.1.2 In-Depth Interleaving

Symbol interleaving in the DVB-H system, as it is in DVB-T, is the part of the FEC process. The purpose of this interleaver is to map v bit words onto the active carries per OFDM symbols. How it can be seen in Fig. 2.2, 12 groups of 126 bit-wise interleaved words in 2K mode, 24 groups in 4K mode and 48 groups in 8K mode are sequentially read to the symbol interleaver to be mapped onto the one OFDM symbol [7], [9], [64].

For the 2K and 4K modes, in-depth interleaver increases the flexibility of the symbol interleaver. Thank to this flexibility, a 2K or 4K signal can be used the memory of 8K symbol interleaver. The overview of the in-depth interleaver is shown in Fig. 2.2.

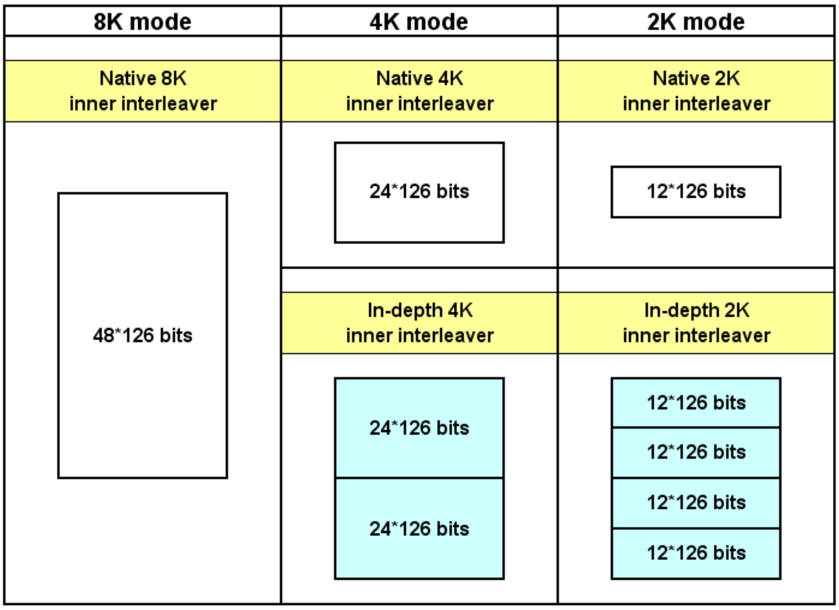


Fig. 2.2 Native and In-depth interleaver for all OFDM modes.

When the in-depth option in DVB-H FEC scheme is active, then symbol interleaver acts on blocks of 6048 (8K) symbols. This value is fixed and not independent on the OFDM mode. In DVB-H, 2K and 4K in-depth symbol interleaver modes then use the same permutation function, defined originally for 8K mode [7]. Interleaved output vectors are then mapped onto four consecutive 2K OFDM symbols or two consecutive 4K OFDM symbols. More precisely, the use of the 8K symbol interleaver for 2K and 4K helps to spread impulse noise power across 4 symbols (2K mode) and 2 symbols (2K mode) [9]. This solution can improve reception in fading mobile TV channels. Moreover, it provides an extra level protection against short noise impulses [13], [64].

In this chapter, two types of symbol interleavers were described. The description especially focused on the in-depth interleaving that is one the main innovations in DVB-H system, which can improved the error correction of the data transmission. More detailed description of the symbol (inner) interleaver will be described in the next part of this thesis. In the next chapter and subchapters the functional block diagram of the DVB-H transmitter will be described.

2.2 BLOCK DIAGRAM OF THE DVB-H STANDARD

Functional block diagram of the DVB-H transmission system (included the FEC and modulator blocks) is presented in Fig. 2.3. How it can be seen, the block diagram of the DVB-H standard is very similar to the block diagram of the DVB-T system [8].

The complete FEC encoder, which DVB-H standard uses, consist of two main parts: outer and inner encoder. These blocks ensure error protection during the data transmission. Outer encoder contains advanced Reed-Solomon encoder and outer interleaving (byte interleaver).

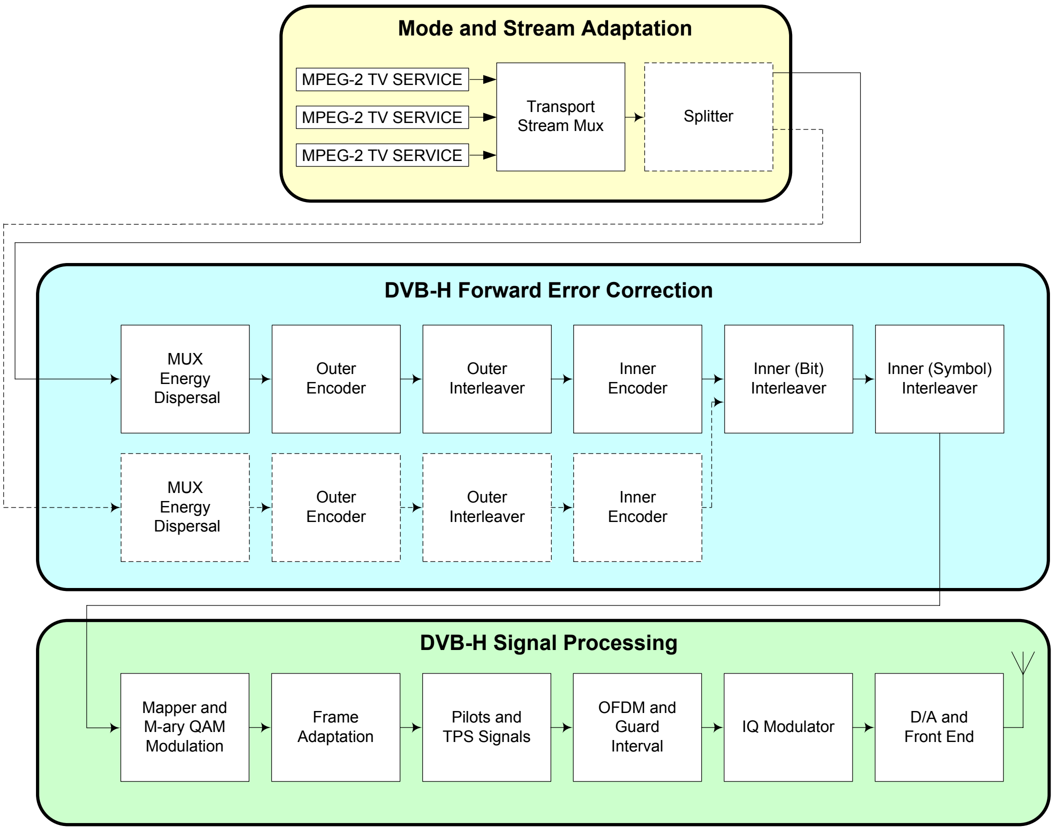


Fig. 2.3 Functional block diagram of the DVB-H transmission system (based on [7]).

The inner encoder follows the outer encoder, which contains convolutional encoder (Trellis coder) and inner interleaving (bit and symbol interleaving process). The purpose of interleavers is elimination the burst errors.

The modulator and signal processing of DVB-H consist of the remaining functional blocks (see Fig. 2.3). The purpose of digital modulator (Mapper) is mapping the output of inner interleaver to the individual symbols of the digital modulation. DVB-H standard uses three digital modulations: QPKS, 16QAM and 64QAM. After the mapping and demultiplexing of these symbols, complete transmission frames in the frequency domain are created. These OFDM frames are then converted to the time domain and the guard interval is inserted. The purpose of guard interval is limiting the ISI (Intersymbol Interference). At the end the D/A (Digital-to-Analog) block is applied, then the signal is amplified and transmitted.

Blocks, which are marked with dotted line in Fig. 2.3, are applied in case, when hierarchical modulation is used. In this dissertation thesis the implementation of hierarchical modulation is not considered.

2.2.1 Scrambling (Energy Dispersal)

The structure of the input stream shall be organized in fixed length packets, following the MPEG-2 transport multiplexer (MUX). The general length of the one packet in the DVB-H standard is 191B [10].

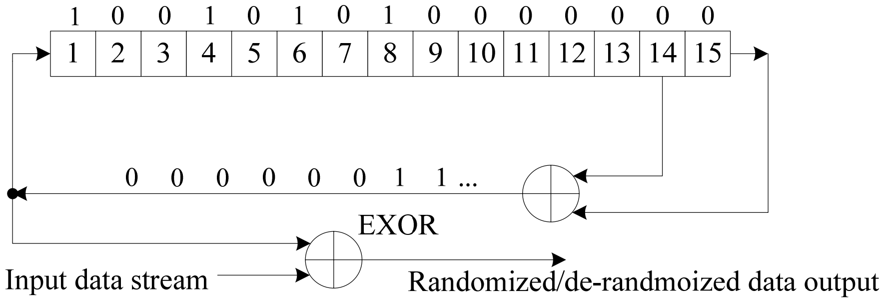


Fig. 2.4 Scrambler/Descrambler schematic diagram (based on [7]).

During the mobile TV broadcasting, probabilities of the relatively long sequences of zeros or ones are very high. These sequences should be occurring purely accidentally in a data signal. On the other hand, these are unwanted since they do not contain any clock information or cause discrete spectral lines over a particular period [3]. For the elimination of these probabilities should be applied energy dispersal [10].

To achieve energy dispersal, PRBS (Pseudo Random Binary Sequence) is first generated and then mixed with the data stream. This operation breaks up long sequence of ones or zeros. The PRBS sequence generation is restarted time and again in a defined way (inverted synchronization byte). More details can be found in [3] and [7].

A functional block diagram of the energy dispersal stage is shown in Fig. 2.4. This block consists of fifteen (15) shift registers. First, PRBS sequence is generated for the randomization. The initialization sequence is equal to 100101010000000. The output bit of PRBS is calculated as a sum of EXOR (Exclusive OR) operation from the outputs of fourteen (14) and fifteen (15) registers. This bit is also brought at the input of the first (1) register and the position of shift registers are shifted by one position on right. The randomization of the input data is realized as EXOR sum of the input stream with the PRBS sequence.

At the receiver side, the energy dispersal must be canceled. It is very simple, because when the energy-dispersed data stream is mixed again with the same PRBS sequence at the receiving end, then the dispersal is cancelled.

2.2.2 Outer Encoder (Reed-Solomon)

Before the modulation and OFDM frame adaptation, the data must be ensured with the error protection against the transmission errors. How it was mentioned, this error correction (FEC) in DVB-H system can be divided to main parts: outer and inner encoding.

As an outer encoder in the DVB-H system, the Reed-Solomon code is used with a field generator polynomial (2.1) and a code generator (2.2), as defined below [7], [10]:

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1 \tag{2.1}$$

$$g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\ldots(x+\lambda^{63}), \, where \, \lambda = 02_{HEX}. \tag{2.2}$$

In the coding theory [65], [66], RS codes are non-binary cyclic error-correcting codes, which could detect and correct multiple random symbol errors. By adding t

check symbols to the data, an RS code can detect any combination of *t* erroneous symbols and correct up to *t/2* symbols [15].

This encoder in the DVB-H system should be implemented as a RS(255,191), which adds 64 correction bytes to 191 input data bytes and it is able to correct up to 32 erroneous bytes.

2.2.3 Outer Interleaving

After the RS encoding, the secured data stream is interleaved. This type of interleaving is also called symbol (outer) interleaving, because the individual symbols are interleaved. All type of interleavers is characterized by two main parameters: depth of interleaving (I) and length of outer frame (M). When these two parameters are known, then can be easily realize a matrix of size $I.M$, where M=17=N/I =255. Parameter N represents the number of cells, which equals to the total size of output packet from RS encoder. Concretely, in this case N equals to 255. Interleaving is realized by writing bytes into the matrix by columns and reading them out by rows [7].

The described method, unfortunately, has two disadvantages: large requirements for memory and synchronization and risk of high burst errors after the deinterleaving of periodic errors [3], [7]. These disadvantages are eliminated by the using of the outer convolutional interleaver, so called Forney convolutional interleaving [3]. The interleaving device consists of a switched bank of 12 FIFOs (First Input First Output) registers of length $M \times j$, which are realized delays in actual branch. Outputs of these registers are again cyclically connected to the output of the interleaver. The block diagram of the convolutional interleaver is shown in Fig. 2.5.

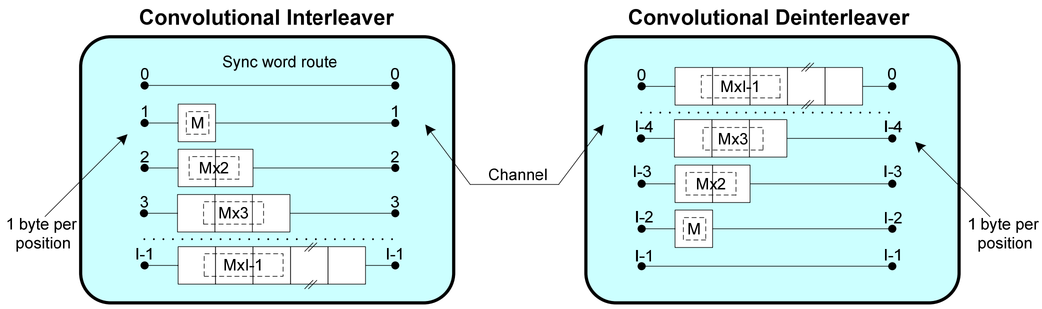


Fig. 2.5 Conceptual diagram of the outer interleaver and deinterleaver (based on [15]).

2.2.4 Inner Encoder

Inner encoder in DVB-H, as well as in DVB-T, is realized by the convulutional encoder. In general, each convolutional encoder consists of stages with more or less delay and with memory, which, in practice, are implemented by using shift registers. The bit streams, which are delayed, taken from registers and are EXORed with the un-delayed bit stream [3]. Therefore, on the output there are two bit streams, each with the same bit-rate as the input stream.

Block diagram of the convolutional encoder, which is using in the DVB-H system, is illustrated in Fig. 2.6. The generator polynomials of the mother code are $G_1 = 171_{OCT}$ and $G_2 = 133_{OCT}$. The basic code rate of this configuration equals to 1/2. This will allow selection of the most appropriate level of error correction for a given services.

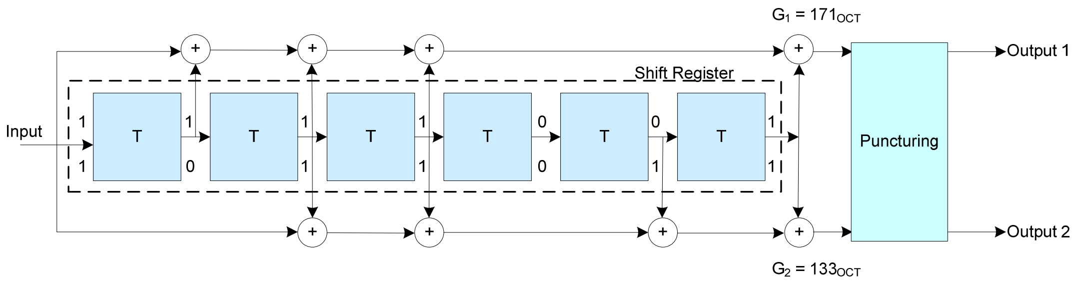


Fig. 2.6 Principle diagram of the DVB-T/H convolutional coder (based on [15]).

Tab. 2.2 Puncturing pattern and transmitted sequence for the possible code rates [15].

Code Rates	Puncturing Pattern	Transmitted Sequence
1/2	X: 1 Y: 1	X_1 Y_1
2/3	X: 1 0 Y: 1 1	X_1 Y_1 Y_2
3/4	X: 1 0 1 Y: 1 1 0	X_1 Y_1 Y_2 X_3
5/6	X: 1 0 1 0 1 Y: 1 1 0 1 0	X_1 Y_1 Y_2 X_3 Y_4 X_5
7/8	X: 1 0 0 0 1 0 1 Y: 1 1 1 1 0 1 0	X_1 Y_1 Y_2 Y_3 Y_4 X_5 Y_6 X_7

If it is necessary, the error protection can be controlled by puncturing, e.g. the data rate can be lowered again by selectively omitting bits. This involves not taking all successive bits of two *X* and *Y* output bitstreams, but only one of the two bits with a certain puncturing ratio [15]. Possible puncturated code rates, according to DVB-T/H specification, are gives in Tab. 2.2. In this table, X and Y refer to the two outputs of the convolutional encoder [3], [7].

2.2.5 Inner (Bit) Interleaver

As depicted in Fig. 2.3, the last part of the DVB-H FEC scheme is included the inner interleaving. The inner interleaving is divided into two steps: bit and symbol interleaving. Both, the bit-wise interleaving and the symbol interleaving processes are block-based.

After the inner (convolutional) encoding, the bit stream is brought at the input of the inner interleaver. The example of the block diagram of the inner interleaver (with mapping of the output modulation symbols) for the non-hierarchical QPSK modulation is shown in the Fig. 2.7. The input stream is demultiplexed into v sub-streams, depending of the modulation used: $v = 2$ for QPSK, $v = 4$ for 16QAM and $v = 6$ for 64QAM [7]. In non-hierarchical mode, the single input stream is demultiplexed only into v sub-stream (see Fig. 2.7). More details (block diagrams for all type of modulations and the equations for the demultiplexing) can be found in [7].

In case of the hierarchical modulations, the HP stream is demultiplexed into 2 sub-streams and LP stream is also demultiplexed into 2 sub-streams. This dissertation thesis deals only with the non-hierarchical mode. More information about the hierarchical mode and block diagrams can be found in [7], [10].

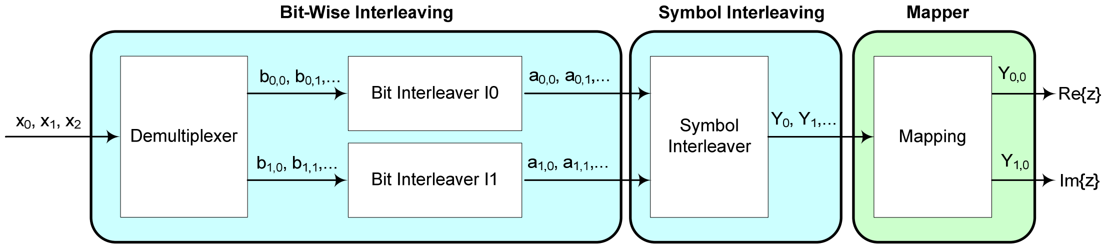


Fig. 2.7 Block diagram of the inner interleaving (bit-wise and symbol interleaving), with mapping of input bits onto output modulation symbols, when QPSK modulation is used (based on [7]).

Each sub-stream from the demultiplexer is processed (interleaved) in the bit interleaver (see Fig. 2.7) with own interleaving sequence, called permutation function. Bit interleaving is performed only on the useful data. The bit interleaving block size is equal to 126 bits and it is the same for each interleaver. For each bit interleaver, the input bit vector [7] is defined by (2.3):

$$B(e)=\left(b_{e,0},b_{e,1},...,b_{e,125}\right), \tag{2.3}$$

where e ranges from 0 to v-1. The interleaved output vector [7] ($A(e)=\left(a_{e,0},a_{e,1},...,a_{e,125}\right)$) is defined by (2.4):

$$a_{e,w}=b_{e,He(w)} \qquad w=0,1,2,...,125, \tag{2.4}$$

where $H_e(w)$ is a permutation function which is different for each interleaver. The exact definition of this permutation function for each interleaver can be found in [7]. The output of the v bit interleavers are grouped to form the digital data symbols, such that each symbol of v bits will consist of exactly one bit from each of the v interleavers [7], [10]. Therefore, the output of the bit-wise interleaver can be defined as a (2.5):

$$y'_w=\left(a_{0,w},a_{1,w},...,a_{v-1,w}\right). \tag{2.5}$$

2.2.6 Inner (Symbol) Interleaver

Symbol (native) interleaving is performed at bit-wise interleaved substream. The purpose of the symbol interleaver is to map v bit words onto the 1512 (2K mode), 3024 (4K mode) or 6048 (8K mode) active carriers per OFDM symbol. The symbol interleaver acts on blocks of 1512, 3024 or 6048 data symbols [7].

The 12 (2K mode), 24 (4K mode) and 48 (8K mode) of 126 data words (see Fig. 2.2) from the bit interleaver are read sequentially into a vector $Y'_w=\left(y'_0,y'_1,...,y'_{N_{\max}-1}\right)$. The interleaved vector $Y=\left(y_0,y_1,...,y_{N_{\max}-1}\right)$ is defined by (2.6):

$$\begin{aligned} y_{H(q)}&=y'_q \qquad \textit{for even symbols for } q=0,...,N_{\max} \\ y_{H(q)}&=y'_{H(q)} \quad \textit{for odd symbols for } q=0,...,N_{\max}, \end{aligned} \tag{2.6}$$

where N_{max} = 1512 (2K mode), N_{max} = 3024 (4K mode) and N_{max} = 6048 (8K mode).

The H(q) is a permutation function of the symbol interleaver, which is generated by an algorithm, depending on the OFDM mode. The symbol index is defining the position of the current OFDM symbol in the OFDM frame. The algorithm, which is defined the generation of the H(q) function, is described in [7].

How it was described in 2.1.2, the DVB-H standard allows using a second type of symbol interleaver, so called in-depth interleaver. When in-depth interleaving is applied in 2K or 4K modes, the block interleaving process is repeated 48 times. In case of in-depth interleaving the definition of the output interleaved vector (2.6) is the same that is in native interleaver. The value of N_{max} in case of in-depth interleaving is always equals to 6048 (8K mode) [7], [10].

2.2.7 Mapper and M-ary QAM Modulation

How it was mentioned, DVB-H standard uses OFDM transmission technique. All data carriers in the actual OFDM frame are modulated, using QPSK, 16QAM or 64QAM constellations. For the mapping of the output of symbol interleaver into selected constellation, the Gray method [7] is applied. Thank to this type of mapping, the error is minimized at the wrong identification of the two neighbor constellation points. The constellations (with the corresponding bit patterns) of all type of modulations (hierarchical and non-hierarchical) and the details of the Gray mapping can be found in [7], [10].

2.2.8 Frame Adaptation

After the mapping and QAM modulation, the data for transmitting are organized in frames. Each frame consists of 68 OFDM symbols [7]. One symbol of the OFDM signal consists of a large number of individually modulated carriers. Of course, this number is depending on the selected type of OFDM mode. In addition to the transmitted data (payload carriers) an OFDM frame contains:

- Scattered carriers – used to the estimate of the signal distortions in transmission channel.
- Continuous carriers - used to synchronize of the frequency (AFC) in the receiver.
- TPS (Transmission Parameter Signaling) carriers – used to the transmission of information of the transmission parameters (code rate, modulation, etc.).
- Zero carriers - inserted at the beginning and at the end of the OFDM symbol for prevention against the cross talk between neighbor channels.

After the generation of the content of individual carriers, together with the useful data, these carriers are inserted in defined positions in the OFDM symbols.

2.2.9 Pilots and TPS Signals

The position of the addition carriers in OFDM frame is exactly defined in [3] and [7]. The complete frame structure of one OFDM symbol is shown in Fig. 2.8, where the TPS (red squares) and continual pilots (green squares) between the K_{min} and K_{max} (carriers number of the lower/largest active carriers) are also indicated.

The continual and scattered pilots are modulated according to a PRBS sequence (w_k), corresponding to their carrier index *k* [7]. The generation of the PRBS sequence

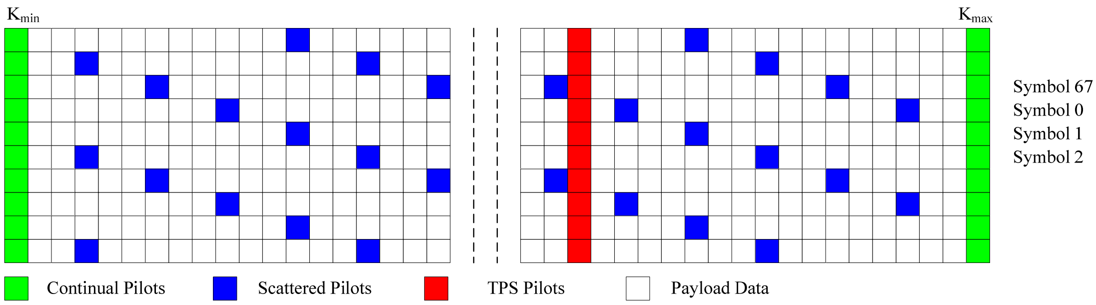


Fig. 2.8 OFDM frame structure in the DVB-H standard (based on [7]).

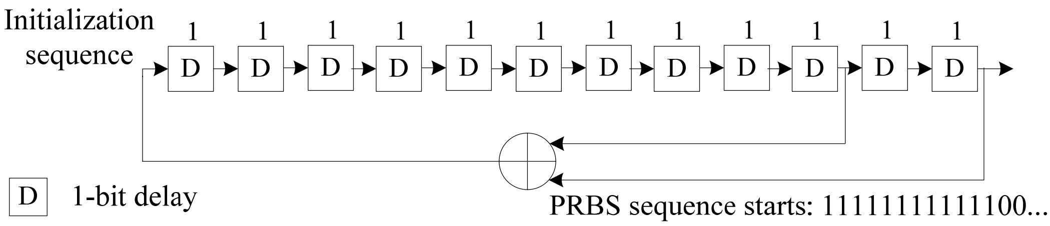


Fig. 2.9 Generation of PRBS sequence (based on [7]).

is depicted on Fig. 2.9. The polynomial for the PRBS generator shall be $X^{11}+X^{2}+1$. The PRBS is initialized so that the first output bit from the PRBS coincides with the first active carrier. A new value is generated by the PRBS on every used carrier [7].

Reference information, obtained from the reference sequence, is transmitted in scattered pilot carriers, of course, in every symbol. Scattered and continual carriers are always transmitted at the “boosted” power level [7]. Therefore, the corresponding modulation is given by (2.7):

$$\mathrm{Re}\{c_{m,l,k}\} = 4/3 \times 2(1/2 - w_k) \qquad \mathrm{Im}\{c_{m,l,k}\} = 0, \tag{2.7}$$

where m is the frame index, k is the frequency index of the carriers and l is the time index of the OFDM symbol. Exact indices for continual pilot carriers can be found in [7].

How it was mentioned, TPS carriers are used for the purpose of signaling parameters related to the transmission scenario. The TPS is defined over 68 consecutive OFDM symbols and every TPS carrier is DBPSK (Differential Binary Phase Shift Keying) modulated. The DPSK modulation (for the case of TPS carriers) can be described by conditions [7]:

$$\text{if } s_1 = 0, \text{ then } \mathrm{Re}\{c_{m,l,k}\} = \mathrm{Re}\{c_{m,l-1,k}\}; \quad \mathrm{Im}\{c_{m,l,k}\} = 0,$$
$$\text{if } s_1 = 1, \text{ then } \mathrm{Re}\{c_{m,l,k}\} = -\mathrm{Re}\{c_{m,l-1,k}\}; \quad \mathrm{Im}\{c_{m,l,k}\} = 0. \tag{2.8}$$

The absolute modulation of the TPS carriers in the first symbol in a frame is derived from the reference sequence w_k (PRBS sequence) as follows [7]:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \times (1/2 - w_k)$$
$$\mathrm{Im}\{c_{m,l,k}\} = 0\,. \tag{2.9}$$

And again, the exact indices for the TPS carriers can be found in [7].

2.2.10 OFDM Modulation

In the previous block (see Fig. 2.3), the complete OFDM frame was assembled. All these processes have been done in the frequency domain. However, for the final signal processing (guard interval insertion and carrier modulation) the complete OFDM signal must be transferred into the time domain. This transfer is performed using the IFFT (Inverse Fast Fourier Transform), which is applied on each OFDM symbol. At the end of this transfer the DVB-H signal has a complex form in the basic band [3], [15].

2.2.11 Guard Interval

At the transmission of radio signals, several transmission effects exist between the transmitter and receiver. Generally, there are many obstructions in communication environments. Thank for these obstructions, signals coming from multiple indirect paths added to the direct path mean that the condition of orthogonality between carriers is no longer fulfilled, which results in ISI (InterSymbol Interference). Therefore, GI (Guard Interval) is inserted between the transmissions of each OFDM symbol. The purpose of the guard interval insertion is to introduce immunity to propagation delays, related reflections and echoes, to which terrestrial signals are very sensitive. According to the DVB-H specification, the options are 1/4, 1/8, 1/16 and 1/32 duration of the symbol period. End part of each symbol is copied to the beginning of the present symbol (see Fig. 2.10).

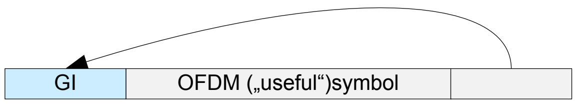


Fig. 2.10 Elaboration of the guard interval.

2.2.12 IQ Modulator

Carrier modulation (so called IQ modulation) is one the last part of signal processing before the signal transmission. Before the carrier modulation the signal should be filtering. The most commonly used filter is called a RCF (Raised Cosine Filter). In order to optimize the bandwidth occupation, filtering is shared equally between the transmitter and receiver [3], [15]. Therefore, a RRCF (Root-RCF) filter is used in the both communication side (transmitter and receiver) with roll-of factor $\alpha = 0.35$, as recommended in [7], [10].

In order to increase the spectral efficiency of the modulation process, the signal after the roll-off filtering should be modulated in the IQ (In-Phase; Quadrature) modulator [3], [15]. The block scheme of the IQ modulator/demodulator, which is used in the DVB-T/H systems, is shown in Fig. 2.11.

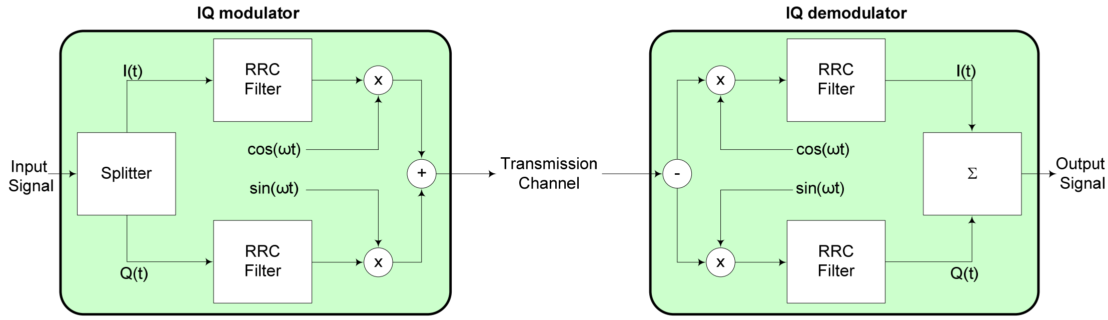


Fig. 2.11 The basic IQ modulation/demodulation process (based on [15]).

The In-Phase channel is multiplied by a cosine signal, while the quadrature channel is multiplied by a sine signal. They are simply added one to the other and sent through the real transmission channel. The process in IQ demodulator is inversed.

In this chapter, the functional block diagram of the DVB-H transmission system was presented. Each block for the FEC of the data signal and for the signal processing were briefly described and discussed.

In [7], [10], [11] is not defined the conception of demodulator and decoder of the standard DVB-H. But it is clear that the conception of receiver consist of the same blocks performing inverse operation which were used in the transmitter. These blocks, of course, are extended of addition blocks, which ensure the synchronization and the correction (equalization) of the received signal.

3 Standard DVB-SH

This chapter briefly describes the main innovations in the DVB-SH standard and its functional block diagram. The description is focused on advanced FEC scheme and new transmission mode. The conceptual structure of DVB-SH system will be described in the next subchapters.

Nowadays, mobile TV is already booming on existing cellular infrastructures in point-to-point mode. Therefore, in areas, where the availability and reception of the mobile TV is bad, especially in urban areas, the classical DVB-H system does not represent the optimal solution. Moreover, the possibilities of improvements in the area of mobile cellular infrastructure and data transmission are limited. For these situations the data stream, transmitted in DVB-SH system, is better suited [13]. This standard was published as ETSI Standard EN 302 583 [11] in February 2010.

DVB-SH is defined as a transmission system standard, capable of delivering IP-based media content and data to handheld terminals like mobile phones and PDAs via satellite. The key feature of DVB-SH is the fact that it is a hybrid satellite/terrestrial system that will allow the use of a satellite to achieve coverage of large regions or even a whole country. Whenever a line of sight between terminal and satellite does not exist, terrestrial gap fillers are employed to provide the missing coverage [11]-[13].

3.1 GENERAL OVERWIEV OF THE DVB-SH SYSTEM

Standard DVB-H is mainly intended for use in the UHF bands. DVB-SH seeks to exploit opportunities in the higher-frequency near to UMTS, S-band (2.17-2.2 GHz), where there is less congestion than in UHF. The S-band requires high demanding signal coverage. The short wavelength requires a large number of terrestrial repeater networks in towns and cities. The DVB-SH standard introduces new tools to enhance the signal robustness that allows the receiver to work with a low SNR. The DVB-SH uses turbo encoding for FEC and also a highly flexible channel interleaver [11], [67].

A typical DVB-SH system is based on a hybrid architecture, combining a satellite component and, where it is necessary, a CGC (Complementary Ground Component), consisting of terrestrial repeaters, fed by a broadcast distribution network. The repeaters, how it can be seen on the Fig. 3.1, may be of three kinds [11]-[13]:

- **Terrestrial transmitters** are broadcast infrastructure transmitters, which complement reception in areas, where satellite reception is difficult, for example in urban areas.
- **Personal gap-fillers** have limited coverage, providing local, on-frequency re-transmission and/or frequency conversion.
- **Mobile transmitters** are mobile broadcast infrastructure transmitters, creating a so called “moving complementary infrastructure”.

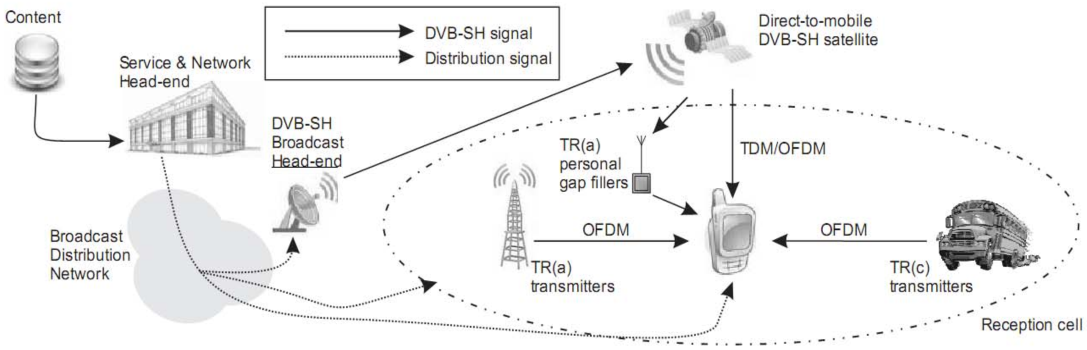


Fig. 3.1 Overall DVB-SH system architecture [57].

3.1.1 DVB-SH Architectures

Of course, OFDM is the absolutely natural choice for the terrestrial modulation, which is using in DVB-T/H systems. For the DVB-SH system, two types of modulations techniques have been selected, which lead to two reference architectures, respecting the variety of possible hybrid satellite/terrestrial system transmission architectures. These two architectures are included in the standard DVB-SH and are completely described in [11]-[13]:

- **SH-A**, which uses COFDM (Coded-OFDM), i.e., FEC, is included in the OFDM modulation block,
- **SH-B** using a TDM (Time Division Multiplex) on the satellite with COFDM on the terrestrial link.

In case of the OFDM transmission mode, the signal is based on the DVB-T/H [7] standard with enhancements. This signal is used on both, the direct and indirect paths. Of course, mode SH-A is very perspectives for spectrum-limited systems [11]-[13].

In the TDM transmission mode [11]-[13], the data are broadcasted to mobile terminals on a direct path from a broadcast stations via satellite. The TDM signal is partly derived from the DVB-S2 standard [48] and it allows optimizing transmission through satellite toward mobile phones or terminals. Of course, according to the DVB-S/S2 features, it is used on the direct path only. Furthermore, the configuration of the DVB-SH standard allows a combination of TDM and OFDM modes (TDM/OFDM), which is increasing the robustness of the transmission in relevant areas (e.g. suburban). Of course, this solution also allows increasing the robustness of the transmission in communication channels with bad reception conditions. However, for equivalent capacity, the TDM/OFDM mode requires a higher spectrum than the OFDM/OFDM mode. Therefore, the TDM/OFDM mode is not frequently used [13].

The block diagram and detailed description of both architectures are described in the next chapter. How it was mentioned, mode SH-A used OFDM modulation for the transmission. This configuration is the same with that, which is used in DVB-T/H systems. Therefore, the description of this part will be shortened.

3.2 BLOCK DIAGRAM OF THE DVB-SH STANDARD

The functional block diagram of the DVB-SH transmission system (included the FEC and modulator blocks) is presented in Fig. 3.2. How it can be seen, the block diagram of the DVB-SH system is divided into two main parts. First part is used for the signal processing, when the OFDM is used (DVB-SH-A) The second one is used for the signal processing, when the TDM mode is used for the transmission.

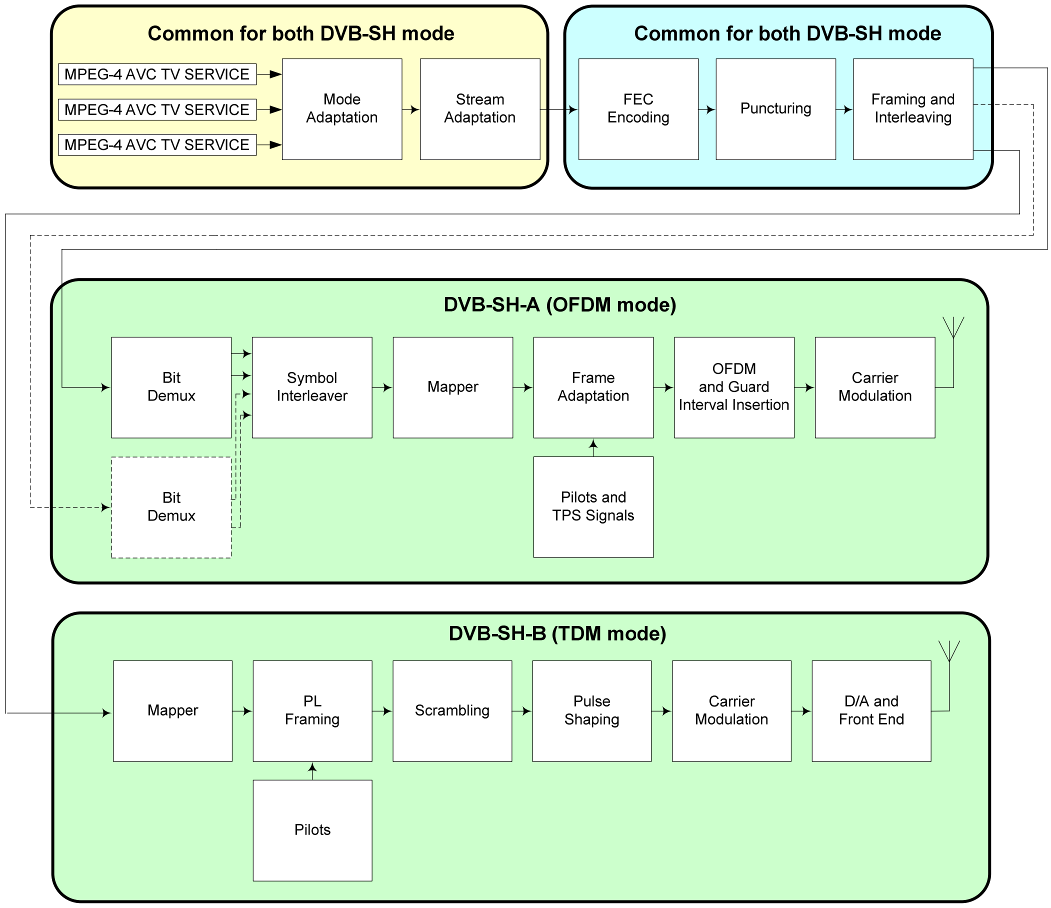


Fig. 3.2 Functional block diagram of the DVB-SH transmission system for both transmission modes (based on [11]).

How it was briefly described above, system DVB-SH is mainly designed to transport mobile TV services. It may support wide range of mobile multimedia services, bigger than the standard DVB-H. Therefore, the FEC scheme, which was applied in DVB-H standard, it can not be used in this case. DVB-SH uses 3GPP2 turbo encoding and also a highly flexible channel interleaver [11]-[13].

In DVB-SH standard, as well as in DVB-H, interleavers are introduced to enhance of the waveform to short-term fading in terrestrial and satellite channels. The interleaver diversity is largely provided by a common channel interleaver [67]. The channel time interleaver is composed of two, cascaded elementary interleavers: a block bit-wise interleaver, working with coded words from the turbo encoder and a convolutional time interleaver, which is used after the bit-wise interleaving. More details can be found in [11] and [12].

The modulator of the DVB-SH, in case of mode DVB-SH-A (OFDM for satellite and terrestrial transmission), has the same block as a modulator of DVB-T/H. The signal processing and mapping are the same, as it is in DVB-T/H. On the other hand, modulation 64QAM is not used in DVB-SH system configuration.

When the DVB-SH-B transmission mode (TDM for satellite transmission) is used, the signal processing and mapping are different. After the FEC scheme (turbo encoding, bit-wise interleaving and time interleaving), the signal information is mapped to the individual symbols of the digital modulation. The QPSK, 8PSK and 16APSK modulations in case of TDM transmission are used. After the mapping of these symbols, the complete transmission frames are created. At the end the D/A block is applied and then the signal is amplified and transmitted.

3.2.1 Mode and Stream Adaptation

How it can be seen in the Fig. 3.2, the first functional blocks are the Mode and Stream Adaptation. Mode Adaptation consists of CRC (Cyclic Redundancy Check) [11] encoding, to provide detection of MPEG packets. Stream Adaptation provides padding to complete a constant length ($L_{TC\text{-}input}$ = 12 282 bits) of one transmitted frame and performs scrambling. Function of the scrambling (and its process) is the same that was used in DVB-H standard. Details of scrambling processing are described in 2.2.1.

3.2.2 FEC Coding and Puncturing

The next stage contains the turbo encoder and puncturing. The turbo code, as it was standardized by the 3GPP2 [68] organization, shall be used in the real implementation. The turbo code is used for the FEC encoding of the input data stream.

A block diagram of the 3GPP2 turbo encoder is shown in Fig. 3.3. This type of turbo encoder, as well as general turbo encoders, employs two RSC (Recursive Systematic Convolutional) encoders, connected in parallel. These encoders are used to code the same input bits, but a special interleaver (so called 3GPP2 interleaver) is placed between the encoders. This turbo interleaver shall be functionally equivalent to an approach, where the entire sequence of turbo interleaver input bits are written sequentially into an array at a sequence of addresses, and then entire sequence is read out from a sequence of addresses that are defined by the special procedure. More details are available in [11].

Each of the RSC encoders produces an output of three bits: X (input bit), Y_0 (systematic bit) and Y_1 (parity bit). After an output symbol sequence is generated and the puncturing is applied. Within a puncturing pattern, a “0” means that the symbol shall be deleted and a “1” means that a symbol shall be passed.

Thank to the configuration of 3GPP2 turbo encoder, DVB-SH standard enables used many type of code rates. These code rates can be divided into two big groups: standard and complementary. Differences between these two groups (formula of the puncturing pattern) are very small. The difference between these two types is only in the position of the “zeros” and “ones” in puncturing form. The code rates and their puncturing patterns are shown in Tab. 3.1.

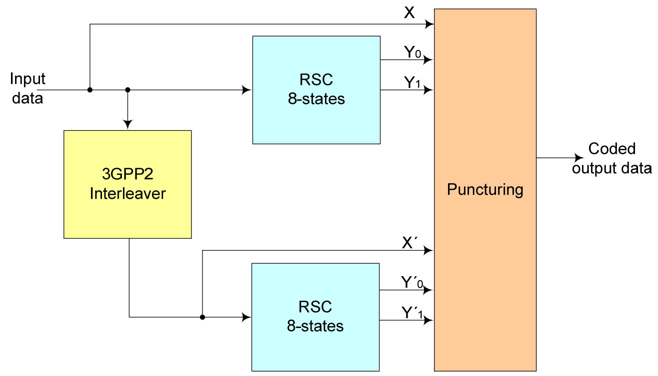


Fig. 3.3 Block diagram of the 3GPP2 turbo encoder (based on [11]).

Tab. 3.1 Puncturing pattern for the possible code rates for the 3GPP2 turbo encoder [11].

Punc_Pat_ID	Code Rate	Pattern Name	Puncturing Pattern
0	1/5	Standard	1;1;1;0;1;1
1	2/9	Standard	1;0;1;0;1;1; 1;1;1;0;1;1; 1;1;1;0;0;1; 1;1;1;0;1;1
2	1/4	Standard	1;1;1;0;0;1; 1;1;0;0;1;1
3	2/7	Standard	1;0;1;0;0;1; 1;0;1;0;1;1; 1;0;1;0;0;1; 1;1;1;0;0;1
4	1/3	Standard	1;1;0;0;1;0
5	1/3	Complementary	1;0;1;0;0;1
6	2/5	Standard	1;0;0;0;0;0; 1;0;1;0;0;1; 0;0;1;0;0;1; 1;0;1;0;0;1; 1;0;1;0;0;1; 0;0;1;0;0;1; 1;0;1;0;0;1; 1;0;1;0;0;1; 0;0;1;0;0;1; 1;0;1;0;0;1; 1;0;1;0;0;1; 0;0;1;0;0;1
7	2/5	Complementary	1;1;0;0;1;0; 0;1;0;0;1;0; 1;1;0;0;1;0; 1;1;0;0;1;0; 0;1;0;0;1;0; 1;0;0;0;0;0; 1;1;0;0;1;0; 0;1;0;0;1;0; 1;1;0;0;1;0; 1;1;0;0;1;0; 0;1;0;0;1;0; 1;1;0;0;1;0
8	1/2	Standard	1;1;0;0;0;0; 1;0;0;0;1;0
9	1/2	Complementary	1;0;0;0;1;0; 1;1;0;0;0;0
10	2/3	Standard	1;0;0;0;0;0; 1;0;0;0;0;0; 1;0;0;0;0;0; 1;0;1;0;0;1
11	2/3	Complementary	1;0;0;0;0;0; 1;0;1;0;0;1; 1;0;0;0;0;0; 1;0;0;0;0;0

3.2.3 Framing and Interleaving

The interleavers are introduced to enhance the resistance of the waveform to short-term fading and medium-term shadowing impairments in satellite and terrestrial channels [11].

In the DVB-SH standard (in contrast to DVB-T/H), the channel is composed of two cascades of elementary interleavers. A block bit-wise interleaver works on individual coded words at the output of the encoder and a convolutional time interleaver, works on IUs (Interleaving Units) of 126 bits. The output of the turbo encoder shall be bit interleaved using a block interleaver. The values for block interleaving are given in [11] and each code rate has own bit-wise interleaver function.

The purpose of the time interleaver is to interleave coded words bits over time, using a convolutional interleaver. Time interleaver takes as input a sequence of non-interleaved IU (Interleaving Unit) of 126 bit cells, which come from the rate adaptation process that punctures the output of the bit interleaver and the padding, generated in the case of the OFDM modes [11]. The conceptual view of the interleaver and more details can be found in [11] and [12].

The bit and time interleaving do not depend on modulation scheme, since they are working on interleaving units. On the other hand, the resulting duration of the interleaving depends on the modulation [11], [12].

The common blocks (mode and stream adaptation, FEC encoder, framing and interleaving) for both DVB-SH modes (SH-A and SH-B) were described. How it was mentioned, DVB-SH standard allows used two different system modes: DVB-SH-A (OFDM mode) and DVB-SH-B (TDM mode). In the next part of this dissertation thesis, the DVB-SH-A system configuration will be described, as a first. On the other hand, many blocks of this system are similar or identical with the functional blocks of the DVB-H standard. Therefore, the description of these blocks will be described very briefly.

3.2.4 Bit Demultiplexing

In case of the OFDM mode (DVB-SH-A), the output of the channel interleaver, is demultiplexed into v sub-streams, depending on the modulation, which is used: $v = 2$ for QPSK and $v = 4$ for 16QAM. More details (include the description of the de-multiplexing in case of the hierarchical modulation) can be found in [11].

3.2.5 Symbol Interleaver

The purpose of the symbol interleaver in DVB-SH-A system, as it was in DVB-H standard, is to map v bit words onto the 756 (1K mode), 1512 (2K mode), 3024 (4K mode) or 6048 (8K mode) active carriers per OFDM symbol [11].

The definition of the output vector of inner symbol interleaver (Y) and its calculation was presented and briefly described in 2.2.6. Moreover, the process of interleaving (definition of permutation tables, etc…) is the same that was in DVB-H standard [7]. Only the 1K mode is a novelty in this part. This mode was added to support higher speeds and/or smaller bandwidths [11]-[13]. In DVB-SH standard, the technique of in-depth interleaving is not used.

3.2.6 Mapper and M-ary QAM Modulation

How it was described in 2.2.7, DVB-H standard uses OFDM transmission technique. DVB-SH-A mode uses also OFDM technique. All data carriers in the actual OFDM frame are modulated, using QPSK or 16QAM constellations [11], [12]. For the mapping of the output of symbol interleaver into selected constellation, the Gray method is applied, how it is in case of DVB-H system. And again, more details can be found in [11] and [12].

After the mapping, the process of frame adaptation, pilots and TPS signal insertions, OFDM modulation (included IFFT operation) and guard interval insertion, in the DVB-SH-A system, is the same that was in DVB-H standard (see from 2.2.8. to 2.2.11). Therefore, the descriptions of these blocks are omitted in this chapter.

3.2.7 Carrier Modulation

Carrier modulation in the DVB-SH-A system is the same that was in DVB-H standard. Before the carrier modulation, the signal should be filtering with RCF (Raised Cosine Filter), respectively. Filtering is shared equally between the transmitter and receiver [3], [15]. Therefore, how it was in DVB-H standard, a RRCF (Root RCF) filter is using in the both side (transmitter and receiver) with roll-of factor $\alpha = 0.35$, as recommended in [11]. More details can be found in 2.2.12.

From 3.2.1 to 3.2.7, the functional block diagram of the DVB-SH-A system was described. Attention was mainly devoted to the description of the FEC processing, which is one of the main innovations in the DVB-SH standard.

In the next subchapters the functional block diagram of the DVB-SH-B (TDM mode) will be presented and clearly described.

3.2.8 Mapper and M-ary PSK Modulation

In case of the DVB-SH-B mode, after the mode and stream adaptation and FEC encoding process, the output of channel interleaver is mapped into the constellation diagram of the selected type of modulation. In contrast with DVB-SH-A system configuration, QAM modulations are not used in DVB-SH-B system. Instead of QAM, PSK modulations are preferred. DVB-SH-B mode used QPSK, 8PSK and 16APSK modulations. These modulations and the associated mapping, as defined by DVB-S2, shall be used. More details can be found in [11] and [48].

3.2.9 TDM Framing and PL Slot Definition

The broadcasted mobile TV is organized in frames. The general and complete structure of one DVB-SH-B frame with the pilot organization in the PL slot is shown in Fig. 3.4. The SH frame to be transmitted in TDM mode, consists of a number of PL (Physical Layer) slots of length $L_{TOT} = 2176$ symbols. Each of them comprising of 2 (QPSK), 3 (8PSK) or 4 (16APSK) CU (Capacity Units) of 2 016 bits. How it can be seen, CU number is depending on the number of modulated symbol and it is transmitted in 476 PL slots, which make the entire frame. Examples of TDM frame for all type of modulations can be found in [11].

From the perspective of the signal transmission, the division of SH frame on the PL slots is important. One PL slot is divided into two equally long sub-slots with a length of 1008 symbols (see Fig. 3.4). A PF (Pilot Field) shall be inserted before each sub-slot. In each PL slots there are two PF of equal duration $L_{PF} = 80$ symbols. Each pilot symbol shall be an un-modulated symbol, identified by [11]:

$$I = \frac{1}{\sqrt{2}} \;\; and \;\; Q = \frac{1}{\sqrt{2}} . \tag{3.1}$$

Finally, one TDM slot has a fixed length equals to L_{TOT}.

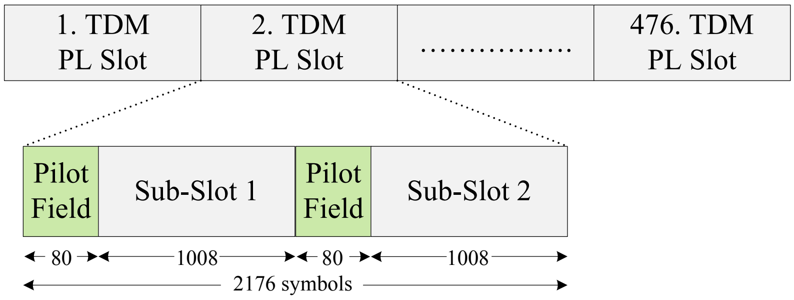


Fig. 3.4 The structure of one TDM frame in the PL slot in the DVB-SH-B system.

3.2.10 Physical Layer Scrambling

Prior to modulation, each PL slot, which is including the PF, shall be randomized for energy dispersal by multiplying for each PL slot of length L_{TOT} the I and Q modulated baseband signal symbol samples by a unique complex randomization sequence [11]:

$$C(i) = C_I(i) + jC_Q(i), \tag{3.2}$$

where i is from 1 to L_{TOT}. The final scrambled I and Q components from (3.2) will therefore be expressed as [11]:

$$\begin{aligned} I_{SCR}(i) &= I(i)C_I(i) - Q(i)C_Q(i), \\ Q_{SCR}(i) &= I(i)C_Q(i) + Q(i)C_I(i). \end{aligned} \tag{3.3}$$

In the DVB-SH-B system, concretely in TDM mode, the scrambling code sequence shall be constructed by combining two real m-sequences into a complex sequence. In this case, the Gold sequences are used. These sequences are a combination of two generator polynomials. The first sequence (x) is constructed using the primitive (over GF (2)) polynomial $1+x^7+x1^{18}$. The second sequence (y) is constructed using the polynomial $1+y^5+y^7+y^{10}+y^{18}$.

The initial condition for the first sequence (x) has set his first variable on one and the others are equal to zero. In case of second sequence (y), all initial variables are set on one [11], [48]. A possible block diagram for PL scrambling sequences generation is showed in Fig. 3.5.

The general form of recursive definition of subsequent symbols and Gold code sequence are available in [11], [48]. The Gold code sequence is defined as [11]:

$$z_0(i) = \left[x\left((i) \bmod \left(2^{18} - 1\right)\right) + y(i)\right] \bmod 2 \ , \tag{3.4}$$

where i is from zero to 2^{18}-2. This binary sequence (3.4) is converted to integer valued sequences R_0. The R_0 assuming integer values 0, 1, 2 and 3. The conversion is done by the following transformation (3.5):

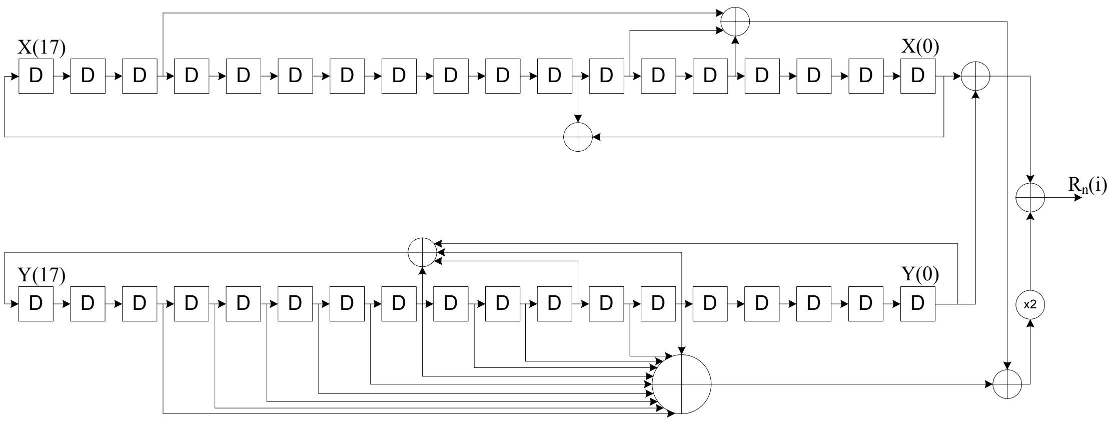


Fig. 3.5 Configuration of the PL scrambling code generator (based on [11]).

$$R_0(i) = 2z_0((i + 2^{17}) \bmod (2^{18} - 1)) + z_0(i), \tag{3.5}$$

where i is from 1 to L_{TOT}. Therefore, the final complex scrambling code sequence is defined as:

$$C(i) = C_I(i) + jC_Q(i) = e^{(jR_0(i)\pi/2)}, \tag{3.6}$$

where i is again from zero to L_{TOT}. All possible examples of sequence scrambling are available in [11] and [48].

3.2.11 Carrier Modulation

After the scrambling, complete SH frame (in TDM mode) signal is available in the time domain [11]. Before the carrier modulation and broadcasting, of course, the signals shall be filtered with RRCF. In the DVB-SH-B system configuration, the roll-off factor shall be α = 0.35; 0.25 and 0.20, depending on the service requirements [11], [48]. Generally, parameter α was set on 0.35.

The carrier modulation shall be performed by multiplying the in-phase and quadrature samples by $sin(2\pi f_0 t)$ and $cos(2\pi f_0 t)$, respectively (f_0 is the carrier frequency of course), how it was in case of DVB-H system (see 2.2.12). Of course, the signal transmission is realized in the S-band. Therefore, in this dissertation thesis, the carrier frequency equals to 2.2 GHz, as recommended in [11] and [12].

In this chapter, the functional block diagram of the DVB-SH transmission system (for both system configurations) was presented. Each block for the FEC of the data signal and for the signal processing were briefly described.

4 Transmission Channel Models

Generally, in terrestrial and mobile TV and radio communications, the emitted electromagnetic waves often do not reach the receiving antenna directly, due to obstacles blocking the LOS (Line of Sight) path. At the transmission of TV and radio signals, several transmission effects exist between the transmitter and receiver side. The signal can be propagated directly, if it is secured optical visibility between the transmitter and receiver. Generally, there are many obstructions in communication environments. This situation is typical especially for the urban area. Some of these obstructions may have occurred in rural areas too. In the environment, like this, there are exist beyond the direct propagation of the signals other possibilities and combinations. If the transmitted signal is propagated into a big surface with proportions larger than its wavelength, then reflections are occurred. This event makes situation, when several reflected signals are present simultaneously with the direct signal at the receiver side. This effect is called multipath propagation and it is a main reason of the fading conception [69]-[71].

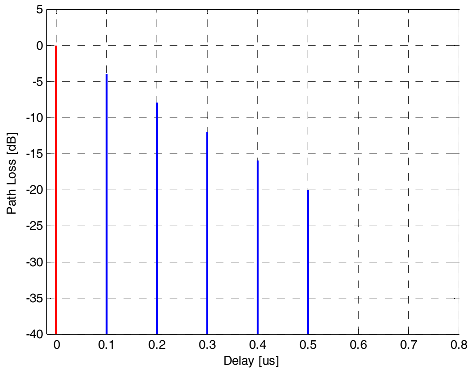
For the analysis and simulation of the signals transmission in the DVB-T/H/SH standards a different fading channel models are used. These models have different parameters and features. Therefore, they can be used for the exploring of different transmission environment. In the next chapters, the most used fading channel models are briefly described. These models are also used in this thesis.

4.1 GAUSSIAN CHANNEL (AWGN)

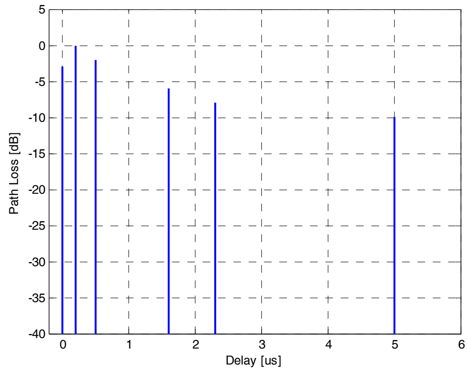
Model of the Gaussian channel describes a case, which is based on a direct signal path from transmitter to receiver only. In this case the received signal is only attenuated and includes a definite level of noise. This channel is overlaid with AWGN (Additive White Gaussian Noise), which is mainly produced in the receiver itself. The best condition for the received data is defined as Gaussian channel [45].

4.2 CHANNEL PROFILES WITH DOPPLERS SHIFT (MOBILE SCENARIO)

The “mobile” means reception while moving at high speeds in cars, buses, trains etc. Mobile antenna reception is defined as the reception at medium to high speed (no walking speed, approx. 50 km/h and higher). Mobile reception suffers from all impairments, relevant for portable reception (noise AWGN, multipath reception, narrowband and impulse interferers etc.) [72]. In addition, Doppler shift is experienced and the properties of the transmission channel change over time. Doppler shift results in a frequency shift of the received OFDM carriers as a function of the speed and the direction of the movement [3], [73]-[76].



a) RA6 (Rural Area)



b) TU6 (Typical Urban)

Fig. 4.1 Impulse response of the RA6 and TU6 channel models.

Tab. 4.1 RA6 (Rural Area) channel model parameters [73]

Path	Path Loss [dB]	Delay [us]	Doppler Spectrum
1	0.0	0.0	*Rice-Jakes*
2	-4.0	0.1	*Rayleigh-Jakes*
3	-8.0	0.2	*Rayleigh-Jakes*
4	-12.0	0.3	*Rayleigh-Jakes*
5	-16.0	0.4	*Rayleigh-Jakes*
6	-20.0	0.5	*Rayleigh-Jakes*
Note: The speed of the receiver is equal to 100 km/h.			

Tab. 4.2 TU6 (Typical Urban) channel model parameters [73]

Path	Path Loss [dB]	Delay [us]	Doppler Spectrum
1	-3.0	0.0	*Rayleigh-Jakes*
2	0.0	0.2	*Rayleigh-Jakes*
3	-2.0	0.5	*Rayleigh-Jakes*
4	-6.0	1.6	*Rayleigh-Jakes*
5	-8.0	2.3	*Rayleigh-Jakes*
6	-10.0	5.0	*Rayleigh-Jakes*
Note: The speed of the receiver is equal to 50 km/h.			

Primary profiles for real-time simulation with Doppler shift (mobile channel simulations) are presented in [73]. They reproduce characteristics of the terrestrial channel propagation with a single transmitter – for Typical Urban reception (TU6) and Rural Area reception (RA6). These profiles are included in Annex K.3 of ETSI technical report as DVB-T/H channel characteristics [73]. These channel profiles were selected to reproduce the service delivery situation in a mobile environment.

4.2.1 Rural Area (RA6)

This profile reproduces the terrestrial propagation in a rural area. It has been defined by COST207 [74] as a "Typical Rural Area" profile and is made of 6 paths having relatively short delay and small power (see Fig. 4.1 a)). The first part of this channel model has zero delay and attenuation; therefore it is a direct path (see Tab. 4.1).

First path has a Doppler spectrum with Rice-Jakes feature [69]-[71]. Other paths have Doppler spectrum whit Rayleigh-Jakes feature. The speed of the receiver is equal to 100 km/h. This channel profile has been used for GSM (Global System for Mobile Communications) and DAB (Digital Audio Broadcasting) tests.

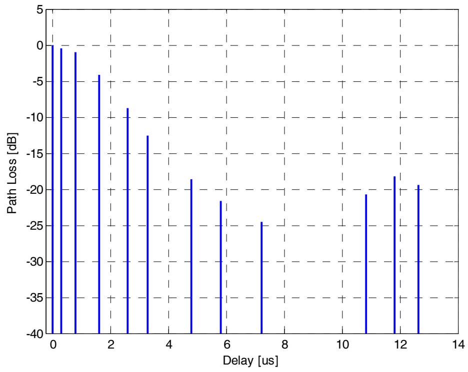
4.2.2 Typical Urban (TU6)

The TU6 profile reproduces the terrestrial propagation in an urban area. It was originally defined by COST207 [74] as a "Typical Urban" profile and is made of 6 paths, having wide dispersion in delay and relatively strong power (see Fig. 4.1 b)). Parameters values fluctuate dynamically, following a Rayleigh law. Each of path have Doppler spectrum with Rayleigh-Jakes feature [69]-[71]. The speed of the receiver is equal to 50 km/h. This channel profile has been proven to present fairly well the general mobile DVB-T reception by several field tests. And again, this channel profile has been used for GSM and DAB tests.

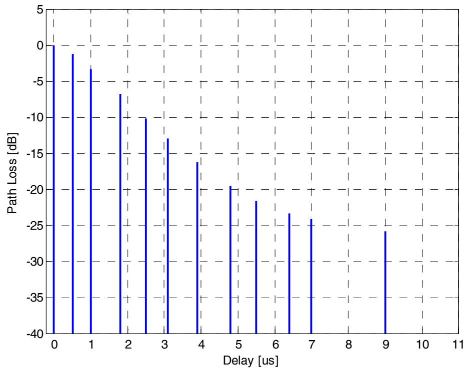
How it can be seen from Tab. 4.1 and Tab. 4.2, there are significant differences between the parameters, which defined both channels. In case of RA6 channel, the delay of paths is not higher than 0.5 us, but in the TU6 channel this value is 5us. Moreover, the first path of the RA6 channel is a direct path and the *K* factor [73] is available and equals to 10. On the other hand, the path losses of echoes are higher in RA6 channels.

4.2.3 Vehicular Urban (VU30) and Motorway Rural (MR100) Channels

The VU30 (Vehicular Urban) and MR100 (Motorway Rural) channel models have been developed by the Wing-TV project [75], [76]. The basis of these channel models were real measurement data, which were acquired from extensive DVB-H field measurements. The measured data were studied extensively and all important parameters, such as delay spread, number of paths, power delay profiles and Doppler spread were obtained [44]. Both channel models, VU and MR consist of 12 independent paths (see Fig. 4.2 a) and b)). First part has a Doppler spectrum with Rayleigh-Gauss feature. Other paths have Doppler spectrum with Rayleigh-Jakes feature [69]-[71]. The VU and MR channel model parameters are summarized in Tab. 4.3.



a) VU30 (Vehicular Urban)



b) MR100 (Motorway Rural)

Fig. 4.2 Impulse response of the VU30 and MR100 channel models.

Tab. 4.3 VU30 (Vehicular Urban) and MR100 (Motorway Rural) channel model parameters [75]

	VU30 (Vehicular Urban)		MR100 (Motorway Rural)		Common for both channels	
Path	**Path Loss [dB]**	**Delay [us]**	**Path Loss [dB]**	**Delay [us]**	**Doppler Spectrum**	**STD Norm.**
1	0.0	0.0	0.0	0.0	*Rayleigh-Gauss*	0.1
2	-0.5	0.3	-1.3	0.5	*Rayleigh- Jakes*	not defined
3	-1.0	0.8	-3.4	1.0	*Rayleigh- Jakes*	not defined
4	-4.1	1.6	-6.8	1.8	*Rayleigh- Jakes*	not defined
5	-8.8	2.6	-10.2	2.5	*Rayleigh- Jakes*	not defined
6	-12.6	3.3	-12.9	3.1	*Rayleigh- Jakes*	not defined
7	-18.6	4.8	-16.3	3.9	*Rayleigh- Jakes*	not defined
8	-21.6	5.8	-19.5	4.8	*Rayleigh- Jakes*	not defined
9	-24.6	7.2	-21.7	5.5	*Rayleigh- Jakes*	not defined
10	-20.7	10.8	-23.3	6.4	*Rayleigh- Jakes*	not defined
11	-18.2	11.8	-24.2	7.0	*Rayleigh- Jakes*	not defined
12	-19.4	12.6	-25.8	9.0	*Rayleigh- Jakes*	not defined
Note: The speed of the receiver is equal to 30 km/h in VU channel. The speed of the receiver is equal to 100 km/h in MR channel.						

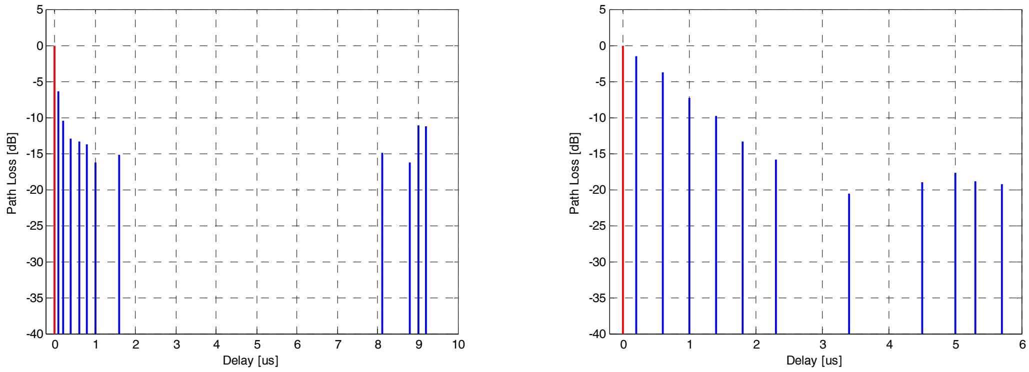
4.3 CHANNEL PROFILE WITH DOPPLERS SHIFT (PORTABLE SCENARIO)

The “portable” means that the device can be easily carried or taken from one point to another. It contains omni directional antenna and it operates in a nomadic mode (not operated while moving fast). In the context of DVB-T/H, portable antenna reception is defined as the reception at no speed or very low speed (walking speed, approx. 3 km/h) [9], [75].

4.3.1 Pedestrian Indoor (PI) and Outdoor (PO) Channels

The PI (Pedestrian Indoor) and PO (Pedestrian Outdoor) channel models have been developed by the Wing-TV project [75], [76] for describing the slowly moving (at speed approx. 3 km/h) handheld indoor and outdoor reception. These channel models are based on measurements in DVB-T/H SFN networks and have paths from two different transmitter locations [44].

Both channels consist of 12 independent paths, from which the first path is the direct (see Fig. 4.3 a) and b)). First part has a Doppler spectrum whit Rice-Gauss feature. Other paths have Doppler spectrum whit Rayleigh-Gauss feature [69]-[71]. And again, PI and PO channel model parameters are summarized in Tab. 4.4.



a) PI (Pedestrian Indoor) b) PO (Pedestrian Outdoor)

Fig. 4.3 Impulse response of the PI and PO channel models.

Tab. 4.4 PI (Pedestrian Indoor) and PO (Pedestrian Outdoor) channel model parameters [75]

	PI (Pedestrian Indoor)		PO (Pedestrian Outdoor)		Common for both channels	
Path	**Path Loss [dB]**	**Delay [us]**	**Path Loss [dB]**	**Delay [us]**	**Doppler Spectrum**	**STD Norm.**
1	0.0	0.0	0.0	0.0	*Rice-Gauss*	0.08
2	-6.4	0.1	-1.5	0.2	*Rayleigh-Gauss*	0.08
3	-10.4	0.2	-3.8	0.6	*Rayleigh-Gauss*	0.08
4	-13.0	0.4	-7.3	1.0	*Rayleigh-Gauss*	0.08
5	-13.3	0.6	-9.8	1.4	*Rayleigh-Gauss*	0.08
6	-13.7	0.8	-13.3	1.8	*Rayleigh-Gauss*	0.08
7	-16.2	1.0	-15.9	2.3	*Rayleigh-Gauss*	0.08
8	-15.2	1.6	-20.6	3.4	*Rayleigh-Gauss*	0.08
9	-14.9	8.1	-19.0	4.5	*Rayleigh-Gauss*	0.08
10	-16.2	8.8	-17.7	5.0	*Rayleigh-Gauss*	0.08
11	-11.1	9.0	-18.9	5.3	*Rayleigh-Gauss*	0.08
12	-11.2	9.2	-19.3	5.7	*Rayleigh-Gauss*	0.08
Note: The speed of the receiver is equal to 3 km/h in both channels.						

4.4 CHANNEL PROFILES WITHOUT DOPPLERS SHIFT (FIXED SCENARIO)

With focus on digital TV implementation aspects, it is most important to determine the reception environment. The option “fixed” is associated with reception by a rooftop outdoor antenna to fixed receiver. Reception with a rooftop antenna can be viewed as stationary reception and the directivity of the antenna can be used either for the selection of the direct signal or at least for choosing a dominant echo signal as the main reception signal and can partially reduce echo impairments, caused by reflection from hills, buildings etc. [72].

4.4.1 Ricean Channel (RC20)

The reception conditions within the service can be described by the Gaussian channel model, which is based on a direct signal path from transmitter to receiver.

However, in practice, at the transmission of data signals several transmission effects exist between the transmitter and receiver side. Generally, there are many obstructions in transmission environments (e.g houses, industrial objects and other objects). In the environment, like this, there exist direct propagation and other reflected paths of the signals. This event makes situations, when several reflected signals (with different delays and levels) are present simultaneously with the direct signal at the receiver side. This effect is called multipath propagation. One of the communication channels, where reflected signals and direct signal already exist, so called Ricean channel [45], [73]. Influence of the channel on received signal is possible described with the following mathematical equation (4.1):

$$y(t) = \frac{\rho_0 x(t) + \sum_{i=1}^{N_e} \rho_i e^{-j2\pi\Theta_i} x(t-\tau_i)}{\sqrt{\sum_{i=0}^{N_e} \rho_i^2}}, \tag{4.1}$$

where ρ_0 is the attenuation in the direct signal path, N_e is the certain number of echoes, ρ_i is the attenuation in echo path i, θ_i is the phase rotation in echo part i, and τ_i is the relative delay time in echo part i. The Rice factor K denotes the ratio of the signal in the direct path to the sum in all echo (reflected) paths (4.2):

$$K = \frac{\rho_0^2}{\sum_{i=0}^{N_e} \rho_i^2}. \tag{4.2}$$

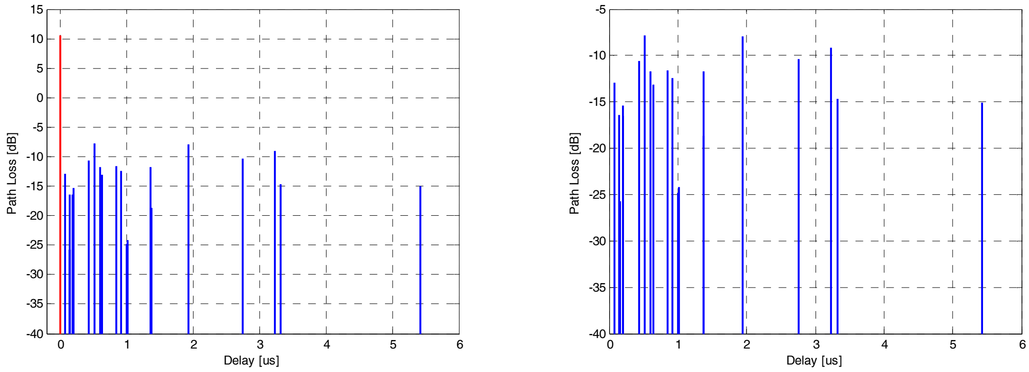
In this dissertation thesis, the value of the *K-factor* is equaled to 10. Therefore, in this case:

$$\rho_0 = \sqrt{10 \sum_{i=1}^{N} \rho_i^2}. \tag{4.3}$$

4.4.2 Rayleigh Channel (RL20)

There are very often cases, when the direct signal path is not secured as dominate signal at the receiver side. Channel environment, which simulates these cases, has a direct signal fully attenuated. The transmission channel with only reflected or echo signals is called Rayleigh channel [45], [73]. The mathematical equation (4.4), which describes the influence of Rayleigh channel on the signal, is following:

$$y(t) = \frac{\sum_{i=1}^{N_e} \rho_i e^{-j2\pi\Theta_i} x(t-\tau_i)}{\sqrt{\sum_{i=0}^{N_e} \rho_i^2}}. \tag{4.4}$$



a) RC20 ANX B b) RL20 ANX B

Fig. 4.4 Impulse response of the RC20 ANX B and RL20 ANX B channels.

Tab. 4.5 RC20 (Ricean) and RL20 (Rayleigh) channel model parameters [73]

Path	Path Loss [dB]	Delay [us]	Phase Shift [°]
1	-24.7822	1.0030	278.1779
2	-15.0499	5.4221	195.9005
3	-7.8046	0.5186	336.0094
4	-10.3544	2.7518	126.9614
5	-11.7413	0.6028	215.3209
6	-24.1759	1.0166	311.1277
7	-16.4585	0.1435	226.4382
8	-25.7581	0.1538	62.6579
9	-14.6531	3.3249	330.8945
10	-7.93780	1.9356	8.8498
11	-10.5823	0.4299	339.6713
12	-9.0982	3.2289	174.9253
13	-11.6039	0.8488	36.0149
14	-12.9219	0.0738	121.9566
15	-15.3403	0.2039	62.9946
16	-16.4942	0.1942	198.4125
17	-12.3907	0.9244	209.9760
18	-18.6670	1.3813	162.3647
19	-13.1061	0.6405	191.0407
20	-11.7096	1.3687	22.5682
Note: Generally, for the Ricean channel the K-factor is equal to 10.			

How it can be seen from the Tab. 4.5, both channel models consist of 20 indirect paths. Each of them is defined by the path loss, delays and phase shift. The interval of the path loss is from -7.80 dB to -25.75 dB; the delay is from 0.07 us to 5.42 us and the phase shift is from 8.84 ^{o} to 339.67 ^{o}.

How it can be seen from the Fig. 4.4 a), Ricean channel model has one direct path. This path has zero gain, delay and phase shift. This path is defined by the *K* factor, and in general, is equal to 10 [73].

5 Program Applications for the Analysis and Simulation

In this chapter the structures of the created applications for the analysis and simulation of the transmission in DVB-H/SH standards are presented and described. Each of them enable set many system parameters, as recommended by ETSI TR 101 190 [8] (DVB-T/H) and by EN 302 583 [11] (DVB-SH) documents. Both of applications are created in program environment MATLAB and enable evaluate and show all main parameters (*BER*, *MER*, OFDM spectrum, constellation diagram, channel environment) at the end of simulation and analysis.

5.1 FLOWCHART OF THE APPLICATION FOR THE TRANSMISSION IN DVB-H STANDARD

5.1.1 Transmitter

The flowchart of the application for the simulation and analysis of the transmission in DVB-H standard is shown in Fig. 5.1. The created application contains all functional blocks of the DVB-H system, presented in chapter 2. After the run of the application in MATLAB, its basic functions and parameters are set and after that there are enable set the concrete configuration parameters for the simulation.

Of course, in the first step it is necessary to select the type of the input data. The application for the simulation of the DVB-H transmission allows selecting between two options. In the first case, the user can specify the number of bits for the generating a random bit sequence. In the second case, the created program is loaded the concrete picture (in format BMP) and converted it into a sequence of ones and zeroes. At the end of simulation, from these ones and zeroes the "received" image is again created.

After the selection of the data type, the scrambling process (energy dispersal) is applied. The data of the input are randomized to ensure adequate binary transitions. The polynomial for the PRBS generator is equal to $1 + X^{14} + X^{15}$. The whole scrambling process is described in 2.2.1 and it is fully implemented into the application.

The following parts of the created program are ensuring the error protection of the input (scrambled) data. As a first, the outer encoder and interleaving is applied. How it was described in 2.2.2, the RS encoder is used in DVB-T/H systems, as an outer encoder. The RS (255,191) encoder adds 64 correction bytes to 191 input bytes and it is able to correct up to 32 erroneous bytes (see 2.1.1). Before this encoding, the length of the input word is checked to be dividable with 191, as the inputs of RS (255,191) are 191 byte groups. In case that input can not be divided, zeros are added to the end. For the implementation of RS encoder to the application, the `rsenc` MATLAB function is used.

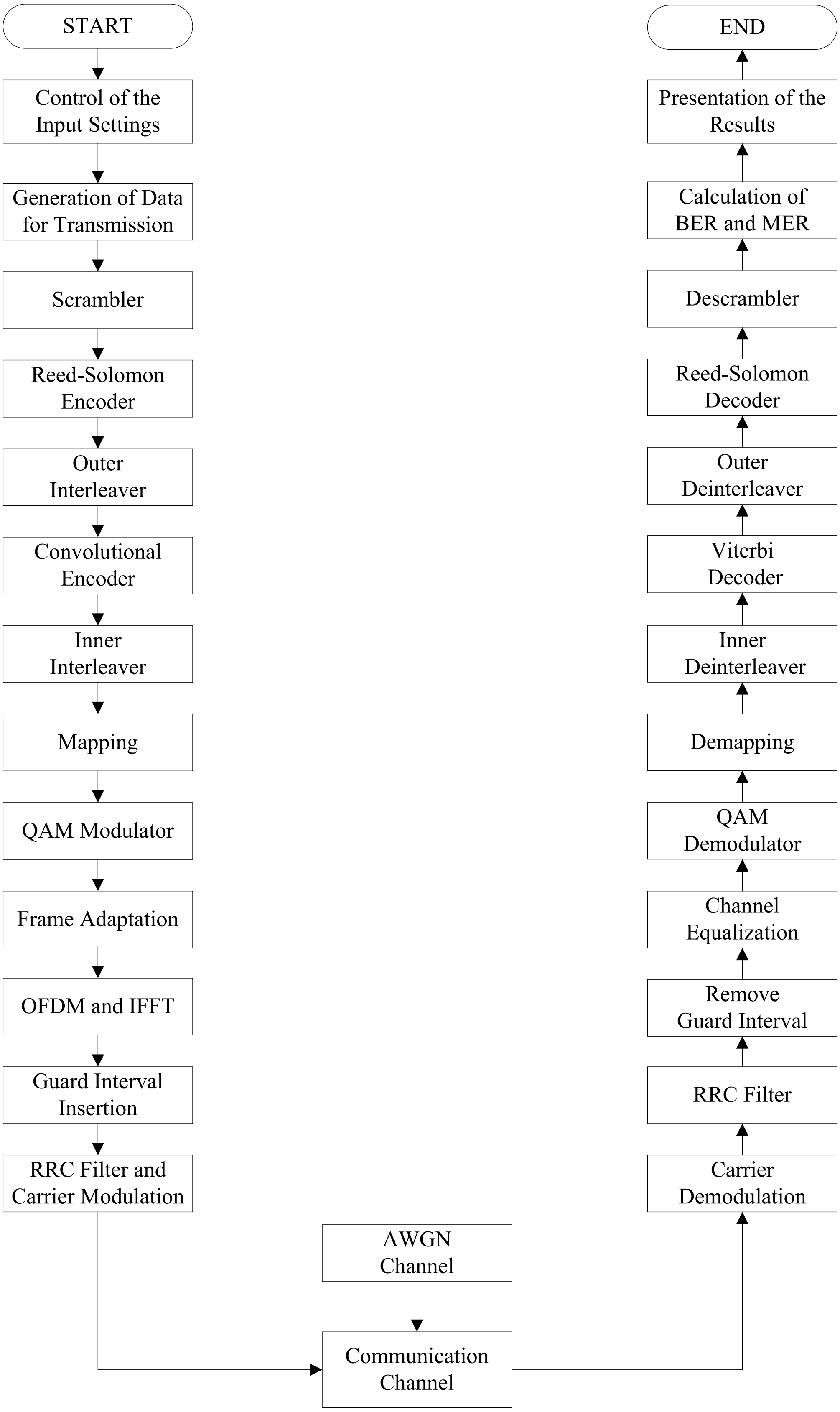


Fig. 5.1 Flowchart of the application for the simulation and analysis of the transmission distortions in the DVB-H standard (left – transmitter, right - receiver).

Frequently burst errors occur during a transmission. If these results are more than 32 errors in a packet, then the RS error protection fails. Therefore, the data after the RS encoding are interleaved. In 2.2.3, the process of outer interleaving was briefly described. In the mentioned application, the outer interleaving is realized simply: bytes are writing into the matrix by columns and reading them out by rows. Function `convintrlv` (for the realization of the outer convolutional interleaver) was not used, as it utilizes shift registers and the simulated stream is finite. This caused problems with initial zeros, stored in the registers, interleaved with useful data [77], [78].

The outer encoder is followed by the inner encoder. Inner encoder consists of the comvolutional encoding (see 2.2.4) and inner interleaving (see 2.2.5). Convolutional encoder is realized by the way, how it was described in 2.2.4. Furthermore, the data rate can be lowered by selectively omitting bits (see Tab. 2.2). This operation is also called as a puncturing. Convolutional encoder in MATLAB is realized by function `convenc`, with parameter `puncpat`, in which the puncturing pattern is defined. And again, when the length of puncturing pattern is not enough (how it was in case of RS encoder), zeros are added to ensure this.

The inner interleaving, which contains the bit and symbol interleaving, is implemented as recommended in [7] and [8]. Of course, the input stream is demultiplexed into *v* sub-streams. Number of sub-streams depended on the type of the modulation, which will be used (see 2.2.5). Each sub-stream from the demultiplexer is then interleaved in the interleaver with own interleaving sequence, called permutation function. The bit interleaving block size is 126 bits and it is the same for each interleaver. After that the symbol interleaving is followed, which is *v* bit words onto the 1512 (2K mode), 3024 (4K mode) or 6048 (8K mode) active carriers per OFDM symbol (see 2.2.6), according to [7]. The inner interleaving is the last block of the FEC in DVB-T/H system.

After previously mentioned FEC blocks, symbols from output of inner interleaver are ready to modulate into QPSK, 16QAM or 64QAM constellations. MATLAB functions and tools support some cases for the modulation and demodulation. In the developed application the `modem.qammod(M)` function was used from Communication Toolbox. This function also enables set up symbols to be mapped. However, the symbol order does not match the mapping in the DVB-T/H specification [7], [8]. The solution of this problem was described and presented in [80] and it was applied in this application too.

Transmission (OFDM) frame adaptation block has to divide modulated stream, carrying useful data, into OFDM symbols and adds the zero, TPS, fixed and scattered pilots (see 2.2.8 a 2.2.9). At this point, a zero matrix is generated, which size is depending on the type of OFDM mode and type of inner modulation. After then the useful (modulated) data and special pilots (zero, TPS, fixed and scattered) are added into the defined positions (see Fig. 2.8). Now, complete OFDM signal in the frequency domain is transformed into the time domain by using IFFT (see 2.2.10). This function is implemented in MATLAB (as an `ifft`) and it can be used very easily.

Once we have OFDM symbols assembled, GI (Guard Interval) can be inserted. According to the DVB-T/H specification, the options are 1/4, 1/8, 1/16 and 1/32 of the symbol period. End part of each symbol is copied to the beginning of the present symbol (see 2.2.11).

Real and imaginary part of the OFDM signal is upsampled and filtered with RRC filter with roll-off factor 0.35 (see 2.2.12) before the carrier modulation. As the filter produces delay, therefore, random bytes are inserted at the beginning of the data to protect them. Of course, these bytes are removed with the delay of the filter on the receiver side, so they do not affect the resulting signal [77], [79]. The carrier modulation is then performed by multiplying the in-phase and quadrature samples by $sin(2\pi f_0 t)$ and $cos(2\pi f_0 t)$, respectively (f_0 is the carrier frequency of course).

At this point, DVB-T/H signal is prepared and it can be transmitted by using transmission channel model (see 4). There exist several types of channel models (AWGN, Rice, Rayleigh, etc.) in MATLAB Communication Toolbox, which can be used for the exploring, how the signal behaves in the terrestrial transmission environment. More details about the implementation (with examples of source codes) of the fading transmission channel models (with Doppler shift) can be found in [110].

In this chapter, the brief description of the created application for the simulation and analysis of the DVB-T/H transmission was presented. The description is focused on the signal ensuring (FEC scheme) and signal processing in frequency and time domain.

5.1.2 Receiver

When the signal is prepared to the transmission, then it is transmitted via different type of fading channels, which are moreover affected by classical AWGN noise. After that the affected (noised) signal is received by the receiver. As it can be seen from Fig. 5.1, the application for the signal renewal consist similar functional blocks.

Firstly, the received signal is demodulated in a carrier demodulator. Signal is divided on real and imaginary part and RRC filter is used with same roll-off factor that was used in the carrier modulator. After the filtering and down-sampling, real and imaginary part of the signal are again added. Before the equalization and QAM demodulator, the GI interval must be removed and the signal must be transformed from time to frequency domain. This transformation is called FFT (Fast Fourier Transformation) and it is easy realized by `fft` MATLAB function.

When the received signal is transformed back to the frequency domain, then the signal renewal, so called equalization, can be started. In this application (and also in this dissertation thesis) the equalization of the signal is done by the inverse frequency characteristic of the transmission channel. Frequency characteristic of the channel can be determined by comparing of the values, obtained from scattered (and eventually from continual) carriers of received signal with the known values, which are transmitted. The process of equalization, used in the created application, can be briefly described as follows. Firstly, an auxiliary vector of length equal to the number of active carrier is created. Of course, the length of this vector is always depending on the selected OFDM mode. After that, values, which were calculated from the positions of scattered carriers, are put in the appropriate positions of the vector. Furthermore, values from continual carriers are added to them from the whole OFDM frame. As a result is a special vector, affected by continual and scattered carriers. This vector is divided by the, so called, original (known) values. The result of this dividing is the transmission characteristic of the channel. However, these "test" carriers are available only on every third active carriers (position of scattered carriers are shifted by 3 active carriers in each symbol), it is necessary to computed values of transmission characteristic on the unmeasured carriers. Therefore, vector of transmission characteristic is down-sampled (by `downsample` MATLAB function). Thank to this, the unmeasured carriers are removed and after that, the vector, with the function `interp`, is increased on the original length and there are always two values interpolated between two samples. By this way it is obtained the estimation of the complete frequency characteristic of the transmission channel. By the transfer function is divided each column of carriers (OFDM symbol) and the equalization of whole framework is done.

In the block of QAM demodulator, the equalized (corrected) signal is demodulated. And again, for this purpose a MATLAB function from Communication Toolbox was used. More precisely, `modem.qamdemod(M)` function was used with same parameters (input type, symbol mapping and so on), how it was presented in [80]. After the demapping, which is necessary for the correct multiplexing, the inner deinterleaving is the first step in FEC decoder processing. The inner deinterleaving (symbol and bit deinterleaving) is realized as an inverse process of inner interleaving.

The next stage is a convolutional decoder, so called Viterbi decoding. In this block (see Fig. 5.1) the decoded bits are obtained with the function `vitdec`. This function moreover enables set (as an input parameter) the type of decoding algorithm. In this application it is possible chose between the soft and hard decision algorithm.

Outer deinterleaving and RS decoder are the last part of the FEC decoding. Both of these blocks are provide inverse operation as it was in transmitter. For the RS decoding the `rsdec` MATLAB function was used.

As a last step before the calculating of *BER* and *MER*, the data must be descrambled. In this block is again applied the PRBS generator and the original input sequence is renewed (the energy dispersal is removed).

At the end, the main important parameters *BER* (before and after Viterbi decoding) and *MER* (Modulation Error Ratio) are calculated. The *BER* can be precisely defined as the number of bits errors, divided by the total number of transferred bits, during a studied interval. In the created application for the assessment of the *BER* before and after Viterbi decoding used a simple method:

- *BER* before Viterbi decoding is determined by comparing of output of interleaved bits (after the bit interleaving) and bits after the demodulation (before the bit deinterleaving).
- *BER* after Viterbi decoding is determined by comparing of output of outer interleaver (in binary form) and bits after Viterbi decoding (before the outer deinterleaving).

The *MER* is a measure to quantity measure used to quantify the performance of a digital transmitter or receiver in a communications system using digital modulation [3]. In area of digital video broadcasting, *MER* is a measure of the sum of all interference effects, occurring on the transmission link. It is usually specified in dB. If only one noise effect is present, *MER* and *S/N* (Signal-to-Noise Ratio) are equal. Detailed description of the equation method of the *MER* can be found in [3] and [73]. The *MER* in this dissertation thesis is calculated by the method, which is recommended in [79]. It is determined by comparing M-QAM modulated symbols (without noise) from transmitter and demodulated (noise and modulator errors impaired) signal from OFDM demodulator.

5.2 FLOWCHART OF THE APPLICATION FOR THE TRANSMISSION IN DVB-SH STANDARD

5.2.1 Transmitter

The flowchart of the application for the simulation of the transmission in DVB-SH standard is shown in Fig. 5.2. The created application almost covers all functional blocks of the DVB-SH system, presented in chapter 3. After the run of application in MATLAB, as it was in case of previous application, its basic functions and parameters are set and there are enable set the concrete configuration parameters for the simulation.

In the first step, the created MATLAB application for the simulation of the DVB-SH transmission is generating the random bit sequence. Other possibilities are not available from reason of system requirements. On the generated input bit sequence is then applied the scrambling processing (see 2.2.1). In contrast to application, presented in 5.1.1, this process could be omitted (the effect of scrambling process on the *BER* is minimal).

The next stage contains the turbo encoder and puncturing. How it was described in 3.2.2, turbo code, as it was standardized by the 3GPP2 organization, shall be used in the real implementation. The turbo code is used for the FEC encoding of the input data stream. However, this type of turbo encoder has several disadvantages from the perspective of simulation:

- Complexity (the transfer function of the basic code of the 3GPP2 RSC encoders is complex),
- Complicated turbo interleaver (the computation of interleaving address for the input data payload is complex and needs high system requirements),
- Turbo decoding method (the DVB-SH turbo encoding process, based on 3GPP2 is well specified in [11], on the other hand, the details of the turbo decoding process are not described).

These are the main reasons, why the research is focused on the alternative and modified turbo schemes (see 1.1.2). The main alternative solutions (modification of the original turbo code, which is preferred in DVB-SH standard) were presented in [57]-[60]. Based on the presented results in these papers, in this dissertation thesis was also used an alternative configuration of the turbo encoder/decoder. The application, created for the simulation, uses PCCC (Parallel Concatenated Convolutional Code) [81], [82]. A block diagram of PCCC turbo encoder is shown in Fig. 5.3.

The PCCC turbo encoder, as well as the 3GPP2 turbo encoder, consists of two recursive convolutional encoders. These encoders, or more precisely, their structures, are defined by generator polynomials $G_1 = 17_{OCT}$ and $G_2 = 15_{OCT}$. The input data stream is divided into two parts. Both parts are them independently encoded by PCCC encoders. One of the main differences between the 3GPP2 and PCCC turbo encoders is that in the PCCC turbo encoder the systematic bits are transmitted only once. It is very important in terms of time consumption of the whole simulation. The process of the puncturing after the PCCC turbo encoding is the same in case of the 3GPP2 turbo encoder. After the generation of the output symbol sequence, puncturing is applied.

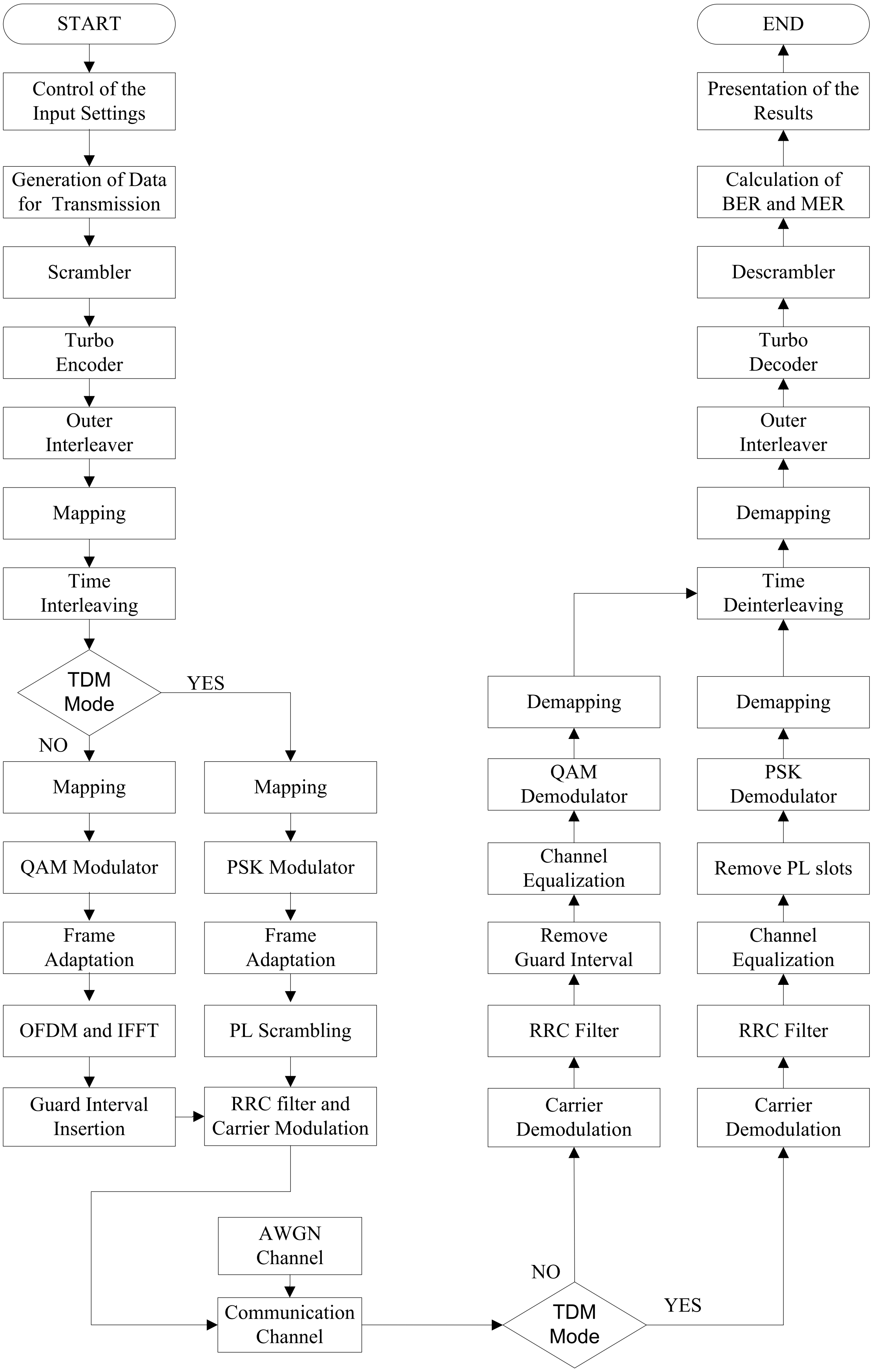


Fig. 5.2 Flowchart of the application for the analysis and simulation of the transmission distortions in DVB-SH standard (left – transmitter, right - receiver).

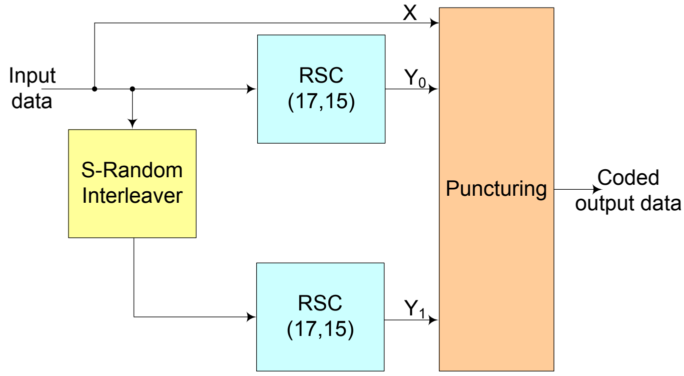


Fig. 5.3 Block diagram of the PCCC turbo encoder.

How it was mentioned, in the 3GPP2 turbo encoder, a special type of interleaver (so called 3GPP2 interleaver) is used. The process and function of this interleaver is described in [11]. Pseudo random interleaver is used to permute the data, encoded by the second RSC encoder. Unfortunately, the output (interleaving) address calculation procedure and its algorithm implementation from the perspective of simulation are not effective [83]. Therefore, instead of mentioned interleaver, a semi random, so called S-random interleaver [84] was used in the program application.

S-random interleaver, from the perspective of structure, is placed between the random interleaver and interleaver with fixed structure. Each, randomly selected integer, is compared with *S* previously selected random integers. If the difference between the current selection and *S* previous selections is smaller than *S*, the random integer is rejected. This process is repeated until *N* distinct integers have been selected [85], [86].

After the turbo encoding, the next step is the interleaving process. The DVB-SH, as well as DVB-H, uses bit-wise interleaving. Generally, the outer interleaver contains channel and time intereavers (see 3.2.3). At this point, the created application has again a little different functional block in contrast to recommendation, presented in [11]. The function of the time interleaver is to interleave coded words and bits over time using a convolutional interleaver. Communication Toolbox of MATLAB contains function `convintrlv` for this purpose. However, this function was not used, as it uses shift registers and the simulated stream is finite. This causes problems with initial zeros, stored in the register and interleaved with payload data of mobile TV [77]. Therefore, a simple `randintrlv` function was used.

To this point, the advanced FEC scheme was presented. Described process of FEC is common for both DVB-SH modes (SH-A and SH-B). When the first one (SH-A) is used, then the whole signal processing (in the transmitter and receiver) is the same that was presented in 5.1.1 and 5.1.2. Therefore, the next part of this subchapter is only focused on the second case, when SH-B mode is used.

After the FEC encoding processing, the output of channel interleaver is mapped into the constellation diagram of the selected type of modulation. As it was described in 3.2.8, instead of QAM, the PSK modulations are preferred. More precisely, DVB-SH-B mode used QPSK, 8PSK and 16APSK modulations. In the developed application the `modem.pskmod(M)` function was used from Communication Toolbox. This function is very effective in case of QPSK and 8PSK modulations, but in case of 16APSK modulation, it can not use. Reason is that the function `modem.pskmod` can not allow changing the properties of `psk.SymbolOrder` and `psk.SymbolMapping`. Therefore, the 16APSK modulation was implemented in the created application by manual way. More details can be found in [117] and [125].

The next stage contains the PL frame adaptation and scrambling process. The technical and implementation background were briefly described in 3.2.9 and 3.2.10. According with contain of these chapters, the whole PL frame adaptation and scrambling process are fully implemented into application for the DVB-SH-B transmission simulation.

Now, complete SH frame (in TDM mode) signal is available in the time domain. After the scrambling, the signals shall be filtered with RRC. The roll-off factor shall be $\alpha = 0.35$; 0.25 and 0.20, depending on the service requirements [11], [12]. And again, the carrier modulation is performed by multiplying the in-phase and quadrature samples by $sin(2\pi f_0 t)$ and $cos(2\pi f_0 t)$, respectively (f_0 is the carrier frequency). Of course, the signal transmission is realized in the S-band. Therefore, the carrier frequency equals to 2.2 GHz, as recommended in [11], [12]. At this point, DVB-SH signal is prepared and it can be transmitted by using transmission channel model (see 4).

5.2.2 Receiver

When the signal is prepared to the transmission, then it is transmitted via different type of fading channels, which are moreover affected by classical AWGN noise. Therefore, at the front end of the receiver is available an affected (noised) signal. And again, how it was in case of DVB-H flowchart (see Fig. 5.1), the DVB-SH application, for the signal renewal, consist similar functional blocks (see Fig. 5.2). How it can be seen from this flowchart, if the SH-A mode (OFDM) is active, then the received signal processing is the same as it was in case of DVB-H application. Therefore, the description of this part is omitted.

In case, when the SH-B (TDM) mode is active, then first part of signal processing is very similar that is in SH-A mode. Moreover, the principle of carrier demodulation and RRC filtering is the same that was in DVB-H/SH-A applications. After the carrier demodulation, the equalization can be started. The process of the equalization, used in the case of the DVB-SH-B mode, is a bit different, how it was presented in 5.1.2. Firstly, the Gold sequence (see 3.2.10), which was applied in transmitter, is removed. After that the carrier phase and carrier amplitude estimation is applied. These estimations were adapted from the DVB-S2 standard and applied in the DVB-SH-B system. More details (equations and their explanation) can be found in [12] and [48]. After the equalization and PL slots removing, the PSK demodulation and demapping are the next stages. For the demodulation a `modem.pskdemod` function was used.

Signal processing, before the FEC decoding, is contain time deinterleaving, demapping and outer deinterleaving. In these blocks, the signal processing is realized as an inverse process.

The last block of FEC decoding is the turbo decoding. Generally, turbo decoder is built in a similar way to the encoder: two elementary decoders are interconnected to each other, but in serial way, not in parallel [82]. As it was described in 3.2.2, DVB-SH standard uses a special type of turbo encoder. Therefore, it is clear that the

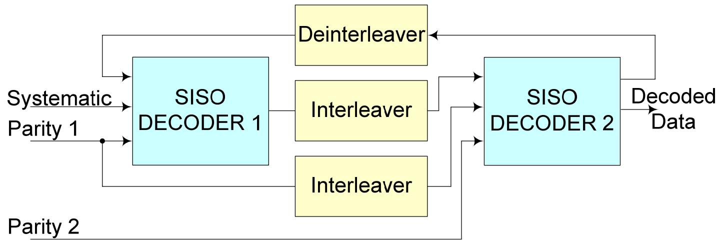


Fig. 5.4 SISO-MAP turbo decoder.

method of decoding will be not general. In [12] it is also mentioned that for the 3GPP2 turbo decoding, the Log-Map algorithm [82] was chosen. On the other hand, in case of other implementations, different methods and algorithms may be used [12]. For the data stream decoding in this simulation model SISO-MAP (Soft Input Soft Output Maximum A Posteriori) method was used [82]. An iterative structure of SISO-MAP detection and SISO decoder is proposed for different turbo coded systems. The block diagram of the SISO-MAP turbo decoder, which was used in the application and in this dissertation thesis, is shown in Fig. 5.4.

As seen in Fig. 5.4, two soft decision decoders are employed. SISO Decoder 1 provides soft output, which is a measure of the reliability of each decoded bit from the probability. From the probable information the extrinsic information is extracted. The extrinsic information is independent on the current decoder input. The extrinsic information, after the interleaving, is passed to the SISO Decoder 2. The second decoder uses this information to decode the interleaved bit sequences. From the soft outputs of SISO Decoder 2 the new extrinsic information is fed back to the input of SISO Decoder 1 and so on. If an error occurs due to noisy input of the first decoder, it may be corrected by the second decoder [82]. Repeating of this turbo decoding process depends on the number of iterations. For example, when the number of iterations is equal to five (5), then the turbo decoding process is repeated five (5) times.

As a last step before the calculating of BER and MER, the data should be descrambled (when the option of scrambling process is chosen in the transmitter). In this block is again applied the PRBS generator and the original input sequence is renewed.

At the end, again, the main important parameters BER (after turbo decoding) and MER are calculated and evaluated. BER after turbo decoding is determined by comparing of generated data sequence (in binary form) with the bits after turbo decoding (in binary form). When the scrambling process is active, then the mentioned comparison is done after the descrambling. The MER ratio is calculated by the same way (comparing of M-QAM/M-PSK modulated symbols from transmitter and demodulated signal from OFDM/TDM demodulator), how it was outlined in 5.1.2.

In this chapter the flowcharts of both created applications for the simulation and analysis of DVB-H and DVB-SH transmission were described. The most important functions, which are used in these applications, were outlined and explained. In case of the DVB-SH application, an alternative method and technique of FEC encoding and decoding, which are used in this dissertation thesis, was also presented and clearly described. The main contribution of this chapter was the simple and clear presentation of simulation methods of both applications, which are unconditionally needed to successful analysis of the obtained results.

6 Analysis of the DVB-T/H Transmission in Fading Channels

This part of dissertation thesis deals with the exploring and analysis of the transmission distortions in DVB-T/H standard in all possible scenarios (mobile, portable and fixed) over fading channels. The detail description of these fading channels and their models (with the parameters) are presented and described in 4. Therefore, their parameters are not presented in this chapter. Furthermore, the DVB-T/H performance was also tested in a laboratory environment, using R&S test and measurements equipments. Obtained results from simulations and measurements are compared.

6.1 MOBILE RECEPTION SCENARIO

Fading channels models, used for the exploring of the signal distortions in DVB-T/H standard in mobile scenarios are defined in [73] and [74]. The RA6 channel model (see Fig. 4.1 a)) is consists of one direct path and five reflected paths. It also clearly seen that the RA6 channel has approx. 10 times shorter path delays, compare to TU6 channel (see Fig. 4.1 b)). In the RA6 channel the speed of the receiver is equal to 100 km/h, so the Doppler shift is two times higher than in TU6, where v = 50 km/h.

Both channel profiles, VU30 and MR100 (see Fig. 4.2 a) and b)) have twelve echo paths. How it can be seen, the delays of paths are very similar, but path losses in the MR100 channel are overall higher, compare to VU30. Moreover, the speed of the receiver in the MR100 channel model is equal to 100 km/h. Therefore, for the simulation and also for the measuring there were chosen 2K OFDM mode and QPSK (RA6 and TU6) and 16QAM (VU30 and MR100) modulations. Thank to this system configuration, the impact of this frequency shift shall be minimized.

The DVB-T/H system transmission parameters were set to the European most common type of DTV broadcasting. These parameters are the most characteristic for the large to small size of the DVB-T/H SFN networks:

- 8 MHz channel (bandwidth 7.068 MHz)
- 2/3 convolutional code (robust protection)
- 2K (mobile) OFDM mode
- QPSK and 16QAM (mobile) non-hierarchical modulations
- 1/4 and 1/16 Guard Interval (large and small size of SFN)
- AWGN (Gaussian), Rural Area (RA6), Typical Urban (TU6), Vehicular Urban (VU30) and Motorway Rural (MR100) channel models
- Viterbi decoding: hard.

6.1.1 Simulation and Measurement

How it was described in the previous chapters, application for the simulation and analysis of the DVB-T/H transmission has been implemented in MATLAB. In the created application, all parameters for the exploring of the signal distortions in mobile scenarios were set as were presented in 6.1. The simulation was done on a PC (Personal Computer) with an Intel Core2Duo E8400 CPU at 2.2 GHz, with 2GB memory, running Microsoft Windows XP Professional.

Experimental testing of the DVB-T/H broadcasting and transmission in fading channels for all transmission scenarios was realized in the laboratory of digital television at Department of Radio Electronics (DREL), Brno University of Technology (BUT), in Czech Republic. The transmitter and receiver test beds (see Fig. 6.1) were consisted of DVB-T/H test transmitter R&S with noise generator and fading simulator (up to 6, 12 and 20 paths), MPEG-2 TS generators, included in SFU (Single Frequency Unit) and external R&S DVRG, reference test receiver Kathrein MSK-33, DVB-T receiver (STB, Set-Top-Box) and DVB-H receiver (mobile phone).

Test & Measurement devices that were used are:

- Rohde & Schwarz SFU [87] – it was used as a coder, modulator and transmission channel simulator
- MSK33 Kathrein DVB-T/H [88] – this test receiver was used for the measuring the *BER* and constellation diagram distortions (*MER*).

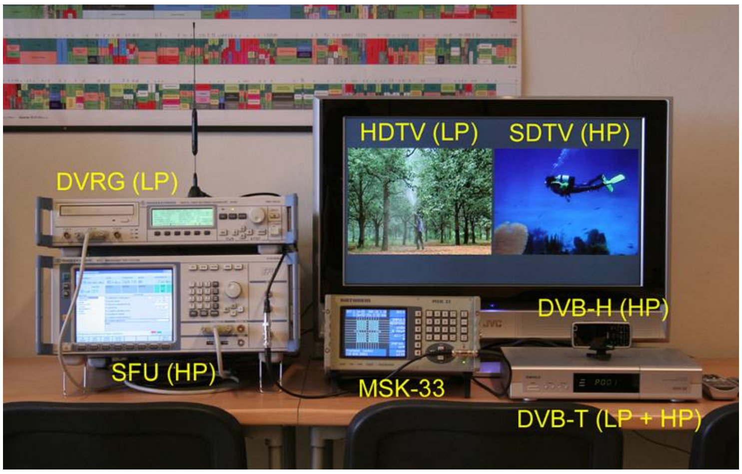
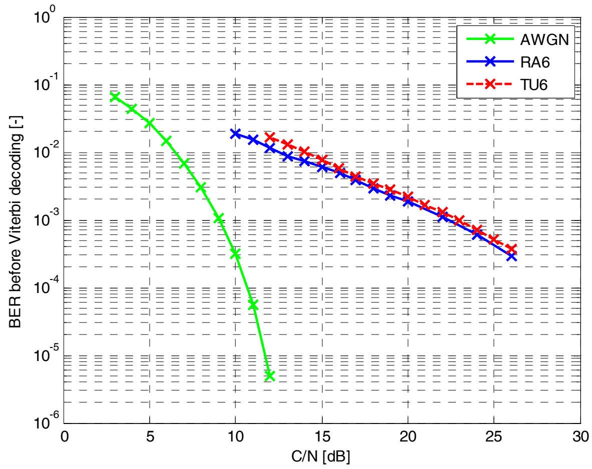


Fig. 6.1 Laboratory environment for DVB-T/H transmission: DVB-T/H transmitter R&S SFU, MPEG-2 TS (Transport Stream) player R&S DVRG, DVB-T reference test receiver Kathrein MSK-33, DVB-T set-top box Topfield with LCD TV screen and DVB-H mobile phone Nokia [42].

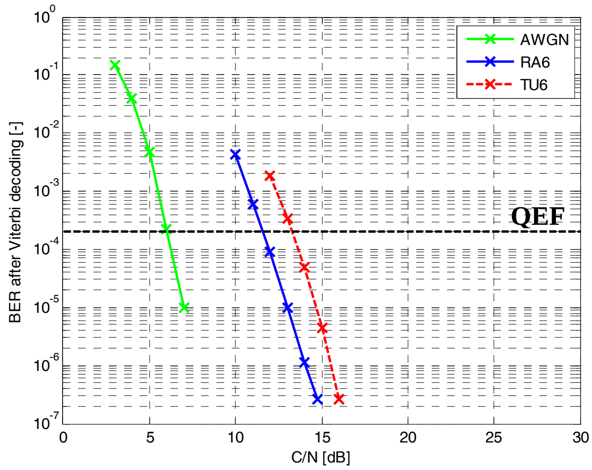
6.1.2 Experimental Results and Their Evaluation

Simulation results of the mobile TV transmission in the DVB-T/H standard for a varying *C*/*N* ratio in the Gaussian channel (AWGN) and in the mobile (RA6, TU6) fading channels are in Fig. 6.2 a) to c). Firstly, dependence of the *BER* on the *C*/*N* in the reference, Gaussian channel was explored.

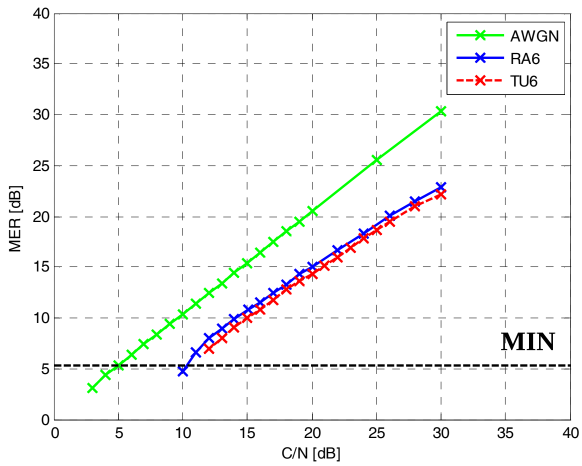
How it was mentioned, the DVB-H standard has been partly developed from the DVB-T standard. Therefore, for the evaluation of *BER* it can be used the QEF operation.



a) BER before Viterbi decoding = f (*C*/*N*)

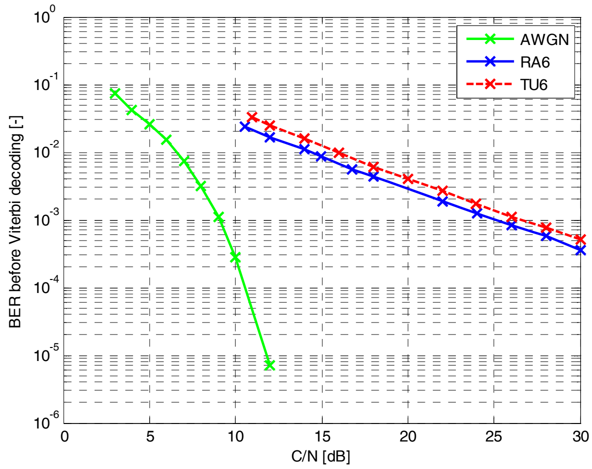


b) BER after Viterbi decoding = f (*C*/*N*)

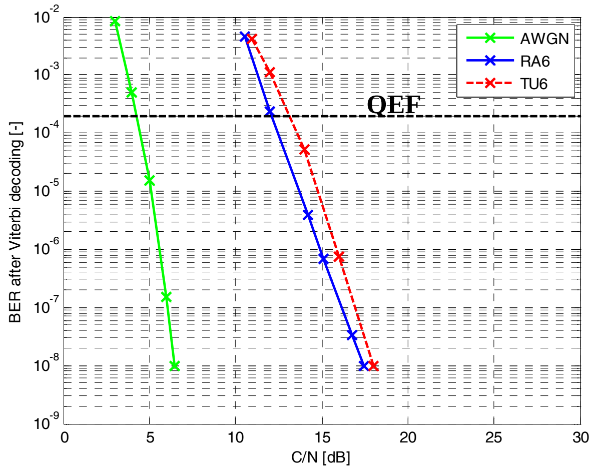


c) MER = f (*C*/*N*)

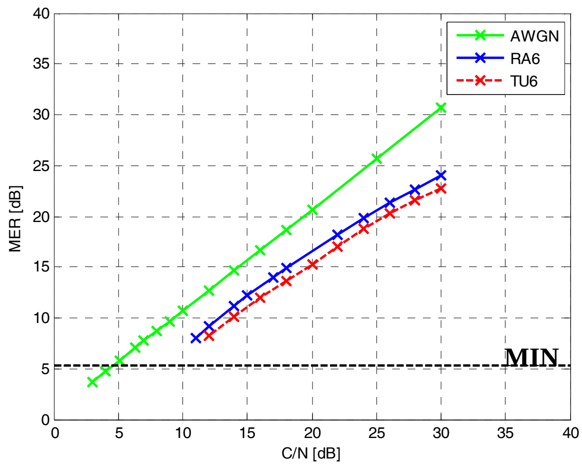
Fig. 6.2 Simulation: Mobile reception scenario (QPSK, 2K mode, code rate 2/3 and GI 1/16) and DVB-T/H performance in typical channel profiles.



a) BER before Viterbi decoding = f (*C*/*N*)

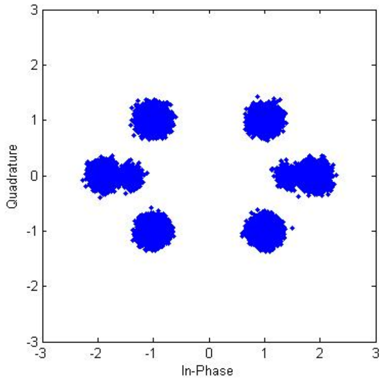


b) BER after Viterbi decoding = f (*C*/*N*)

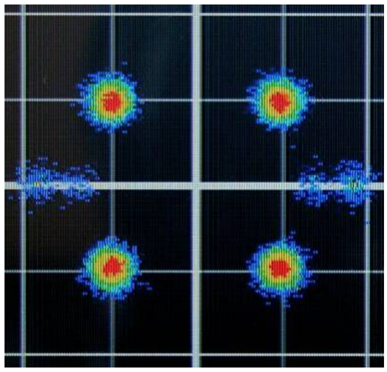


c) MER = f (*C*/*N*)

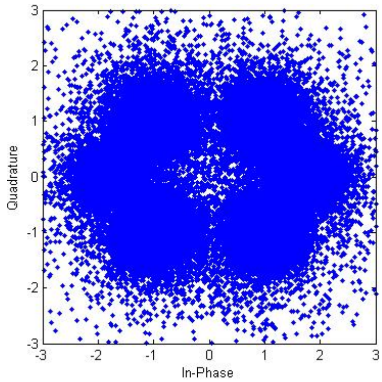
Fig. 6.3 Measurement: Mobile reception scenario (QPSK, 2K mode, code rate 2/3 and GI 1/16) and DVB-T/H performance in typical channel profiles.



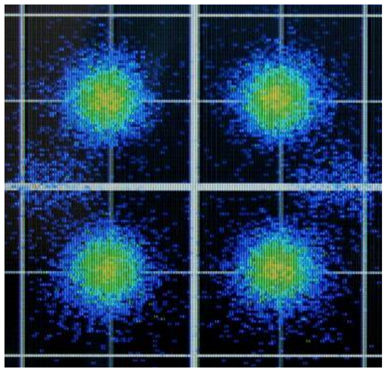
a) AWGN channel and mobile reception scenario,
MER = 20.5 dB; $BER_1 < 1\cdot10^{-8}$; $BER_2 < 1\cdot10^{-8}$



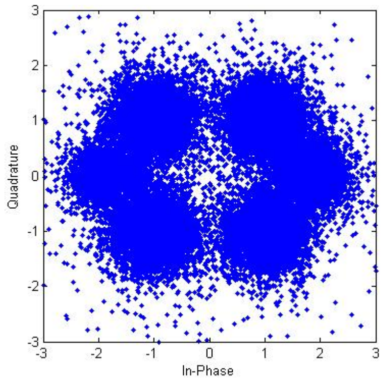
d) AWGN channel and mobile reception scenario,
MER = 20.7 dB; $BER_1 < 1\cdot10^{-8}$; $BER_2 < 1\cdot10^{-8}$



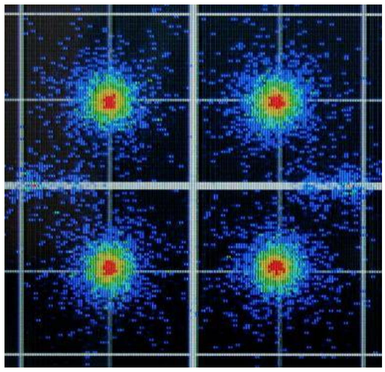
b) RA6 channel and mobile reception scenario,
MER = 15.0 dB; $BER_1 = 1.9\cdot10^{-3}$; $BER_2 < 1\cdot10^{-8}$



e) RA6 channel and mobile reception scenario,
MER = 16.5 dB; $BER_1 = 3.0\cdot10^{-3}$; $BER_2 < 1.0\cdot10^{-8}$



c) TU6 channel and mobile reception scenario,
MER = 14.3 dB; $BER_1 = 2.2\cdot10^{-3}$; $BER_2 < 1\cdot10^{-8}$



f) TU6 channel and mobile reception scenario,
MER = 15.3 dB; $BER_1 = 4.1\cdot10^{-3}$; $BER_2 < 1.0\cdot10^{-8}$

Fig. 6.4 Simulation and measurement: I/Q constellation of: a) to c) mobile scenario with QPSK (simulation), d) to f) mobile scenario with QPSK (measurement) also within typical DVB-T/H fading channels (all the constellations include channel correction and pilots, *C*/*N* = 20 dB).

The QEF [3] operation is defined as a bit error rate after Viterbi decoding less or equal to 2.10^{-4} [8], [10]. Then the *BER* ratio after Reed-Solomon decoding is less or equal to 2.10^{-11}.

The Fig. 6.2 from a) to b) shows the simulated dependences of the *BER* on the *C*/*N* ratio in mobile channel before and after Viterbi decoding. How it can be seen in case of Gaussiah channel (green line), the *BER* ratio before and the Viterbi decoding is very low and in both cases the dependeces have waterfall form. The reason is that the

Gaussian channel does not account for fading or interference, therefore the FEC scheme can be corrected all errors at lower *C*/*N* ratio. In case of Gaussian (AWGN) channel it can be achieved a 1.10^{-5} *BER* ratio before the Viterbi decoding, when the *C*/*N* ratio is equal to 11.7 dB. As it can be assumed, the QEF value, after the Viterbi decoding, can be achieved at low *C*/*N* ratio. In case of AWGN channel that is at 6.0 dB.

The Fig. 6.2 a) illustrates the *BER* before Viterbi decoding in RA6 (Rural Area) fading channel model. How it was described in 4.2, the RA6 channel profile models the signal transmission in a rural area. It consists of 1 direct path and 5 echo paths. Moreover, the speed of the receiver is also considered in this channel model. It is equal to 100 km/h. Therefore, the Doppler's shift also exists. The Doppler's shift [89] can be determined by as a:

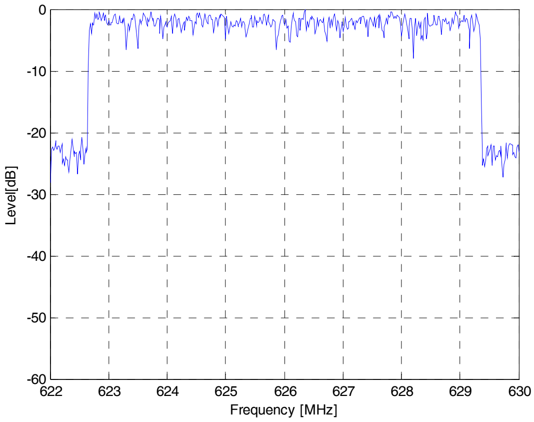
$$f_d = \frac{f_c . v}{c} . \cos(\varphi), \tag{6.1}$$

where f_c is carrier frequency (for the simulation and measuring f_c = 626 MHz), v is the speed of the receiver, c is the speed of the light ($c = 3.10^8$ m/s) and φ is the angle between the direction of movement and direction to receiver. This angle can have values from interval <0;π>. In this dissertation thesis φ is always equal to 0°. More precisely, in this case the receiver is moving toward the transmitter. In case of the RA6 channel profile (v = 100 km/h) the Doppler's shift is equal to 57.96 Hz.

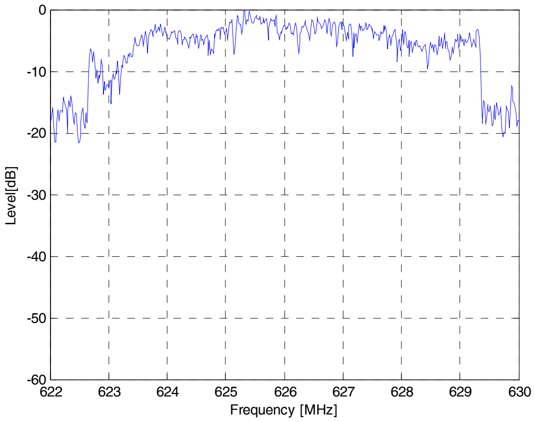
How it can be seen from the Fig. 6.2 a), all these effects are reflected on the obtained *BER* (blue line) before the Viterbi decoding. On the other hand, thank to the LOS between the transmitter and receiver (first path), the impact of higher Doppler's shift is more minimized. Thank to this it is possible to achieve a 10^{-3} *BER* ratio before the Viterbi decoding at 22.5 dB *C*/*N* ratio. In comparison with Gaussian channel, this value is approx. two times higher. The situation after the Viterbi decoding, in comparison with the Gaussian channel (see Fig. 6.2 b)), is similar. More precisely, the QEF reception can be achieved at two times higher *C*/*N* ratio, concretely at 11.5 dB.

As a last one, the TU6 fading channel model is used for the exploring of the signal distortions in a mobile TV channel. This channel profile, as it was briefly described above (see 4.2), models the terrestrial propagation in an urban area. In comparison with RA6 model, TU6 channel model has only echo paths (6 independent paths). Moreover, delay of each path is generally ten (10) times higher than it was in Rural Area model. On the other hand, the path losses are lower. The speed of the receiver is equal to 50 km/h. Therefore, the Doppler's shift is two times lower (28.98 Hz) than in RA6.

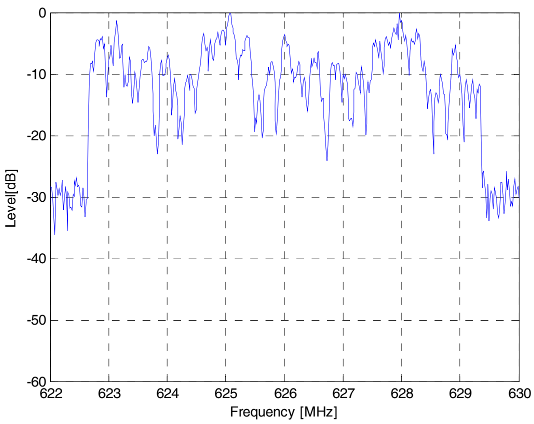
The Fig. 6.2 a) also illustrates the dependence of the *BER* on the *C*/*N* ratio before the Viterbi decoding, when the TU6 channel model was used for the transmission (red line). As it was in the RA6 channels, in the TU6 channel it can be also observed a very high *BER* ratio before the Viterbi decoding. In comparison with the RA6 channel, these errors are a bit higher, thank to fact that is no direct path between the transmitter and receiver. It is also can be seen that the less value of Doppler's shift has not significant effect on the *BER*. To achieve a 10^{-3} *BER* ratio before the Viterbi decoding is needed a higher value of *C*/*N* ratio. In this case it is equal to 23.0 dB. On the other hand, thank to a several time mentioned advanced FEC scheme, after the equalization and Viterbi decoding, the QEF reception can be achieved at 13.3 dB. This value is very close to the value, which was achieved in the RA6 channel model.



a) AWGN channel and mobile reception scenario



b) RA6 channel and mobile reception scenario



c) TU6 channel and mobile reception scenario

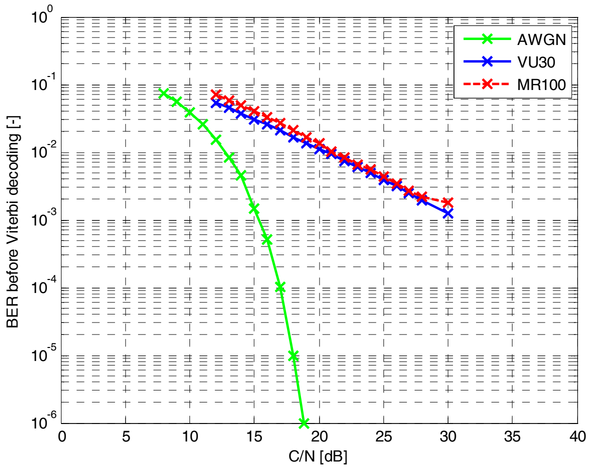
Fig. 6.5 Spectrum of one OFDM symbol in DVB-T/H with QPSK, 2K mode in channels a) Gaussian (AWGN), b) RA6 and c) TU6 (in all cases the C/N = 20 dB).

Dependences of the *MER* on *C/N* ratio as a result of the simulation in all used transmission channels were also obtained and there are shown in Fig. 6.2 c). The minimal value, which is necessary to achieve the QEF [7], is marked in the graphs by MIN dashed line. In case of the Gaussian channel the dependence between the *MER* and *C*/*N* ratio is linear. It means that with the increasing values of *C/N* ratios are linearly increases the *MER* ratios. The required min value of *MER* can be achieved at very low value of *C*/*N* ratio, approx. at 5.0 dB. Of course, the reason is simple: in this channel only a white noise is available. In case of the fading channels (RA6 and TU6 profiles), for the higher *MER* higher *C*/*N* ratio is needed, but the dependence of them is not linear. From the Fig. 6.2 c) is also clearly seen that all type of noises (path delays, path losses and Doppler's shift) have impact on the *MER*. For the achieving of higher *MER* ratio (20.0 dB) in case of RA6 profile is needed 26.0 dB of *C*/*N*. In case of TU6 channel it is approx. 26.8 dB. It is clearly seen that the differences between RA6 and TU6 profiles are very low and for the achieving a higher *MER* ratio is needed higher *C*/*N*.

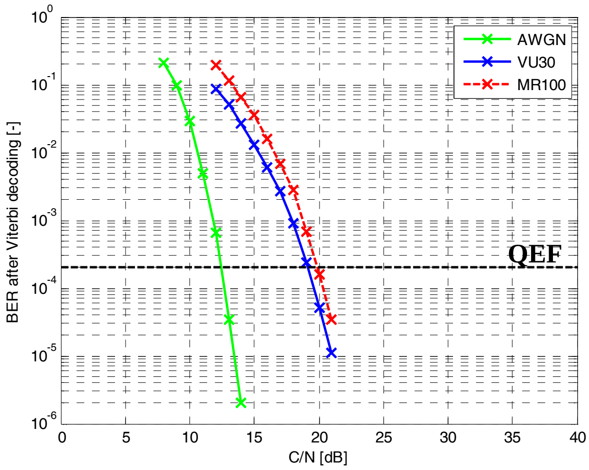
Detailed results of the laboratory measurement of the *BER* before and after Viterbi decoding characteristics and *MER* from constellation analysis in dB for DVB-T/H mobile services are available in Fig. 6.3 a) to Fig. 6.3 c). The results from measuring are obtained at same system conditions and settings, which were used for the simulation. Dependences of the *BER* and *MER* on the *C*/*N* ratio in Gaussian channel (AWGN) were measured first and then in RA6 and TU6 channels. Firstly, dependeces of the *BER* before the Viterbi decoding were compared. In case of the AWGN channel, there are no differences between the simulated and measurement results. In case of the RA6 and TU6 channels, there are slightly higher differences. More precisely, the results from simulations are better. The reason is that MATLAB has a tendency to minimize the effect of "Rayleigh" fading, which is in the combination of so called Jakes spectrum [69]. This corresponds to a significantly lower *BER* ratio in case of RA6 model, whose paths (from second to six) have this type of Doppler spectrum (see Tab. 4.1). Secondly, dependeces of the *BER* after the Viterbi decoding were compared. In this case, bewtween the results (simulated and measured) there are small differences. For the QEF operation are needed 4.2 dB, 12.1 dB and 13.0 dB of *C*/*N* in AWGN, RA6 and TU6 channels, respectively.

Typical results and the constellation diagrams for the mobile transmission scenarios and channel types are also easy to see in the Fig. 6.4. There are presented the simulation (see Fig. 6.4 a) to c)) and measurement (see Fig. 6.4 d) to f)) constellation diagrams, when *C*/*N* was set on the 20.0 dB. All the constellations include channel correction and OFDM pilots. Abbreviations BER_1 and BER_2 are represent the *BER* ratio before and after Viterbi decoding. In case of the Gaussian and channel, after the equalization, the constellation diagram has any significant distortions. With this corresponds the high values of *MER*. Constellation diagrams in case of the RA6 and TU6 channels profile has a higher distortions, thank to the higher Doppler's shift.

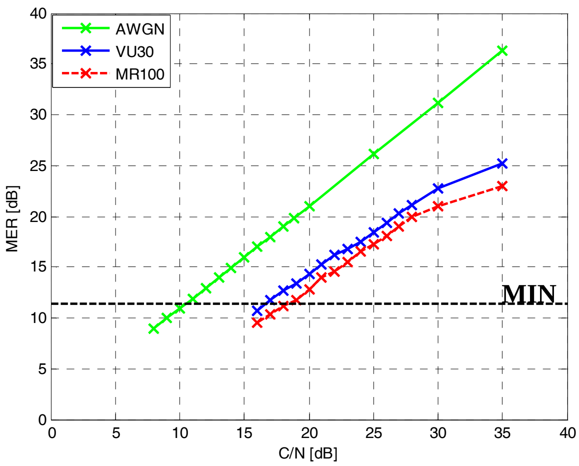
Finally, the spectrum of the DVB-T/H signal in all explored channel model, when 2K mode is used, is shown in Fig. 6.5 a) to Fig. 6.5 c). Firstly, of course, the spectrum is presented in Gaussian channel, as a reference (see Fig. 6.5 a)). After then the spectrums were explored in RA6 (Fig. 6.5 b)) and TU6 (Fig. 6.5 c)) channels. The dominance of the direct path and small delays between the paths in RA6 profile is reflected as a slow decrease to only one significant fading at the edge of the frequency range. On the other hand, the level of the signal is less, thank to higher path losses. In contrast to RA6 profile, in TU6 channel the spectrum is affected by the fadings in all frequency ranges.



a) BER before Viterbi decoding = f (*C/N*)

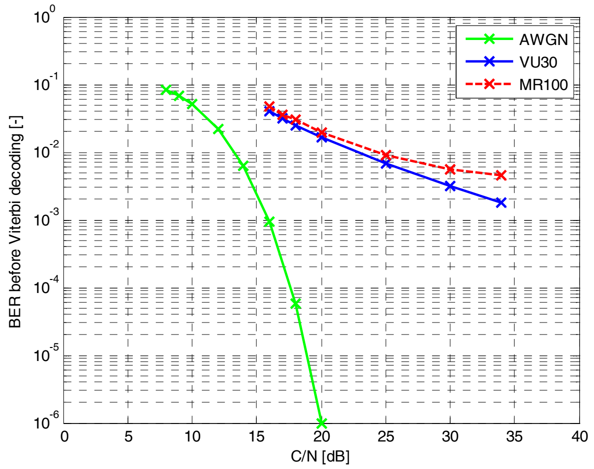


b) BER after Viterbi decoding = f (*C/N*)

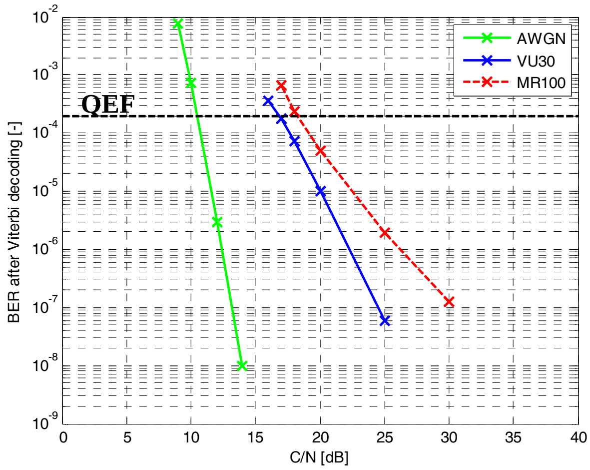


c) MER = f (*C/N*)

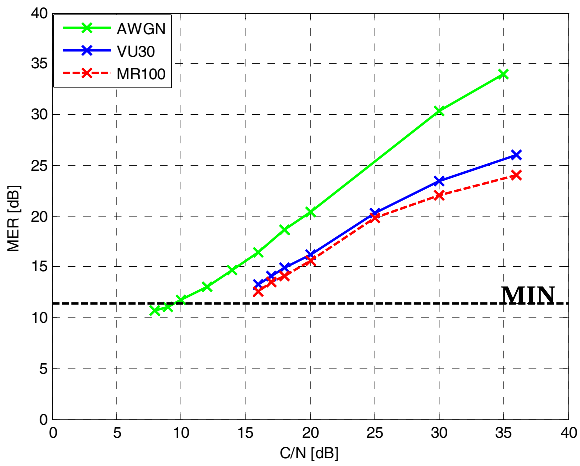
Fig. 6.6 Simulation: Mobile reception scenario (16QAM, 2K mode, code rate 2/3 and GI 1/4) and DVB-T/H performance in typical channel profiles.



a) BER before Viterbi decoding = f (*C*/*N*)

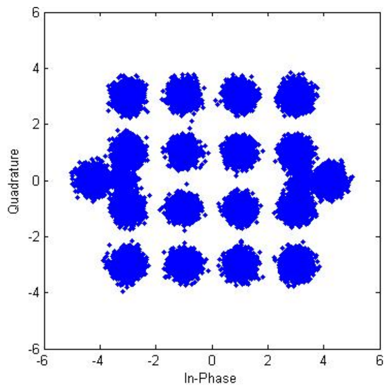


b) BER after Viterbi decoding = f (*C*/*N*)

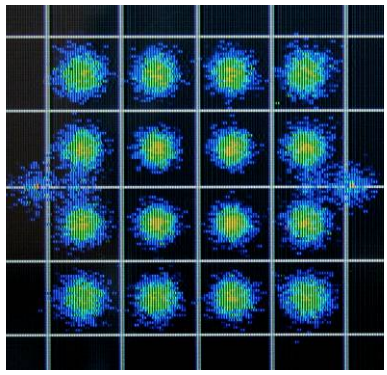


c) MER = f (*C*/*N*)

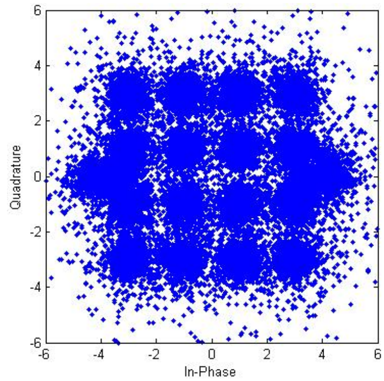
Fig. 6.7 Measurement: Mobile reception scenario (16QAM, 2K mode, code rate 2/3 and GI 1/4) and DVB-T/H performance in typical channel profiles.



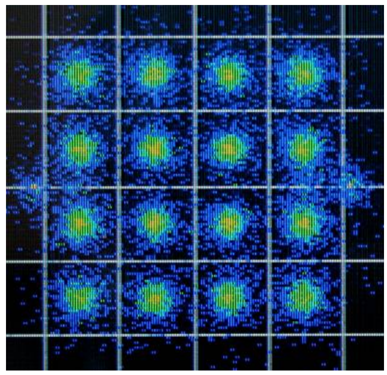
a) AWGN channel and mobile reception scenario, MER = 21.0 dB; $BER_1 < 1\cdot10^{-6}$; $BER_2 < 1\cdot10^{-8}$



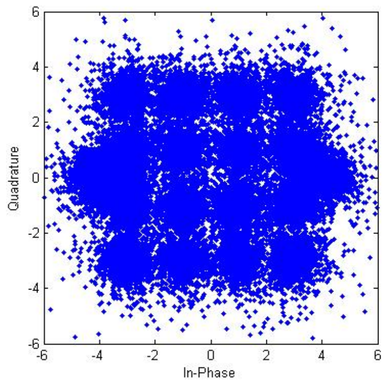
d) AWGN channel and mobile reception scenario, MER = 20.4 dB; $BER_1 = 1.0\cdot10^{-6}$; $BER_2 < 1\cdot10^{-8}$



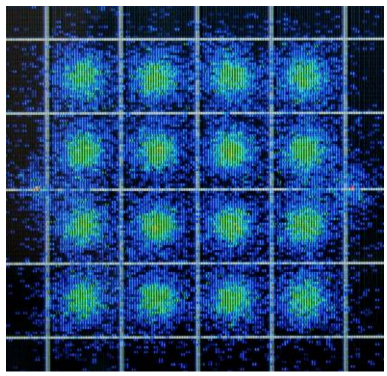
b) VU30 channel and mobile reception scenario, MER = 14.3 dB; $BER_1 = 1.1\cdot10^{-2}$; $BER_2 = 5.2\cdot10^{-5}$



e) VU30 channel and mobile reception scenario, MER = 16.2 dB; $BER_1 = 1.7\cdot10^{-2}$; $BER_2 = 1.0\cdot10^{-5}$



c) MR100 channel and mobile reception scenario, MER = 12.8 dB; $BER_1 = 1.3\cdot10^{-2}$; $BER_2 = 1.6\cdot10^{-4}$

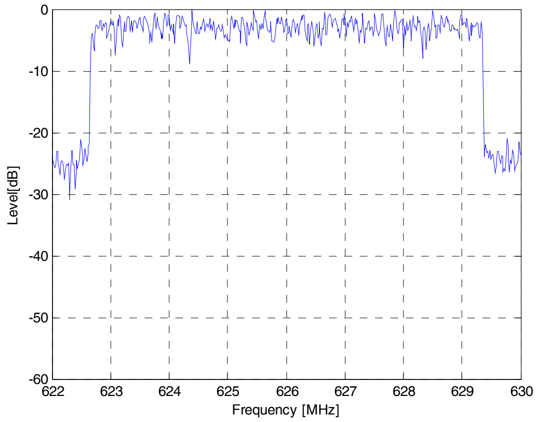


f) MR100 channel and mobile reception scenario, MER = 15.6 dB; $BER_1 = 2.0\cdot10^{-2}$; $BER_2 = 5.1\cdot10^{-5}$

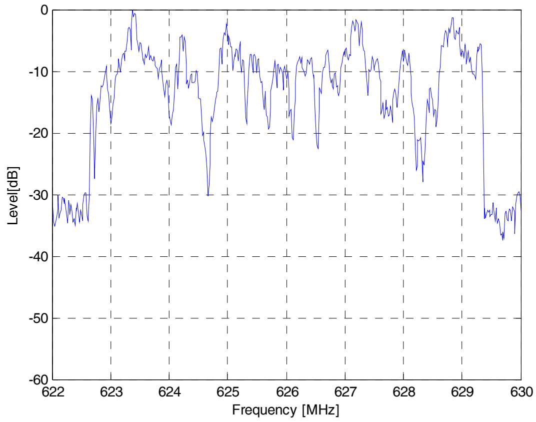
Fig. 6.8 Simulation and measurement: I/Q constellation of: a) to c) mobile scenario with 16QAM (simulation), d) to f) mobile scenario with 16QAM (measurement) also within typical DVB-T/H fading channels (all the constellations include channel correction and pilots, C/N = 20 dB).

Simulation results of the mobile TV transmission in the DVB-T/H standard for a varying *C*/*N* ratio in the Gaussian channel (AWGN) and in the mobile (VU30 and MR100) fading channels are in Fig. 6.6 a) to c). For the evaluation of the obtained results, the QEF operation is again used.

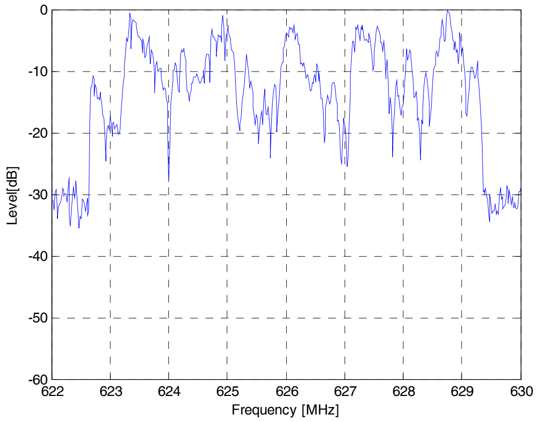
Firstly, dependences of the *BER* before (see Fig. 6.6 a)) and after (see Fig. 6.6 b)) Viterbi decoding on the *C*/*N* ratio in the Gaussian channel were obtained.



a) AWGN channel and mobile reception scenario



b) VU30 channel and mobile reception scenario



c) MR100 channel and mobile reception scenario

Fig. 6.9 Spectrum of one OFDM symbol in the DVB-T/H with 16QAM, 2K mode in channels a) Gaussian (AWGN), b) VU30 and c) MR100 (in all cases the *C*/*N* = 20 dB).

In the Gaussian channel, the obtained curve has a typical ("clear") waterfall effect, thank to the fact that there are available only a Gaussian distribution of a apmlitude. Before the channel corrections, a very low *BER* ratio (1.10^{-5}) can be achieved at 18.0 dB. Of course, from this fact can be expected that the *BER* after Viterbi decoding will be less and it can be achieved at less *C/N* ratio. From the Fig. 6.6 b) can be seen that this assumption was right, because the QEF reception is occurred at 12.5 dB.

Secondly, the *BER* ratio before (see Fig. 6.6 a)) and after (see Fig. 6.6 b)) the Viterbi decoding in the VU30 and MR100 mobile fading channels was explored. As it was briefly outlined in 4.2.3, both channel models have 12 independent paths. Concrete parameters (delays, path loss and Doppler spread) and their values for each path were obtained and determined from the real measurement data. Therefore, results in these channel models better reflected the features of the transmission environment. Of course, both channel models have different parameters. In the VU30 channel model the delays of paths are higher than in the MR100 model. On the other hand, paths losses are higher in the MR100 channel. Moreover, the speed of the receiver in the MR100 fading channel model is approx. 3 times higher than in the VU30 channel. Therefore, the Doppler shift is 17.38 Hz in the VU30 channel and 57.96 Hz in the MR100 channel.

How it can be seen from the Fig. 6.6 a) and b), the *BER* ratios before and after Viterbi decoding in both fading channel models are very similar and the features of the channels are reflected on the obtained results. More precisely, for the achieving a low bit error ratio is needed similar carrier-to-noise ratio. For the achieving of lower *BER* before the Viterbi (1.10^{-3}) decoding is approx. needed 31.0 dB in VU30 channel and 34.0 dB in MR100 channel, respectively. On the other hand, thank to the optimal system configuration (mainly for the OFDM mode and the length of guard interval), the situation after the Viterbi decoding (see Fig. 6.6 b)) is much better. The limit of the QEF reception (when the *BER* after Viterbi decoding ratio is equal to 2.10^{-4}) can be achieved at 19.1 dB in VU30 channel and at 19.9 dB in MR100 channel, respectively.

Dependences of the *MER* on the *C/N* in the all channel models were obtained and are graphically shown in Fig. 6.6 c). And again, minimal value, which is necessary to achieve for the QEF [7], is marked in the graph by MIN dashed line. How it can be seen, in the Gaussian channel, the curve of *MER* has a linear form and for the QEF operation is needed only 10.2 dB. Of course, in case of the VU30 and MR100 fading channel models, mainly thank to the higher Doppler's shift, the *MER* ratio is worse. The min. value for the QEF reception in this case can be achieved at 16.2 dB in VU30 channel. This value in MR100 channel is equal to 18.0 dB.

Detailed results of the laboratory measurement of the *BER* before (Fig. 6.7 a)) and after (Fig. 6.7 b)) the Viterbi decoding characteristics and *MER* (Fig. 6.7 a)) from constellation analysis in dB for DVB-T/H mobile services are evaluated and compared with results from simulations. In case of the measurement, the dependences of the *BER* on the *C/N* before the Viterbi decoding are slightly higher, than they were in case of the simulation. On the other hand, the *BER* ratios after the Viterbi decoding and *MER*, obtained by the measurement, are slightly better, in comparison with the results, achieved by the simulations. For the achieving of the QEF reception are needed 10.5 dB, 16.9 dB and 18.2 dB of *C/N* in AWGN, VU30, and MR100 channels, respectively.

Typical results and the constellation diagrams (simulated and measured) for the mobile transmission scenarios and channel types are also easy to see in Fig. 6.8 a) to f).

Finally, the spectrum of the DVB-T/H signal in all explored mobile channel models (VU30, MR100), when 2K mode is used, is shown in Fig. 6.9 a) to Fig. 6.9 c). How it can be seen, in both fading channel models (VU30, MR100), the spectrum is affected by the deep fadings in all frequency ranges (see Fig. 6.9 b) and c)).

6.2 PORTABLE RECEPTION SCENARIO

This part of dissertation thesis deals with the exploring of the signal distortions of DVB-T/H transmission in portable TV channels. In the context of DVB-T/H standard, the portable scenario represents the situation, when the mobile phone or terminal can be easily taken from one place to another at very low speed. For the modeling of this scenario there are used two fading channels, respect the low speed of the receiver (low Doppler's shift), namely the PI (Pedestrian Indoor) and the PO (Pedestrian Outdoor) channel profiles.

Both channel profiles, PI (see Fig. 4.3 a)) and PO (see Fig. 4.3 b)) [74], are fundamentally similar. Both channel models have one direct path (see Tab. 4.4), which is shifted in frequency by half of the maximum value of the Doppler shift. This value is the same for PI and PO channels, as well as a speed of the receiver (v = 3 km/h). The main difference between these channel models is in the length of the impulse response and the delay of output paths. The PI model has longer maximum delay, but all paths (with delays) are more attenuated than in PO model. For the simulation and also for the measuring were chosen 4K OFDM mode and 16QAM modulation (better used for portable reception), thank to the low Doppler's shift.

The DVB-T/H system transmission parameters were set again to the European most common type of DTV broadcasting. These parameters are the most characteristic for the mid size of the DVB-T/H SFN networks:

- 8 MHz channel (bandwidth 7.068 MHz)
- 2/3 convolutional code (robust protection)
- 4K (portable) OFDM mode
- 16QAM (portable) non-hierarchical modulation
- 1/8 Guard Interval (mid size of SFN)
- AWGN (Gaussian), Pedestrian Indoor and Outdoor (PI and PO) channel models
- Viterbi decoding: hard.

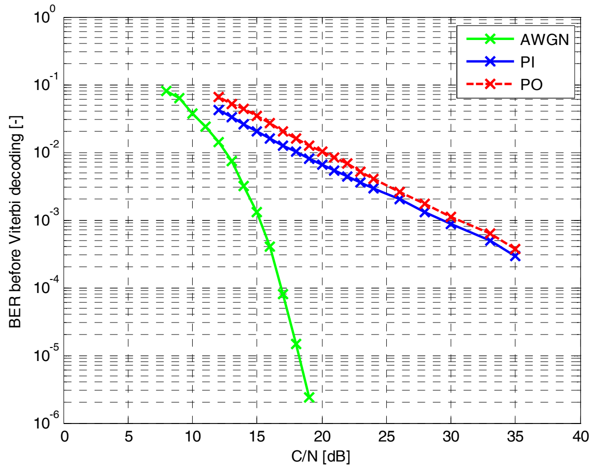
6.2.1 Simulation and Measurement

The simulation and measurement of the DVB-T/H transmission in portable transmission scenario were done by the same way as it was presented in 6.1.1, only the parameters were changed. Therefore, the detail description of the method of measurement in this part is omitted.

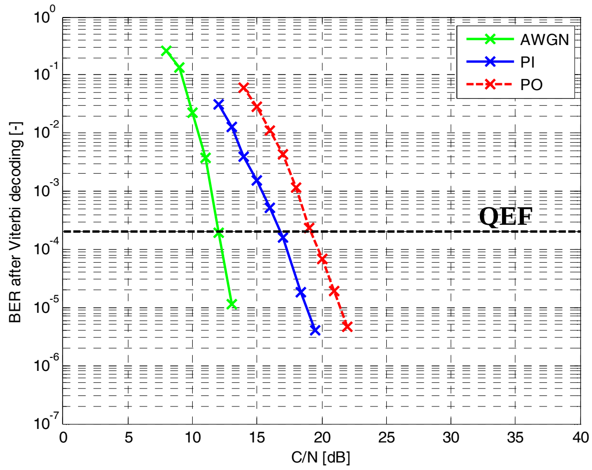
6.2.2 Experimental Results and Their Evaluation

Simulation results of the portable TV transmission in the DVB-T/H standard for a varying *C*/*N* ratio in the Gaussian channel (AWGN) and in the portable (PI and PO) fading channels are in Fig. 6.10 a) to c).

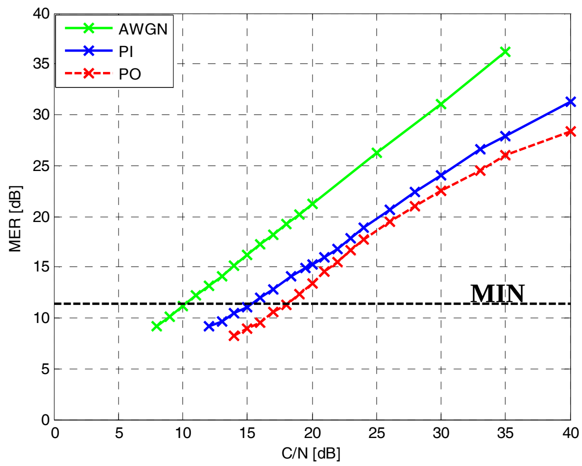
The QEF [3] operation is defined by same way, as it was described in 6.1.2.



a) BER before Viterbi decoding = f (C/N)

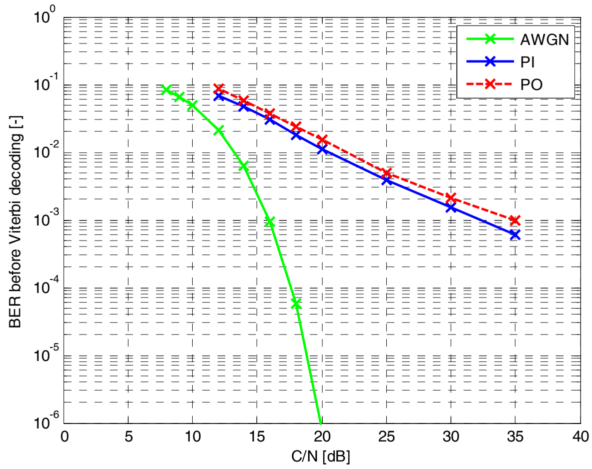


b) BER after Viterbi decoding = f (C/N)

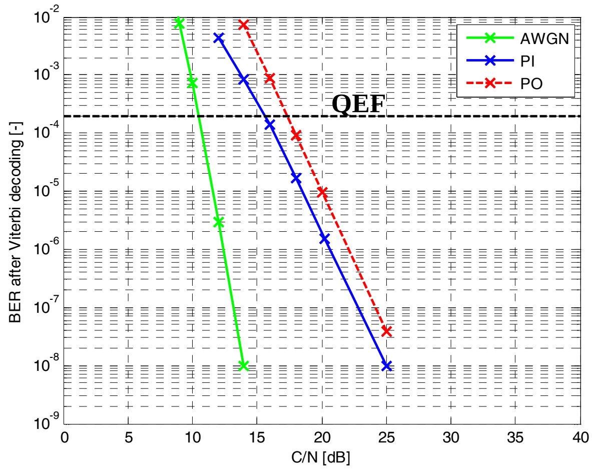


c) MER = f (C/N)

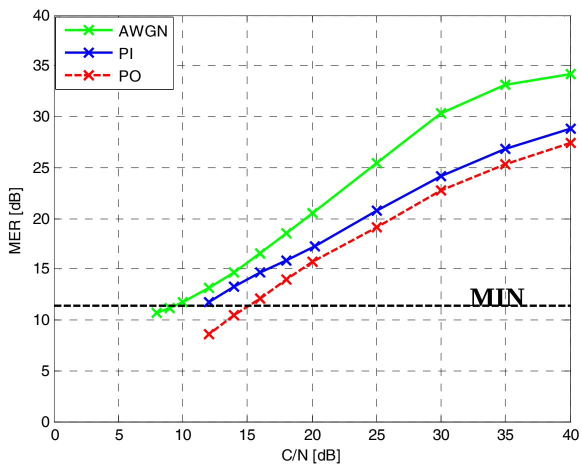
Fig. 6.10 Simulation: Portable reception scenario (16QAM, 4K mode, code rate 2/3 and GI 1/8) and DVB-T/H performance in typical channel profiles.



a) BER before Viterbi decoding = f (C/N)

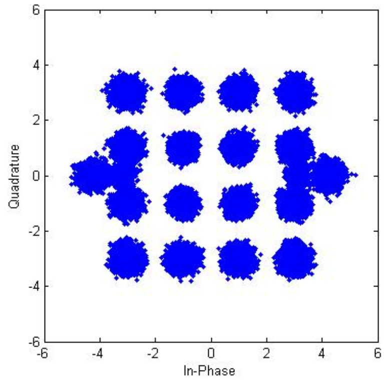


b) BER after Viterbi decoding = f (C/N)

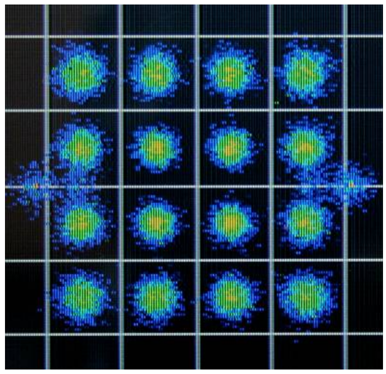


c) MER = f (C/N)

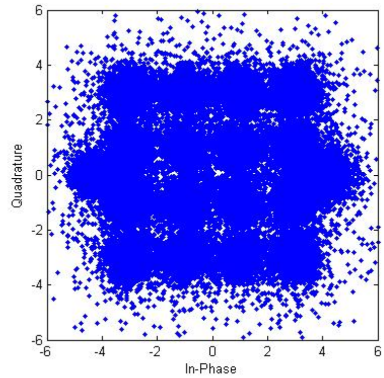
Fig. 6.11 Measurement: Portable reception scenario (16QAM, 4K mode, code rate 2/3 and GI 1/8) and DVB-T/H performance in typical channel profiles.



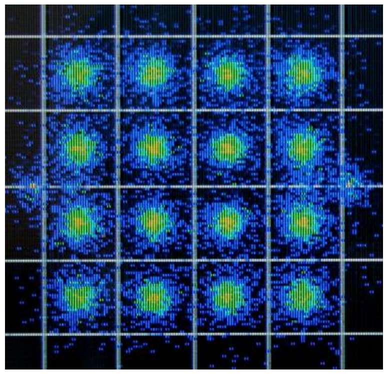
a) AWGN channel and portable reception scenario, MER = 21.2 dB; $BER_1 < 1\cdot10^{-6}$; $BER_2 < 1\cdot10^{-9}$



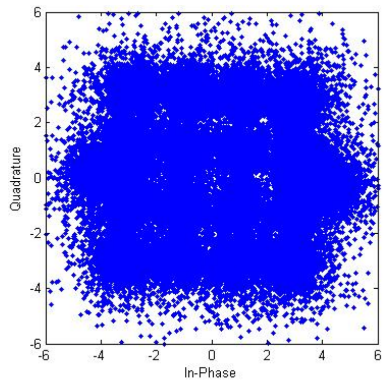
d) AWGN channel and portable reception scenario, MER = 20.5 dB; $BER_1 = 1.0\cdot10^{-6}$; $BER_2 < 1\cdot10^{-9}$



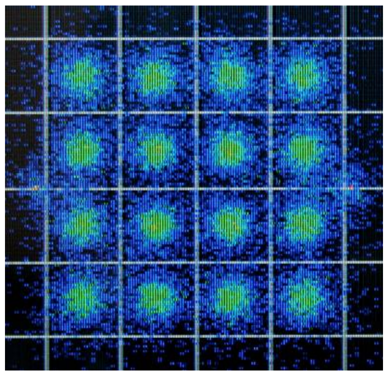
b) PI channel and portable reception scenario, MER = 15.3 dB; $BER_1 = 6.6\cdot10^{-3}$; $BER_2 = 2.0\cdot10^{-6}$



e) PI channel and portable reception scenario, MER = 17.0 dB; $BER_1 = 1.1\cdot10^{-2}$; $BER_2 = 1.5\cdot10^{-6}$



c) PO channel and portable reception scenario, MER = 13.4 dB; $BER_1 = 1.0\cdot10^{-2}$; $BER_2 = 6.8\cdot10^{-5}$



f) PO channel and portable reception scenario, MER = 15.8 dB; $BER_1 = 1.5\cdot10^{-2}$; $BER_2 = 9.4\cdot10^{-6}$

Fig. 6.12 Simulation and measurement: I/Q constellation of: a) to c) portable scenario with 16QAM (simulation), d) to f) portable scenario with 16QAM (measurement) also within typical DVB-T/H fading channels (all the constellations include channel correction and pilots, C/N = 20 dB).

The Fig. 6.10 from a) to b) shows the simulated dependences of the *BER* on the *C*/*N* ratio in portable channel before and after Viterbi decoding. Firstly, of course, dependence of the *BER* on the *C*/*N* in the reference, Gaussian channel is investigated. As it can be seen, dependence of error rate on *C*/*N* ratio has again a waterfall form. Of course, in this channel is always needed the lower *C*/*N* ratio for the achieving of low *BER* ratio. More precisely, a 1.10^{-5} *BER* ratio before the Viterbi decoding it can be achieved at 18.1 dB. This value is higher, how it was in case, when QPSK modulation was used. Reason is that the 16QAM modulation has less resistance to the white noise.

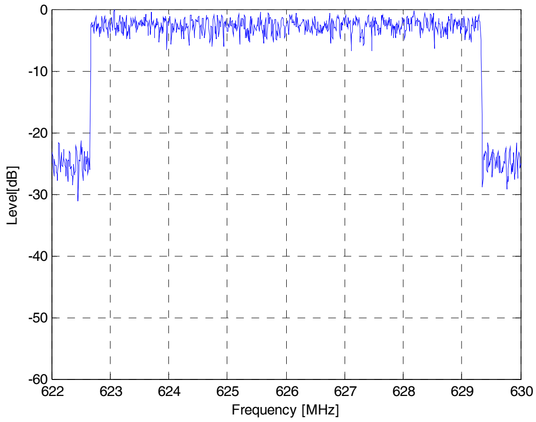
The Fig. 6.10 a) also illustrates the *BER* before Viterbi decoding in the PI (Pedestrian Indoor) fading channel model. As it was described in 4.2.3, PI channel profile models the signal transmission inside of buildings. It consists of 1direct path and 11 echo paths. This channel profile has longer delays of paths (the longest delay is equal to 9.2 us), compare to PO (Pedestrian Outdoor) channel profile, but the losses of paths are less (the max attenuation is equal to -16.2 dB), as are in PO channel. How it was described above, the portable scenario represents the situation, when the speed of the receiver is very slow (around 3 km/h). Therefore, a low Doppler's shift will be available and its value is equal to 1.738 Hz. This value was calculated by the same way, as it was presented in 6.1.2. Parameters (carrier frequency, speed of light and angle φ) are the same, only the speed of the receiver is different.

How it can be seen from the Fig. 6.10 a) all these effects are again reflected on the *BER*, as it was in case of RA6 and TU6 channels. Dependence of the error ratio on the *C*/*N* ratio has not a typical waterfall form. It has a more linear form, as it was in VU30 and MR100 channels (see Fig. 6.6 a)). With the increasing of the signal power the error rate is decreasing linearly. Therefore, it is possible to achieve a 10^{-3} *BER* ratio before the Viterbi decoding in case, when *C*/*N* ratio is equal to 29.0 dB. The situation after Viterbi decoding is different (see Fig. 6.10 b)). Thank to the advanced FEC scheme and optimal system configuration, the QEF reception can be achieved at less *C*/*N* ratio, approx. at 16.9 dB. Before the Viterbi decoding, at 12.0 dB it can be achieved only $3.2.10^{-2}$ error rate.

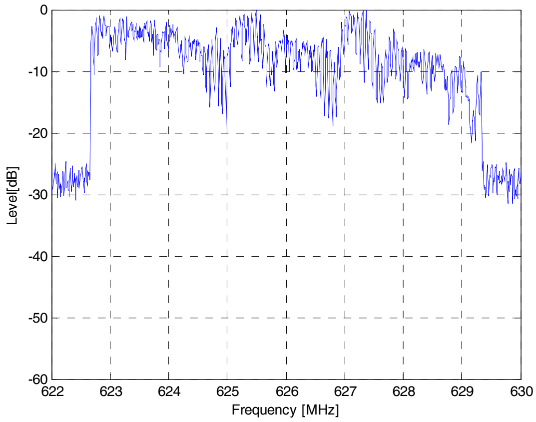
As a last one, the PO fading channel model was used for the exploring of the signal distortions in case of the portable scenario. This channel profile, as it was briefly described above (see 4.3), models the outdoor reception. In comparison of the PI channel, this channel model has again 1 direct path and 11 echo paths. The PO profile is very similar to PI profile, as it was mentioned several times. It is considered the same speed of the receiver (Doppler's shift) and the spectral performance of each path is also the same, how it is in the PI model. The PO channel profile has smaller delays of paths (the smallest delay is equal to 5.7 us), but the losses of paths are higher (the max attenuation is equal to -20.6 dB). Generally, in both channel models there is dominant influence of attenuation. Therefore, the PO model has worse results in simulation.

The Fig. 6.10 a) illustrates the dependence of the *BER* on the *C*/*N* ratio before Viterbi decoding, when the PO channel model was used. In comparison with PI channel, there it can be observed a very similar, high *BER* ratio before Viterbi decoding. Dependence of the error ratio on the *C*/*N* ratio has again a linear form. Moreover, the similarity of parameters, which have both channels, is also reflected on the obtained results. To achieve a 10^{-3} *BER* ratio before Viterbi decoding is needed a little bit higher value of *C*/*N* ratio, as it was in PI channel, approx. 30.5 dB. On the other hand, after the Viterbi decoding for the QEF reception is needed only 19.1 dB.

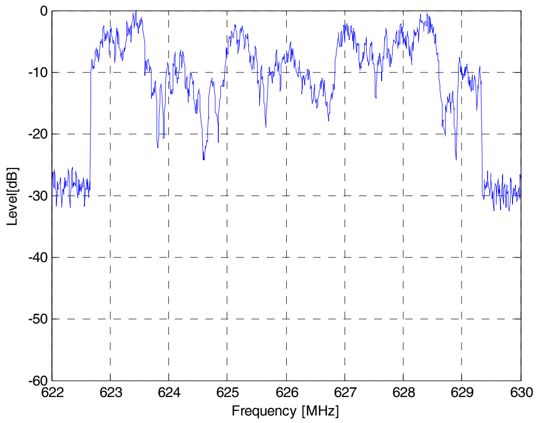
Dependences of the *MER* on the *C/N* in the systems DVB-T/H in case of portable reception scenario were obtained and there are shown in Fig. 6.10 c). And again, the minimal value, which it is necessary to achieve the QEF reception [7], is marked in the graph by MIN dashed line. Firstly, the *MER* ratio is explored in the (Gaussian) channel. The dependence between the *MER* and the *C*/*N* ratio is again linear.



a) AWGN channel and portable reception scenario



b) PI channel and portable reception scenario



c) PO channel and portable reception scenario

Fig. 6.13 Spectrum of one OFDM symbol in the DVB-T/H with 16QAM, 4K mode in channels a) Gaussian (AWGN), b) PI and c) PO (in all cases the C/N = 20 dB).

The reason is the same, as it was in case of mobile scenario. On the other hand, for the achieving of min. *MER* ratio is needed higher level of signal (approx. 10.0 dB), thank to the fact that it is used 16QAM modulation. Surprisingly, in case of portable scenarios (PI and PO channels) the dependence between the modulation error ratio and level of the signal has nearly linear character. Moreover, both dependences in PI and PO channels are very similar. Of course, this effect is thanked to the similar features, which PI and PO channel profiles have. As it can be seen from Fig. 6.10 c), in PI channel is needed 15.2 dB for achieving a min value for the *MER* ratio. This value in PO channel is equal to 18.0 dB.

Obtained results from the laboratory measurement of the *BER* before and after Viterbi decoding characteristics and *MER* from constellation analysis in dB for DVB-T/H portable services are available in the Fig. 6.11 a) to Fig. 6.11 c). And again, results from measuring are obtained at same system conditions and settings, which were used for the simulation. From the comparison of both results (simulation and measuring) is clearly seen that the the obtained results have similar form, as it was in the case of mobile scenario, when the VU30 and MR100 channels were considered. More precisely, dependences of the *BER* after the Viterbi decoding and *MER* on the *C*/*N* ratio are slightly better, in comparison with the simulation results.

Typical results and the constellation diagrams for the portable transmission scenarios and channel types are also easy to see in the Fig. 6.12 a) to f). There are again presented the simulation (Fig. 6.12 a) to c)) and measurement ((Fig. 6.12 d) to f)) constellation diagrams, when *C*/*N* was set on the 20 dB. All the constellations include channel correction and OFDM pilots and the abbreviations BER_1 and BER_2 are again represented the bit error ratio before and after Viterbi decoding. In case of Gaussian channel the constellation diagrams are without any significant distortions and the *MER* ratio is very high. Constellation diagram (after the channel corrections) in the PI channel has a little bit higher distortions. Of course, these are caused by the Doppler's shift and higher path delays. Finally, the constellation diagram in the PO channel has obtained and explored. In this case, the distortions in constellation diagram are high, which are mainly caused by the parameters, which has PO channel and by the fact that 16QAM modulation has less resistance to the noises (caused by the multipath propagation).

The spectrum of the DVB-T/H signal in all explored channel models, when 4K mode is used, is shown in Fig. 6.13 a) to Fig. 6.13 c). Spectrum in the Gaussian channel, as a reference is explored firstly (see Fig. 6.13 a)). In the spectrum can not see any higher distortions or noises. Spectrum of signal in PI (see Fig. 6.13 b)) and PO (see Fig. 6.13 c)) channels are explored too. In these spectrums can be clearly seen the differences in the depth of the frequency fadings. These deep fadings are mainly caused by higher power levels of paths of the channel model. On the other hand, higher number of repeating fadings in PI channel is caused by the generally higher delays of paths.

6.3 FIXED RECEPTION SCENARIO

This part of dissertation thesis deals with the exploring of the signal distortions of DVB-T/H transmission in fixed TV channels. There are used two fading channel profiles without Doppler's shift, namely RC20 (Ricean) and RL20 (Rayleigh) channels.

Performance of the DVB-T/H has been simulated during the development of the standard [7], [73] with two channel models for fixed reception – Ricean (RC20) and Rayleigh (RL20), respectively. These are theoretical channel profiles for simulation without Doppler shift. For DVB-T/H transmission analysis the RC20 and RL20 channels with twenty paths is convenient and it was used for C/N performance evaluation [7], [73].

Both channel profiles, RC20 (see Fig. 4.4 a)) and RL20 (see Fig. 4.4 b)) [8], are almost similar. Ricean channel represents the transmission model with several reflected echo signals and one direct path. For the modeling of the Ricean channel, the ETSI standard [8] defines 20 paths. Each of these paths have own delay, gain and phase shift. Furthermore, in RC20 model also available a direct path between the transmitter and receiver. Its level is characterized by the parameter *K* (see 4.4.1). In contrast to RC20 channel model, RL 20 channel has only echo paths (no direct signal between the communication parts).

The DVB-T/H system transmission parameters were set again to the European most common type of DTV broadcasting. These parameters are the most characteristic for the mid size of the DVB-T/H SFN networks:

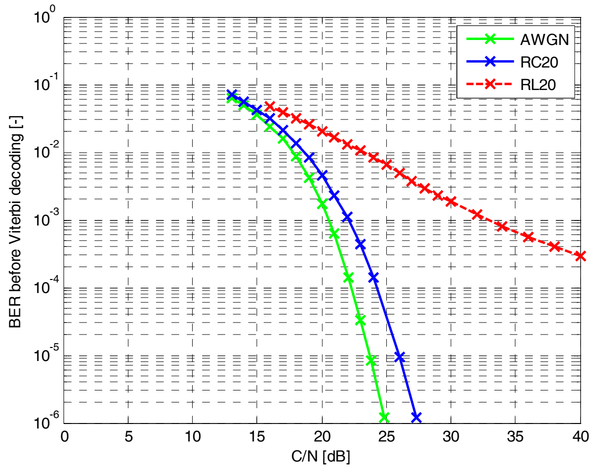
- 8 MHz channel (bandwidth 7.068 MHz)
- 2/3 convolutional code (robust protection)
- 8K (fixed) OFDM mode
- 64QAM (fixed) non-hierarchical modulation
- 1/8 Guard Interval (mid size of SFN)
- AWGN (Gaussian), Ricean and Rayleigh (RC20 and RL20) channel models
- Viterbi decoding: hard.

6.3.1 Simulation and Measurement

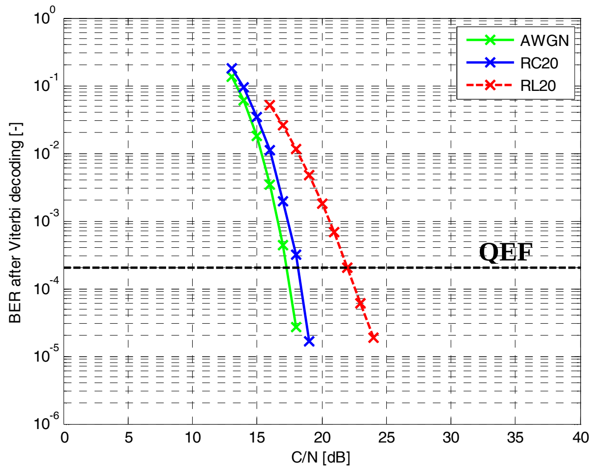
The simulation and measurement of the DVB-T/H transmission in fixed transmission scenario were done by the same way as it was presented in 6.1.1, only the system parameters were changed. Therefore, the detail description of the method of measurement in this part is omitted.

6.3.2 Experimental Results and Their Evaluation

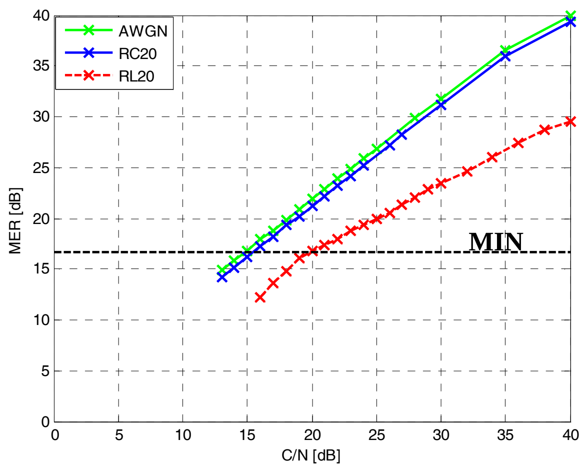
Simulation results of the fixed TV transmission in the DVB-T/H standard for a varying *C*/*N* ratio in the Gaussian channel (AWGN) and in the fixed (RC20 and RL20) fading channels are in Fig. 6.14 a) to c). Firstly, dependence of the *BER* on the *C*/*N* ratio in the reference, Gaussian channel was explored.



a) BER before Viterbi decoding = f (*C*/*N*)

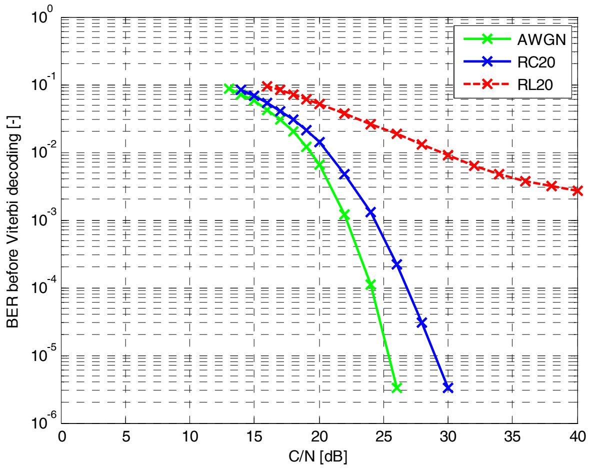


b) BER after Viterbi decoding = f (*C*/*N*)

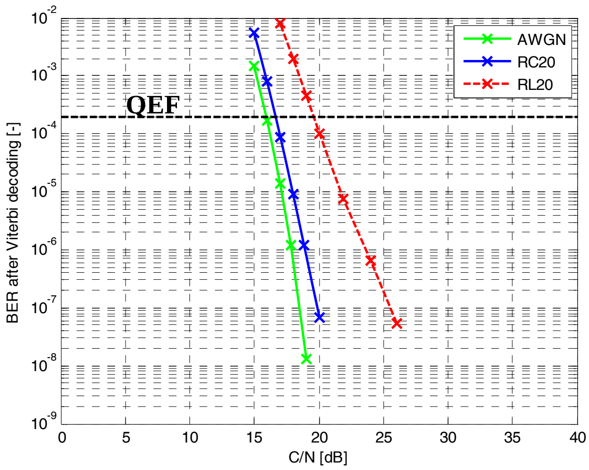


c) MER = f (*C*/*N*)

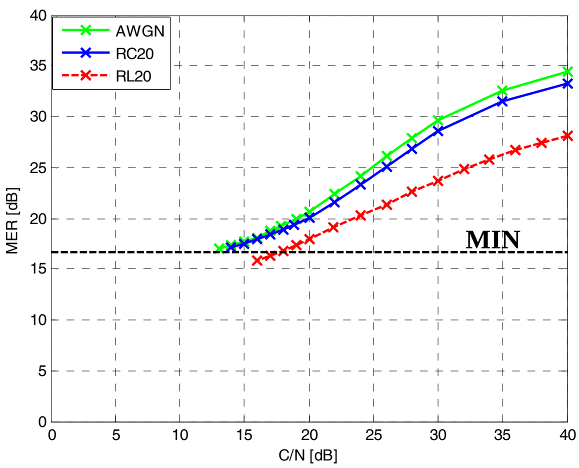
Fig. 6.14 Simulation: Fixed reception scenario (64QAM, 8K mode, code rate 2/3 and GI 1/8) and DVB-T/H performance in typical channel profiles.



a) BER before Viterbi decoding = f (C/N)

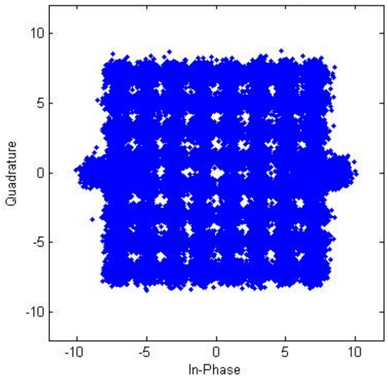


b) BER after Viterbi decoding = f (C/N)

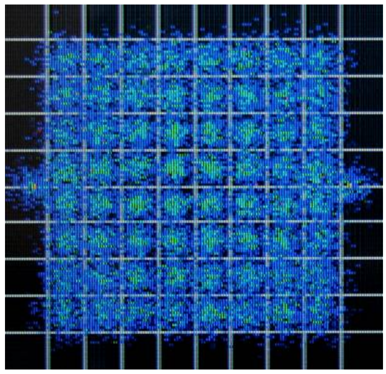


c) MER = f (C/N)

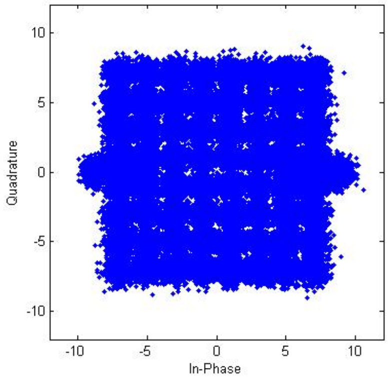
Fig. 6.15 Measurement: Fixed reception scenario (64QAM, 8K mode, code rate 2/3 and GI 1/8) and DVB-T/H performance in typical channel profiles.



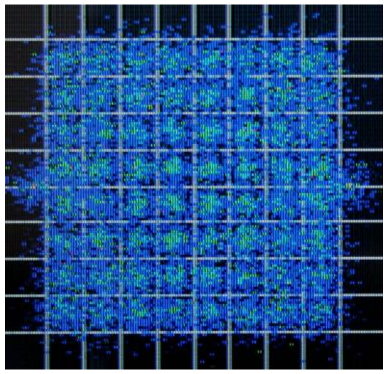
a) AWGN channel and fixed reception scenario, MER = 21.9 dB; $BER_1 = 1.7 \cdot 10^{-3}$; $BER_2 < 1 \cdot 10^{-6}$



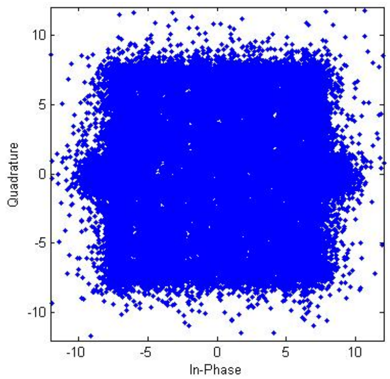
d) AWGN channel and fixed reception scenario, MER = 20.6 dB; $BER_1 = 6.4 \cdot 10^{-3}$; $BER_2 < 1 \cdot 10^{-8}$



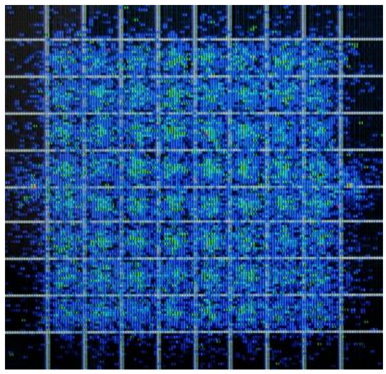
b) RC20 channel and fixed reception scenario, MER = 21.2 dB; $BER_1 = 4.6 \cdot 10^{-3}$; $BER_2 < 1.1 \cdot 10^{-5}$



e) RC20 channel and fixed reception scenario, MER = 20.1 dB; $BER_1 = 1.4 \cdot 10^{-2}$; $BER_2 < 1 \cdot 10^{-6}$



c) RL20 channel and fixed reception scenario, MER = 16.8 dB; $BER_1 = 2.1 \cdot 10^{-2}$; $BER_2 = 1.8 \cdot 10^{-3}$



f) RL20 channel and fixed reception scenario, MER = 17.9 dB; $BER_1 = 5.1 \cdot 10^{-2}$; $BER_2 = 1.0 \cdot 10^{-4}$

Fig. 6.16 Simulation and measurement: I/Q constellation of: a) to c) fixed scenario with 64QAM (simulation), d) to f) fixed scenario with 64QAM (measurement) also within typical DVB-T/H fading channels (all the constellations include channel correction and pilots, C/N = 20 dB).

Dependences of the *BER* on the *C*/*N* ratio before and after Viterbi decoding in fixed TV channel are shown in Fig. 6.14 a) to b). All these dependences are obtained from the simulation. Firstly, the signal distortions in the reference, Gaussian (AWGN) channel is investigated. The obtained curve has typical waterfall form and a 1.10^{-5} *BER* ratio before Viterbi decoding it can be achieved approximately at 23.8 dB. This value is high, but on the other hand, 64QAM modulation is used. This type of modulation has a lowest resistance to the noises, but data stream, which is transferred, are the largest.

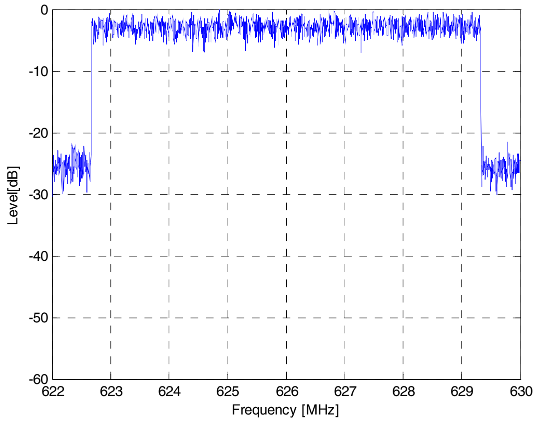
The *BER* ratio before Viterbi decoding, obtained by simulation, in the RC20 (Ricean) fading channel model is illustrated in the Fig. 6.14 a). How it was briefly described in 4.4, this channel profile consists of 1 direct path and 20 indirect paths. These paths are defined by the path loss, delay and phase shift. The receiver is in the fixed position. Therefore, the Doppler's shift is equal to zero. The properties of this channel profile reflect realistic reception conditions and worst-case scenarios and generally used to verify specific features of the DVB-T/H standard [73]. In the RC20 channel model the longest delay of path is equal to 5.42 us, the highest path loss is equal to -25.75 dB and highest phase shift is equal to 339.67°.

How it can be seen, dependence of the error ratio on the carrier-to-noise ratio in the RC20 channel has a typical waterfall effect (see Fig. 6.14 a)). Moreover, the shape of curve is very similar to the curve, which was obtained in the Gaussian channel. The main reason is the several time mentioned direct path and a fact that *K* factor is equal to 10. From the results is also clear that the delay, path loss and phase shift of paths has not significant effect on the error ratio (thank to again a strong direct path). To achieve a 1.10^{-5} *BER* ratio before the Viterbi decoding is needed 26.0 dB. Thank to the advanced FEC scheme, the QEF reception (after the Viterbi decoding) can be achieved at very low *C*/*N* ratio, concretely at 18.1 dB.

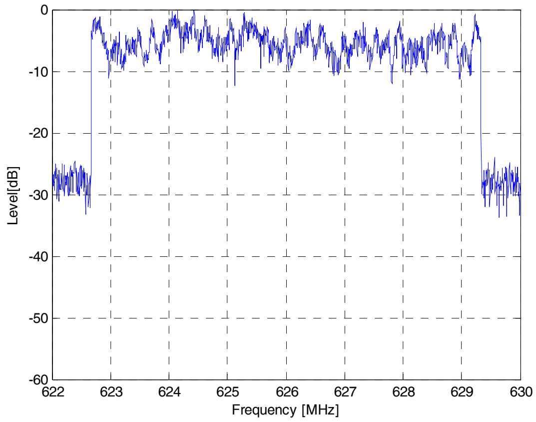
The second channel model, which is generally used for the exploring of transmission distortions in the fixed TV channels, is called RL20 (Rayleigh). This channel model has the same parameters, as the RC 20 model (20 independent echo paths, delays, path loss and phase shift), but the direct path between the transmitter and receiver is missing. Thank to this "disadvantage", ensure to good reception conditions between communications sides are more difficult. On the other hand, this channel profile is much better for modeling of the real fixed scenario reception, because, in general, between the transmitter and receiver does not exist a direct connection. Therefore, it can be expected that in the Rayleigh channel will be obtained worse results.

The Fig. 6.14 a) also illustrates the dependence of the *BER* on the *C*/*N* ratio before the Viterbi decoding, when the RL20 channel model is used. In comparison with Gaussian and RC20 channels, it can be observed a higher *BER* ratio before the Viterbi decoding. This is mainly thanked to the absence of the direct path. To achieve a 10^{-3} *BER* ratio before the Viterbi decoding is needed a much higher value of *C*/*N* ratio, as it was in Gaussian and RC20 channels, approximately 33.0 dB. After the Viterbi decoding (see Fig. 6.14 b)), the QEF reception is possible achieve at 22.0 dB.

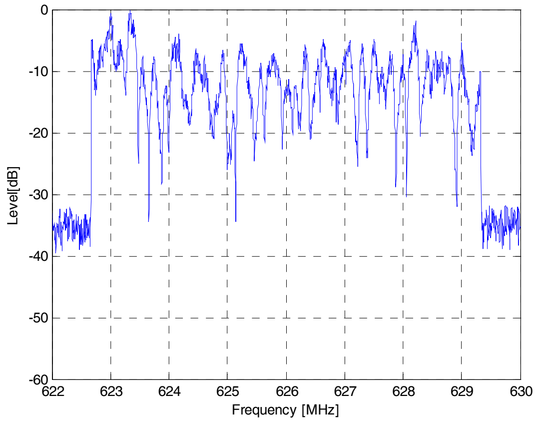
Dependences of the *MER* on *C*/*N* ratio at transmission in DVB-T/H system, when the fixed reception scenario was explored, are also obtained and are clearly shown in Fig. 6.14 c). And again, the minimal value for the achieving of the QEF operation is marked in the graph by MIN dashed line. In case of the reference (Gaussian) and RC20 channel the dependences of the *MER* on *C*/*N* are very similar. The reason is that in the RC20 channel model is also available a very strong direct path between the transmitter and receiver. Thank to this fact, the required min value of *MER* it can be achieved at 15.0 dB in Gaussian and at 15.9 dB in RC20 channels, respectively. The RL20 channel model contains only echo paths and reflections. Therefore, in this channel for the achieving of the appropriate *MER* value is needed 20.0 dB.



a) AWGN channel and fixed reception scenario



b) RC20 channel and fixed reception scenario



c) RL20 channel and fixed reception scenario

Fig. 6.17 Spectrum of one OFDM symbol in the DVB-T/H with 64QAM, 8K mode in channels a) Gaussian (AWGN), b) RC20 and c) RL20 (in all cases the $C/N = 20$ dB).

Detailed results of the laboratory measurement of the *BER* before and after Viterbi decoding characteristics and *MER* from constellation analysis in dB for DVB-T/H fixed TV services are available in the Fig. 6.15 a) to c). Results from measuring are obtained at same conditions and settings, which were used for the simulation. Of course, *BER* before Viterbi decoding (see Fig. 6.15 a)) was explored firstly in the reference (AWGN) channel and then in the fixed fading channel models (RC20 and RL20). From the comparison of both results (simulation and measurement) is clearly visible that the obtained dependences are slightly different. In case of Gaussian and RC 20 channels, the bit error ratio curve has a well known waterfall form. In RL20, the form of curve has more linear dependences on the actual carrier-to-noise ratio. On the other hand, obtained dependences from simulation and measurement after the Viterbi decoding are very similar. In case of simulation, for the QEF operation is needed 17.2 dB (AWGN), 18.1 dB (RC20) and 22.0 dB (RL20), respectively. In case of measuring, these value are 15.9 dB (AWGN), 16.7 dB (RC20) and 19.6 (RL20).

Typical results and the constellation diagrams for the fixed TV transmission scenarios and channel types are also easy to see in the Fig. 6.16 a) to f). In case of Gaussian and RC20 channels, after the equalization the constellation diagrams are without any significant distortions. In case of RL20 channel profile, the constellation diagram is much worse. There are two reasons. Firstly, in the RL20 channel can be always obtain a worse signal quality. Secondly, 64QAM modulation (thank to higher number of states in multistate modulation) has a very low resistance to the noises.

Finally, the spectrum of the DVB-T/H signal in all explored channel model, when 8K mode is used, is shown in Fig. 6.17 a) to Fig. 6.17 c). Of course, firstly the spectrum in Gaussian channel is explored, as a reference (see Fig. 6.17 a)). After then the spectrums in RC20 (Fig. 6.17 b)) and RL20 (Fig. 6.17 c)) channels were explored. The dominance of the direct path in RC20 profile is reflected as a slow decrease of the signal level in all frequency range. In contrast to RC20 profile, in RL20 channel the spectrum is very affected by the fadings and echoes in all frequency range.

The differences in *BER* and *MER* results for the various transmission scenarios and channel types for 20 dB *C*/*N* ratio are also easy to compare in the Tab. 6.1.

Tab. 6.1 Required C/N for QEF operation in the DVB-T/H standard in different scenarios

Scenario	**Modulation**	**Channel**	**ETSI EN 300 744**	**Simulation**	**Measurement**
			C/N [dB]	**C/N [dB]**	**C/N [dB]**
Mobile (2K mode)	QPSK	AWGN	5.3	6.0	4.2
		RA6	-	11.5	12.1
		TU6	-	13.3	13.0
	16QAM	AWGN	11.4	12.5	10.5
		VU30	-	19.1	16.9
		MR100	-	19.9	18.2
Portable (4K mode)	16QAM	AWGN	11.4	12.0	10.5
		PI	-	16.9	15.7
		PO	-	19.1	17.5
Fixed (8K mode)	64QAM	AWGN	16.7	17.2	15.9
		RC20	17.3	18.1	16.7
		RL20	20.3	22.0	19.6

7 Analysis of the DVB-SH Transmission in Fading Channels

This part of dissertation thesis deals with the exploring and analysis of the transmission distortions in DVB-SH standard (in both SH-A and SH-B modes) in all most used scenarios (mobile, portable and flexible) over fading channels. The DVB-SH performance was not tested in a laboratory environment, because appropriate measurement devices, during at the work on this dissertation thesis, were not available. Therefore, there are presented only the results, which were obtained from simulations.

7.1 MOBILE RECEPTION SCENARIO

Typical fading channel models, which are generally used for the exploring of the performance of mobile TV transmission, were outlined in this dissertation thesis and there were described several times. Therefore, their description in this part will be omitted.

As it was described in 3.2.2, thank to very flexible 3GPP2 turbo encoder, there are exist many type of code rates, which are enable flexible encoding (or puncturing) of the input stream. Therefore, the settings of the transmission modes are much higher. One of the most important goals of this dissertation thesis is the examination of the transmission distortions of the DVB-H/SH standards in different transmission scenarios. For this purpose it is very important to ensure that for the exploring would be used same parameters for both standards. For all investigated scenario (mobile, portable and flexible) in DVB-H has set the CR (Code Rate) to 2/3. This CR represents the case of quite robust transmission. However, in the DVB-SH standard this code rate represents the lowest robustness of the transmission. Therefore, after the detail study of performance of the turbo code rates, the CR for DVB-SH was set to 1/4.

The DVB-SH-A (OFDM mode) system transmission parameters, which were used for the exploring of the signal distortions in mobile TV channels, are follows:

- 8 MHz channel (bandwidth 7.068 MHz)
- 1/4 turbo code (robust protection)
- 2K (mobile) OFDM mode
- QPSK (mobile) non-hierarchical modulation
- 1/16 Guard Interval (small size of SFN)
- AWGN (Gaussian), Rural Area (RA6) and Typical Urban (TU6) channel models
- Turbo decoding: SISO-MAP (see 5.2.2)
- Number of iterations: 8 (as recommended in [12]).

7.1.1 Experimental Results and Their Evaluation

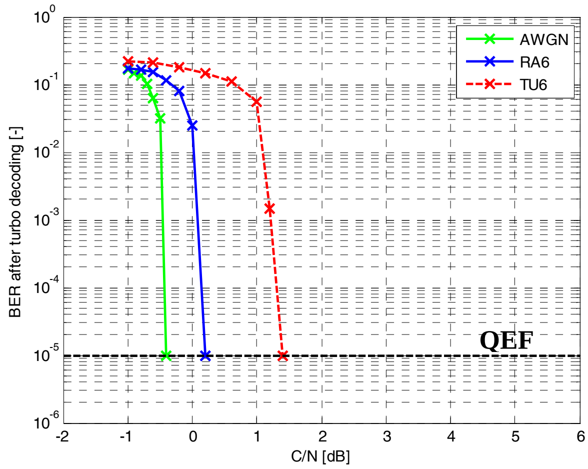
Simulation results of the mobile TV transmission in the DVB-SH-A standard for a varying *C/N* ratio in the Gaussian channel (AWGN) and in the mobile (RA6 and TU6) fading channels are in Fig. 7.1 a) to b). Firstly, dependence of the *BER* on the *C/N* in the reference, Gaussian channel was explored and analyzed.

How it was mentioned several times, for the evaluation of the bit error ratio it can be used QEF operation. In the DVB-T/H standard it is defined as a *BER* after Viterbi decoding less or equal to 2.10^{-4} [8]. However, DVB-SH standard for the FEC uses turbo encoding and advanced channel and time interleaving. Therefore, for the evaluation of the *BER* ratio it can not be used QEF operation. The limit of the error-free reception is considered for *C/N*, where the *BER* is equal to 1.10^{-5} after the turbo decoding, as recommended in [12]. Furthermore, contrast to DVB-T/H standard, in DVB-SH standard is generally explored and evaluated only the *BER* ratio after the turbo decoding, as it is presented in [12]. Therefore, in this dissertations thesis, in case of DVB-SH standard, dependences of the *BER* after the turbo decoding and *MER* on the *C/N* will be explored and evaluated.

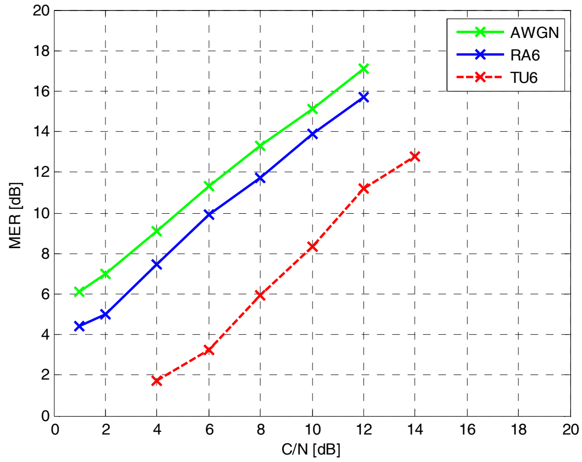
The Fig. 7.1 a) illustrates the *BER* after turbo decoding in Gaussian and typical mobile (RA6 and TU6) fading channels. All dependences have waterfall form, but shape of all curves is a slightly different, as it was in DVB-T/H system. In DVB-SH system, when the value of the *C/N* ratio is increasing, then the error ratio is decreasing. On the other hand, this decreasing is not gradual, but it is happened “suddenly”. More precisely, when the *C/N* ratio is achieved the appropriate value (sometimes also called as a “critical” value), then turbo decoder can repair all errors, which are occurred at the transmission. The reason is that in the DVB-SH system is used a turbo encoder/decoder. One of the main advantages of turbo encoding/decoding is that it allows achieved a very low error ratio at very low signal-to-noise ratio, thank to the advanced decoding algorithms [82]. Moreover, the number of turbo decoding (iteration number) can be increased. Therefore, the minimal value of signal-to-noise ratio can be decreased.

Firstly, as it was done in case of DVB-T/H standard, the transmission distortions in the reference (Gaussian) channel were explored. In the Gaussian channel (see Fig. 7.1 a)), the *BER* ratio after the turbo decoding is very low. The reason is the same, as it was in case of the DVB-T/H standard: in the classical Gaussian channel only ISI interferences are occurred. Thank to the relatively high number of repeating turbo decoding (8), the QEF operation (the *BER* ratio is equal to 1.10^{-5}) can be achieved at -0.4 dB. When the turbo decoding process was done only once, then for the QEF is needed 2.1 dB. Compare to the *C/N* ratio, obtained in DVB-T/H standard (when the mobile scenario was explored) for the QEF, the difference is approximately 3.4 dB. Therefore, it can be expected that the results will be also better in the fading channels.

The Fig. 7.1 a) also illustrates the *BER* after turbo decoding in RA6 mobile fading channel model. As it was described and mentioned several time in this dissertation thesis, this channel model consists one direct and 5 echo paths with different delays and path losses. Moreover, it is also respected the speed of the receiver, which is equal to 100 km/h. And again, all these “negative” effects are reflected on the obtained bit error ratio. On the other hand, thank to the strong direct path between the transmitter and receiver and eight times applied turbo decoding, it can be achieved a very good error ratio at low carrier-to-noise ratio.



a) BER after turbo decoding = f (*C*/*N*)

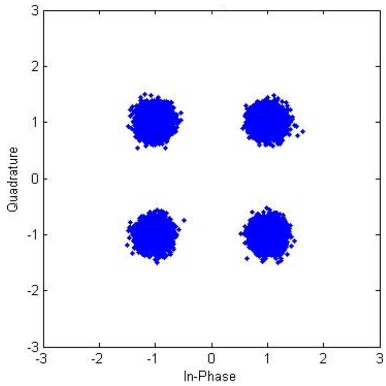


b) MER = f (*C*/*N*)

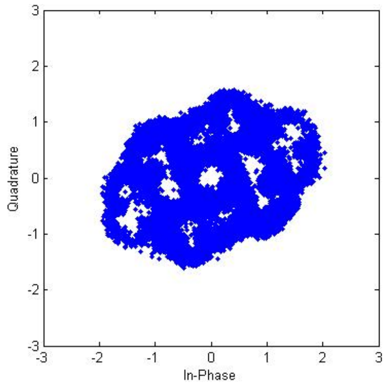
Fig. 7.1 Simulation: Mobile reception scenario (QPSK, 2K mode, code rate 1/4 and GI 1/16) and DVB-SH-A performance in typical channel profiles.

Concretely, for the 1.10^{-5} *BER* ratio is needed only 0.2 dB. In case of simple turbo decoding, this value is equal to 3.0 dB. In the DVB-T/H standard, for the QEF operation in the RA6 channel is needed 4.9 dB.

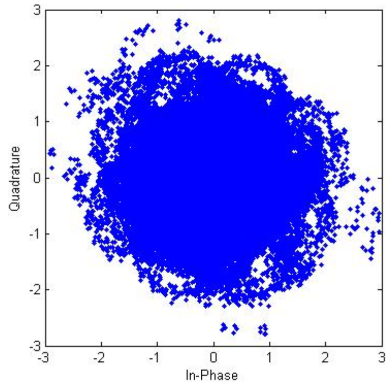
Dependence of the error ratio after the eighth turbo decoding process on the carrier-to-noise ratio in the TU6 channel is also shown in Fig. 7.1 a). As it was in DVB-T/H system configuration, TU6 channel models the properties of the typical urban area with six echo paths. Moreover, the speed of the receiver is 50 km/h. Results in this mobile fading channel model, in comparison with results in Gaussian and RA6 channels, are worse. In the DVB-T/H standard, the *C*/*N* ratio, needed for the QEF operation, is equaled to 9.0 dB. For the QEF operation in the DVB-SH-A standard it is needed only 1.4 dB (in case of simple turbo decoding, this value is equal to 5.8 dB). From the comparison of the obtained results (in DVB-T/H and DVB-SH-A systems) is clearly seen that there are big differences. The error ratio in DVB-SH-A system is much better how it was in DVB-H system.



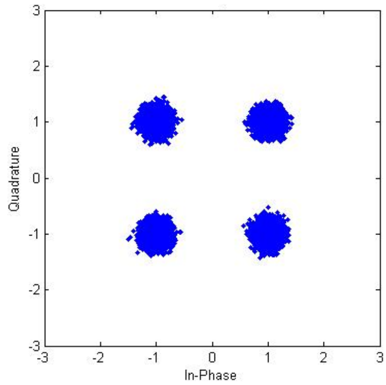
a) AWGN channel and mobile reception scenario (before the channel correction), MER = 20.2 dB; BER_1 = <$1\cdot10^{-4}$



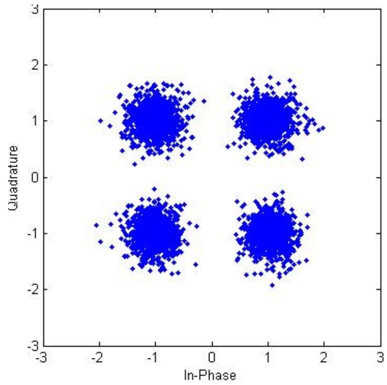
b) RA6 channel and mobile reception scenario (before the channel correction), MER is unknown; BER_1 = >$1\cdot10^{-2}$



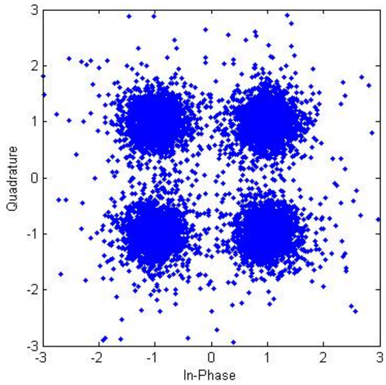
c) TU6 channel and mobile reception scenario (before the channel correction), MER is unknown; BER_1 = >$1\cdot10^{-2}$



d) AWGN channel and mobile reception scenario (after the channel correction), MER = 20.2 dB; BER_2 = <$1\cdot10^{-5}$



e) RA6 channel and mobile reception scenario (after the channel correction), MER = 18.8 dB; BER_2 = <$1\cdot10^{-5}$



f) TU6 channel and mobile reception scenario (after the channel correction), MER = 14.0 dB; BER_2 = <$1\cdot10^{-5}$

Fig. 7.2 Simulation: I/Q constellation of: a) to c) mobile scenario with QPSK (before the channel correction), d) to f) mobile scenario with QPSK (after the channel correction) also within typical DVB-SH-A fading channels (all the constellations include channel correction and pilots, *C*/*N* = 15 dB).

The main reason is that the process of turbo decoding is repeated 8 times. However, the time for the decoding is therefore higher.

Dependences of the *MER* on *C/N* in mobile TV channels in DVB-SH-A standard were also obtained and there are shown in Fig. 7.1 b). Firstly, as it was done every time in this dissertation thesis, the *MER* ratio in the Gaussian channel is explored firstly. In this reference channel the dependence between the *MER* and *C*/*N* ratio is linear.

For each value of the *C*/*N* ratio the modulation error ratio is better approx. by 1.0 dB. The reason is the same as it was in DVB-T/H standard: this channel has not any echo paths and fading components.

In the RA6 mobile channel model, the form of the curve is also linear. This is not a big surprise, because the dependence of the *MER* on the *C*/*N* in the DVB-T/H standard was also linear. On the other hand, there is a little bit difference. When the obtained dependences in the DVB-T/H (see Fig. 6.2 c)) and DVB-SH-A standards are compared, then it is visible that in case of the DVB-SH-A standard the results are closer to the result, which were obtained in the AWGN channel. The main reason is in the different types of FEC scheme, which, as it can be seen, in the DVB-SH standard is better. In the TU6 channel model, the obtained results (*MER*) are approximately same, as it was in the DVB-T/H system.

Typical results and the constellation diagrams for the mobile transmission scenarios and channel types are also easy to see in the Fig. 7.2 a) to f). As it was briefly mentioned at the beginning of this chapter, measurement of the signal distortions in the DVB-SH standard was unfortunately omitted, because the appropriate measurement devices, during at the work on this dissertation thesis, were not available. Therefore, in this part of dissertation thesis the imperfections in the constellation diagrams, which are occurred at the transmission (before the channel correction-equalization), are explored and evaluated. For the better evaluation, all constellation diagrams were explored in case, when the *C*/*N* ratio is equal to 15.0 dB.

As it can be seen, constellation diagram in the Gaussian channel before (see Fig. 7.2 a)) and after ((see Fig. 7.2 d)) the equalization is the same, because the signal is affected only by ISI interferences. Of course, in the RA6 channel between ISI interferences fadings are also available. All these effects can be observed in the IQ diagram before the equalization (see Fig. 7.2 b)). Thank to the direct path and Doppler's shift, the constellation diagram of the QPSK modulation is rotated of a constant angle. This angle corresponds to the phase shift, induced by the Doppler's shift of LOS component. On the other hand, thank to direct path component, the "square" form of the IQ diagram was maintained. Constellation diagram of the QPSK modulation, after the equalization, is shown in the Fig. 7.2 e).

As a last one, the signal distortions in the IQ diagram in the TU6 mobile fading channel model is explored. How it can be seen, this type of channel makes very high distortions in the constellation diagram (see Fig. 7.2 c)). Only echo paths (no direct path between the transmitter and receiver) with Doppler's shift are caused, so called, chaotic rotation of the constellation diagram in the whole range of 360 degree. Moreover, on the IQ diagram is an also visible effect of the frequency fading, which are can be found in the spectrum (see Fig. 7.2 c)). Thank to the optimal parameter settings (2K OFDM mode and QPSK modulation), all these effects are minimized, and after the equalization it can be corrected the distortions in the constellation diagram (see Fig. 7.2 f)).

The spectrum of the DVB-T/H signal in all explored channel model, when 2K mode is used (see Fig. 6.5 a) to Fig. 6.5 c)), is evaluated and discussed in 6.1. These spectrums in case of mobile scenario in DVB-SH-A system were almost same. Therefore, in this part, these figures and their description are omitted.

7.2 PORTABLE RECEPTION SCENARIO

This part of dissertation thesis deals with the investigation of the signal distortions of DVB-SH-A transmission in portable TV channels. How it was previously, when the portable scenario was explored in DVB-T/H system, there are also used two fading channel models (Pedestrian Indoor and Outdoor), respecting the very low speed of the receiver. The features of both channels models and differences between them are described in 4.2.3.

As it was mentioned previously, in this part of dissertation thesis (exploring of signal distortions in the DVB-SH standard) there are presented only a simulation results.

The DVB-SH-A system transmission parameters, which were used for the investigation of the signal distortions in portable TV channels, are follows:

- 8 MHz channel (bandwidth 7.068 MHz)
- 1/4 turbo code (robust protection)
- 4K (portable) OFDM mode
- 16QAM (portable) non-hierarchical modulation
- 1/8 Guard Interval (mid size of SFN)
- AWGN (Gaussian), Pedestrian Indoor and Outdoor (PI and PO) channel model
- Turbo decoding: SISO-MAP (see 5.2.2)
- Number of iterations: 8 (as recommended in [12]).

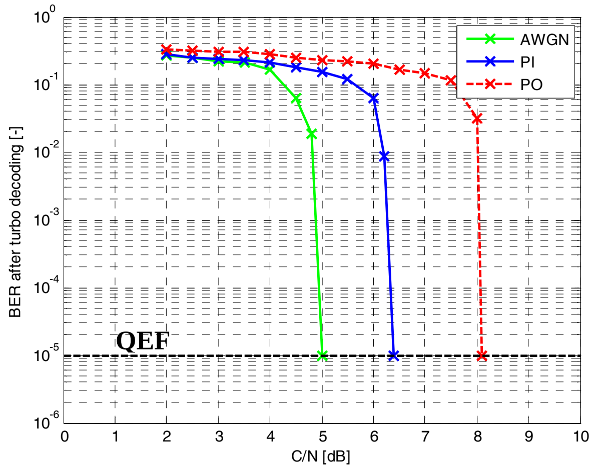
7.2.1 Experimental Results and Their Evaluation

Dependences of the *BER* ratio after turbo decoding on the *C*/*N* ratio in the Gaussian (reference) and typical portable fading channel models (PI and PO) are shown in Fig. 7.3 a) to f). And again, all these dependences are obtained after eighth turbo decoding processes.

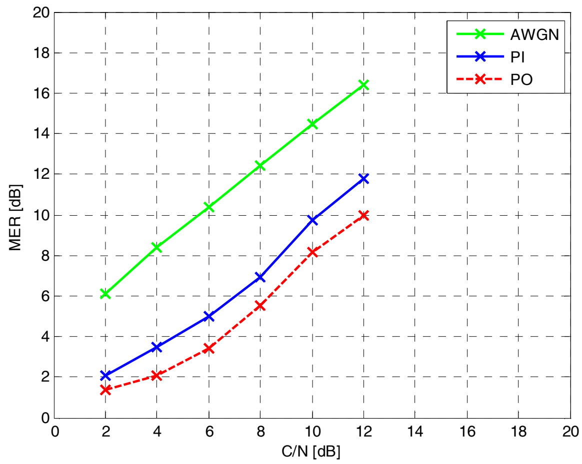
The QEF [12] operation is defined by same way, as it was described in 7.1.1.

The transmission performance of the DVB-SH-A standard in portable TV channels is firstly explored in classical Gaussian (AWGN) channel. The obtained error ratio, depending on the carrier-to-noise ratio (in the AWGN channel) is shown in Fig. 7.3 a). For the achieving of the 1.10^{-5} *BER* after the eighth turbo decoding is needed 5.0 dB. This value after the simple turbo decoding is equaled to 8.3 dB. Compare to mobile scenario (2K mode, QPSK modulation) in DVB-SH-A, this value is much times higher. The main reason of this high value is in the type of the modulation. As it has been shown earlier (see 6.2.2), 16QAM modulation has less resistance to the intersymbol interferences. Therefore, it can be also expected that the results in portable fading channel models will be worse.

The Fig. 7.3 a) also illustrates the *BER* after turbo decoding in the PI (Pedestrian Indoor) and PO (Pedestrian Outdoor) fading channel models. As it was highlighted several times in this dissertation thesis, both these channel models are very similar. However, thank to higher path losses, it can be expected worse results in PO channel.



a) BER after turbo decoding = f (*C*/*N*)

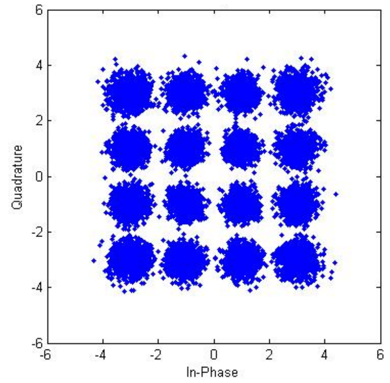


b) MER = f (*C*/*N*)

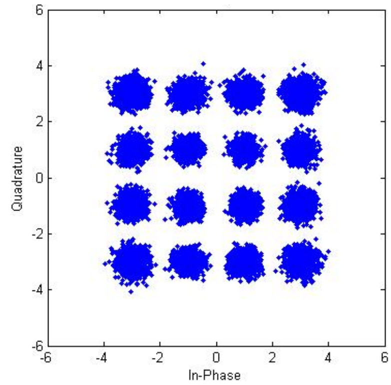
Fig. 7.3 Simulation: Portable reception scenario (16QAM, 4K mode, code rate 1/4 and GI 1/8) and DVB-SH-A performance in typical channel profiles.

From the Fig. 7.3 a) is clearly seen that in PI channel, when the carrier-to-noise ratio is equal to 6.4 dB, then the error ratio is decreases to 10^{-5} (limit for the QEF reception in the DVB-SH system). Of course, this low *C/N* ratio can be achieved after the eighth turbo decoding process. When the simple turbo decoding is applied, then the *C/N* ratio is equaled to 12.4 dB. When the dependence of the error ratio on the carrier-to-noise ratio, obtained in DVB-SH-A system, is compared to dependence, which is obtained in case of the DVB-T/H system (portable scenario, see 6.2), then there is again visible the effect of advanced FEC scheme, which is used in DVB-SH standard. In DVB-T/H portable system configuration, for the QEF operation was needed 12.0 dB. As it can be seen, in the DVB-T/H standard is needed two times higher carrier-to-noise ratio for the achieving of the QEF reception.

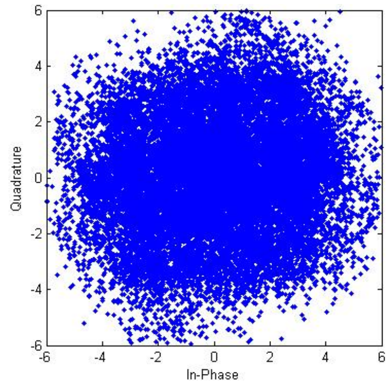
As a last one, the portable reception scenario in DVB-SH-A system is explored in the PO channel model. The obtained dependence of the *BER* ratio on the *C/N* ratio is shown in the Fig. 7.3 a). As it was expected, obtained results are worse then there were



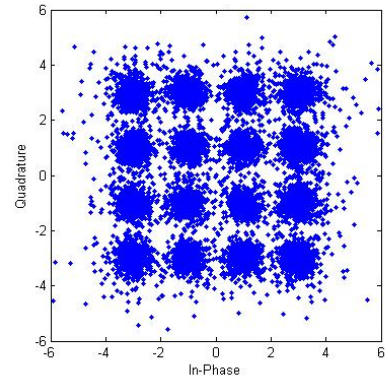
a) AWGN channel and portable reception scenario (before the channel correction), MER = 19.5 dB; BER_1 = <1·10^{-4}



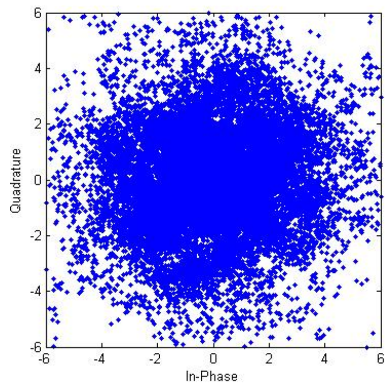
d) AWGN channel and portable reception scenario (after the channel correction), MER = 19.5 dB; BER_2 = <1·10^{-5}



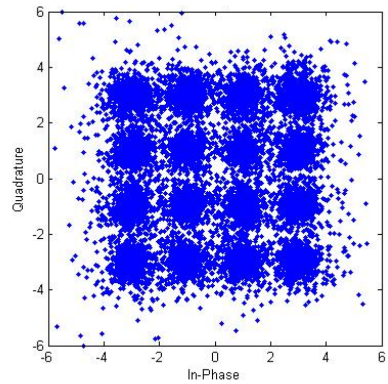
b) PI channel and portable reception scenario (before the channel correction), MER is unknown; BER_1 = >1·10^{-2}



e) PI channel and portable reception scenario (after the channel correction), MER = 14.5 dB; BER_2 = <1·10^{-5}



c) PO channel and portable reception scenario (before the channel correction), MER is unknown; BER_1 = >1·10^{-2}



f) PO channel and portable reception scenario (after the channel correction), MER = 13.0 dB; BER_2 = <1·10^{-5}

Fig. 7.4 Simulation: I/Q constellation of: a) to c) portable scenario with 16QAM (before the channel correction), d) to f) mobile scenario with 16QAM (after the channel correction) also within typical DVB-SH-A fading channels (all constellations include channel correction and pilots, C/N = 15 dB).

in the PI channel. However, the carrier-to-noise ratio, which is needed for the quasi-error-free reception, is again very low. More precisely, for the 10^{-5} *BER* ratio, after the eighth turbo decoding is needed approx. 8.1 dB. In case of simple turbo decoding (the decoding process is done only once), the QEF limit can be achieved at 14.0 dB. The difference between the PI and PO channel in DVB-SH-A system, is only 1.7 dB (after the eighth turbo decoding process). In case of the DVB-T/H standard, this difference is equaled to 4.0 dB. The main reason, why is this difference in the DVB-T/H system higher is that the DVB-SH-A system configuration (advanced turbo encoding/decoding and time interleaving). Thank to the appropriate signal processing, it can be decreased the demand of the higher path delays (in the PI channel) and path losses (in the PO channel).

Dependences of the *MER* on *C/N* in DVB-SH-A system for typical portable TV channels are shown in Fig. 7.3 b). The *MER* ratio firstly was analyzed in the reference channel (see Fig. 7.3 b)), which is marked by green line. In this channel and also for the portable reception scenario in DVB-SH-A it was obtained a linear dependence between the modulation error ratio and the level of the signal. At 12.0 dB it can be achieved a very good 16.4 dB *MER* ratio. This value is very similar to the value, which was obtained in the DVB-T/H system in the portable scenario.

In the PI and PO portable fading channel models, dependences of the *MER* on the level of the signal (carrier) were also explored and obtained. As it can be seen in the Fig. 7.3 b), the modulation error ratios are less (more precisely worse) in both channel models (compare to AWGN channel) and the form of their curve have not a typical linear form. On the other hand, compare to results, which were obtained in the DVB-T/H system, there are visible that the results are very similar and slightly higher (better). For example, in case of DVB-T/H system, at 12.0 dB level of signal the modulation error ratio is equal to 10.4 dB in PI channel and 11.0 dB in the PO channel. These values in DVB-SH-A system were 11.8 dB and 10.0. How it can be seen, the positive effect of the advanced FEC scheme, which is used in the DVB-SH standard, has not significant effect on the obtained results. The reason is that the 16QAM modulation has less resistance to the ISI interferences and fadings.

Typical results and the constellation diagrams for the portable transmission scenarios and channel types in the DVB-SH-B are also easy to see in the Fig. 7.2 a) to f). As it was mentioned before, in this part of dissertation thesis, distortions in the constellation diagrams, which are occurred at transmission, are explored deeper. These distortions, for the better visibility in IQ diagrams, are explored at 15.0 dB of carrier-of-noise ratio.

Firstly, the distortions in the IQ diagram were investigated in the Gaussian (AWGN) channel before (Fig. 7.4 a)) and after (Fig. 7.4 d)) the channel corrections. In case of Gaussian channel there are only white noise, which are caused by the ISI interferences. The quite (square) form of the constellation diagram is the same, so the noises are distributed around a defined points of IQ diagram.

Of course, in case of PI channel, the situation is different, because in the IQ diagram are reflected the path delays and losses and Doppler’s shift. Constellation diagram in the PI portable channel, after the receiving, but before the equalization, is shown in Fig. 7.4 b). As it was described and highlighted in this dissertation thesis, both portable fading channel models (PI and PO) contain a direct path between the transmitter and the receiver. When the constellation diagram is explored a little better, then it can be observed that its typical “square” form was maintained. This situation is also occurred in the RA6 channel (see Fig. 7.2 b)). As it was mentioned in the case of the RA6 channel model, this effect is caused by the line of sight component, which is available in the first path of the channel model (path with zero delay and zero path loss). On the other hand, first path of PI channel, more precisely, its spectrum has a Rice-Gaussian character. It means that in the first path, contrast to direct path, there is also considered an effect of the Doppler’s shift. Thank to this small shift (the speed of the receiver is equal to 3 km/h) constellation diagram of the 16QAM modulation is rotated of a defined angle, which corresponds to the phase shift, caused by the Doppler's shift of the LOS. Its exact value is defined in the channel model, and it can be found in [75]. The IQ diagram, after the equalization is shown in Fig. 7.4 e).

Distortions in the constellation diagram, caused by the PO channel model, are visible in the Fig. 7.4 c). This channel model has the same features (Doppler's shift and Doppler spectrum). Therefore, the distortions are very similar to the distortions, which were observed in the PI channel. Of course, distortions in the PO channel a bit worse, which are caused by the higher path losses. Thank to the optimal settings (4K OFDM mode and 16QAM modulation), after the channel corrections, the errors in the constellation diagram are minimized (see Fig. 7.4 f)).

The OFDM spectrums of the DVB-T/H signal in all explored channel models, when 4K mode (OFDM mode for the portable scenario) is used (see Fig. 4.3 a) to Fig. 4.3 c)), are evaluated and discussed in 6.2. These spectrums, in case of portable scenario in DVB-SH-A were almost same.

7.3 FIXED RECEPTION SCENARIO

As it was described in 1.1.2, in many cases, mobile operators want to cover large regions or even a whole country with mobile services. When these situations are occurred, then classical terrestrial broadcasting, which is used in DVB-T/H and partly in DVB-SH (OFDM mode) standards, is not the best choice. However, the options and possibilities of the DVB-SH standard allow the solution of this problem.

The DVB-SH standard allows mobile TV transmission in two principle modes: OFDM (for satellite and terrestrial mode) and TDM (for satellite mode). In the TDM transmission mode, the useful data are broadcasted to mobile terminals in a, so called, fixed (satellite) channels. More precisely, the data between the transmitter and receiver are broadcasted on a direct path from a broadcast station via satellite. The TDM signal is partly derived from the DVB-S2 standard. More details can be found in [48].

The DVB-SH-A mode (OFDM mode) is also allows used the transmission in fixed TV channels too. On the other hand, this solution is not typical. The reason (problems with covering of large regions) is mentioned above. Therefore, this part of dissertation thesis is focused on the signal distortions in fixed TV channels, when for the transmission the DVB-SH-B mode is used. For the investigation of the performance of the DVB-SH-B mode in fixed TV channels, a Gaussian (AWGN) and Ricean (RC20) channels is used. Generally, in case of satellite communication, for the exploring of the signal distortions only the Gaussian channel is used. However, in case of "fixed" scenario is also necessary to consider the reflections and delays of echo paths. Therefore, as a second channel model, the Ricean (RC20) fading model with different K-factors [8], [12] (level of the direct path) is used. And again, in this part of dissertation thesis (exploring of signal distortions in the DVB-SH standard), there are presented only a simulation results.

The DVB-SH-B system transmission parameters, which were used for the investigation of the signal distortions in fixed TV channels, are follows:

- 8 MHz channel (bandwidth 7.068 MHz)
- 2.2 GHz carrier frequency (S-band, generally used in the DVB-SH-B mode)
- 1/4 turbo code (robust protection)
- TDM (satellite) mode
- QPSK (satellite and fixed), 8PSK and 16APSK (both satellite)
- AWGN (Gaussian) and Ricean (RC20) fixed channel models
- K-factor of RC20 channel model set on 10 (strong direct path) and 5 (weak direct path)
- Turbo decoding: SISO-MAP (see 5.2.2)
- Number of iterations: 8 (as recommended in [12]).

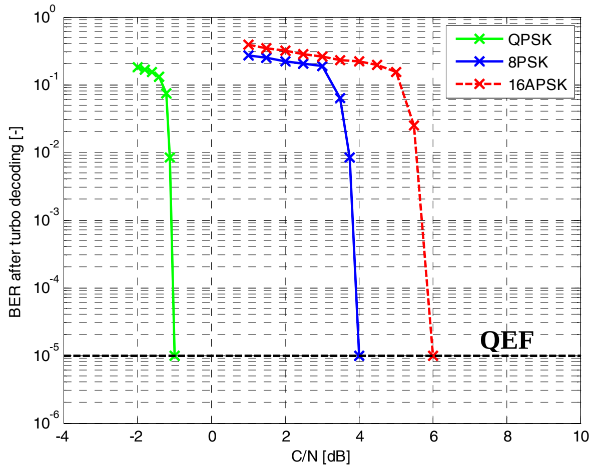
7.3.1 Experimental Results and Their Evaluation

How it was outlined in the previous chapter, DVB-SH-A mode is generally used in the situations, when the operators want to covered very big regions or even a whole country with mobile TV services. In many cases this is very difficult, thank to the geographical imperfections and obstacles (e.g. hills), which decreased the level of the signal, broadcasted by the DVB-SH-A (OFDM mode) system. Therefore, it is better used to a DVB-SH-B system (mode TDM), sometimes also called as a satellite mode. Therefore, in contrast with DVB-SH-A, QAM modulations are not used in DVB-SH-B. Instead of QAM, PSK modulations are preferred. More precisely, there are used QPSK, 8PSK and 16APSK modulations. When the satellite mode is used, as a transmission environment, generally, a Gaussian channel is considered. This is the reason, why is important to analyze the signal distortions for all type of modulations, which are used in the DVB-SH-B.

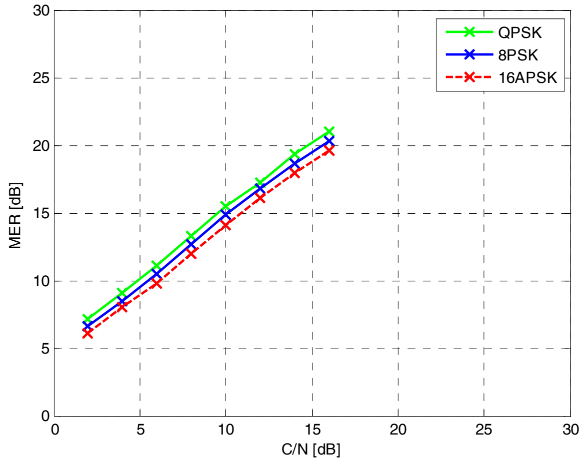
Simulation results of the fixed TV transmission in the DVB-SH-B standard for a varying *C*/*N* ratio in the Gaussian channel (AWGN) for all types of modulation are in Fig. 7.5 a) and b). Of course, all obtained dependences are obtained after the eighth turbo decoding process. The QEF [12] operation for the DVB-SH-B mode is defined by same way, as it was described in 7.1.1.

Firstly, the performance of the DVB-SH-B system was tested, when the QPSK modulation is used. Generally, how it is known, QPSK modulation has a highest resistance to the ISI interferences and fadings, caused by the flat channels. However, this modulation gives a lowest transmission speed at the broadcasting (it is can encode/decode only two bits per symbol). How it can be seen from the Fig. 7.5 a), thank to mentioned resistance, it can be achieved a very low error-ratio at very low carrier-to-noise ratio. After the eighth turbo decoding process, as recommended in [12], the QEF limit can be achieved at -1.0 dB. This value is equaled to 2.2 dB, when the turbo decoding process is provided only once.

Secondly, the performance of the DVB-SH-B system was tested in the fixed TV channels, when the 8PSK modulation is used. Compare to QPSK modulation, 8PSK modulation can encode/decode 3 bits per symbol. Therefore, it gives higher speed at the broadcasting. On the other hand, thank to the higher number of decision stages (in the constellation diagram there are 8 positions), the resistance of this modulation is less.



a) BER after turbo decoding = f (*C*/*N*)

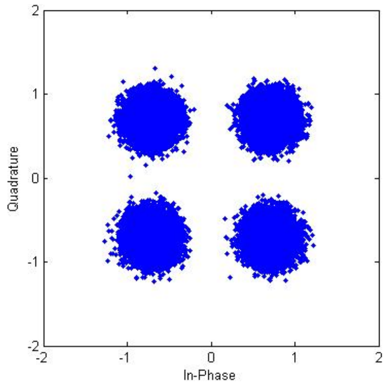


b) MER = f (*C*/*N*)

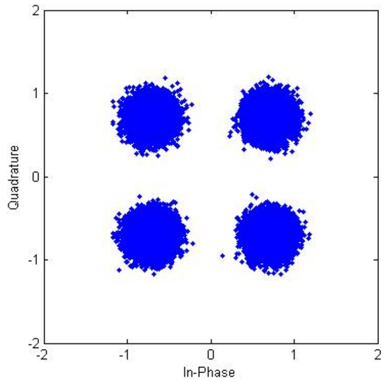
Fig. 7.5 Simulation: Fixed reception scenario (QPSK, 8PSK, 16APSK, mode TDM and code rate 1/4) and DVB-SH-B performance in the Gaussian (AWGN) channel.

Therefore, it can be expected that for the achieving of a low error ratio will be needed higher level of carrier-to-noise ratio. Dependence of the *BER* ratio on the *C*/*N* ratio in the Gaussian channel, when the 8PSK modulation is used, is shown in the Fig. 7.5 a). From the obtained dependence can be clearly seen that the error ratio is much higher as it was in case of QPSK modulation. For the achieving of the 10^{-5} *BER* ratio (limit for the QEF) can be achieved at 4.0 dB. Compare to QPSK modulation, there is a very big difference between the obtained results, concretely 5.0 dB. The main reason of this difference is outlined above. When the turbo decoding process is provided only once, then the required value of the *C*/*N* ratio for the QEF operation is equaled to 7.6 dB.

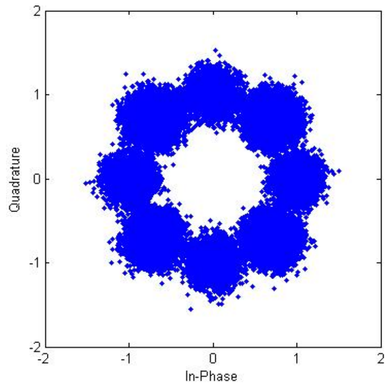
Thirdly, the performance of the DVB-SH-B system (TDM mode) was explored in case, when the 16APSK modulation is used. As it was described in 5.2.1, the 16APSK modulation was implemented into MATLAB by manual way, because the available function in MATLAB does not correspond to the symbol mapping (Gray mapping), which is defined in [11].



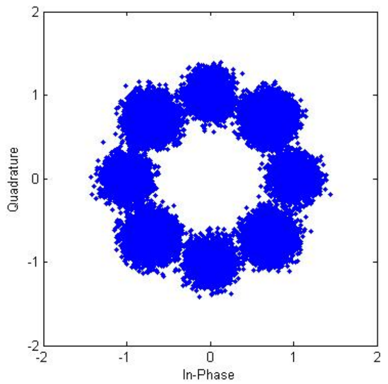
a) AWGN channel and satellite reception scenario (before the channel correction), MER = 13.2 dB (with QPSK); $BER_1 = 4.6 \cdot 10^{-5}$



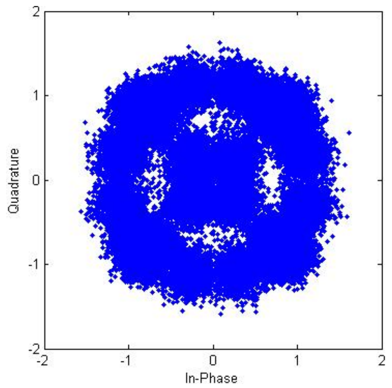
d) AWGN channel and satellite reception scenario (after the channel correction), MER = 15.5 dB (with QPSK); $BER_2 =< 1 \cdot 10^{-5}$



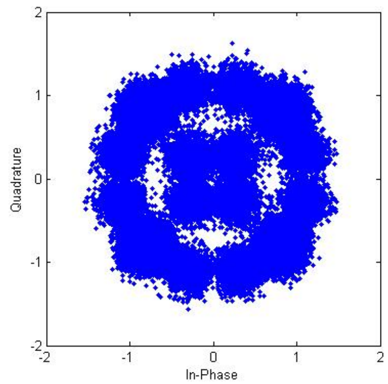
b) AWGN channel and satellite reception scenario (before the channel correction), MER = 12.9 dB (with 8PSK); $BER_1 = 1.2 \cdot 10^{-3}$



e) AWGN channel and satellite reception scenario (after the channel correction), MER = 14.9 dB (with 8PSK); $BER_2 =< 1 \cdot 10^{-5}$



c) AWGN channel and satellite reception scenario (before the channel correction), MER = 12.5 dB (with 16APSK); $BER_1 = 2.3 \cdot 10^{-2}$



f) AWGN channel and satellite reception scenario (after the channel correction), MER = 14.1 dB (with 16APSK); $BER_2 =< 1 \cdot 10^{-5}$

Fig. 7.6 Simulation: I/Q constellation in AWGN channel and satellite reception scenario and MER equal to: a) 15.5 dB (with QPSK), b) 14.9 dB (with 8PSK), c) 14.1 dB (with 16APSK) - all the constellations includes channel correction and $C/N = 10$ dB.

This modulation allows achieved the highest transmission speed at the DVB-SH-B broadcasting, but its resistance to ISI interferences is the lowest. Obtained dependence of the error ratio on the C/N ratio, when the 16APSK modulation is used, is also shown in the Fig. 7.5 a). The form of the obtained curve is very similar to the curve, which was obtained for the 8PSK modulation.

When the 16APSK modulation was used, then after the eighth turbo decoding process it can be achieved the QEF reception at the 6.0 dB. For the simple turbo decoding process (number of the iteration is equaled to one) this value is equaled to 10.6 dB.

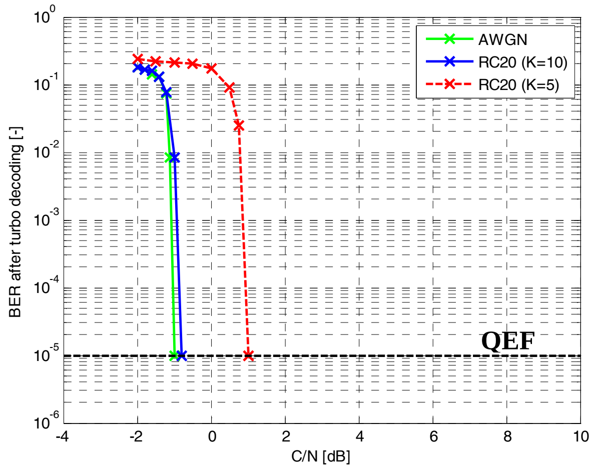
Dependences of the *MER* on the carrier-to-noise ratio for the all type of modulations, which are used in the DVB-SH-B system for the fixed reception scenario, were obtained too and there are shown in the Fig. 7.5 b). From the form of the curves (all of them have identical form) can be clearly seen that the channel environment has only a Gaussian (AWGN) features. More precisely, modulation error ratio for all type of modulations is linearly depending on the level of the carrier-to-noise ratio. Surprisingly, differences between achieved *MER* ratios for the QPSK, 8PSK and 16APSK modulations are very similar. It can be said, they are identical. A very good, 20.0 dB *MER* ratio can be achieved in case of the QPSK modulation at 15.0 dB *C*/*N* ratio. This value is equal to 16.5 dB for the 8PSK modulation and 16.0 dB for the 16APSK modulation. The reason is that all type of modulations has same features in the Gaussian channel. In this channel is available only a simple AWGN noise without echo paths, delays, attenuations and phase shifts.

Typical results and the constellation diagrams for the fixed transmission scenarios and Gaussian channel in the DVB-SH-B are also easy to see in the Fig. 7.6 a) to f). For the better visibility, distortions in the IQ diagrams are explored at 10.0 dB of carrier-of-noise ratio. Between the obtained IQ diagrams (before and after channel corrections) there are any significant differences. Moreover, this is also reflected on the obtained *MER* ratios. The explanation of this can be found between the features of used channel.

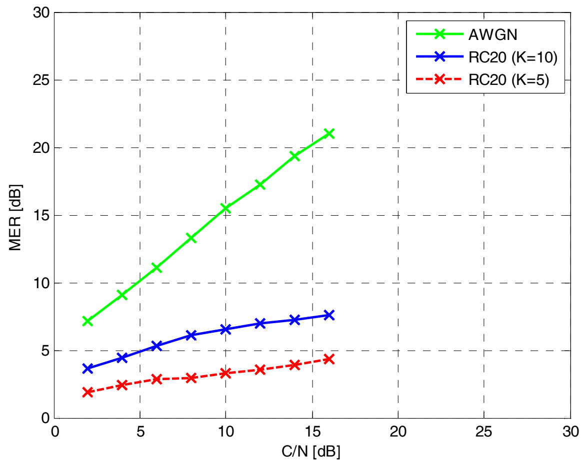
Generally, signal distortions at the transmission between the transmitter and receiver in the DVB-S/S2 standard, are explored in the Gaussian channel [5], [48]. Thank to the advanced signal processing in the transmitter (FEC scheme and interleaving) and receiver (improved decoding algorithms), used in the DVB-S2/SH standards, it can be also used a more realistic channel model, which considers reflections, delays, level attenuation of the signal and phase shifts between the echoes. Therefore, as it recommended by [12] and [48], for the exploring of the DVB-S2/SH performance in fixed satellite TV channels should be used the Ricean (RC20) channel model with 20 independent echo paths. Therefore, in this dissertation thesis, this recommendation was also considered and it was applied for the exploring of signal distortions in fixed satellite TV channels in case of DVB-SH-B mode.

Dependences for the *BER* ratio after eight turbo decoding process on the *C*/*N* ratio in the Gaussian (reference) and typical fixed fading channel model (RC20), which respect the LOS effect, are shown in Fig. 7.7 a). As it was outlined above, there are explored signal distortions in RC20 channel model with different level of direct signal path (different *K*-factor). Of course, for the compare and evaluation of obtained results, there is used a Gaussian (reference) channel. In all type of communication channels (AWGN and RC20) a QPSK modulation was used. Dependence of the error ratio on the level of the signal in the Gaussian channel was explored firstly (see Fig. 7.7 a)). The QEF operation after the eighth turbo decoding can be achieved at -1.0 dB. This value is equaled to 2.2 dB, when the turbo decoding process is done only once.

Dependence of the *BER* ratio on the level of carrier-to-noise ratio in the RC20 fading channel model was investigated secondly (see Fig. 7.7 a)). This fixed fading channel model contains 1 direct and 20 indirect echo paths.



a) BER after turbo decoding = f (*C*/*N*)

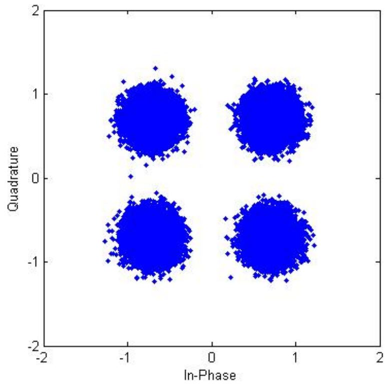


b) MER = f (*C*/*N*)

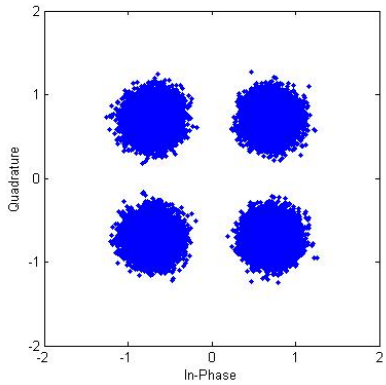
Fig. 7.7 Simulation: Fixed reception scenario (QPSK, mode TDM and code rate 1/4) and DVB-SH-B performance in the Gaussian (AWGN) and in RC20 channel with different K-factors.

The level of the direct signal path is characterized by the *K-factor*. Generally, this parameter is equal to 10 [73]. When the *K-factor* is less, the level of the direct signal will be also less. In the special case, when the *K-factor* is equal to zero (0), then the direct path will be fully attenuated and the Ricean channel will have features of the Rayleigh channel. In this part of the dissertation thesis, it will be used two different *K-factors*: 10 (strong direct path) and 5 (weak direct path).

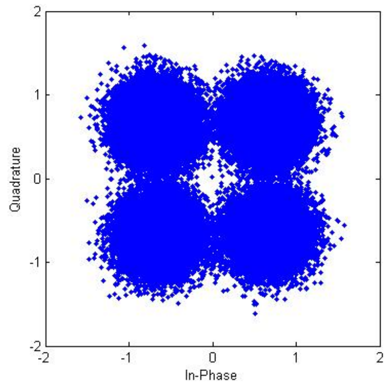
Dependence of the error ratio on the *C*/*N* ratio in the RC20 channel, when the *K-factor* is equal to 10, is shown in Fig. 7.7 a). In this channel model, the obtained results (blue line), compare to reference (AWGN) channel, are very similar. The reason is in the advanced FEC encoding/decoding process and in the used type of the modulation (QPSK), which has a high resistance to the echo paths. For the QEF operation it is needed only -0.8 dB after the eighth turbo decoding process. For the simple turbo decoding process (number of the iteration is equaled to one) this value is equaled to 3.2 dB.



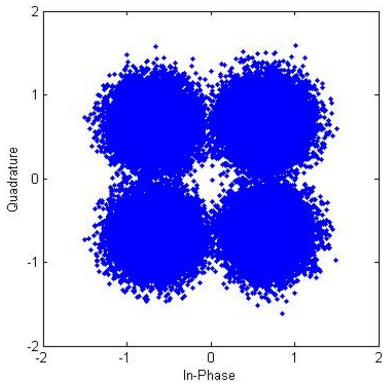
a) AWGN channel and fixed reception scenario (before the channel correction), MER = 13.2 dB (with QPSK); $BER_1 = 4.6 \cdot 10^{-5}$



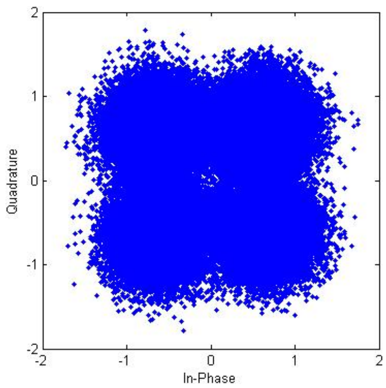
d) AWGN channel and fixed reception scenario (after the channel correction), MER = 15.5 dB (with QPSK); $BER_2 =< 1 \cdot 10^{-5}$



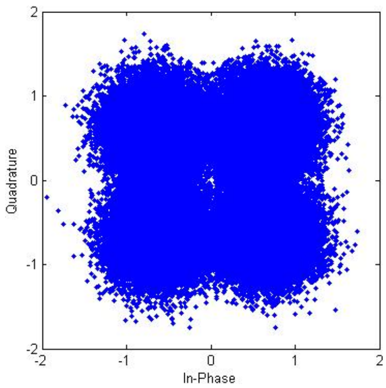
b) RC20 (K=10) channel and fixed reception scenario (before the channel correction), MER =6.1 dB (with QPSK); $BER_1 = 3.8 \cdot 10^{-4}$



e) RC20 (K=10) channel and fixed reception scenario (after the channel correction), MER = 6.6 dB (with QPSK); $BER_2 =< 1 \cdot 10^{-5}$



c) RC20 (K=5) channel and fixed reception scenario (before the channel correction), MER =3.0 dB (with QPSK); $BER_1 = 2.4 \cdot 10^{-3}$



f) RC20 (K=5) channel and fixed reception scenario (after the channel correction), MER = 3.3 dB (with QPSK); $BER_2 =< 1 \cdot 10^{-5}$

Fig. 7.8 Simulation: I/Q constellation with QPSK modulation in RC20 fading channel and satellite reception scenario and MER equal to: a) 15.5 dB (AWGN), b) 6.8 dB (K=10), c) 3.7 dB (K=5) – all the constellations includes channel correction and *C*/*N* = 10 dB.

Finally, the signal distortions in the DVB-SH-B system were explore in the RC20 channel, when the *K-factor* is equal to 5 (see Fig. 7.7 a)). It means that, the level of the direct path is a half. As it can be seen, the less level of the direct path is significantly reflected on the error ratio. The *BER* ratio is started decreased at 0.0 dB. After the eighth turbo decoding process, the 10^{-5} *BER* ratio can be achieved at 1.0 dB (red line). This value is equal to 12.0 dB, when the iteration number is equaled to 1.

Dependences of the *MER* on *C/N* ratio in fixed TV channels were also explored and the obtained results are clearly shown in Fig. 7.7 b). The mentioned investigation is mainly focused on the modulation error ratio, which occur at the transmission in the RC20 channel model with different *K-factors.* However, for the better evaluation of the results are needed a reference dependence of *MER* on the *C/N*. As a reference, the Gaussian channel was used. In this channel, the *MER* is linearly increasing by increasing value of *C/N*.

In the RC20 fixed channel model, were the *K-factor* is equal to 10 (strong direct path), the form of the obtained curve has a non-linear form (see Fig. 7.7 b)). As it can be seen (blue line), at the beginning (from 2.0 to 8.0 dB) the *MER* ratio is increasing linearly with the level of the carrier-to-noise ratio. On the other hand, from 8.0 dB the error ratio is increased only slightly. From 15.0 dB the error ratio is practically constant. This "untypical" form of the obtained curve is closely related with the features of the channel model and with the type of modulation. Firstly, in the RC20 channel, thank to the echo paths and phase shifts, the modulation error ratio will be always lower then in the Gaussian channel, as it was showed many times in this dissertation thesis. Secondly, in the DVB-SH-B mode there are used PSK modulations. These types of modulations have generally less resistance to the ISI interferences. Furthermore, this resistance is the lowest in the fading channels.

Finally, dependence of the modulation error ratio on the carrier-to-noise ratio was explored in the RC20 channel model with the weak direct path (*K-factor* is equal to 5). The obtained dependence (see Fig. 7.7 b)), compare with the previous dependence, is very similar. More precisely, the form of the curve (red line) is the same as it was in case, when the *K-factor* is equaled to 10. There is only one small difference: the constant error ratio is occurred from the 16.0 dB, thank to less value of the *K-factor*.

Constellation diagrams for the fixed transmission scenarios and channel types (Gaussian and RC20 with different level of direct path) are easy to see in the Fig. 7.8 a) to f). There are shown constellation diagrams before (see Fig. 7.8 a) to c)) and after (see Fig. 7.8 d) to f)) the channel corrections. All constellation diagrams were explored in case, when carrier-to noise ratio (*C/N*) is equal to 10 dB. Firstly, the distortions in the IQ diagram were explored in the Gaussian (AWGN) channel (see Fig. 7.8 a) and d)).

Secondly and thirdly, the signal distortions in the IQ diagrams were investigated in the RC20 channel model with different level of the direct path. Constellation IQ diagrams, when the *K-factor* is equal to 10, are shown in Fig. 7.8 b) and e) and for the *K-factor*, equaled to 5, are shown in Fig. 7.8 c) and f). As it can be seen, there are any significant effects in the IQ diagrams before and after the channel corrections. Moreover, these IQ diagrams do not reflect significantly the features of the RC20 (delays of paths, path losses and phase shift). There are looking as a constellation diagrams, which are show a signal distortions in the Gaussian channel at lower level of the signal.

8 Conclusion

This dissertation thesis dealt with the analysis, simulation and measurement of the signal distortions in the DVB-H and DVB-SH standards, which are used for the broadcasting of digital TV services to mobile phones and terminals (handsets). The content of this dissertation thesis can be divided into 8 main chapters.

The introduction (chapter 1) and its first part contain a very short introduction to the area of the DVB broadcasting. There are briefly presented all, nowadays most used DVB standards for the broadcasting of the digital TV services. This first part also contains a very brief introduction to the new DVB standards, which are developed for the broadcasting of the mobile TV services (DVB-H and DVB-SH) to mobile terminals. There are also presented an overview of countries, where are the broadcasting of mobile TV services, in DVB-H/SH standards are launch or are tested. The second part of the introduction deals with the actual state-of-the-art in the DVB-H/SH standards. The research and development in the DVB-H and DVB-SH standards can be divided onto several areas. All these areas for both standards were shortly presented and the references (papers), where actual results were presented, were also given. Finally, in the second part of the introduction were specified the main aims of this dissertation thesis:

- Exploring of the system configurations (on the level of physical layer) of the DVB-H/SH standards and their possibilities for the transmission of TV services.
- Exploring and analysis of different transmission channel models, which are respecting the features of all transmission scenarios (path delays, path losses, phase shift, movement of the receiver, Doppler's shift, etc.).
- Creation of appropriate program applications in MATLAB, which are allow simulate and analyze the signal distortions at transmission in DVB-H/SH standards.
- Measurement of the transmission distortions in typical scenarios and channel models, according to the technical and laboratory possibilities.
- Evaluation and discussion of the obtained results from simulations and measurements and determination of critical *C*/*N* values for achieving a good signal quality in real transmission scenarios for DVB-H /SH standards.

The second chapter (2) of this dissertation thesis dealt with the description of the DVB-H standard and its functional block diagram. The description is focused on the link and physical layers, where the main innovations (in comparison with DVB-T) in the DVB-H standard are implemented. Therefore, this chapter was divided into two parts. First part was focused on the most important innovations in the DVB-H system, like as MPE-FEC scheme and in-depth interleaving, which can significantly improved the error correction of the data transmission. As it was outlined, in this dissertation thesis, the RS(191,64) variant (in this case MPE-FEC code rate is equal to 3/4) was used for the analysis of the DVB-H system performance, because this variant is the most used in the real transmission. The second part of the second chapter was focused on the description of the functional block diagram of the DVB-H transmitter. There were presented and briefly described all functional parts from the FEC scheme to the signal processing. Furthermore, there were also presented the most important theoretical backgrounds, which are needed for the successful implementation of whole system in the program MATLAB and for the exploration of the obtained results.

The content of the third chapter (3) was very similar to the content of the previous (second) chapter. The third chapter dealt with the brief and clear description of the DVB-SH standard and its functional block diagram. And again, the main description was focused on the link and physical layers. In these layers there are realized and implemented the most significant system innovations (compare to DVB-T/H) in DVB-SH standard. This chapter, as a previous, was divided into two main parts. In the first part there were presented the main system innovations, mainly two reference architectures (DVB-SH-A and DVB-SH-B), which respect the hybrid satellite/terrestrial system transmission architectures. The second part dealt with the presentation and description of the functional block diagram of the DVB-SH transmitter for both possible system architectures. In case of the DVB-SH-A system (OFDM mode), the description was shortened, because several blocs and their functions are the same with blocks of the DVB-H system. On the other hand, the DVB-SH-B (TDM mode) system architecture was described in details. This system mode is used for the broadcasting of mobile TV via satellite. Main attention is devoted on the TDM framing and physical layer scrambling processes, because these parts have a key role in the equalization on the receiver side. In the second and third chapter, the first objective of this dissertation thesis was fulfilled.

Properties and main parameters of transmission channel models, which are used for the exploring and analysis of DVB-H/SH performance, were presented in the fourth chapter (4). This chapter was divided into three important parts. First part was dealt with description with channel models with higher Doppler's shift (mobile scenario). Expression "higher Doppler's shift" means that these channel models also respected the speed of the receiver, which is generally between 50 and 100 km/h. Concretely, there were presented RA6 and TU6 channel models, which are modeled terrestrial propagation in a typical rural area (RA6) and in an urban area (TU6). Number in the abbreviations is indexed the number of echo paths. Moreover, there were also presented other two channel models: VU30 and MR100. These channel models based on the real measurement data. In this case, number in the abbreviations is indexed the speed of the receiver. Second part of the fourth chapter presented two channel model profiles with low Doppler's shift (portable scenario). More precisely, there were presented PI and PO channel models, which modeled handheld indoor (PI) and outdoor (PO) reception. In these channel models the speed of the receiver is equal to 3 km/h that is also explained the reason of very low Doppler's shift. Last part of this chapter was focused on the description of channel profiles without Doppler's shift (fixed scenario). There were presented two well known (mainly from DVB-T) fixed channel models, Ricean (RC20) and Rayleigh (RL20) channels. All recommended channel models were explored and described. Therefore, the second objective of this dissertation thesis was completed.

Flow charts and detail descriptions of the created applications, which can used for the analysis of signal distortions in the DVB-H and DVB-SH standards, were presented and described in the fifth chapter (5). First application for the simulation and analysis of the transmission in DVB-H system is a complex program, which allows to choose the type of input data (randomly generated bits or a simple, black and white picture), with control of error protection (puncturing with all available coding rates – 1/2, 2/3, 3/4, 5/6 and 7/8). Furthermore, the application also contains functional blocks for the OFDM frame generation (with pilot carriers) and OFDM signal processing (IFFT process, guard interval and IQ modulator). The created application also included a special stand-alone simulator (common for both main applications for the simulation of transmission in DVB-H/SH systems), which enable to choose a several type of communication channel models for the simulation. Overall, there were implemented 8 different channel models, which can use for the exploring of the signal distortions in different transmission scenarios: mobile (RA6, TU6, VU and MR models), portable (PI and PO models) and fixed (RC20 and RL20 models). Moreover, implementation of own channel model, with specific parameters, is also possible. At the end of the simulation, the application is analyzed and shows the most important results: *BER* (before and after Viterbi decoding) and *MER* ratios, constellation diagrams (transmitted, received and corrected), spectrum of the signal (transmitted and received) and impulse response of the channel (path delays and path losses of the channel).

Second application, created and used in this dissertation thesis, allows simulate and analyzed signal transmission in DVB-SH standard. This application allows simulating both transmission modes (DVB-SH-A/B), how it was clearly shown in the flow chart (see Fig. 5.2). The FEC scheme (turbo encoder and covolutional interleaver), which is implemented into the created application is a little different, as it is recommended by ETSI standard [11]. Main reasons of this step were clearly described in chapter 5.2. In the created application, instead of 3GPP2 turbo encoder and convolutional interleaver, a PCCC turbo encoder and simple channel interleaver were used. As a turbo decoding method, the SISO method was used. And again, at the end of the simulation, the application is analyzed and shows the most important results: *BER* (after the turbo decoding) and *MER* ratios, constellation diagrams (transmitted, received and corrected), spectrum of the signal in the case of the DVB-SH-A (OFDM) mode (transmitted and received) and impulse response of the channel (path delays and path losses of the channel).

Both applications were designed for the PC platform (with MS Windows operation system) and were created in the program MATLAB - version R2008b. This version is recommended for the correct run of the programs. Of course, these applications can be run too on the higher version of the MATLAB. However, their current run is not guaranteed. For both applications a simple GUI (Graphical User Interface) interface was created for the easier settings of the parameters for the simulation and for the better evaluation of the achieved results (see appendix A and B). At this point (after the creation of appropriate applications for the simulation and analysis of the signal transmission and its distortions in DVB-H/SH standards), third aim of this dissertation thesis was completed.

Chapters six (6) and seven (7) contain the most important parts of this dissertation thesis. In these chapters there were explored all real possible transmission scenarios, which can occurred in the DVB-H/-SH standards. Generally, in both standards there were investigated three different transmission scenarios: mobile, portable and fixed. Furthermore, the DVB-H performance was also tested in a laboratory environment.

The transmission distortions of the DVB-T/H standard in mobile TV over fading channels were explored firstly. For the exploring of the signal distortions in mobile TV scenarios, there were used special mobile fading channel models (RA6, TU6, VU30 and MR100), respect the speed of the receiver (it is between 30 km/h and 100 km/h). As a reference channel, the Gaussian (AWGN) channel was used. System configuration parameters, which were used for the simulation and measuring for the first two channel models (RA6 and TU6), were presented in 6.1. Thank to the fact that there are used channel profiles with higher Doppler's shift, there were used a 2K OFDM mode with QPSK modulation. This configuration has the most resistance against the deep fadings and higher Doppler's shift. The code rate was set on 2/3 and the length of the guard interval was equaled to 1/16. At this value of the guard interval, the time length of one OFDM symbol is 14 us. The TU6 channel model has a highest path delay (5 us). Therefore, the length of the guard interval was suitable.

System configuration parameters, which were used for the simulation and measuring for the second two channel models (VU30 and MR100), were also presented in 6.1. These channel models are based on the real measurement results. Therefore, they give more realistic and credible picture about the signal propagation. Thank to system configuration, (2K OFDM mode, 16QAM modulation, 2/3 code rate), the demands of echo path was minimized. The length of the GI is equaled to 1/4. Therefore, time duration of one OFDM symbol is 56 us, which is enough for the minimizing of the ISI interferences.

For the numerical evaluation of the obtained results in all type of communication channels, there were used *BER* ratios before and after Viterbi decoding. Furthermore, for the evaluation of the distortions in the constellation diagram, the *MER* ratio was used. For the overall evaluation of *BER* and *MER*, a QEF operation was used [3]. The QEF limit approximately corresponds to one error per day.

The Fig. 6.2 (Fig. 6.3) and Fig. 6.6 (Fig. 6.7) illustrate *BER* before and after the Viterbi decoding and *MER* ratio in Gaussian and four fading channel models – RA6, TU6, VU30 and MR100 for mobile scenarios, obtained from simulation (measurement). Results, obtained from simulation and measurement are slightly different. Possible reason of these differences (slightly different implementation methods of fading channel models in MATLAB and measurement devices) was described in 6.1.2. Typical results and the constellation diagrams for the mobile scenarios and channel types from simulations (see Fig. 6.4 from a) to c) and Fig. 6.8 from a) to c)) and measurements (see Fig. 6.4 from d) to f) and Fig. 6.8 from d) to f)) were also obtained and evaluated. Furthermore, spectrum of one OFDM symbol of DVB-T/H signal in all explored channel model from the simulations were also obtained (see Fig. 6.5 and Fig. 6.9).

The transmission distortions of the DVB-T/H standard in portable TV over fading channels were explored secondly. For the modeling and exploring of this transmission scenario there were used special fading channel models, recommended by [9], which are respect the "portable" speed of the receiver (approx. 3 km/h). These channels were PI and PO (Portable Indoor and Outdoor) models, which have very similar features (same spectrum characteristics for each path and speed of the receiver), but the delays and path losses are different. And again, system configuration parameters, which were used for the simulation and measuring, were presented in 6.2. Thank to the less speed of the receiver, there were used a 4K OFDM mode with 16QAM modulation. The code rate was again set on 2/3. The length of the GI was equaled to 1/8. Therefore, time duration of one OFDM symbol was 56 us. This value was enough, because the highest path delay (in the PO channel) was equaled to 9.2 us.

The Fig. 6.10 (Fig. 6.11) illustrates *BER* before and after the Viterbi decoding and *MER* ratio in Gaussian and two fading channel models – PI and PO for portable scenarios, obtained from simulation (measurement). Results, obtained from simulation and measurement are very similar. Furthermore, thank to optimal system configuration, impact of fading channels on the received signal quality was minimized. Detail description of obtained results and their evaluation were clearly presented in 6.2. Typical results and the constellation diagrams for the portable scenarios and channel types from simulations (see Fig. 6.12 from a) to c) and Fig. 6.12 from a) to c)) and measurements (see Fig. 6.12 from d) to f) and Fig. 6.12 from d) to f)) were also obtained and evaluated. And again, spectrum of one OFDM symbol of DVB-T/H signal in all explored channel model from the simulations were also obtained and evaluated (see Fig. 6.13 a) to c)).

Thirdly and also finally, signal distortions in the DVB-T/H standard were investigated in fixed TV channel. For the modeling and exploring of this scenario there were used a fixed channel profiles, known from the DVB-T standard [7]. These channel models were RC20 (Ricean) and RL20 (Rayleigh), which have same path parameters (delay, path loss and phase shift). One main difference between them is the availability of the direct path. The RC20 channel model contains a direct path, but RL20 channel has only echoes (without direct path). System configuration parameters, used for the simulation and measuring, were presented in 6.3. There was used 8K OFDM mode with 64QAM modulation. The code rate was set on 2/3 and the length of the GI was equaled to 1/8. Therefore, time duration of one OFDM symbol is 112 us. The highest path delay (in both channels) is equal to 5.5 us. Therefore, the ISI interferences were sufficiently attenuated.

Simulation and measurement results of the fixed TV transmission in the DVB-T/H standard for a varying *C*/*N* ratio in the Gaussian (reference) and in the fixed (RC20 and RL20) channel models are from Fig. 6.14 (simulation) to Fig. 6.15 (measurement). Results, obtained from simulation and measurement are slightly different, as it was in case of mobile scenario. These differences are probably caused by slightly different signal processing, used in software (MATLAB) and hardware (measurement devices) implementations. Typical results and the constellation diagrams for the fixed scenarios and channel types from simulations (see Fig. 6.16 from a) to c)) and measurements (see Fig. 6.16 from d) to f)) were also obtained and evaluated. Spectrum of one OFDM symbol of DVB-T/H signal in all explored channel model from the simulations were also obtained and evaluated (see Fig. 6.17 from a) to c)).

Overall, from the obtained results can be determined some general conclusions:

- Signal level is descending by decreasing value of the carrier-to-noise ratio (in all type of channel models), but this value is limited.
- In case of the lower *C*/*N* ratio it is going to dispersion of points in constellation diagram, mainly in cases, when type of the modulation has with higher number of states (16QAM and 64QAM). If the ratio of *C*/*N* is larger then the number of wrongly assessed symbols is less.
- Advanced MPE-FEC encoding (outer and inner interleaving) and optimal system configuration provide greater protection of data transmissions.
- Differences between the results, obtained from the simulations and measurements, are slightly different (mainly in case of mobile and fixed

scenarios). These differences are probably caused by the little different implementation of the fading channel models in MATLAB and R&S SFU software option (used in R&S measurement devices).

- The DVB-T/H system has highest requirements (from the point of signal quality) in the TU6 and RL20 channel models.

Publications of the main results from the simulations, measurements and analysis of the signals transmission in DVB-T/H standard can be divided onto following points:

- Application in MATLAB, which can simulate the transmission in the DVB-T/H standard: [104], [105], [107]-[109], [111].
- Simulation of the transmission in Gaussian and different fading channel models in DVB-T/H standard: [106], [107], [110], [121], [123], [126].
- Simulation and measurement of the transmission distortions of the digital television DVB-T/H: [110].

In the seventh chapter (7) the signal transmission in DVB-SH standard in different transmission scenarios was explored. Of course, how it was done in DVB-T/H standard, there were also investigated three transmission scenarios: mobile, portable and fixed. For the exploring of the signal distortions in the mobile and portable scenarios, the DVB-SH-A system architecture (OFDM mode) was used. In case of the fixed scenario, the DVB-SH-B system architecture (TDM mode) was preferred. Of course, the system parameters, used for the exploring of the signal distortions in both DVB-SH systems over fading channels, were same values (if that was possible), as it was in DVB-H system. This was very important for the credible comparison of obtained results in both DVB-H/SH standards.

The transmission distortions of the DVB-SH-A standard in mobile TV over fading channels were explored firstly, as it was done in case of DVB-T/H system. For the exploring of the signal distortions in mobile TV scenarios, there were used RA6 and TU6 mobile fading channel models. The Gaussian (AWGN) channel was used again as a reference channel. System configuration parameters, which were used for the simulation, were presented in 7.1. For all investigated scenario (mobile, portable and fixed), in DVB-H had set the code ratio to 2/3. This ratio represents the case of quite robust transmission. In the standard of DVB-SH this value represents the lowest robustness of the transmission. Therefore, the code ratio for DVB-SH was set to 1/4. Thank to the fact that there are used channel profiles with higher Doppler's shift, there were used a 2K OFDM mode with QPSK modulation. The length of the guard interval was equaled to 1/16. At this value of the guard interval, the time length of one OFDM symbol was 14 us. As a decoding process, a SISO-MAP method was used and the decoding process was repeated eight times, as recommended in [12].

For the numerical evaluation of the obtained results in all type of communication channels, there were used *BER* ratios after turbo decoding. Of course, for the evaluation of the distortions in the constellation diagram, the *MER* ratio was used. For the overall evaluation of *BER* and *MER*, a QEF operation was used. The DVB-SH standard, for the FEC, uses turbo encoding and advanced channel/time interleaving. The limit of the error-free reception is considered for *C*/*N*, where the *BER* is equal to 1.10^{-5} after the eighth turbo decoding [12].

The Fig. 7.1 a) (Fig. 7.1 b)) illustrates *BER* after turbo decoding (*MER* ratio) in Gaussian and two fading channel models – RA6 and TU6 for mobile scenarios, obtained from simulation. Thank to advance signal processing (turbo encoding/decoding) and optimal system configuration (2K OFDM mode, QPSK modulation and length of guard interval), impact of fading channels on the received signal quality was minimized. Detail description of obtained results and their evaluation were clearly presented in 7.1.1. Typical results and the constellation diagrams for the mobile scenarios and channel types from simulations were also obtained. How it was mentioned several times in this dissertation thesis, the measurement of the signal distortions in the DVB-SH standard was not possible in the laboratory environment. Therefore, distortions in the constellation diagrams were explored in cases, when the signal was received and when it was equalized (corrected). Pictures were divided into two groups and were clearly described: before the equalization (see Fig. 7.2 from a) to c)) and after the equalization (see Fig. 7.2 from d) to f)).

The transmission distortions of the DVB-SH-A system in portable TV over fading channels were explored secondly. For the exploring of this transmission scenario there were again used the PI and PO portable channel models. System configuration parameters, which were used for the simulation and measuring, were presented in 7.2. Thank to the less speed of the receiver, there were used a 4K OFDM mode with 16QAM modulation, as it was in DVB-T/H. The code rate was again set on 1/4. The length of the GI was equaled to 1/8. Therefore, time duration of one OFDM symbol was 56 us. As a decoding process a SISO-MAP method were used again. The number of the iterations (number of repeated turbo decoding) was eight (8).

Dependences (obtained from the simulations) of the *BER* ratio after the turbo decoding (see Fig. 7.3 a)) and *MER* ratio (see Fig. 7.3 b)) on the *C*/*N* ratio were explored and discussed in 7.2.1. When the results (in DVB-SH-A system) are compared with the results, obtained in DVB-T/H, then is clearly seen the advantages of system configuration of DVB-SH. Better results were also obtained in mobile scenario. Typical results and the constellation diagrams for the mobile scenarios and channel types from simulations were also obtained. Examples of constellation diagrams before (see Fig. 7.4 from a) to c)) and after (see Fig. 7.4 from a) to c)) the channel corrections in all portable TV channel were also explored.

Thirdly and also finally, signal distortions in the DVB-SH standard were explored in fixed TV channel. The DVB-SH-B (mode TDM) system configuration was used in this case. The reason of this decision was described in the 7.3. Investigation of signal transmission in fixed scenarios was divided into two parts: DVB-SH-B performance in the Gaussian channel and DVB-SH-B performance in the RC20 channel model with different level of the direct path (different values of *K-factor*). System parameters for the transmission were summarized in the 7.3. There are two important differences. First one is the carrier frequency, which was set on 2.2 GHz (satellite transmission). The second one is a fact that the guard interval is not used.

Simulation results of the DVB-SH-B performance in Gaussian channel for all types of modulations are shown in Fig. 7.5 a). Dependences of the *MER* ratio on the *C*/*N* ratio are practically same for all modulations (see Fig. 7.5 b)). The reason is that there was used only a Gaussian channel. Of course, distortions in the constellation diagrams (before and after the channel corrections) for all modulations were also obtained and there are shown in the Fig. 7.6 from a) to f).

Simulation results of the DVB-SH-B performance in RC20 fading channel model with different *K-factor* are shown in Fig. 7.7 a). When the *K-factor* is equal to 10, then there were no significant differences between the results in the Gaussian and RC20 channels. In case of the RC20 channel with half value of the *K-factor*, the obtained results were worse. Dependences of the *MER* ratio on the *C*/*N* ratio are shown in Fig. 7.7 b). Distortions in the constellation diagrams (before and after the channel corrections) for all modulations were obtained and described and there are shown in the Fig. 7.8 from a) to f).

Overall, from the obtained results can be determined some general conclusions:

- As it was in case of DVB-T/H system, in the DVB-SH standard the signal level is also descending by decreasing value of the carrier-to-noise ratio (in all type of channel models). Of course, this value is again limited.
- In case of the lower *C*/*N* ratio it is going to dispersion of points in constellation diagram, mainly in cases, when type of the modulation has with higher number of states (8PSK and 16APSK). Furthermore, types of PSK modulations have less resistance to the noises as the types of QAM modulations (used in DVB-H).
- Advanced FEC encoding (turbo encoding, advanced channel and time interleaver) and optimal system configuration and provide greater protection of data transmissions.
- Thank to the advanced turbo decoding method (SISO-MAP) and the fact that the number of decoding process is adjustable, it can be achieved a lower *BER* ratio at lower *C*/*N* ratio. If the number of iterations (number of turbo decoding process) is higher then the achieved *BER* ratio at constant *C*/*N* ratio is lower. However, with higher number of iterations the time, needs for the turbo decoding, is also higher and depending on the hardware performance.
- The DVB-SH system has highest requirements (from the point of signal quality) in the TU6 and RC20 channel (with half value of *K-factor*) models.

Publications of the main results from the analysis and simulation of the signals transmission in DVB-SH standard can be divided onto following points:

- Application in MATLAB, which can simulate the transmission in the DVB-SH standard (in both, SH-A and SH-B system architectures): [112], [113], [117], [120], [131].
- Simulation of the transmission in Gaussian and different fading channel models in DVB-SH standard: [114], [116], [119], [122], [123], [125].

At the end of this dissertation thesis it is appropriate to mention the limitations of the created applications and propose possible solutions or exploring the possibilities, building upon the results of this work:

- In this dissertation thesis, more precisely, in the created applications, was not explored the performance of the *hierarchical modulation*. In case of the hierarchical modulation, the DVB-T/H and DVB-SH modulators have two transport stream inputs and two FEC blocks, how it was briefly described in 1.1.1. Thank to this configuration it can be chose different level of error protection for the transmission, depending on the conditions of the transmission channel environment. Performance of the hierarchical modulation in the DVB-T/H and partly in the DVB-SH standards has been explored. Obtained results were evaluated, described and published in [42], [43], [61], [62] and [80]. On the other hand, in these publications not all transmission scenarios were tested. Moreover, the performance of the α-factor, which is one of the most important parameters in hierarchical modulation, has not completly explored. Therefore, this area needed more detailed analysis.

- In case of the DVB-T/H standard, the signal reception can be also improved with the in-depth interleaving (see 2.1.2). This interleaving technique provides extra level protection against short noise impulses, how it has been explored and published in [64] and [90]. Of course, the in-depth symbol interleaving should be improved the signal reception in different transmission scenarios (mainly in mobile and portable transmission). Impact of this improvement on the signal quality was partly explored and the obtained results were published in [64] and [126]. However, not all transmission scenarios were tested. Therefore, this part of DVB-H system configuration should be explored and analyzed.

Nowadays, thank to the rapid technical innovations, between the DVB-H and DVB-SH standards exist another DVB standard, which is also appropriate for the broadcasting of mobile TV services [91], [92]. An ever increasing demands for capacity and higher picture quality, it has been developed new DVB standard, so called DVB-T2 (2^{nd} Generation Digital Terrestrial Television Broadcasting) [93], [94]. It is an improved variant of DVB-T, providing higher capacity and/or more robustness. However, DVB-T2 (between the technical and system innovations) also provides new technological solutions and possibilities for robust and reliable mobile broadcasting and reception. To facilitate the implementation of mobile applications DVB has defined a mobile profile/version of DVB-T2, called T2-Lite [93], [95]. The T2-Lite component will allow simpler receiver implementations for very low capacity applications such as mobile broadcasting. This new profile will provide the most efficient air interface, achievable with current technologies (DVB-T/H/SH, HSPA and LTE).

In recent research, thank to these above mentioned innovations in DVB-T2, this standard is considered as a reference for the next generation mobile TV standard DVB-NGH (Next Generation for Handhelds) [91], [96]. In the most recent works [97]-[100], [119] and [121], the possibilities of the DVB-T2 from the perspective of mobile TV broadcasting have been explored. From the obtained results is clear that the DVB-T2 standard is a favorite technology for the broadcasting of mobile TV services, mainly in HDTV quality. Flexibility gives DVB-T2 the potential to provide huge operational benefits for broadcasting of mobile TV in the future. On the other hand, mobile phones, which are available on the market, should be innovated. Therefore, the development of smart and fast hardware devices (mainly for fast signal processing) is unavoidable.

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List of Appendices

A APPLICATION FOR THE SIMULATION OF THE DVB-T/H TRANSMISSION

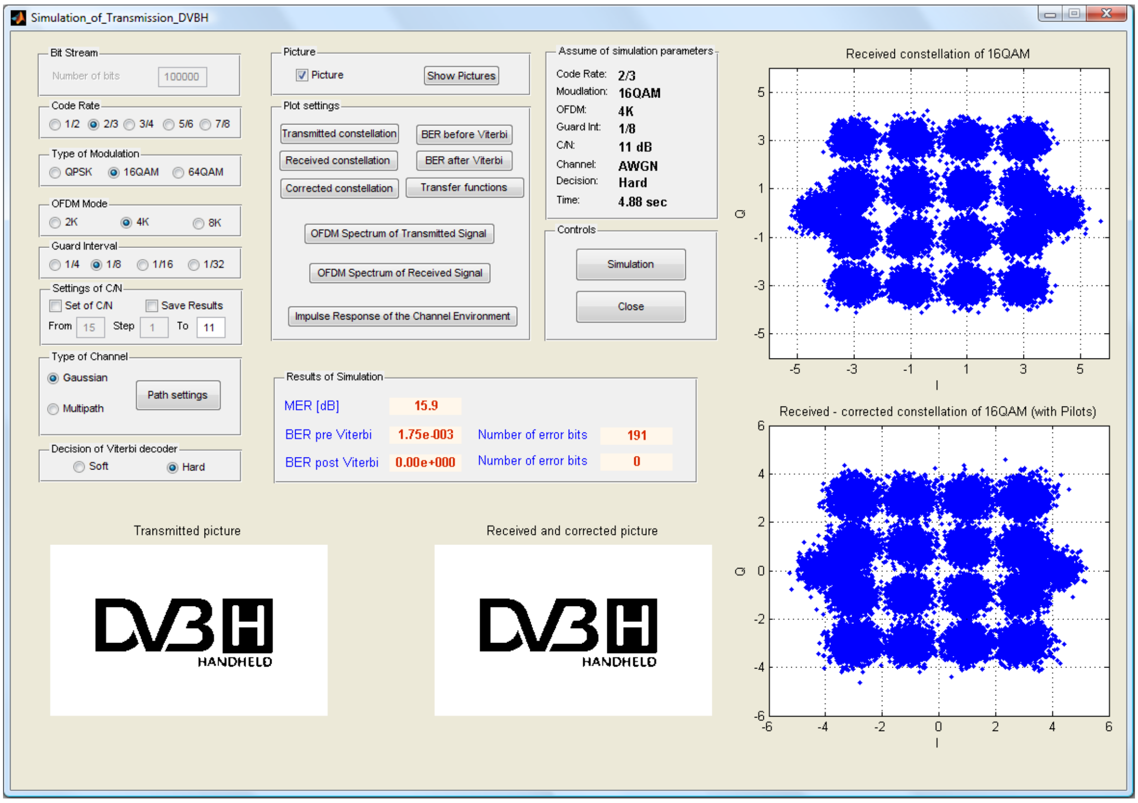

Fig. 8.1 Main window of the created MATLAB application for the DVB-T/H.

Main window of the MATLAB application, which can simulate and analyze the transmission of DVB-T/H in different transmission scenarios, is shown in Fig. 8.1.

In the first step it is necessary to order a number of bits for the input sequence generation. The created application allows selecting between two options. In the first case the user can specify the number of bits for generating input bit sequence. This number the user can write to table *Number of bits*. When checkbox *Picture* is active, that presented the second option. In this case the created program is loaded the *DVBH.Bmp* (see Fig. 1) picture and converted it into a sequence of ones and zeroes.

The *Code Rate* option allows controlled the error protection of the transmitted data, e.g. the data rate can be lowered again by selectively omitting bits. Possible punctuated code rates are, according to DVB specification, from 1/2 (no puncturing), to 7/8 (minimum error protection).

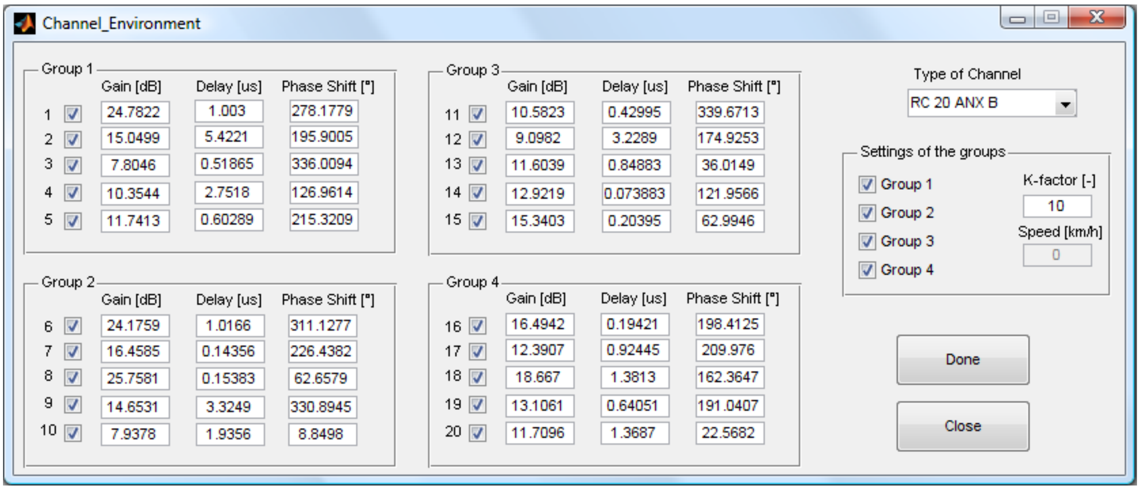

Fig. 8.2 Main window of the created MATLAB application for the channel model settings.

The *Type of Modulation* and *OFDM mode* options enable choose of type of modulation (QPSK, 16QAM and 64QAM) and OFDM modes (2K, 4K and 8K), which used in DVB-T/H standard. The option *Guard Interval* enables set values, defined by the DVB-T/H standard: 1/4 (longest), 1/8, 1/16 and 1/32 (shortest).

The *Type of Channel* option allows choose the type of communication environment, in which it is possible to simulate behavior of the transmitted data. There are two possibilities: *Gaussian* and *Multipath* channel. The first one is represented the classical, Gaussian (AWGN) channel. The *Set of C/N* is given the value of the Carrier-to-Noise Ratio in dB. The second one enables chose and set different type of multipath fading channels. For the better settings of the parameters of each path (e.g. delay, path loss), there were created sub application with GUI (see Fig. 8.2). It is activated by the button *Path Settings*. The application is called *Channel_Environment* and enables set and modified the parameters of mobile, portable and fixed fading channel models. How it can be seen in Fig. 8.2, the loss of each path is defined in a tables *Gain [dB]*. Of course, values of path loss are in negative form, but in the mentioned tables they are loaded or added in positive form. This solution is voted, because by this way the editing of these tables (and also their values) is much easier. Of course, in the concrete application these values are multiplied by constant (-1) for the achieving of their negative form.

Option *Decision of Viterbi Decoder* allows chooses the type of decision in Viterbi decoding process. Here exits to cases: soft decision and hard decision.

Option *Plot settings* enables show additional dependences and graphs in separate windows, like a constellation diagrams (transmitted, received and corrected after the equalization), impulse response of the channel environment, transfer function, dependence of the *BER* on the level of the signal before and after Viterbi decoding and OFDM spectrum of the transmitted and received signal.

After the setting of all parameters first case the user can click on the *Simulation* button for the start of simulation.

B APPLICATION FOR THE SIMULATION OF THE DVB-SH TRANSMISSION

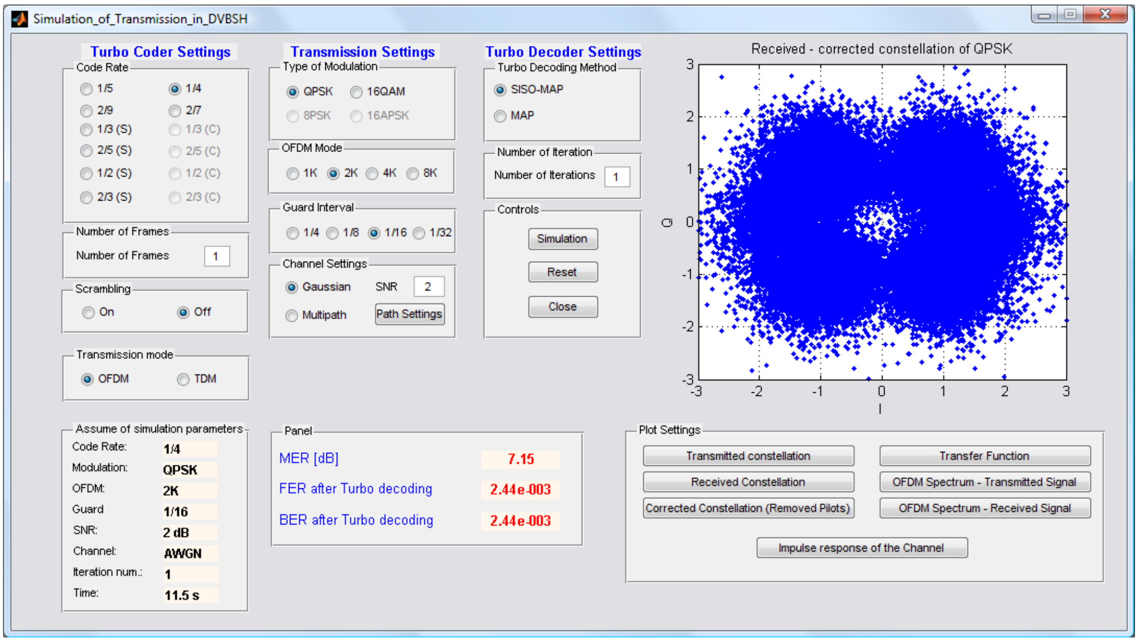

Fig. 8.3 Main window of the created MATLAB application for the DVB-SH.

Main window of the created application in MATLAB for the simulation of complete transmission in DVB-SH standard can be seen in Fig. 8.3.

Before the simulation, it must be defined the input parameters of the system configuration. Firstly, the user must define the mode of transmission: OFDM (SH-A mode) or TDM (SH-B) in the option *Transmission mode*. Moreover, it is also possible controlled the *Scrambling* process (*on/off*) and the number of generated frames (*Number of Frames*).

The *Code Rate* option allows control the error protection of the transmitted data. It can be choice between twelve code rates (according to DVB-SH-A/B specification). Codes rates with *"S"* abbreviation are represented the "standard" form of the puncturing. Codes rates with *"C"* are represented the "complementary" form. The difference between these two types is only in the position of the "ones" and "zeros" in puncturing form.

The *Type of Modulation* and *OFDM mode* options enable choose of modulation. DVB-SH-A standard defines two types of modulations: QPSK and 16QAM. User can set the following OFDM modes: 1K, 2K, 4K and 8K. The option *Guard Interval* enables set values, defined by the DVB-SH standard: from 1/4 (longest) to 1/32 (shortest). In case of TDM mode, there are possible choose between modulations QPSK, 8PSK and 16APSK. Of course, *OFDM mode* and *Guard Interval* modes are not available in this case.

It is visible in the Fig. 8.3 that in table *Channel Settings* it is possible set the type of transmission environment. It gives a choice for a user selected between the *Gaussian*

(AWGN) and *Multipath* channel. The button *Path settings* enables set up different types of fading channels. The way is the same, as it was described in the previous chapter.

Option *Turbo Decoding Method* allows choosing the type of turbo decoding process. Here exist two cases: SISO-MAP (Soft Input Soft Output - Maximum A Posteriori) and MAP. As a last it is important to define the number of the decoding process, so called *Number of iterations*. In this field it can be set the number of decoding process.

After the setting of all parameters first case the user can click on the *Simulation* button for the start of simulation.

The table *Results of simulation* shows the *MER* (Modulation Error Ratio), *FER* (Frame Error Ratio) *after Turbo decoding and BER* (Bit Error Ratio) *after Turbo decoding*. The outputs of each simulation are also the constellation diagrams. Application shows the received and corrected (after equalization) constellation diagram. Of course, user can show these diagrams in separate windows. For this step serves buttons in the table *Plot Settings*.

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