TUCS

Piritta Hakala | Heidi Himmanen

Evaluation of DVB-H Broadcast Systems Using New Radio Channel Models

Turku Centre for Computer Science

TUCS Technical Report
No 817, March 2007

Evaluation of DVB-H Broadcast Systems Using New Radio Channel Models

Piritta Hakala
University of Turku, Department of Information Technology
Heidi Himmanen
University of Turku, Department of Information Technology

TUCS Technical Report
No 817, March 2007

Abstract

The commonly used channel model for mobile reception has been the 6-tap Typical Urban (TU6) model developed by the European COST207 project in 1989. The CELTIC WingTV project discovered that TU6 does not model the DVB-H channel, particularly pedestrian use cases, very well. An extensive field measurement campaign was carried out and new channel models were created based on the measurements in 2006. The new models cover pedestrian indoor, pedestrian outdoor, vehicular urban and motorway use cases and are used for evaluation of DVB-H broadcast systems in this report. Simulations were performed for different modulation modes and code rates and the simulation results were compared to laboratory and field measurements. It was concluded that the use of Multi Protocol Encapsulation - Forward Error Correction (MPE-FEC) at the link layer is not needed in the pedestrian use cases, whereas the vehicular use cases show considerable MPE-FEC coding gains. The study on parameter selection leads to five recommended options for combinations of modulation, convolutional and MPE-FEC code rates for networks covering all modeled use cases.

Keywords: DVB-H, simulation, new channel models, link layer, MPE-FEC, system optimization

TUCS Laboratory
Communication Systems

1. Introduction

The Digital Video Broadcasting system for transmission to Handheld terminals (DVB-H) [1] is a standard for delivery of Internet Protocol (IP) based services to battery powered mobile receivers. DVB-H is based on the physical layer terrestrial DVB-T standard and was ratified by ETSI (European Telecommunications Standards Institute) in November 2004. The two main changes compared to the terrestrial standard was additional link layer error correction, to enable error correction and time-interleaving in challenging mobile receiving conditions, and time slicing, to enable power saving for the battery powered receivers.

The standard defines a large set of parameters. The physical layer defines three different options for modulation: QPSK, 16-QAM, 64-QAM, three OFDM modes: 2K, 4K and 8K, five convolutional code rates and four possible guard interval values. For the link layer an optional Multi Protocol Encapsulation - Forward Error Correction (MPE-FEC) is defined, with five possible code rates and four options for MPE-FEC frame size. With this large set of options, computer simulations provide good means for optimizing the system, before carrying out time consuming laboratory and field measurements.

Previously the DVB-H system has been analyzed in a six-tap Typical Urban radio channel model, developed by the COST 207 project [2]. In the CELTIC WingTV project [3] new channel models were developed to provide better representation of the radio channel especially in pedestrian use cases. The new channel models characterize the following four use cases: pedestrian indoor (3 km/h), pedestrian outdoor (3 km/h), vehicular urban (30 km/h) and motorway (100 km/h).

Previous simulation, laboratory and field measurement work in the WingTV -project has shown that the best options for physical layer modulation and coding are QPSK 1/2, QPSK 2/3, 16-QAM 1/2 and 16-QAM 2/3. In this report these modes are compared using all possible link layer code rates, to find the best combinations for modulation and coding in the different use cases and service bit rate scenarios.

After comparing the results based on average energy per bit comparisons, it can be concluded that there are five recommended modes when building networks covering all the new channel models. Also, the simulations show that for the pedestrian channels there is no particular need for MPE-FEC coding at the link layer.

The report is organized as follows: Chapter 2 gives an overview of the DVB-H system. Time slicing and MPE-FEC at the link layer are introduced and the extensions from DVB-T to DVB-H at the physical layer. The new channel models are presented in chapter 3, and the physical and link layer simulation descriptions are explained in chapter 4. In chapter 5 the simulation results for the pedestrian and vehicular use cases are presented and the average energy per source bit for every mode in all use cases is depicted. Also, the preferred modes are stated. The simulation results are compared to laboratory and field measurements in chapter 6 and chapter 7 draws the final conclusions of the report.

2. DVB-H system description

A conceptual description of the DVB-H system is depicted in Figure 1. The DVB-H system is a combination of elements of the physical and link layers. The physical layer in DVB-H is the DVB-T physical layer with a few extensions. In the DVB-H system the IP services and MPEG-2 services are carried over the same multiplex. The modulator offers different transmission modes, 8K, 4K and 2K, with the corresponding transmitter parameter signaling (TPS) and transforms the MPEG-2 transport stream (TS) to a radio frequency (RF) signal after which the signal goes through the channel. The physical layer demodulator in the receiver side recovers the TS packets from the received RF signal. The IP datagrams are then decapsulated at the link layer and DVB-H terminals are able to receive the IP services. The link layer, built on top of the physical layer, has two main elements: time slicing and forward error correction for multiprotocol encapsulated data (MPE-FEC). The time slicing element enables bursty transmission and switching off receiver parts between the bursts to save power. The additional error correction enables reception at higher velocities than DVB-T, which was designed for fixed reception. These two elements were needed to enable transmission to mobile battery-powered devices.

In the following we will give an overview of the link layer and the amendments to the physical layer introduced by the DVB-H standard. The purpose is not only to give a background to the simulation results presented in chapter 5, but also to demonstrate the required changes to adjust a transmission system for fixed reception to serve mobile users with handheld battery-powered receivers.

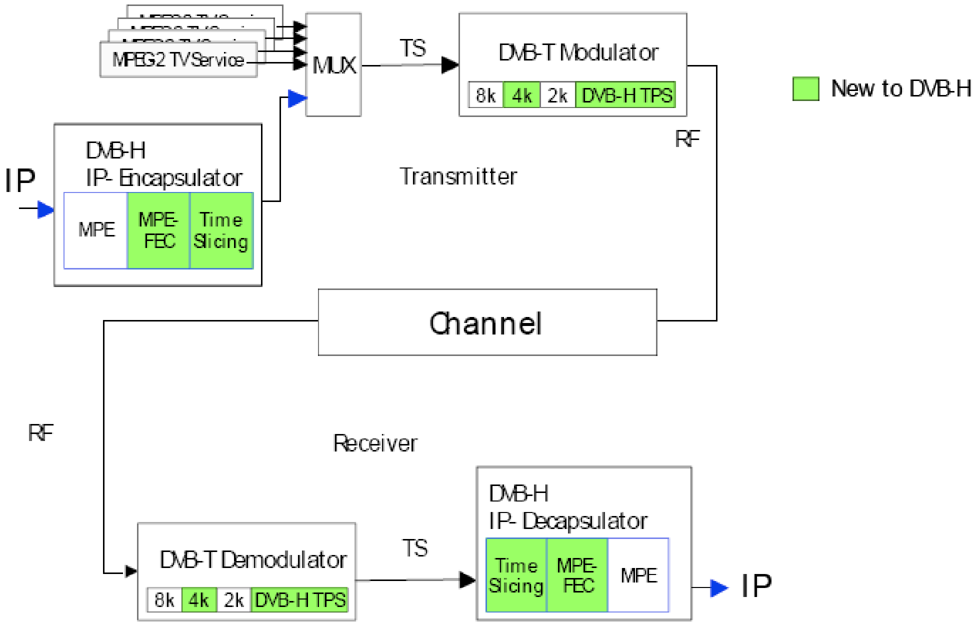

Figure 1 A conceptual description of the DVB-H system [5]

2.1. Link layer

Time slicing reduces the average power consumption in the receiver up to about 90% - 95% [4]. When a user moves to another cell, time slicing enables smooth and seamless frequency handover. Time slicing is mandatory for DVB-H. MPE-FEC (MultiProtocol Encapsulation-Forward Error Correction) improves carrier-to-noise (C/N) and Doppler performances in mobile channels. It improves tolerance to impulse interference as well. Use of MPE-FEC is optional for DVB-H. These link layer elements do not affect the DVB-T physical layer in any way. DVB-H is backward compatible to DVB-T and DVB-H signals do not interfere with DVB-T receivers.

2.1.1. Time slicing

With time slicing data are transmitted in bursts with a very high bit rate compared to a constant low bit rate (that is, the average bit rate required when time slicing is not used). A delta-t parameter indicates the time to the beginning of the next burst (Figure 2) and its value is pointed in the MPE (MultiProtocol Encapsulation) and MPE-FEC section headers (Figure 3) [5]. The delta-t method removes the need for synchronization of clocks between a transmitter and a receiver.

Between bursts there is an off-time period, as depicted in Figure 2, during which the data of a particular elementary stream (ES) is not transmitted (ES means here a stream of MPEG-2 TS packets). The off-time reduces the power consumption, since the receiver is turned off. For example, if the burst length is 110 ms, with 90% reduction of the power consumption the off-time periods are about 990 ms. The burst size and the constant bit rate affect the power consumption as well. Smooth and seamless handover is possible with time slicing, since the receiver is able to monitor neighboring cells without an interruption of the service reception. The receiver may scan for other available signals during the off-time periods to find the best potential alternative signal [4].

2.1.2. MPE-FEC

The IP datagrams are encapsulated column-wise into the MPE-FEC frame [5] as illustrated in Figure 3. The frame is then encoded row-wise using a Reed-Solomon (255,191) code. The IP datagrams are carried by MPE sections and the RS redundancy columns by MPE-FEC sections. The CRC-32 bytes are calculated over each section separately, after the section headers have been attached. The sections are carried by an MPEG-2 transport stream (TS). So called *virtual time-interleaving* is achieved over the entire MPE-FEC frame, when the data are encoded in a different direction than it is transmitted.

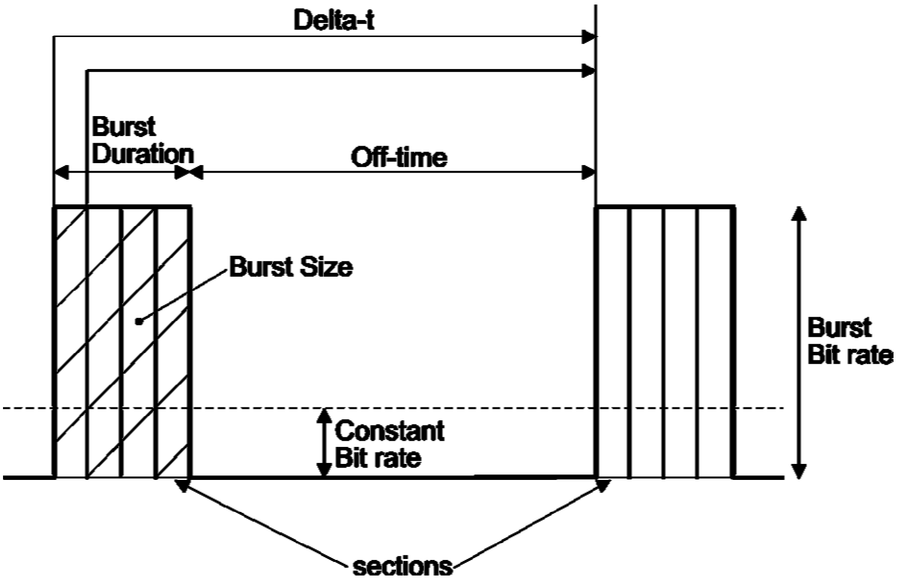

Figure 2 Burst parameters

The MPE-FEC frame consists of an application data table (ADT), which contains IP datagrams and possible padding, and of an RS data table, which contains the RS redundancy data. The number of rows in the MPE-FEC frame can vary; possible values are 256, 512, 768 and 1024, thus one frame can carry 500 kb, 1 Mb, 1.5 Mb or 2 Mb of data if it is filled entirely. When all 191 ADT columns and 64 RS columns are used, the achieved code rate is 3/4. Other code rates are obtained by discarding some columns of the application data table and the RS data table. Table 1 describes one way of achieving the code rates defined by the standard. When no MPE-FEC coding is used, the whole MPE-FEC frame is filled with data and no RS information for error correction is transmitted. If the results with MPE-FEC are compared to an uncoded transmission, the gain of using MPE-FEC is obtained.

When time slicing and MPE-FEC are used together, one burst carries one MPE-FEC frame.

Table 1 Obtaining different MPE-FEC code rates

FEC code rate	Data columns	RS columns	Total
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
Uncoded	255	0	255

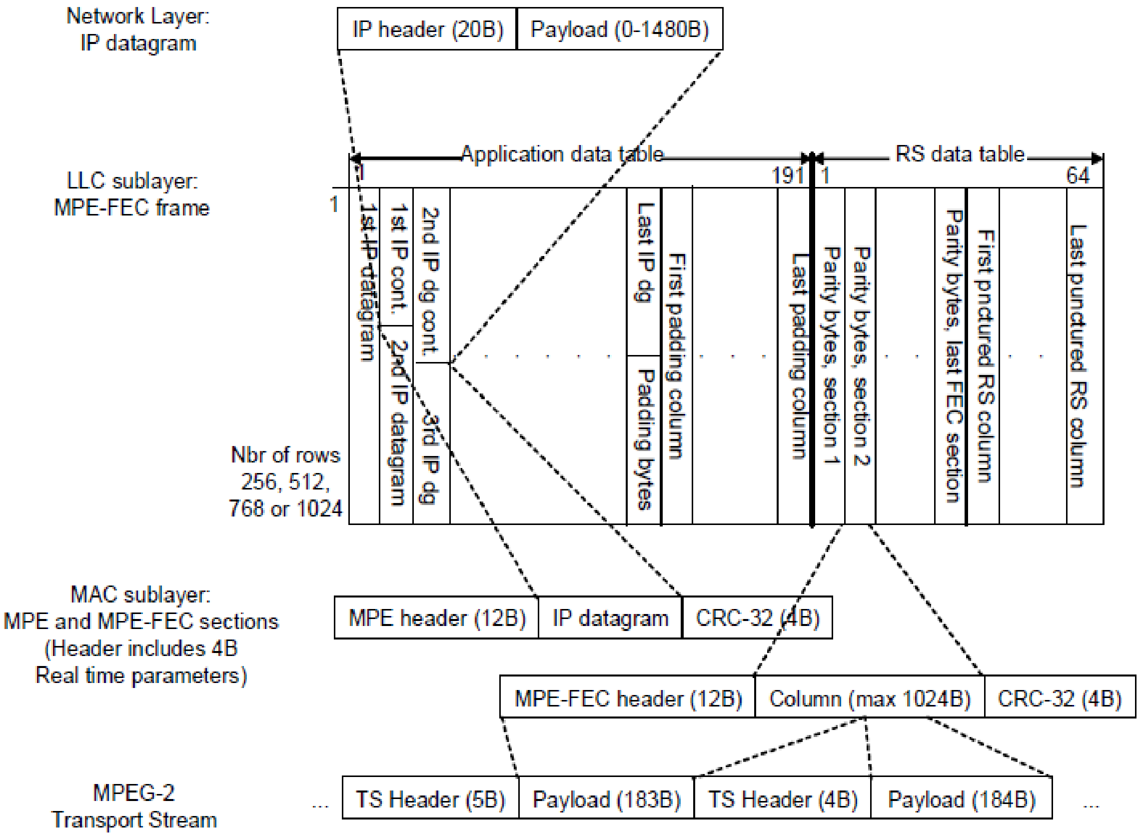

Figure 3 The link layer packets of DVB-H

2.2.Physical layer

In DVB-H the DVB-T physical layer has four extensions [4]. The transmitter parameter signaling (TPS) bits have been upgraded. Two bits are added to indicate the presence of DVB-H services and possible use of MPE-FEC to enhance and speed up the service discovery. The second extension is a 4K mode orthogonal frequency division multiplexing (OFDM) for trading off mobility and the single frequency network (SFN) cell size. The 4K mode enhances the flexibility of the network design along with the 2K and 8K modes. The third extension is an in-depth interleaver for the 2K and 4K modes. Bits are interleaved over four or two OFDM symbols, respectively, contrary to interleaving bits over one OFDM symbol with the native interleaver (8K mode). In-depth interleaving enhances the tolerance to impulse noise and improves the robustness in the mobile environment. The fourth extension is the 5-MHz channel bandwidth for non-broadcast bands.

2.2.1. 4K mode and in-depth interleavers

The 4K mode is an intermediate mode between the 2K and 8K modes and is added to the DVB-T physical layer to improve network planning flexibility [5]. It offers an additional tradeoff between the size of SFN networks and mobile reception performance (i.e. Doppler performance). In DVB-T, the 2K mode provides significantly better mobile reception performance than the 8K mode, due to the larger inter-carrier spacing. However, the duration of the 2K mode OFDM symbols and guard intervals are very short, which makes the 2K mode only suitable for small size SFNs. The 4K mode breaks the gap between the 2K and 8K modes. For an 8 MHz channel the OFDM symbol durations for 8K, 4K and 2K modes are 896 μs, 448 μs and 224 μs, respectively.

Terms of the tradeoff expressed in [4]:

- The DVB-T 8K mode can be used both for single-transmitter operation [multifrequency networks (MFNs)] and for small, medium and large SFNs. It provides a Doppler tolerance allowing for high-speed reception.
- The DVB-T 4K mode can be used both for single-transmitter operation and for small and medium SFNs. It provides a Doppler tolerance allowing for very high-speed reception.
- The DVB-T 2K mode is suitable for single-transmitter operation and for small SFNs with limited transmitter distances. It provides a Doppler tolerance allowing for extremely high-speed reception.

An in-depth interleaver is used with the 2K and 4K modes. Benefit of the memory of the 8K symbol interleaver is taken by quadrupling or doubling the symbol interleaver depth for the 2K or 4K modes, respectively, to improve the reception in fading channels [5]. In-depth interleaving provides an extra level of protection against short noise impulses, for example caused by ignition interference or electrical appliances. Impulse noise power is spread over two symbols for the 4K mode and over four symbols for the 2K mode, which improves the impulse noise immunity.

The physical layer is affected by the 4K mode and in-depth interleavers, but their implementations do not require large increase in equipment complexity. Neither the 4K mode nor in-depth interleavers are mandatory for DVB-H.

2.2.2. DVB-H signaling

The DVB-H system uses two TPS bits to indicate the presence of time slicing and optional MPE-FEC [5]. A time slicing indicator signals that at least one time sliced DVB-H service is available in the transmission channel. A MPE-FEC indicator signals that at least one DVB-H service in the transmission channel is protected by MPE-FEC. The signaling can also be used to indicate the 4K mode, the symbol interleaver depth and the cell identifier.

3. The new channel models

Traditionally the channel models used in the planning of the terrestrial digital television broadcasting are intended to describe the rooftop antenna reception, portable indoor reception and mobile reception [7]. For rooftop antenna reception a multipath static Ricean channel has been widely used and for portable reception a rather similar static multipath Rayleigh channel has been used [6]. For mobile reception the Typical Urban channel model from the COST 207 project [2] has been used with rather good results.

A new area of digital television broadcasting has emerged in the form of handheld reception. This differs from reception conditions of the previous channel models by being a slowly moving multipath channel. Various attempts have been made to characterize the static and pedestrian handheld reception conditions by the static Rayleigh channel or by decreasing the Doppler frequencies of the mobile channels like the Typical Urban (TU) to speeds corresponding normal walking speeds. However it has been found in the measurements that the static Rayleigh channel seems to be too pessimistic when compared to the real channel conditions. Similarly the mobile TU channel with small Doppler seems to overestimate the channel conditions and leads to too high C/N requirements. Therefore new channel models, better suited especially for portable indoor and portable outdoor (pedestrian) reception conditions, have been under development.

The new channel models are Pedestrian Indoor (PI, 3 km/h), Pedestrian Outdoor (PO, 3 km/h), Vehicular Urban (VU, 30 km/h) and Motorway (MR, 100 km/h). The pedestrian indoor and outdoor channels have been submitted to ITU for approval as new channel models for DVB-H [7]. Vehicular urban and motorway channel models were used in the WingTV project but were not submitted for official approval, as they are quite similar to the commonly used TU6 channel. Table 2 and Table 3 depict the time delays and average powers of the 6-tap Typical Urban channel model and the 12-tap multipath model of the new channels, respectively.

The two types of Doppler spectra used in the physical layer simulations in the WingTV project were:

The Gaussian spectrum, which is given by

$$G(f;\sigma) = \exp(-\frac{f^2}{2\sigma^2}),$$

where σ is the standard deviation parameter of the spectrum and the classical Doppler spectrum, which is given by

$$K(f;f_D) = \frac{1}{\sqrt{1-(f/f_D)^2}},$$

where f_D is the maximum Doppler frequency.

Table 4 describes the simplified Doppler spectra proposed to be used with the 12-tap multipath model.

Table 2 Delays and powers of the 6-tap Typical Urban radio channel model [3]

TU6	
Delay µs	Power dB
0,0	-3
0,2	0
0,5	-2
1,6	-6
2,3	-8
5,0	-10

Table 3 Delays and powers of the 12-tap multipath model of the new channels [7]

PI 3km/h		PO 3km/h		VU 30 km/h		MR 100 km/h	
Delay µs	Power dB	Delay µs	Power dB	Delay µs	Power dB	Delay µs	Power dB
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	-6.4	0.2	-1.5	0.3	-0.5	0.5	-1.3
0.2	-10.4	0.6	-3.8	0.8	-1.0	1.0	-3.4
0.4	-13.0	1.0	-7.3	1.6	-4.1	1.8	-6.8
0.6	-13.3	1.4	-9.8	2.6	-8.8	2.5	-10.2
0.8	-13.7	1.8	-13.3	3.3	-12.6	3.1	-12.9
1.0	-16.2	2.3	-15.9	4.8	-18.6	3.9	-16.3
1.6	-15.2	3.4	-20.6	5.8	-21.6	4.8	-19.5
8.1	-14.9	4.5	-19.0	7.2	-24.6	5.5	-21.7
8.8	-16.2	5.0	-17.7	10.8	-20.7	6.4	-23.3
9.0	-11.1	5.3	-18.0	11.8	-18.2	7.0	-24.2
9.2	-11.2	5.7	-19.3	12.6	-19.4	9.0	-25.8

Table 4 Doppler spectra for the proposed channel models

	Spectrum for 1st tap	Spectrum for remaining taps
PI	**$0.1G(f;0.08f_D)+\delta(f-0.5f_D)$**	$G(f;0.08f_D)$
PO	**$0.1G(f;0.08f_D)+\delta(f-0.5f_D)$**	$G(f;0.08f_D)$
VU30	**$G(f;0.1f_D)$**	$K(f;f_D)$
MR100	$G(f;0.1f_D)$	$K(f;f_D)$

4. Simulations

Models for computer simulations were implemented separately for the physical and link layers. The physical layer simulation results are used as input to the link layer simulator in the form of error traces. The physical layer simulator is not work performed by the authors but it was implemented at Tampere University of Technology and the results were provided through co-operation in the CELTIC WingTV project [3]. Presenting the simulator here is, however, necessary for understanding the simulation results.

4.1. Physical layer simulations

A computer simulation chain of the DVB-H physical layer was implemented in using a Co-centric system studio environment. It comprises a DVB-T/H transmitter, a channel and a bit-true DVB-T/H receiver. At the transmitter side, it is assumed that the output of the MUX and the energy dispersal block can be modeled by a pseudo random binary source generator implemented as a maximum period linear feedback shift register. The binary stream is converted to a byte stream and fed to the outer coder. The other blocks in the transmitter are implemented according to the DVB-T standard. At the output of the DVB-T/H transmitter the signal will be passed through the channel. At the receiver side, and after demodulation, channel estimation is performed. After equalization, a Viterbi decoder is used to estimate the transmitted bits. In order to reduce the excessive duration of the bit-true computer simulation, the RS decoder is implemented conceptually. [3]

Two types of error streams are available for the link layer, the byte error indicator stream, which indicates the location of erroneous bytes, and the packet error indicator stream, which indicates the locations of erroneous TS packets.

The simulated physical layer parameters were QPSK and 16-QAM modulation with 1/2 and 2/3 convolutional code rates. The OFDM mode was 8K and the guard interval 1/4 of the duration of an OFDM symbol.

4.2. Link layer simulations

The link layer simulator models the receiver functions illustrated in Figure 3. The simulator, its inputs and outputs are described in Figure 4. The error trace received from the physical layer simulator is mapped on to the bytes of the transport stream. The MPE- and MPE-FEC sections are parsed from the transport stream and the TS headers are removed. If a section contains at least one error, its bytes are marked with 1 in the Erasure Info Table and the section is not decapsulated into the MPE-FEC frame. The Erasure Info Table is a table of the same size as the MPE-FEC frame, but with binary elements (0 for correct and 1 for erasure). Its purpose is to keep track of which bytes are erased for the Reed-Solomon erasure decoder. Finally, the RS decoding of the MPE-FEC frame is performed row-wise.

In the simulations presented in this report a TS packet error trace was used as link layer input and all bytes in an erroneous TS packet were assumed erroneous. This assumption is justified when using the section erasure decoding method suggested in the ETSI DVB-H Implementation Guidelines [5]. The section erasure decoding method assumes that if an MPE- or MPE-FEC section is erroneous, all bytes carried by the section are erased.

As the interface to the link layer is a TS error trace, the same link layer simulator can be used together with measured error masks from laboratory tests or field trials. This has been done to achieve the laboratory and field measurement results presented for comparison in section 6.1.

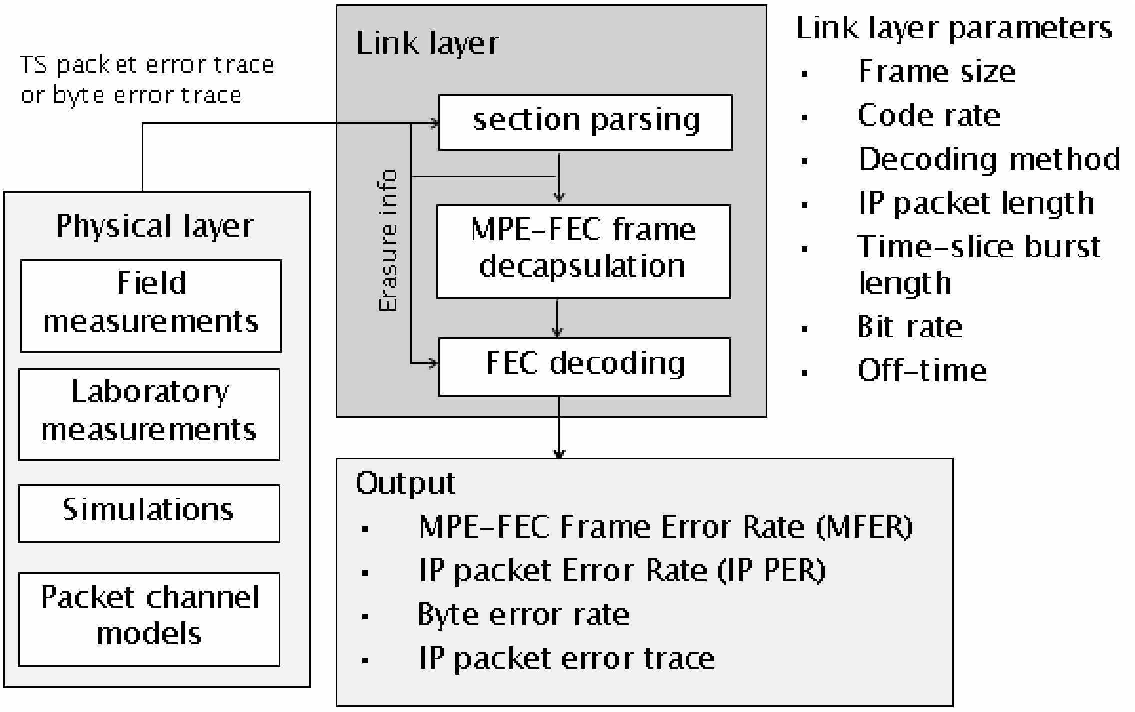

Figure 4 **The link layer simulator**

5. Simulation results

5.1.IP packet error ratios

5.1.1. The pedestrian use cases

Figure 5 - Figure 16 depict the IP packet error ratio, using section erasure decoding of the MPE-FEC frame, (IP PER SE) as a function of signal to noise ratio (SNR) for different channel models and modulations. In the pedestrian use cases (PI and PO) it can be seen that the use of MPE-FEC coding does not improve the performance. Hence, MPE-FEC is not needed at the link layer in the pedestrian use cases. This is shown in the figures by the curves being bundled together. When different convolutional code rates are used within a modulation mode the groups of curves are separated. With the same convolutional code rate a distinction can not be made between the different MPE-FEC code rates. In the pedestrian figures the left and right clusters of curves are the modes with convolutional code rates 1/2 and 2/3, respectively.

The figures show that both the pedestrian use cases are quite alike. If we look at Figure 5 and Figure 7, we see that the shapes of the curves for QPSK modulation are similar. This holds true also when comparing 16-QAM modulation in pedestrian indoor and outdoor cases (Figure 6 and Figure 8, respectively).

If the physical layer simulations are too short, this can lead to possible inaccuracies in the simulation results at the link layer, as can be seen for example at 7 dB and 8 dB points in Figure 7.

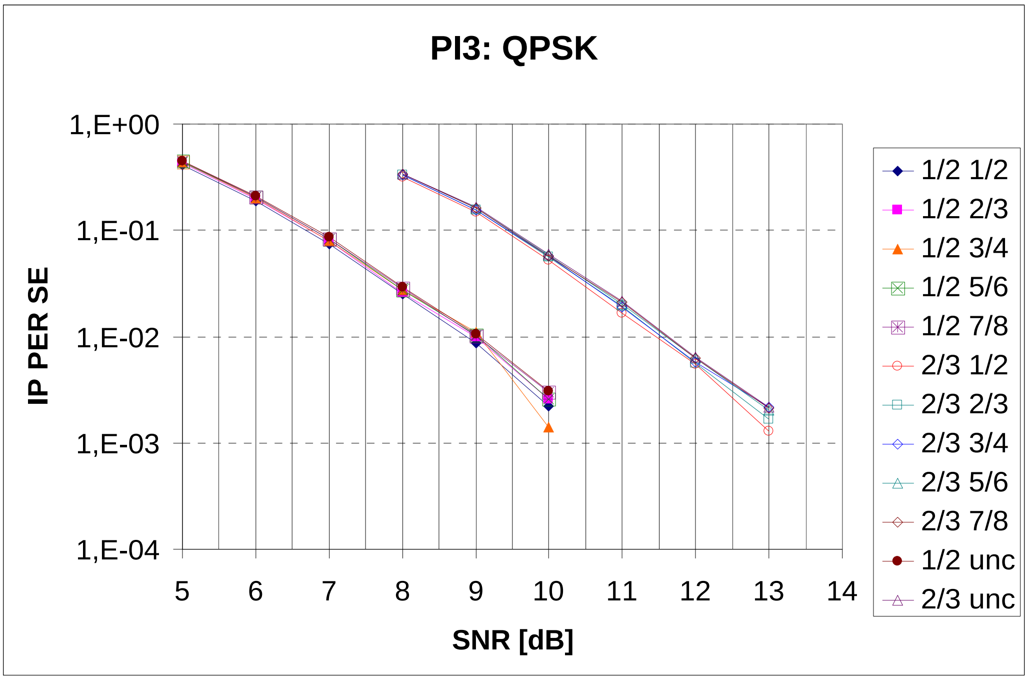

Figure 5 IP PER SE for Pedestrian Indoor channel with QPSK, convolutional code rates 1/2 and 2/3, and all MPE-FEC code rates

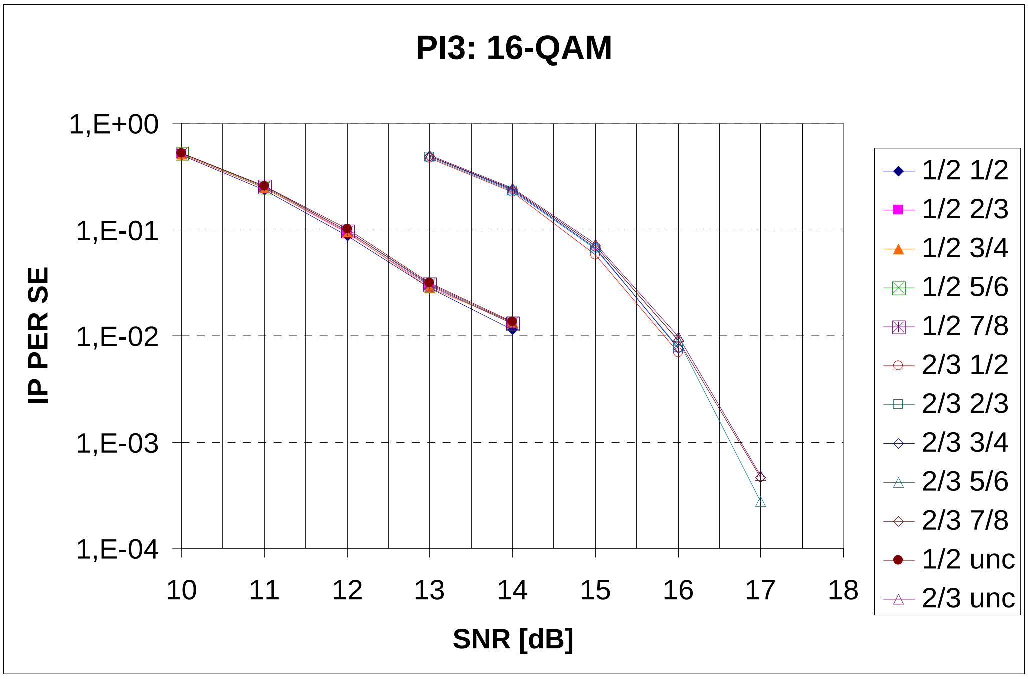

Figure 6 IP PER SE for Pedestrian Indoor channel with 16-QAM, convolutional code rates 1/2 and 2/3, and all MPE-FEC code rates

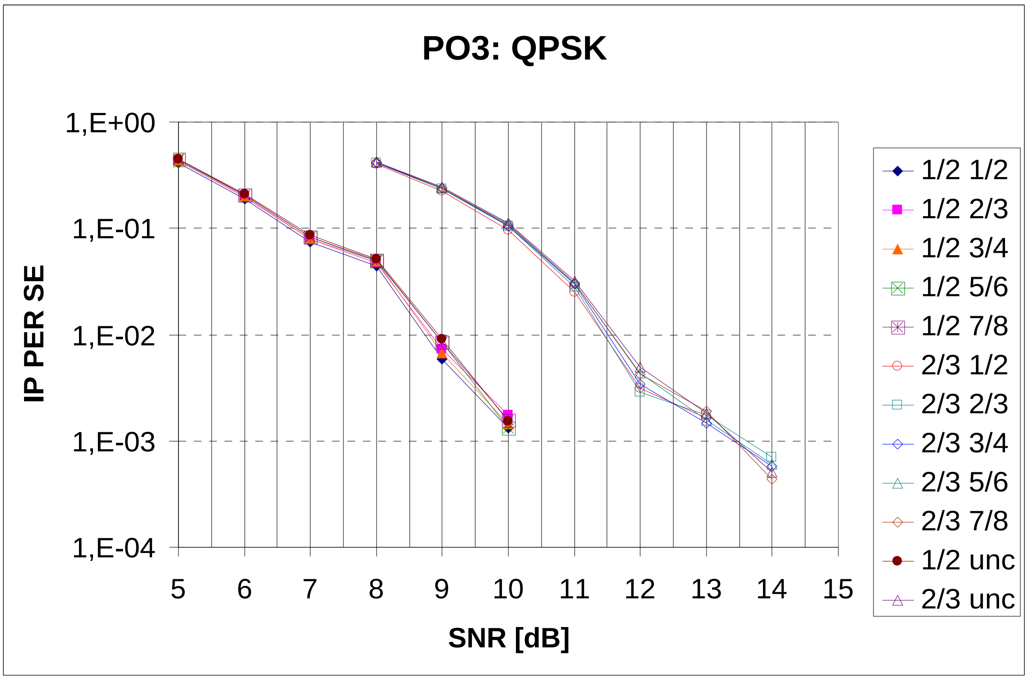

Figure 7 IP PER SE for Pedestrian Outdoor channel with QPSK, convolutional code rates 1/2 and 2/3, and all MPE-FEC code rates

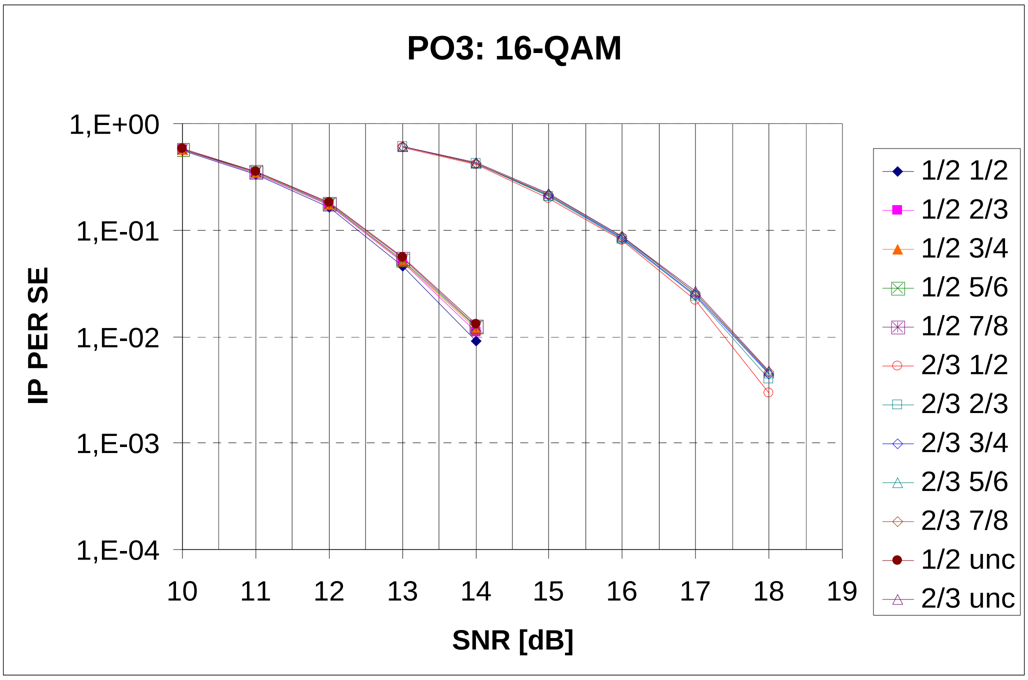

Figure 8 IP PER SE for Pedestrian Outdoor channel with 16-QAM, convolutional code rates 1/2 and 2/3, and all MPE-FEC code rates

5.1.2. The vehicular use cases

The vehicular urban and motorway channel models differ severely from the pedestrian cases. With these models, in which the receiver is moving faster, it can be seen clearly that the use of MPE-FEC coding at the link layer is beneficial. The curves in the vehicular urban and motorway cases are distinctly separated, unlike in the pedestrian cases. The greater the velocity is, the more separated the curves are. Thus, in the motorway use case the curves are more scattered than in the vehicular urban use case.

When comparing the curves with different MPE-FEC code rates to the uncoded ones, we get different MPE-FEC coding gains. For example, when using the mode 16-QAM 1/2 3/4 and regarding the IP PER 5% point in the vehicular urban case (Figure 11), the MPE-FEC coding gain is about 1.3 dB and in the motorway case (Figure 15) the gain is about 2.3 dB. The MPE-FEC coding gains are presented and compared to measurements in section 6.1.

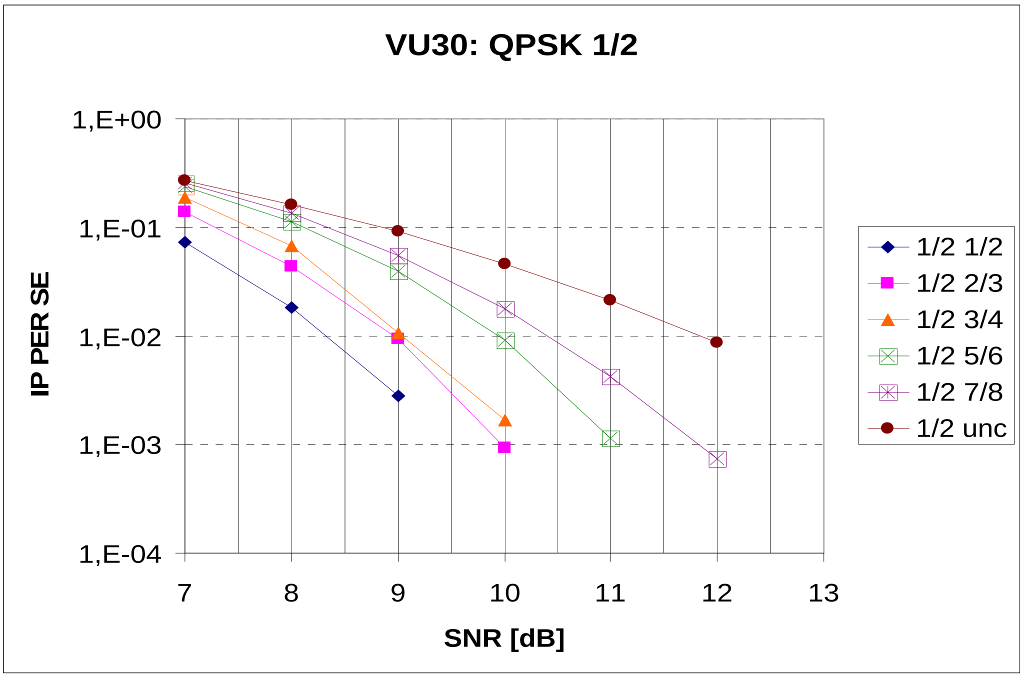

Figure 9 **IP PER SE for Vehicular Urban channel with QPSK, convolutional code rate 1/2, and all MPE-FEC code rates**

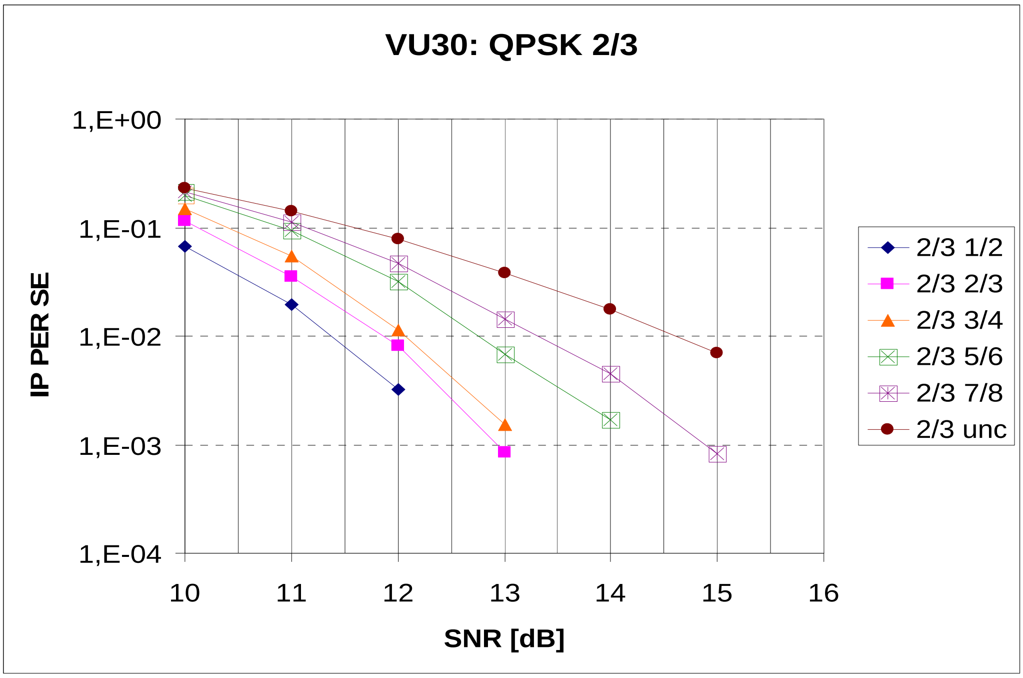

Figure 10 IP PER SE for Vehicular Urban channel with QPSK, convolutional code rate 2/3, and all MPE-FEC code rates

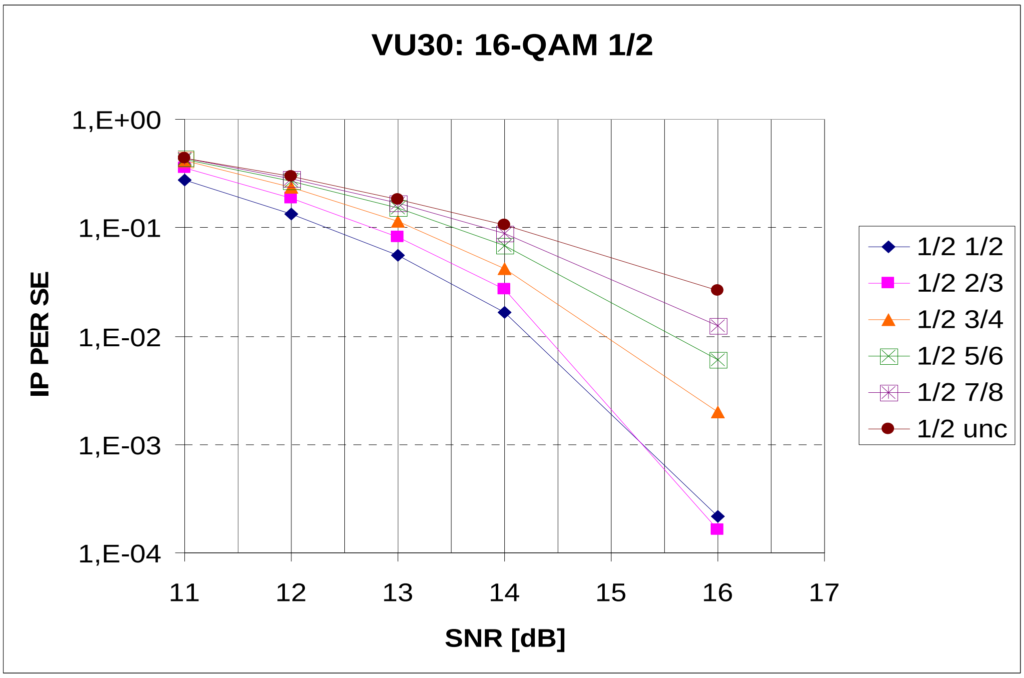

Figure 11 IP PER SE for Vehicular Urban channel with 16-QAM, convolutional code rate 1/2, and all MPE-FEC code rates

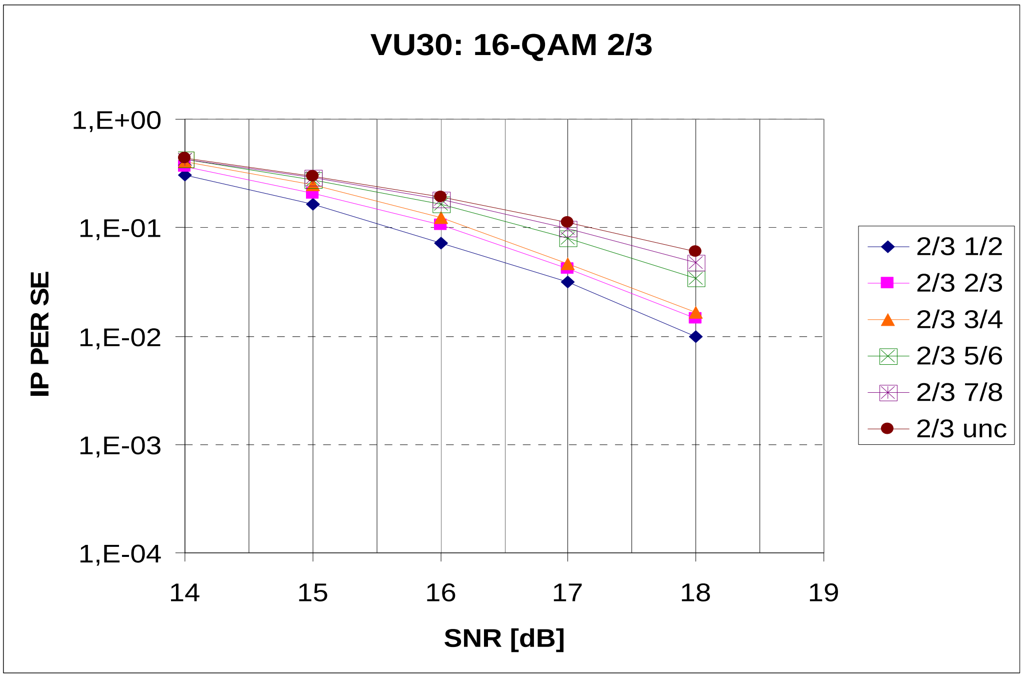

Figure 12 IP PER SE for Vehicular Urban channel with 16-QAM, convolutional code rate 2/3, and all MPE-FEC code rates

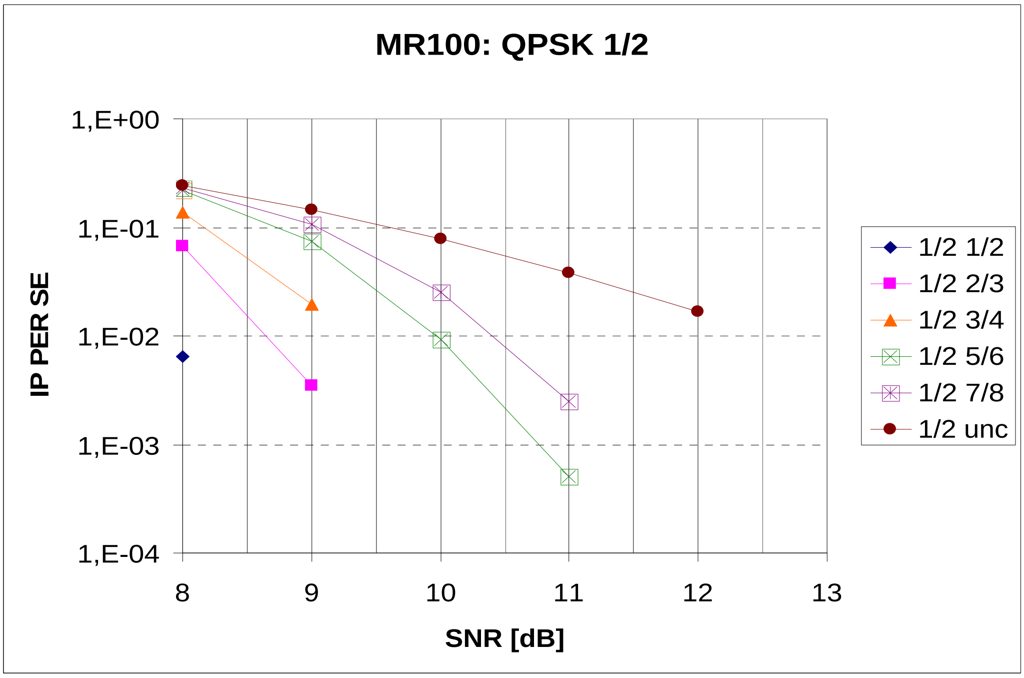

Figure 13 IP PER SE for Motorway channel with QPSK, convolutional code rate 1/2, and all MPE-FEC code rates

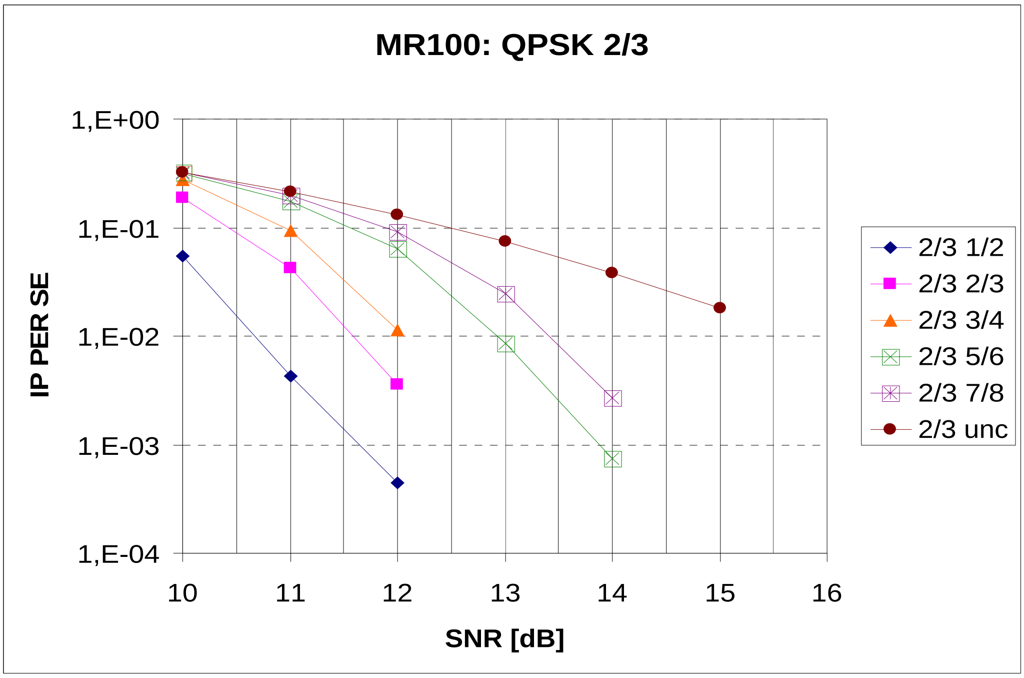

Figure 14 IP PER SE for Motorway channel with QPSK, convolutional code rate 2/3, and all MPE-FEC code rates

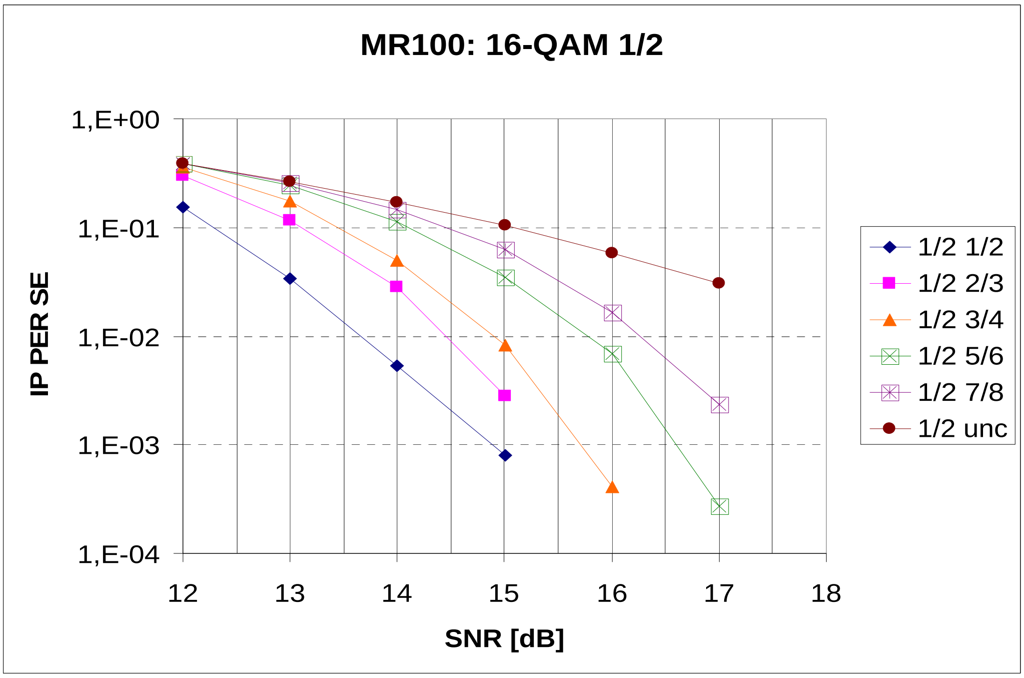

Figure 15 IP PER SE for Motorway channel with 16-QAM, convolutional code rate 1/2, and all MPE-FEC code rates

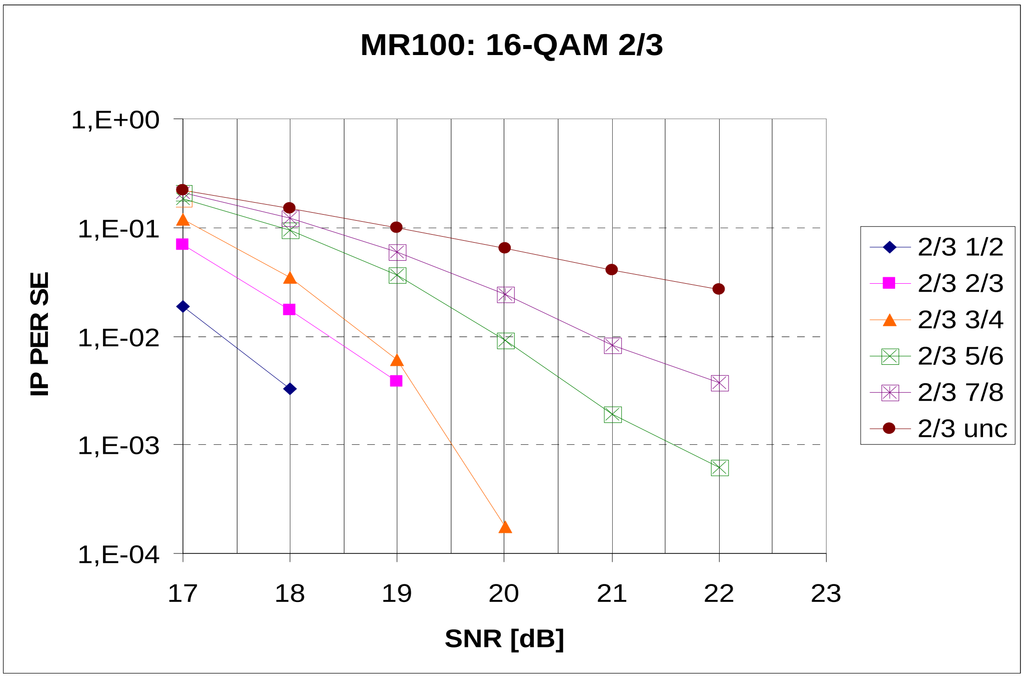

Figure 16 **IP PER SE for Motorway channel with 16-QAM, convolutional code rate 2/3, and all MPE-FEC code rates**

5.2. Average energy per source bit

The mode comparison is based on the signal-to-noise ratio (SNR) to achieve IP packet error rate (IP PER) of 1%. The comparison of different modulations and code rates is enabled by calculating the average energy per bit using the formula $\frac{E}{bit} = \frac{P_s}{R}$, where P_s is the signal power and R is the IP level bit rate after the link layer. P_s is calculated using the formula $\frac{P_s}{P_n} = 10^{SNR/10}$ and assuming the noise power P_n to be constant (here $P_n = 1$).

The C/N at IP PER 1% for all QPSK and 16-QAM modes in the new channel models are presented in Figure 17 and Figure 18, respectively. The corresponding required average energies per source bit are presented in Figure 19 - Figure 22. The results obtained here are used to compare and find the preferable modes presented in section 5.3.

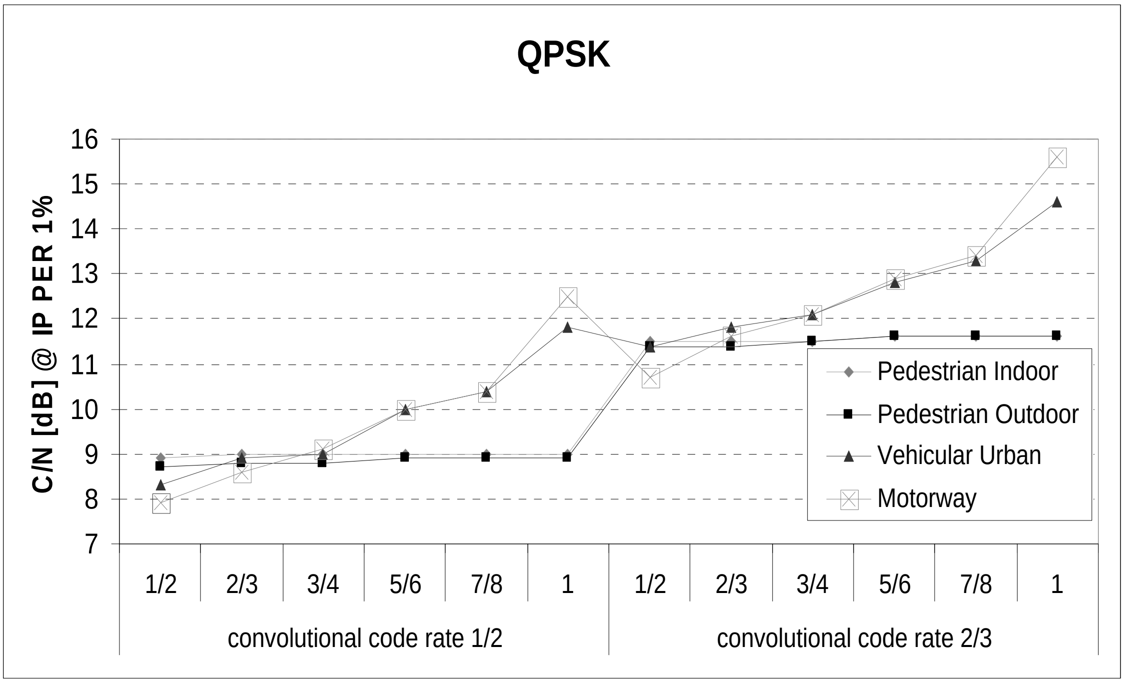

Figure 17 C/N at IP packet error ratio 1% for QPSK modes

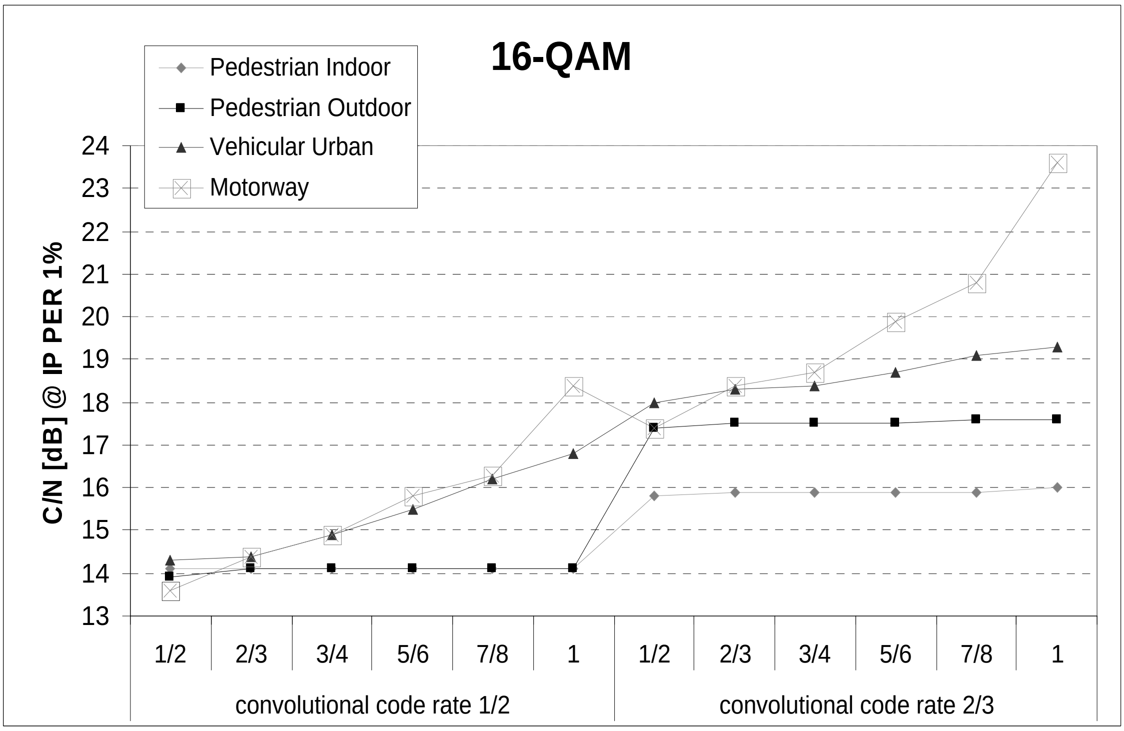

Figure 18 C/N at IP packet error ratio 1% for 16-QAM modes

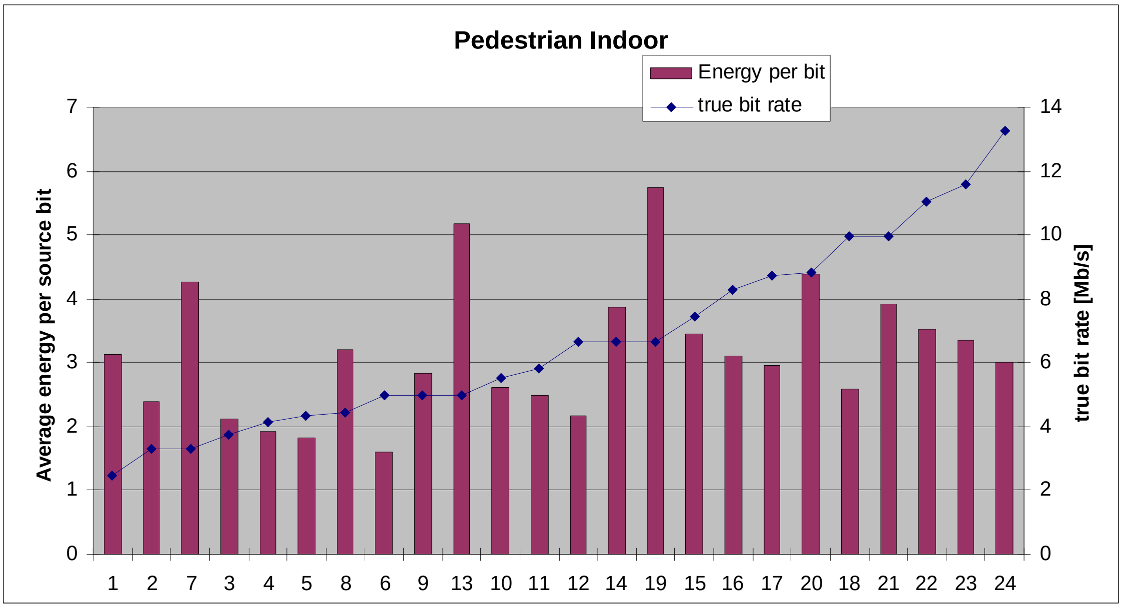

Figure 19 Average energy per source bit for the Pedestrian Indoor channel

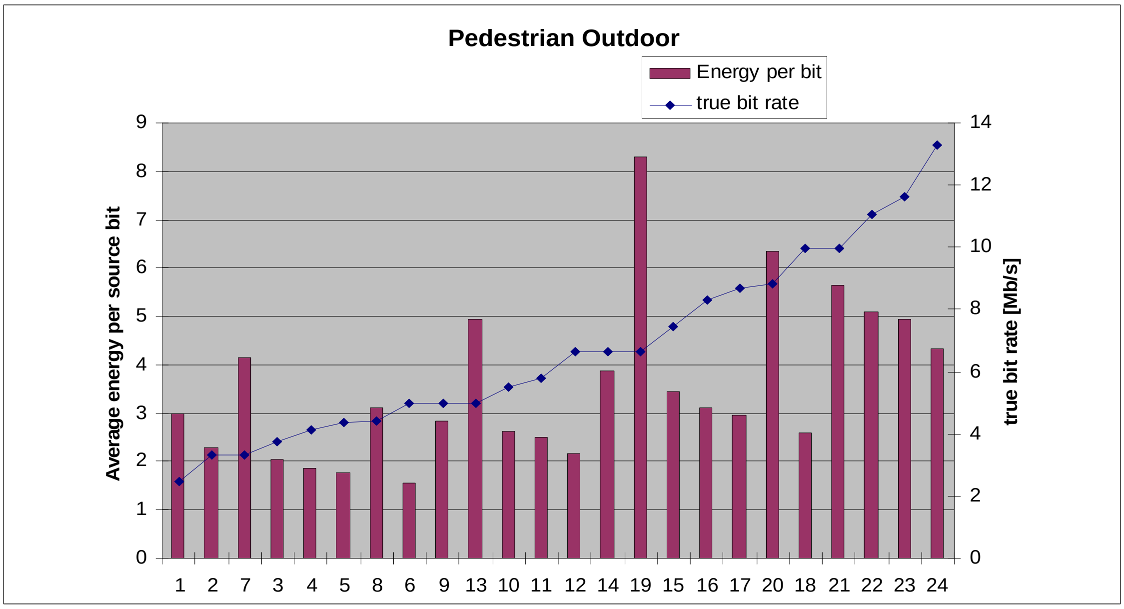

Figure 20 Average energy per source bit for the Pedestrian Outdoor channel

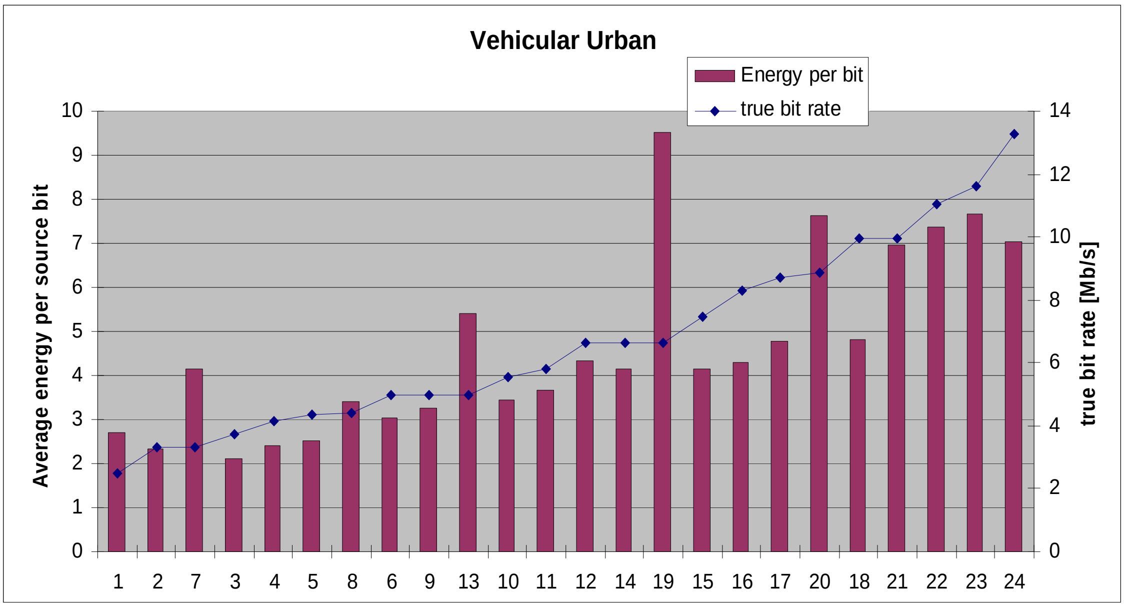

Figure 21 Average energy per source bit for the Vehicular Urban channel

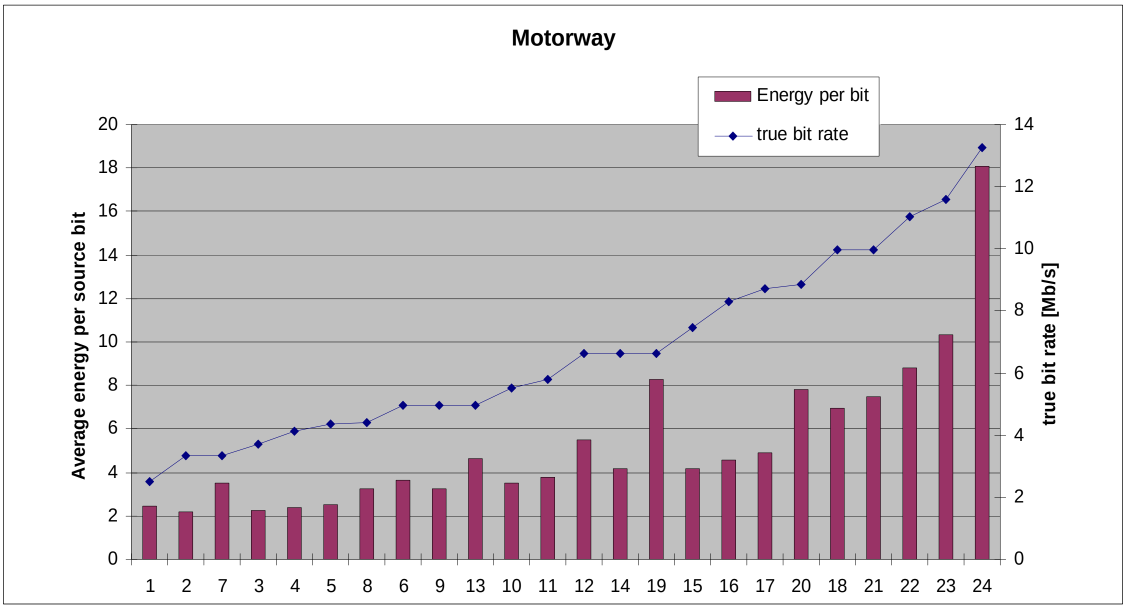

Figure 22 Average energy per source bit for the Motorway channel

5.3.Preferable modes

The simulation modes are presented in Table 5 and the mode is marked with 1 if it is a preferable mode in the corresponding channel. The same comparison is made for simulations in a TU6 channel with Doppler frequency 10 Hz for comparison. The preferable modes are defined as follows:

- The modes are compared based on the IP bit rate, i.e. the bit rate after the link layer, and the SNR needed to achieve IP PER 1%. First, modes with similar bit rate are compared and modes that require higher SNR to achieve the same or lower bit rate than some other mode are excluded.

- The remaining modes are compared based on the average energy per source bit. Modes that require higher energy / bit to achieve a lower bit rate than some other mode are excluded.

Mode 24 is a good mode in MR100 channel based on the comparison described above, but Figure 22 shows that this requires high average energy / bit. Thus, this mode is marked with (1) in the table. The modes not marked with 1 do not all give bad results, only there are better modes for this particular channel model.

It can be concluded that in pedestrian channels no link layer coding is needed. Further, it is possible to find good modes that enable high bit rates using 16-QAM 2/3. However, these results show that it is better to choose convolutional code rate 1/2 and use no MPE-FEC (modes 6 and 18) instead of using convolutional code rate 2/3 and MPE-FEC code rate 3/4 (modes 9 and 21). MPE-FEC code rates 1/2 and 2/3 should not be used. It should be noted that when building a network including all use cases from pedestrian to motorway, it is recommended to choose MPE-FEC code rates 3/4 or 5/6 to enable good mobile reception. MPE-FEC works very well for what it was designed: to cope with errors caused by the Doppler shift at high velocities. The best modes for networks covering vehicular use are QPSK 1/2 3/4, QPSK 1/2 5/6, QPSK 2/3 5/6, 16-QAM 1/2 3/4 and 16-QAM 1/2 5/6.

In real receiver implementations the implementation loss is approximately 2-3 dBs compared to simulations. When taking this into considerations in the average energy / bit calculations, the only effect on the preferred modes in Table 5 is that the 1 for mode 2 in the MR channel should be removed. In this sense, the recommendations hold also for real receiver implementations.

Table 5 The simulated modes

mode	modulation	CCR	MFCR	IP rate [Mb/s]	PI	PO	VU	MR	TU6 10 Hz
1	QPSK	1/2	1/2	2.49					
2	QPSK	1/2	2/3	3.32				1	
3	QPSK	1/2	3/4	3.73			1	1	1
4	QPSK	1/2	5/6	4.15			1	1	1
5	QPSK	1/2	7/8	4.35			1	1	1
6	QPSK	1/2	1	4.98	1	1	1		1
7	QPSK	2/3	1/2	3.32					
8	QPSK	2/3	2/3	4.42					
9	QPSK	2/3	3/4	4.98				1	
10	QPSK	2/3	5/6	5.53			1	1	
11	QPSK	2/3	7/8	5.80			1	1	1
12	QPSK	2/3	1	6.63	1	1			1
13	16-QAM	1/2	1/2	4.98					
14	16-QAM	1/2	2/3	6.63					
15	16-QAM	1/2	3/4	7.46			1	1	1
16	16-QAM	1/2	5/6	8.29			1	1	1
17	16-QAM	1/2	7/8	8.71			1	1	
18	16-QAM	1/2	1	9.95	1	1	1	1	1
19	16-QAM	2/3	1/2	6.63					
20	16-QAM	2/3	2/3	8.84					
21	16-QAM	2/3	3/4	9.95					
22	16-QAM	2/3	5/6	11.06				1	
23	16-QAM	2/3	7/8	11.61				1	
24	16-QAM	2/3	1	13.27	1	1	1	(1)	1

6. Comparison to results from TU6, field trials and laboratory measurements

In this section the simulations are compared to measurements in the laboratory and in the field. In the laboratory and field measurements a TS error trace is measured and the link layer is simulated as described in section 4.2. Thus, the physical layer simulator is replaced by the receiver implementation of the physical layer. Usually, there is an implementation loss of 2-3 dBs when comparing simulations and measurements. As the difference in measured C/N at specific error ratios is not constant, due to both implementation loss and channel estimation algorithms, the results are not presented as error rate curves. As the scope of this report is to provide insight in the selection of modulation and channel coding, we have compared the MPE-FEC gain in the simulations, in the laboratory and in the field.

6.1. MPE-FEC gain

The parameters used in this comparison are 16-QAM modulation, convolutional code rate 1/2 and MPE-FEC code rate 3/4 or uncoded link layer (MPE-FEC code rate = 1). Every TS packet is considered for the transmitted services, so the burst length, i.e. the duration of one MPE-FEC frame, is 110 ms and the burst bit rate is 9.95 Mb/s at TS level. The comparison is made based on the gain in signal strength of using MPE-FEC or not. As the simulations are performed over the whole TS, the number can also be seen as a comparison between DVB-H and DVB-T measured over all transmitted services.

The field trials are presented in detail in [8]. In [8] the burst length studied is 220 ms and therefore the presented gains are slightly different than the ones presented in Table 6. Also, the field measurements should only be seen as indicative. The simulated results are more accurate than the laboratory and field results due to receiver implementation and channel estimation algorithms. The accuracy of 0.5 dB can be considered good in the measurements. In the field measurements, especially in the PI and MR use cases there were not enough observations at low error rates to make definite conclusions. Hence, this can lead to less accurate results, as the 0.8 dB difference can be seen between simulation and field results in the MR use case. IP PER 5% was chosen for comparison point to achieve more reliable results from the field trials.

When comparing the results in Table 6, the new channel models show similar results in the simulations and measurements. The gain of using MPE-FEC is small in pedestrian use cases and increases with increasing speed of the receiver. The Doppler frequency of the pedestrian models is 1.4 Hz. The lowest available simulated and measured Doppler frequency in TU6 was 5Hz, which gives slightly higher gains than PI and PO. VU and MR can be compared to TU6 15Hz and TU6 45 Hz respectively. The new models and TU6 give the same results.

Table 6 Measured and simulated MPE-FEC gain (code rate ¾ vs. uncoded) at IP PER = 5%

	Simulations	Laboratory	Field
PI	0.1 dB	0.0 dB	~ 0.1 dB
PO	0.1 dB	0.1 dB	~ 0.3 dB
VU	1.3 dB	1.8 dB	~ 1.0 dB
MR	2.3 dB	2.2 dB	~ 1.5 dB
TU6 (5Hz)	0.5 dB	0.4 dB	
TU6 (10Hz)	0.9 dB	1.0 dB	
TU6 (15Hz)		1.5 dB	
TU6 (30Hz)	1.6 dB		
TU6 (45Hz)		2.3 dB	

6.2. A closer look at the pedestrian models

The simulated MPE-FEC frame error ratio (MFER) and IP packet error ratio (IP PER) are presented in Figure 23 and Figure 24 in TU6 and the pedestrian channels. In Figure 25 the IP packet errors are presented cumulatively, including also the PO measured in the field. The filed measurement is carried out in downtown Turku. Additional attenuation was used to receive errors, as the error distribution is the interesting part to study. Without attenuation the outdoor reception is nearly error-free in the city centre, as a transmitter is located a few blocks from the market square.

The comparisons indicate the different error distributions in the TU6 and new channels. In the PI and PO channels the receiver might experience good reception for some time. The errors occur in larger bursts than in the TU6 channel but these larger bursts appear less frequently. This is also the case after error correction, as many of the error bursts in a pedestrian channel are too large for MPE-FEC to handle. The different error distributions also explain the big difference between MFER and IP PER in TU6 compared to PI and PO. In total the IP PER is quite similar but the smaller error bursts in TU6 occur more frequently than the larger error bursts in PI and PO. This results in a larger frame error rate. When considering for example streaming video applications, this difference in error behavior might result in different audiovisual quality. When optimizing the system performance, erroneous conclusions about time-interleaving mechanisms probably are made, if only relying on the TU6 model

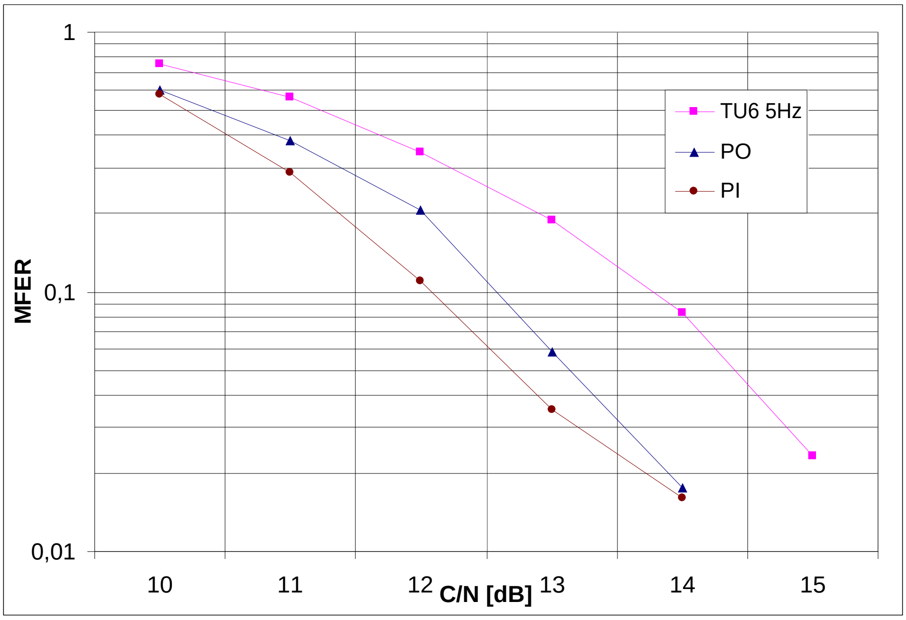

Figure 23 MPE-FEC frame error ratio for simulated TU6, PI and PO for 16-QAM 1/2 3/4

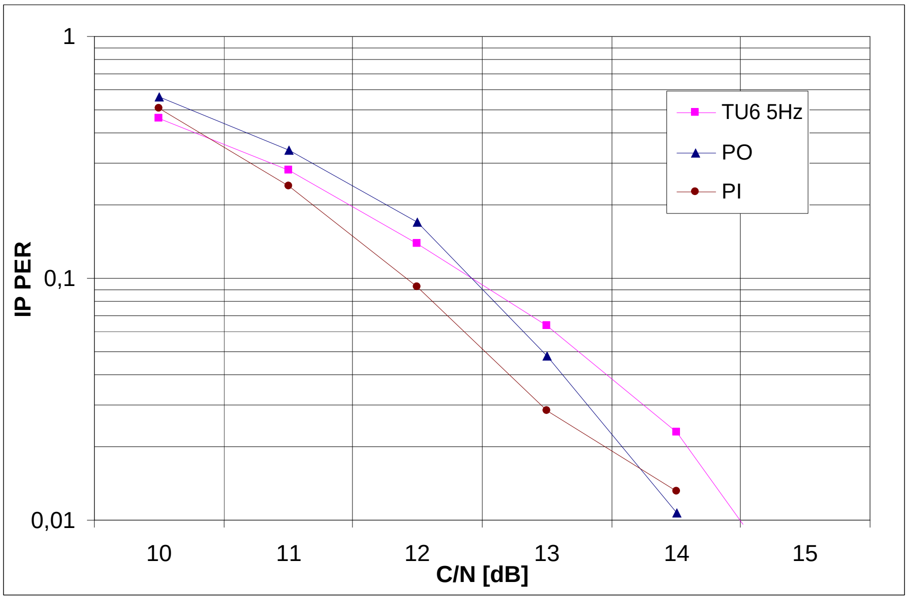

Figure 24 IP PER for simulated TU6, PI and PO for 16-QAM 1/2 3/4

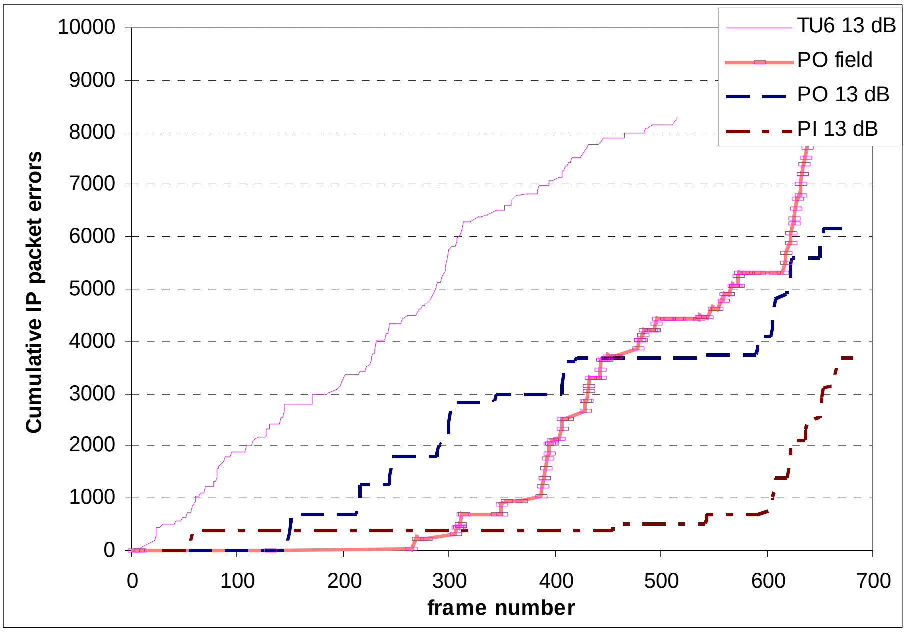

Figure 25 Cumulative IP packet errors

7. Conclusions

New radio channel models were used for evaluation of DVB-H broadcast systems by extensive simulations. The new channel models characterize the following four use cases: pedestrian indoor (3 km/h), pedestrian outdoor (3 km/h), vehicular urban (30 km/h) and motorway (100 km/h). The simulations were performed for physical layer coding and modulation modes QPSK 1/2, QPSK 2/3, 16-QAM 1/2 and 16-QAM 2/3 with different MPE-FEC code rates at the link layer. The simulation results were compared to laboratory and field measurements.

Based on average energy per bit comparisons, the following can be concluded

- For pedestrian channels there is no particular need for MPE-FEC link layer coding.

- If building networks covering all channels (PI3, PO3, VU30 and MR100), it is recommended to use MPE-FEC code rates 3/4 or 5/6 to enable good mobile reception, preferably using one of modes QPSK 1/2 3/4, QPSK 1/2 5/6, QPSK 2/3 5/6, 16-QAM 1/2 3/4 or 16-QAM 1/2 5/6.

The vehicular urban and motorway channel models are quite similar to the commonly used TU6 channel. The pedestrian indoor and outdoor channel models, in contrary, correspond much better to reality than TU6 at small Doppler frequencies.

8. References

[1] ETSI EN 302 304: Digital Video Broadcasting (DVB): Transmission System for Handheld Terminals (DVB-H) , European Telecommunication Standard, Nov. 2004

[2] COST207, Digital land mobile radio communications (final report), Commission of the European Communities, Directorate General Telecommunications, Information Industries and Innovation, 1989, pp. 135 147

[3] EUREKA CELTIC Wing-TV deliverable D15, Simulation report , August 2006 [available online: http://projects.celtic-initiative.org/WING-TV/]

[4] Faria et al., DVB-H: Digital Broadcast Services to Handheld Devices , *Proc. IEEE*, vol. 94, no. 1, pp.194-209, January 2006

[5] ETSI, Digital Video Broadcasting (DVB); DVB-H Implementation Guidelines", Technical report, TR 102 377 (V0.1.0), Jan. 2005

[6] DVB Project, Digital Video Broadcasting (DVB): Framing structure, channel coding and modulation for digital terrestrial television , *ETSI EN 300744, v1.5.1*, 2004

[7] ITU Radiocommunication Study Groups, Preliminary Report on the Channel Model Development for Hand Held Reception , Document 6E/335-E, March 2006 [available online: http://projects.celtic-initiative.org/WING-TV/]

[8] H. Himmanen and T. Jokela: DVB-H Field Trials: Studying Radio Channel Characteristics , IEEE International Symposium on Broadband Multimedia and Broadcasting, Orlando, Florida, Mar. 2007

TURKU
CENTRE *for*
COMPUTER
SCIENCE

Lemminkäisenkatu 14 A, 20520 Turku, Finland | www.tucs.fi

University of Turku
- Department of Information Technology
- Department of Mathematics

Åbo Akademi University
- Department of Computer Science
- Institute for Advanced Management Systems Research

Turku School of Economics and Business Administration
- Institute of Information Systems Sciences

ISBN 978-952-12-1878-1
ISSN 1239-1891