DVB-H: Digital Broadcast Services to Handheld Devices

GERARD FARIA, JUKKA A. HENRIKSSON, SENIOR MEMBER, IEEE, ERIK STARE, AND
PEKKA TALMOLA

Invited Paper

This paper gives a brief review of the new Digital Video Broadcasting—Handheld (DVB-H) standard. This is based on the earlier standard DVB-T, which is used for terrestrial digital TV broadcasting. The new extension brings features that make it possible to receive digital video broadcast type services in handheld, mobile terminals. The paper discusses the key technology elements—4K mode and in-depth interleavers, time slicing and additional forward error correction—in some detail. It also gives extensive range of performance results based on laboratory measurements and real field tests. Finally it presents viewpoints relevant for DVB-H network design and system use in general.

Keywords—*Digital TV, DVB, Digital Video Broadcasting—Handheld (DVB-H), field tests, handheld terminals, IP datacast, IPDC, mobile channel, mobile TV, network planning.*

I. HISTORY AND BACKGROUND

The Digital Video Broadcast (DVB) Project started research work related to mobile reception of DVB—Terrestrial (DVB-T) signals as early as 1998, accompanying the introduction of commercial terrestrial digital TV services in Europe.

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 (i.e., constellation and coding rate) than broadcast networks planned for fixed DVB-T reception.

Later in 2002, the EU-sponsored Multimedia Car Platform (MCP) project explored the excellent behavior of antenna diversity reception which, introducing spatial diversity in addition to the frequency and time diversities provided by the DVB-T transmission layer, improved sufficiently reception performance to allow a mobile receiver to access DVB-T signals broadcast for fixed receivers.

Five years after its inception, DVB-T shows sufficient flexibility to permit mobile broadcast services deployment in cities like Singapore or in Germany.

But, during these five years, consumer habits have evolved, and in early 2002, the DVB community was asked to provide technical specifications to allow delivery of rich multimedia contents to handheld terminals, a property that has been missing in the original DVB-T. This would make it possible to receive TV-type services in a small, handheld device like a mobile phone.

This approach requires specific features from the transmission system serving such devices. First, as these devices are battery powered, the transmission system shall offer them the possibility to repeatedly power off some part of the reception chain to increase the battery usage duration. Second, as the technology is targeting mobile users, the transmission system shall ease access to the services when receivers leave a given transmission cell and enter a new one. Third, as services are expected to be delivered in an environment suffering severe mobile multipath channels and high levels of man-made noise, the transmission system shall offer additional means to mitigate these effects on the receiving capabilities. Additionally, the system should be capable to handle a number of reception scenarios; indoor, outdoor, pedestrian and inside a moving vehicle; and, consequently, the transmission system shall offer sufficient flexibility and scalability to allow the reception of the services at various speeds, while optimizing transmitter coverage. Also, the system should be usable in various parts of the world and should offer the flexibility to be used in various transmission bands and channel

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G. Faria is with TeamCast, Rennes Cedex F35769, France (e-mail: gerard.faria@teamcast.com).

J. Henriksson is with the Nokia Research Center, Helsinki FI-00180, Finland (e-mail: jukka.henriksson@nokia.com).

E. Stare is with Teracom, Sundbyberg SE-172 27, Sweden (e-mail: erik.stare@teracom.se).

P. Talmola is with Nokia Multimedia, Turku FI-20521, Finland (e-mail: pekka.talmola@nokia.com).

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bandwidths. All this should be achieved with a system based on DVB-T in order to have maximal compatibility with the existing DVB-T networks and implementations.

The work to define such a system within the DVB Project started in the beginning of year 2002 first by defining a set of commercial requirements for a system supporting handheld devices. The technical work then led to a system called Digital Video Broadcasting—Handheld (DVB-H), which was published as European Telecommunications Standards Institute (ETSI) Standard EN 302 304 in November 2004 [1]. This standard is an umbrella standard defining in which way to combine the earlier existing—now updated—ETSI standards to form the DVB-H system [2]–[5].

The following sections first describe the general features of DVB-H, then a closer look into the central new elements—time-slicing and multiprotocol encapsulation–forward error correction (MPE-FEC)—is taken. A section describing the performance issues of DVB-H including also the first measurement results from laboratory tests and from the field follows. The crucial points of network planning and operation of DVB-H in general are then tackled, and, finally, some conclusive remarks are made. General background about DVB-T is given, e.g., in this special issue of the PROCEEDINGS OF THE IEEE [9], [10], and in [11].

II. DVB-H SYSTEM AND STANDARDS

The DVB-H system is defined based on the existing DVB-T standard for fixed and in-car reception of digital TV. The main additional elements in the link layer (i.e., the layer above the physical layer) are time slicing and additional forward error correction (FEC) coding. Time slicing reduces the average power in the receiver front-end significantly—up to about 90%–95%—and also enables smooth and seamless frequency handover when the user leaves one service area in order to enter a new cell. Use of time slicing is mandatory in DVB-H.

FEC for multiprotocol encapsulated data (MPE-FEC) gives an improvement in carrier-to-noise (C/N) performance and Doppler performance in mobile channels and, moreover, also improves tolerance to impulse interference. Use of MPE-FEC is optional for DVB-H.

It should be emphasized that neither time slicing nor MPE-FEC technology elements, as they are implemented on the link layer, touch the DVB-T physical layer in any way. This means that the existing receivers for DVB-T are not disturbed by DVB-H signals—DVB-H is totally backward compatible to DVB-T. It is also important to notice that the payload of DVB-H is IP-datagrams or other network layer datagrams encapsulated into MPE-sections. In view of the restricted data rates suggested for individual DVB-H services and the small displays of typical handheld terminals, the classical audio and video coding schemes used in digital broadcasting do not suit DVB-H well. It is therefore suggested to exchange MPEG-2 video by H.264/AVC or other high-efficiency video coding standards.

The physical layer has four extensions to the existing DVB-T physical layer. First, the bits in transmitter parameter signaling (TPS) have been upgraded to include two additional bits to indicate presence of DVB-H services and possible use of MPE-FEC to enhance and speed up the service discovery. For more detail see [10]. Second, a new 4K mode orthogonal frequency division multiplexing (OFDM) mode is adopted for trading off mobility and single-frequency network (SFN) cell size, allowing single-antenna reception in medium SFNs at very high speeds. This gives additional flexibility for the network design. 4K mode is an option for DVB-H complementing the 2K and 8K modes that are as well available. Also all the modulation formats, QPSK, 16QAM and 64QAM with nonhierarchical or hierarchical modes, are possible to use for DVB-H. Third, a new way of using the symbol interleaver of DVB-T has been defined. For 2K and 4K modes, the operator may select (instead of native interleaver that interleaves the bits over one OFDM symbol) the option of an in-depth interleaver that interleaves the bits over four or two OFDM symbols, respectively. This approach brings the basic tolerance to impulse noise of these modes up to the level attainable with the 8K mode and also improves the robustness in mobile environment. Finally, the fourth addition to DVB-T physical layer is the 5-MHz channel bandwidth to be used in nonbroadcast bands. This is of interest, e.g., in the United States, where a network at about 1.7 GHz is running using DVB-H with a 5-MHz channel.

The conceptual structure of DVB-H user equipment is depicted in Fig. 1. It includes a DVB-H receiver (a DVB-T demodulator, a time-slicing module, and an optional MPE-FEC module) and a DVB-H terminal. The DVB-T demodulator recovers the MPEG-2 transport stream (TS) packets from the received DVB-T RF signal. It offers three transmission modes: 8K, 4K, and 2K with the corresponding signaling. The time-slicing module controls the receiver to decode the wanted service and shut off during the other service bits. It aims to reduce receiver power consumption while also enabling a smooth and seamless frequency handover. The MPE-FEC module, provided by DVB-H, offers in addition to the error correction in the physical layer transmission, a complementary FEC function that allows the receiver to cope with particularly difficult reception situations.

An example of using DVB-H for transmission of IP-services is given in Fig. 2. In this example, both traditional MPEG-2 services and time-sliced “DVB-H services” are carried over the same multiplex. The handheld terminal decodes/uses IP-services only. Note that 4K mode and the in-depth interleavers are not available, for compatibility reasons, in cases where the multiplex is shared between services intended for fixed DVB-T receivers and services for DVB-H devices.

Some of the basic parameters of DVB-H physical layer are given in Tables 1 –3. Table 1 gives the frequency domain parameters for the 8-MHz channel. For other bandwidths, simple scaling offers the parameters where narrowing channel bandwidth means increased symbol length. Note that the number of active carriers is smaller than directly proposed by the FFT size. As in DVB-T, this is due to having some guard band with zero amplitude carriers. Table 2 gives the OFDM symbol lengths in time domain with and without

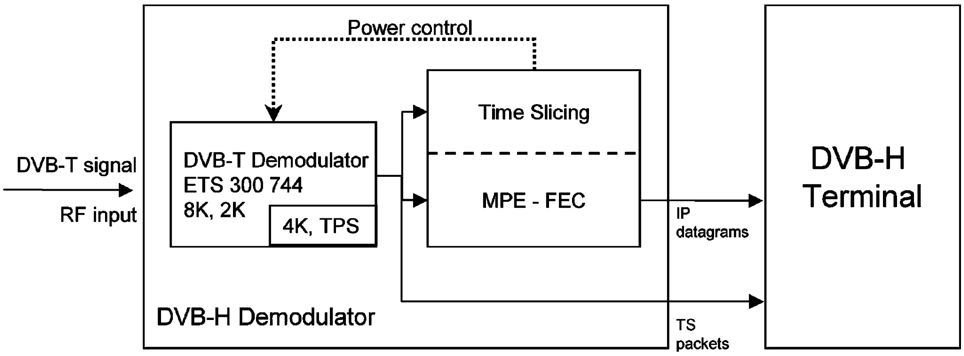

Fig. 1. Conceptual structure of a DVB-H receiver.

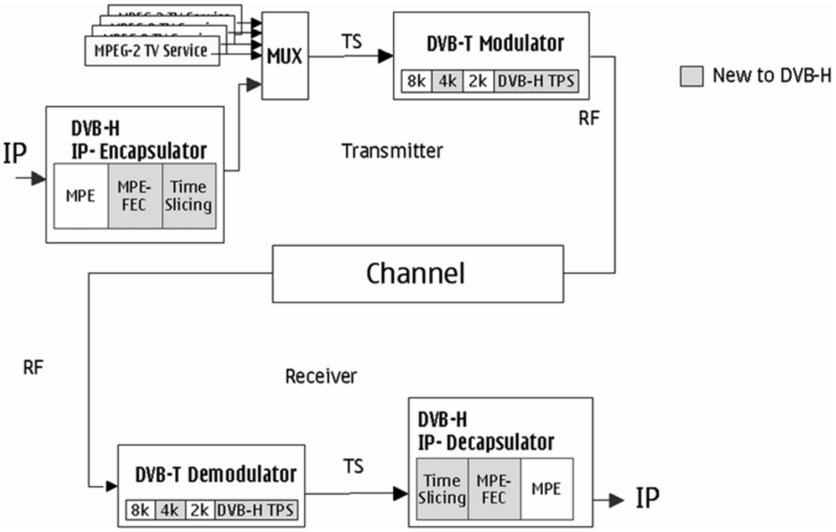

Fig. 2. A conceptual description of using a DVB-H system (sharing a MUX with MPEG-2 services).

Table 1
Frequency Domain Parameters for DVB-H OFDM Signal (8 MHZ Channel)

Parameter	2K mode	4K mode	8K mode
Number of active carriers K	1 705	3 409	6 817
Number of datacarriers	1512	3024	6048
Elementary period T	7/64 µs	7/64 µs	7/64 µs
Useful symbol part T_U	224 µs	448 µs	896 µs
Carrier spacing $1/T_U$	*4 464 Hz*	*2 232 Hz*	*1 116 Hz*
Spacing between carriers K_{min} and K_{max} = $(K-1)/T_U$	*7,61 MHz*	*7,61 MHz*	*7,61 MHz*
NOTE: Values in italics are approximate values.			

guard intervals. It is worth noting that with the longest guard interval and using 4K mode one can build SFN networks using up to about 33–35-km transmitter distances. The maximum distance is dictated by the transmission delay between the transmitter sites. This should be smaller than the guard interval length.

Table 3 gives some examples of the achievable multiplex capacities with various modulation schemes and convolutional coding rates. The given numbers assume that MPE-FEC has been used with code rate 3/4. It should be noted that the DVB-H standard allows use of various code rates for MPE-FEC or even having no MPE-FEC at all. Again the figures can be scaled directly to other code rates and/or channel bandwidths where needed. For practical purposes, in networks aiming to serve mobile handheld terminals, mainly the strongest code rates (i.e., 1/2 or 2/3) for convolutional coding lead to networks with good coverage and total performance.

III. 4K MODE AND IN-DEPTH INTERLEAVERS

The objective of the 4K mode is to improve network planning flexibility by trading off mobility and SFN size. To further improve robustness of the DVB-H 2K and 4K modes in a mobile environment and impulse noise reception conditions, an in-depth symbol interleaver has also been added to the standard.

The additional 4K transmission mode is a scaled set of the parameters defined for the 2K and 8K transmission modes as seen in Tables 1 and 2. It aims to offer an additional tradeoff between SFN cell size and mobile reception performance, providing an additional degree of flexibility for network planning. The operator of a dedicated DVB-H network can then select one of the three FFT sizes that best responds to the actual needs.

Terms of the tradeoff can be expressed as follows.

- *The DVB-T 8K mode* can be used both for single-transmitter operation [multifrequency networks (MFNs)]

Table 2
Time Domain Parameters for DVB-H OFDM Signal (8 MHZ Channel)

Parameter	2K mode				4K mode				8K mode			
Useful symbol part Tu	2 048 T				4 096 T				8 192 T			
	224 µs				448 µs				896 µs			
Guard interval part Δ / Tu	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
Guard interval duration Tg	512 T	256 T	128 T	64 T	1 024 T	512 T	256 T	128 T	2 048 T	1 024 T	512 T	256 T
	56 µs	28 µs	14 µs	7 µs	112 µs	56 µs	28 µs	14 µs	224 µs	112 µs	56 µs	28 µs
Total symbol duration Ts = Δ + Tu	2 560 T	2 304 T	2 176 T	2 112 T	5 120 T	4 608 T	4 352 T	4 224 T	10 240 T	9 216 T	8 704 T	8 448 T
	280 µs	252 µs	238 µs	231 µs	560 µs	504 µs	476 µs	462 µs	1 120 µs	1 008 µs	952 µs	924 µs

Table 3
Useful Net Bitrates (Mb/s) for Nonhierarchical Systems in 8-MHz Channels With MPE-FEC Code Rate 3/4; Full Multiplex Assumed to be DVB-H

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	3.74	4.15	4.39	4.52
	2/3	4.98	5.53	5.86	6.03
	3/4	5.6	6.22	6.59	6.79
	5/6	6.22	6.92	7.32	7.54
	7/8	6.53	7.26	7.69	7.92
16-QAM	1/2	7.46	8.3	8.78	9.05
	2/3	9.95	11.06	11.71	12.07
	3/4	11.2	12.44	13.17	13.58
	5/6	12.44	13.82	14.64	15.08
	7/8	13.07	14.51	15.37	15.83
64-QAM	1/2	11.2	12.44	13.17	13.58
	2/3	14.93	16.59	17.57	18.1
	3/4	16.79	18.66	19.76	20.36
	5/6	18.66	20.74	21.95	22.62
	7/8	19.6	21.77	23.06	23.75

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.

For 2K and 4K modes, the in-depth interleavers increase the flexibility of the symbol interleaving, by decoupling the choice of the inner interleaver from the transmission mode used. This flexibility allows a 2K or 4K signal to take benefit of the memory of the 8K symbol interleaver to effectively quadruple (for 2K) or double (for 4K) the symbol interleaver depth to improve reception in fading channels. This provides also an extra level of protection against short noise impulses caused by, e.g., ignition interference and interference from various electrical appliances.

The conceptual principle of the in-depth interleaver is depicted in Fig. 3, where the situation for 4K mode with 8K interleaver is sketched. The figure represents the OFDM symbols in the time and frequency domain. Each OFDM symbol at time i has a collection of carriers j, each carrier having phase and amplitude determined by n-tuples of bits $S_{i,j}$. The n-tuple size n is determined by the carrier modulation: n is 2 for QPSK, 4 for 16QAM, and 6 for 64QAM. Note that for simplicity reasons only eight carriers are shown per each OFDM symbol. With the "normal" native interleaver these n-tuples would be reallocated along the carriers within one OFDM symbol. For the in-depth interleaver n-tuples of two consecutive OFDM symbols, at time i and $i+1$, are taken and reallocated as shown in the lower part of the picture. In this way an error event in the channel, concentrated either in the time domain or in the frequency domain, is more uniformly distributed and enhances the convolutional code possibilities to decode the original bits correctly. The 2K mode behaves similarly, having interleaving over four OFDM symbols instead of two.

4K mode and in-depth interleavers affect the physical layer; however, their implementations do not imply large increase in equipment complexity (i.e., logic gates and memory) over the earlier version of DVB-T standard EN 300 744 for either transmitters or receivers. A typical mobile demodulator already incorporates enough RAM and logic for the management of 8K signals, which exceed that required for 4K operation.

The emitted spectrum of the 4K mode is similar to the 2K and 8K modes; thus, no changes in transmitter filters are needed.

IV. TIME SLICING AND MPE-FEC

A. *Time Slicing*

The standard DVB way of carrying IP datagrams in an MPEG-2 TS is to use multiprotocol encapsulation (MPE). With MPE each IP datagram is encapsulated into one MPE section. A stream of MPE sections are then put into an elementary stream (ES), i.e., a stream of MPEG-2 TS packets with a particular program identifier (PID). Each MPE section has a 12-B header, a 4-B cyclic redundancy check (CRC-32) tail and a payload length, which is identical to the length of the IP datagram, which is carried by the MPE section.

A typical situation for future handheld DVB-H devices may be to receive audio/video services transmitted over IP

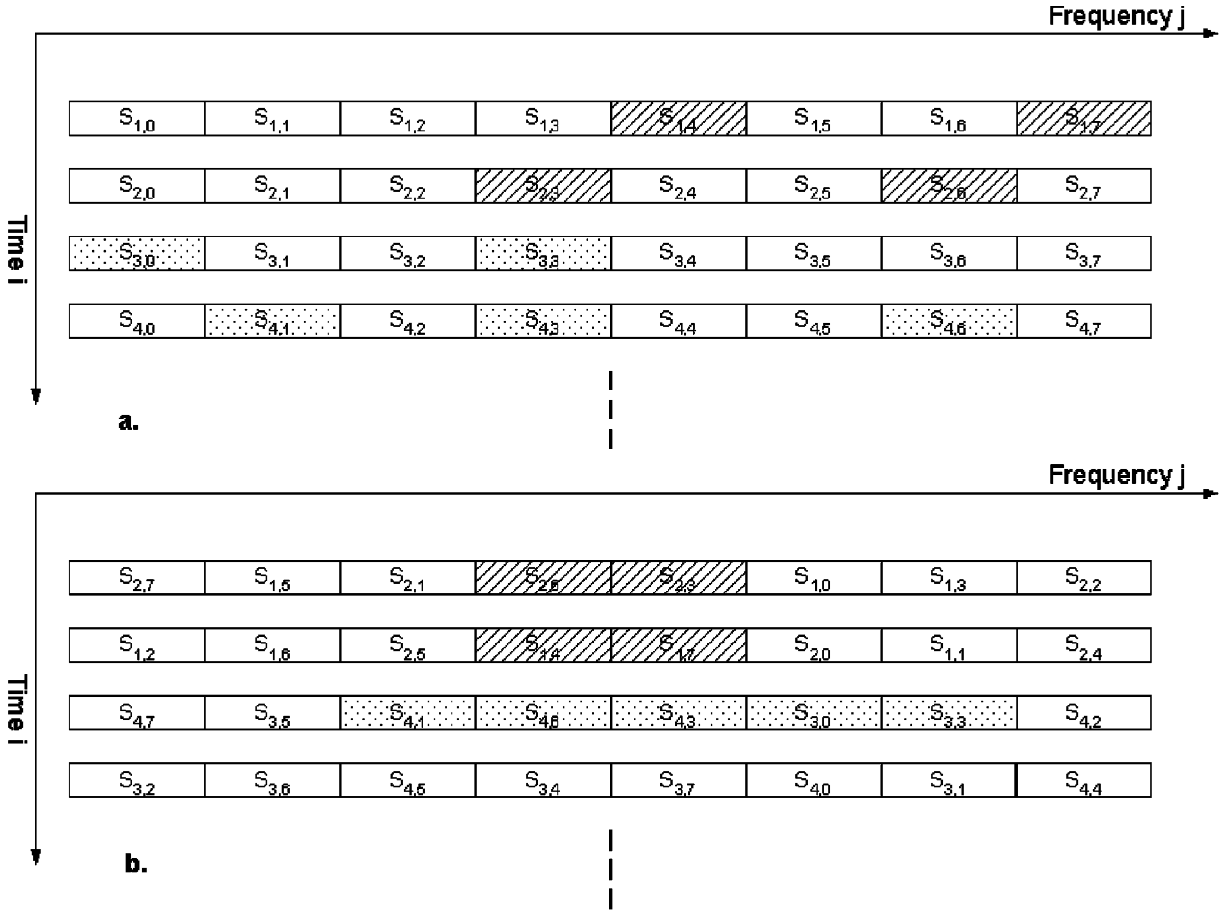

Fig. 3. 4k mode with 8k interleaving, conceptual drawing with 8 carriers. (a) The symbol order before in-depth interleaving and after deinterleaving. (b) The symbol order after interleaving in the channel. The shaded areas in (b) demonstrate how the influence of frequency-concentrated (oblique lines) and time-concentrated (dots) interference in the channel is randomly distributed after deinterleaving [see (a)].

on ESs having a fairly low bitrate, probably in the order of 250 kb/s. The MPEG-2 TS may, however, have a bitrate of e.g., 10 Mb/s. The particular ES of interest thus occupies only a fraction (in this example, 2.5%) of the total MPEG-2 TS bitrate. In order to drastically reduce power consumption, one would ideally like the receiver to demodulate and decode only the 2.5% portion of interest, and not the full MPEG-2 TS. With time slicing this is possible, since the MPE sections of a particular ES are sent in high bitrate bursts instead of with a constant low bitrate. During the time between the bursts—the off-time—no sections of the particular ES are transmitted. This allows the receiver to power off completely during off-time; see Fig. 4. The receiver will, however, have to know when to power on again to receive the next burst. In a particular burst the start time of the following burst of the same ES is signaled via a delta_t parameter in the header of all sections of the burst, which makes the signaling very robust against transmission errors. During off time bursts from other time sliced ESs are typically transmitted.

The peak bitrate of the bursts may potentially be the full MPEG-2 TS bitrate, but could also be any lower peak value allocated for the ES. If the value is lower than the peak bitrate, the MPEG-2 TS packets of a particular burst may be interleaved with MPEG-2 TS packets belonging to other ESs (DVB-H or other, e.g., SI or MPEG-2 audio/video).

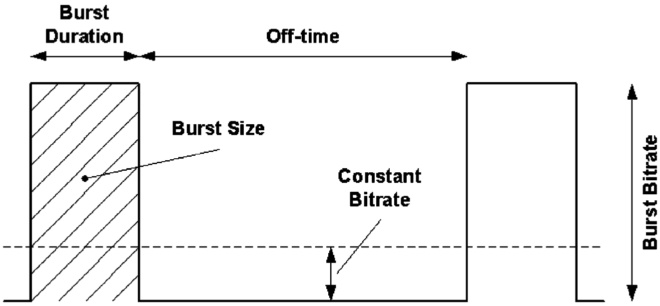

Fig. 4. Principle of time slicing.

Thanks to the flexible delta_t signaling there are no requirements to have fixed burst sizes or fixed time between bursts. A variable-bit-rate coded video stream could therefore use a variable burst size and/or a variable time between bursts. It should be noted that one burst could contain several services, which would then share PID but could e.g., be discriminated by different IP addresses.

If the average bitrate of the ES is 500 kb/s, the peak bitrate is 10 Mb/s and the burst size is 2 Mb (maximum allowed value), the burst time becomes 200 ms, and the burst cycle time 4 s. The receiver, however, has to wake up a little bit before the burst to synchronize and be prepared to receive the

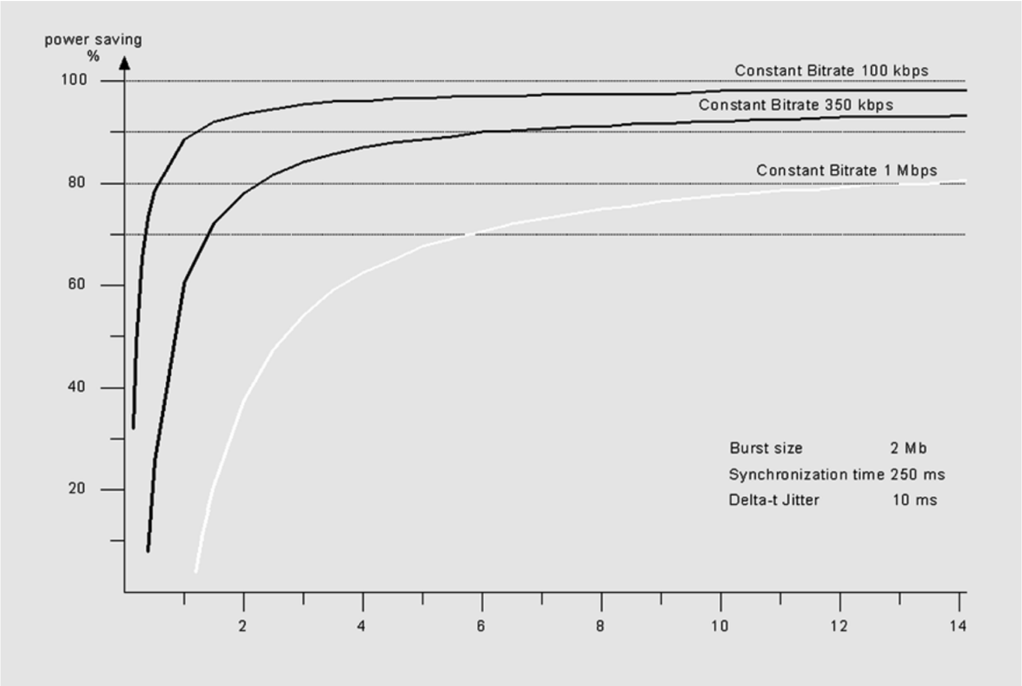

Fig. 5. Example of power saving depending on burst bitrate and service bitrate.

sections. Assuming a figure of 200 ms for the total preparation time, including some margin for delta_t jitter, the power saving in the example becomes 90%. It is probable that the actual parameters used for Time Slicing will be a compromise between power consumption and other factors, such as service access time and RF performance. Examples of how power saving depends on burst bitrate and bitrate of the ES is shown in Fig 5. Note that the assumed total preparation time in Fig. 5 is slightly larger than 200 ms (260 ms).

B. *MPE-FEC*

With MPE-FEC the IP datagrams of each time sliced burst are protected by Reed–Solomon parity data (RS data), calculated from the IP datagrams of the burst. The RS data are encapsulated into MPE-FEC sections, which are also part of the burst and are sent immediately after the last MPE section of the burst, in the same ES, but with different table_id than the MPE sections, which enables the receiver to discriminate between the two types of sections in the ES.

For the calculation of the RS data an MPE-FEC frame is used. The MPE-FEC frame consists of an application data table (ADT), which hosts the IP datagrams (and possible padding), and an RS data table, which hosts the RS data; see Fig. 6.

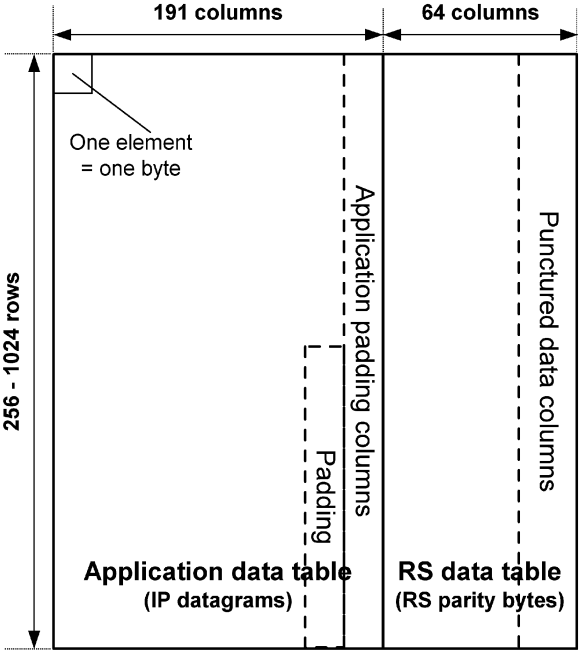

Fig. 6. MPE-FEC frame.

The number of rows in the MPE-FEC frame is signaled in the service information (SI) and may take any of the values 256, 512, 768, or 1024. The number of columns is 191 for the ADT and 64 for the RS data table. The IP datagrams of a particular burst are introduced vertically column-by-column in the ADT, starting in the upper left corner. If an IP datagram does not end exactly at the bottom of a column, the remaining bytes continue from the top of the next column. If the IP datagrams do not exactly fill the ADT, the remaining byte positions are padded with zeros. On each row the 64 parity bytes of the RS data table are then calculated from the 191 IP datagram bytes (and padding bytes, if applicable) of the same row, using the Reed–Solomon code RS(255 191). This provides a large virtual time interleaving, since all RS data bytes are calculated from IP datagrams distributed all over the burst.

Each IP datagram is transmitted in an MPE section and each column of the RS data table is transmitted in an

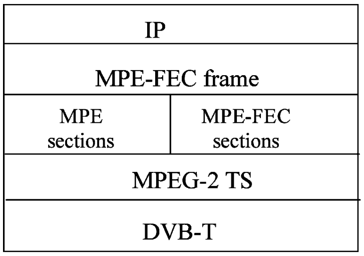

Fig. 7. Protocol stack for DVB-H.

MPE-FEC section. All headers of the MPE and MPE-FEC sections contain a 4-B real time parameters field, which include a 12-b start address, which indicates the byte number (counted from the start of the table) of the start position of the corresponding IP datagram or RS data column, as well as the 18-b delta_t parameter and 1-bit flags to signal end-of-table and end-of-frame. The resulting protocol stack for DVB-H (when MPE-FEC is used) is depicted in Fig. 7.

One possible receiver decoding strategy could be the following: The receiver checks the CRC-32 of all received sections of the selected ES. As pointed out above, the CRC-32 normally enables detection of all erroneous sections, which may then be discarded by the receiver. In this way only fully correct sections are passed to the MPE-FEC decoding. Each correctly received IP datagram or RS data column can then be introduced at the correct place in the MPE-FEC frame with the help of the start address of each section. If there are transmission errors, there will be some remaining gaps within the MPE-FEC frame, corresponding to lost sections. The receiver will treat all introduced bytes as "reliable" and all other byte positions as "unreliable." On each row of the MPE-FEC frame it is therefore known exactly which byte positions are correct ("reliable") and which are missing ("unreliable"). The receiver may therefore perform erasure-based decoding of the RS(255 191) code, which allows correction of twice the number of byte errors, which in our case means up to 64 per row. Assuming e.g., exactly one IP datagram per column this corresponds to an error-correction capability of up to 64 lost columns per frame, i.e., every fourth section is lost. Assuming further a 10% section loss probability, the resulting ratio of uncorrected frames after MPE-FEC decoding becomes 10^{-12} .

This powerful error correcting capability, together with the virtual time interleaving, allows a large reduction in required C/N on mobile channels. Measurements (see Section V) show that the resulting C/N performance is similar to what can be achieved using antenna diversity, although it is recognized that in the case of MPE-FEC there is also a penalty in terms of a reduced throughput, due to the overhead introduced by the MPE-FEC sections. However, using a weaker DVB-T convolutional code rate can compensate for this—when code rate 2/3 is used together with MPE-FEC (code rate 3/4) the performance is far better than convolutional code rate 1/2 without MPE-FEC, even though the IP throughput is the same.

In case the ADT is not completely filled with IP datagrams, the remaining part will be padded with zeros. This padding is only used for the calculation of the RS data and not transmitted. In the header of the MPE-FEC sections, it is possible to signal the number of complete padding columns. In the receiver such complete padding columns can be reintroduced and be marked as "reliable," since the content is known.

Use of padding columns is in effect a shortening of the RS code, which lowers the effective code rate and improves the error correction capability somewhat, but also introduces a larger percentage overhead for the RS data. Puncturing some of the RS columns can compensate for this. Puncturing simply means that some of the last RS columns are not transmitted and this has the effect of weakening the code (i.e., higher effective code rate) and reducing the RS data overhead. The shortening and puncturing operations can be done independently of each other and may be done dynamically, i.e., different shortening and/or puncturing on consecutive MPE-FEC frames.

A reduction of the burst/frame size from the maximum value can be done in two different ways, or even combined. The first variant is to decrease the number of rows from 1024 to 768, 512, or 256. Number of rows is a quasi-static parameter, signaled by SI, and may not vary dynamically. The second variant is to introduce padding columns and puncturing. The number of padding columns may dynamically vary between 0 and 190. The corresponding puncturing range is 0–63 punctured columns.

From a coding performance point of view, the two methods are roughly equivalent. The larger the effective MPE-FEC frame, the more effective becomes the MPE-FEC scheme. Halving the frame size corresponds to halving the interleaving depth. For best mobile performance, the largest frame size may be the fittest option.

C. *Handover Considerations*

DVB-H supports very efficient handover behavior including seamless handover. This is due to the existence of the off periods in time slicing, where the receiver may scan other frequencies in order to find the best potential alternative frequency, or actually execute the handover. It should be emphasized that the possibility of "silently" evaluating alternative frequencies, without disturbing the ongoing reception of the service, is a very important feature of the DVB-H system.

If the same TS is available in a number of adjacent cells, the transmission of the TS should preferably be time synchronized. This is in principle straightforward to achieve, since the same methods could be used as in SFNs and the required time accuracy is much less strict than in the SFN case.

If the transmissions of the TS on different frequencies are time synchronized, a receiver will receive the next burst at the time indicated by delta_t also on any new frequency carrying this TS. Since the TS is the same also, the content of the bursts are the same, which means that the handover will naturally be seamless.

V. PERFORMANCE: EXPECTED AND MEASURED

Broadcast transmission systems shall offer a simple way to cope with the multiple signal replicas reaching the receivers.

With the terrestrial version of the DVB transmission standards, this echo resilience is obtained by the insertion of a "guard interval" between each modulated symbols, delineating a "intersymbol" transition period during which the channel is simply ignored by the receivers, thus minimizing intersymbol interference resulting from delayed reception of previous modulated symbols.

This echo nuisance is easily circumvented while broadcasts target fixed receivers, having a nice roof top selective antenna pointed to the transmitter site. However, when targeting mobile or portable receivers, using an omnidirectional antenna to track signals at 1 m above the ground level, the problem is naturally far more complex to solve.

A. Doppler: The Devil for Mobile

For receivers in motion, complexity comes not only from the multiplicity of received echoes delayed in the time domain, but also from the frequency-shift affecting such echoes.

As described by the Austrian mathematician Christian Andreas Doppler (1803–1853) and depicted in the following formula, signals received in motion are affected by a "frequency Doppler shift" which is in relation with the receiver speed and the relative angle between the motion direction and the signal incoming direction:

$$\Delta f_D = V * \frac{f_{rf}}{C} * \cos(\Phi) \tag{1}$$

where

V receiver velocity

f_{rf} carrier frequency of transmitted signal

C speed of light (299.792.458 m/s in vacuum)

Φ angle between motion direction and signal incoming direction

While the incoming angle provides a sign and weighting factor to the Doppler frequency shift, both the radio-channel frequency and the speed of the receiver will proportionally increase its value.

Echoes affected by Doppler frequency shifts are perceived as a noise contributing to intercarrier interference (ICI). ICI can be mitigated, in receivers using dedicated signal processing techniques, until a level at which the orthogonality of the subcarriers is broken, making demodulation impossible.

In other words, with respect to a signal received in motion being a sum of echoes, each variably affected by a Doppler frequency shift (i.e., $\cos \phi$), the resulting "ICI" noise level is proportional to the receiver speed (i.e., V) and to the radio-channel frequency in use to broadcast the signal (i.e., f_{rf}/C).

B. Environment for Measurement

The DVB-T standard specifies, for each used coded constellation, the C/N threshold needed to reach the quasi-error-free (QEF) reception criteria[1] in various propagation contexts. Three channel profiles (i.e., Gaussian, Rice, and Rayleigh), which do not include Doppler noise, are used for this purpose.

Table 4
TU6 Channel Model

Tap Number	Delay (μs)	Power (Lin)	Power (dB)	Doppler Spectrum
1	0,0	0,5	-3	Rayleigh
2	0,2	1	0	Rayleigh
3	0,5	0,63	-2	Rayleigh
4	1,6	0,25	-6	Rayleigh
5	2,3	0,16	-8	Rayleigh
6	5,0	0,1	-10	Rayleigh

For broadcast services to a mobile receiver, other channel profiles and criteria shall be used.

1) Channel Modeling: In 1989, the EU-COST207 project (1984–1988) deeply studied channel propagation models to be used for mobile communications. The Typical Urban 6-paths model (TU6) depicted in Table 4 [6], proven to be representative for the typical mobile reception with Doppler frequency above 10 Hz.

Assessment of mobile reception performance requires setting up a reproducible environment. The TU6 has been heavily used both for simulation and for laboratory test (using a channel simulator), and results from numerous field trials highly correlate with the obtained results.

Nevertheless, concerns remain in regard to the TU6 suitability for reception with Doppler frequency below 10 Hz (i.e., the pedestrian and indoor reception) suggesting further modeling work.

2) Quality of Restitution (QoR) Criteria: Instead of a QoS criterion, which embeds a lot of subjective aspects, including clever error concealment processing in the receiver, an objective failure point or QoR criterion has been defined to characterize the operative limit of the mobile reception.

Basically, the QEF criterion cannot be used for instantaneous measurement, due to the high variation occurring in the mobile channel.

In the case of DVB-T services to mobile devices, corresponding to a service continuously delivered, an erroneous seconds ratio (ESR) of 5%[2] has shown to be highly correlated with the subjectively perceived reception quality.

In the case of DVB-H, where services are delivered in MPE-FEC protected time slice bursts, other criteria have been defined: FER and MFER.

Frame error ratio (FER) is the ratio of ADTs containing errors, without MPE-FEC error correction being applied, during an observation period. FER5 consequently corresponds to 5% ADTs containing errors. MPE FER (MFER) is the ratio of uncorrected MPE-FEC frames during an

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[1] QEF means less than one uncorrected error event per hour, corresponding to BER $= 10^{-11}$ at the input of the MPEG-2 demultiplexer. For static channels this is assumed to correspond to a BER of 2×10^{-4} after Viterbi decoding.

[2] ESR: seconds with errors over the observation period. ESR5 corresponds to 1 s with error over a 20-s observation period.

observation period. MFER5 therefore corresponds to 5% uncorrected MPE-FEC frames during the observation period.

FER (reception without MPE-FEC correction) and MFER (reception after MPE-FEC correction) showed to be extremely good indicators of the QoR for each service. Moreover, FER constitutes a mimic of a DVB-T like transmission, while MFER highlights the improvement brought by DVB-H transmissions.

FER5 and MFER5 have been used during laboratory tests sessions where their drawbacks (i.e., to wait for the reception of a large number of MPE-FEC frames) are tolerable.

For field trials, where QoR assessment shall be as instantaneous as possible, the observation period has been reduced to a time interval equals to the duration of one burst (i.e., transmission of one service time-slice). FER0 and MFER0 constitute then a bad/good indicator for each transmitted service burst.

C. DVB-T and DVB-H Reception Behavior in Motion

From 1998 to 2000, a European Collaborative Research project (MOTIVATE—ACTS318) studied the DVB-T capability to serve mobile receivers. Field trials confirmed laboratory tests results and showed the strong relations between the DVB-T transmission modes and the QoR achievable by the receivers in motion. This behavior has been modeled using the "C/N versus Doppler" curve depicted in Fig. 7.

Fig. 7 shows, on the Y axis, the C/N required by receivers to demodulate a signal affected by a mobile channel; the X axis corresponds to the Doppler frequency shift value resulting from the receiver speed.

First, from static to slow motion situations, the C/N request increases suddenly (see T4 point) corresponding to a so-called mobile penalty. While the Doppler frequency (the speed) increases, only a small C/N improvement (T2) is needed, until the Doppler frequency reaches a value (T1) where the demodulation process becomes impossible.

In a DVB-T context, numerous tests and trials have shown that the minimum C/N for mobile reception is strictly related to the coded constellation in use (i.e., strong constellations—like QPSK CR 1/2—decrease the "mobile penalty") while the maximum speed is directly related to the intercarrier spacing (ICS) of the multicarrier transmitted signal (i.e., in a 8-MHz channel bandwidth, the 8K mode offers ~ 1 KHz ICS while the 2K mode offers ~ 4 KHz ICS). In other words, the minimum C/N is relatively independent of the receiver implementation, relying on the coded constellation robustness, while the maximum speed characteristic is heavily dependent on the channel estimation/correction techniques implemented as well as techniques for reducing the negative effect of ICI, but remains, for all implementation cases, proportional to the intercarrier distance.

In a DVB-H context, further protection is defined to each DVB-H service on top of the protection mechanisms offered to the whole services multiplex by the DVB-T physical layer. The MPE-FEC scheme provides to each DVB-H service bursts—or service time slices—a set of Reed–Solomon code-words allowing receivers to perform further correction on the IP datagrams imperfectly received as described in Section IV.

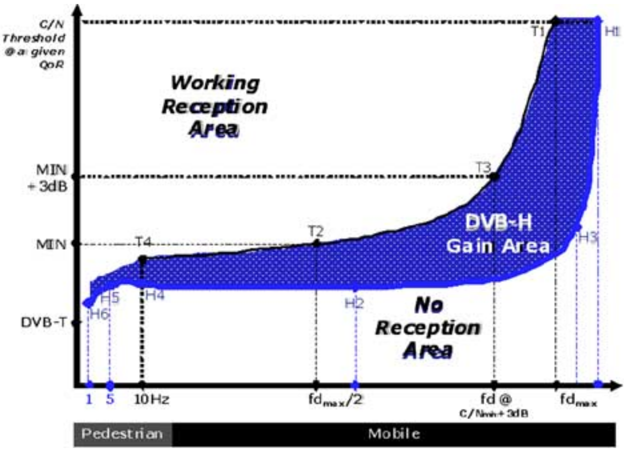


Fig. 8. C/N versus Doppler for receivers in motion.

The second curve (H1 to H6 points) in Fig. 8 illustrates the effects of the Reed–Solomon correction power reinforced by the virtual time interleaver.

For mobile situations, above 10 Hz of Doppler, the MPE-FEC protection scheme lowers the required C/N further while receiving speed increases, and moreover the MPE-FEC enables increasing the maximum speed (see H1 point) at which demodulation remains possible without MPE-FEC.

For pedestrian situations, below 10 Hz of Doppler, the effects of the virtual time interleaver are less efficient and DVB-H transmissions benefits mainly from the ruggedness brought by the Reed–Solomon protection and DVB-T in general. But, in this area, the absolute duration of the service bursts are expected to bring further advantages.

In brief, the use of MPE-FEC in DVB-H transmissions nicely makes the service availability independent of the receiving speed while canceling a large part of the C/N penalty suffered by the receiver in motion.

D. DVB-H: The Validation Exercise

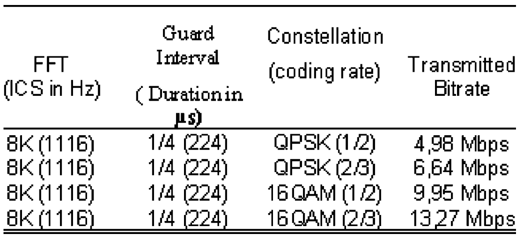
The DVB-H complexity is more related to the overall transmission system than to its individual techniques used to provide efficient delivery to handheld terminals.

This suggested to the DVB-H *ad hoc* group of the DVB Technical Module to organize a validation exercise in order to capture possible standards inaccuracies, to help early implementers and to estimate the DVB-H transmission system performance.

In October 2004, a DVB-H test session involving up to 25 equipments and 12 companies has been performed in the laboratory of T-Systems in Berlin, Germany. In December 2004, DVB-H field trials have been performed using the facilities set up by Télédiffusion de France in Metz in order to verify the laboratory results. Major findings are reported hereafter.

The laboratory session checked interoperability of numerous equipments, including full DVB-H receivers

Table 5
DVB-H Transmission Modes Used



FFT (ICS in Hz)	Guard Interval (Duration in µs)	Constellation (coding rate)	Transmitted Bitrate
8K (1116)	1/4 (224)	QPSK (1/2)	4,98 Mbps
8K (1116)	1/4 (224)	QPSK (2/3)	6,64 Mbps
8K (1116)	1/4 (224)	16QAM (1/2)	9,95 Mbps
8K (1116)	1/4 (224)	16QAM (2/3)	13,27 Mbps

prototyped with large-sized set of field programmable gate arrays (FPGAs).

Full interoperability between network equipment and receivers has been stated, in all possible transmission modes (2K/4K/8K; all coded constellations), channel bandwidths (5/6/7/8 MHz) and network operation (MFN/SFN, hierarchical/regular transmissions).

1) Laboratory Test Methodology: To evaluate DVB-H performances in the laboratory and in the field (i.e., to determine the "C/N versus Doppler" curve), the various parameters of the transmission systems have been selected in order to obtain figures in the most probable or the most demanding modes offered by the DVB-H, which also constitute the worst cases for the receivers.

a) Physical layer: The DVB-T physical layer offers a wide flexibility to trade off transmitted bitrate against signal robustness. The flexibility has been enlarged with DVB-H, bringing an additional dimension to the tradeoff: transmission cell size versus maximum receiving speed.

DVB-H experimentation has been performed using the transmission modes listed in Table 5.

All tests have been performed using the "8K GI 1/4" transmission frame structure, which constitutes the worst transmission scheme for the receivers from the speed point of view. Effectively, the 8K mode implements the smallest ICS and thus offers the smallest room for Doppler frequency shifts. In addition, even if the longest guard interval (1/4) allows one to maximize the transmission cell (i.e., largest room for delayed echoes) it leads to a longer symbol length decreasing tolerance to mobility.

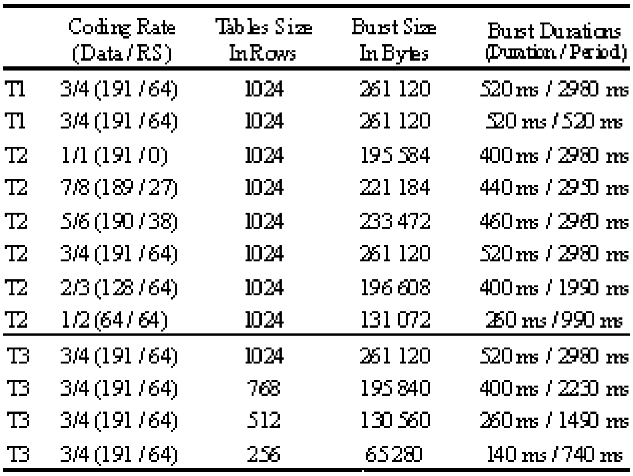
The range of coded constellation has been selected to provide various DVB-H transmission capabilities, thus to explore the tridimensional tradeoff of bitrate versus robustness versus speed."

The objective of this selection of transmission modes is to compare reception performances in DVB-T like (i.e., FER criteria) and DVB-H (i.e., MFER criteria) situations.

b) Data layer: The MPE-FEC protection scheme applied at the link layer in DVB-H, allows for producing various time-slice burst shapes, characterized, e.g., by the FEC coding rate and the absolute burst durations. In order to weigh the influence of these parameters, the set of burst shapes depicted in Table 6, has been utilized.

For all tests, the peak TS bitrate for DVB-H services has been limited to a constant bitrate of 4 Mb/s, this size being compatible with all bitrate made available by the physical layer and moreover corresponding roughly to the average bitrate of one regular standard definition TV program.

Table 6
DVB-H Burst Shapes Used



	Coding Rate (Data / RS)	Tables Size In Rows	Burst Size In Bytes	Burst Durations (Duration / Period)
T1	3/4 (191 / 64)	1024	261 120	520 ms / 2980 ms
T1	3/4 (191 / 64)	1024	261 120	520 ms / 520 ms
T2	1/1 (191 / 0)	1024	195 584	400 ms / 2980 ms
T2	7/8 (189 / 27)	1024	221 184	440 ms / 2950 ms
T2	5/6 (190 / 38)	1024	233 472	460 ms / 2980 ms
T2	3/4 (191 / 64)	1024	261 120	520 ms / 2980 ms
T2	2/3 (128 / 64)	1024	196 608	400 ms / 1990 ms
T2	1/2 (64 / 64)	1024	131 072	260 ms / 990 ms
T3	3/4 (191 / 64)	1024	261 120	520 ms / 2980 ms
T3	3/4 (191 / 64)	768	195 840	400 ms / 2230 ms
T3	3/4 (191 / 64)	512	130 560	260 ms / 1490 ms
T3	3/4 (191 / 64)	256	65 280	140 ms / 740 ms

Then, for the purpose of the performance exploration tests, three sets of burst shapes (labeled T1, T2, and T3 in Table 6) have been defined in order to explore the influences of DVB-H versus DVB-T, MPE-FEC coding rates and absolute burst durations, respectively.

It can be noted that the definitions of the MPE-FEC coding rate with the number of table rows drive the size of the bursts, and accordingly, the bitrate allocated for the whole DVB-H multiplex drives the absolute burst duration while the average elementary stream bitrate drives the burst periodicity.

Variations of the absolute burst duration can be obtained by modifying the number of table rows and/or the bitrate allocated for DVB-H.

2) Laboratory Test Results: Numerous results have been obtained from the large-scale laboratory test campaign performed by the DVB-H standardization members. The main results are presented hereafter. The colors indicate the two different prototype receivers in test.

a) DVB-T Versus DVB-H: For this assessment, using MPE-FEC 3/4 service bursts, the C/N versus Doppler characteristic of two receivers has been established, for QPSK and 16QAM, using coding rates 1/2 and 2/3.

In Figs. 9 and 10, the "FER5" curve corresponds to a DVB-T like situation, while the "MFER5" curve shows the DVB-H benefit brought by the MPE-FEC 3/4 protection.

From these figures, it could be appreciated that in a mobile situation $(f_D > 10 \text{ Hz})$, the MPE-FEC not only decreases the C/N requirement from 6 to 8 dB but also makes the service availability nicely independent of the receiving speed.

As far as the maximum speed (high f_D) is concerned, the MPE-FEC nicely pushes further the maximum speed limit, acting in combination with the ICI cancellation algorithms implemented in the demodulators.

Fig. 10 shows the results obtained with 16QAM CR 2/3 mode. A 5–6 dB "C/N gain" brought by the MPE-FEC 3/4 can be observed, but interestingly, for the second receiver,

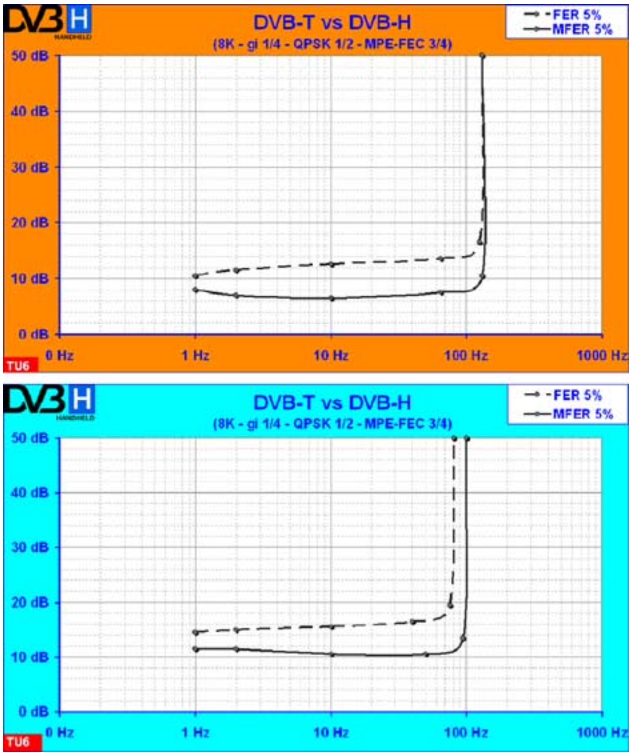


Fig. 9. DVB-H gains in QPSK 1/2.

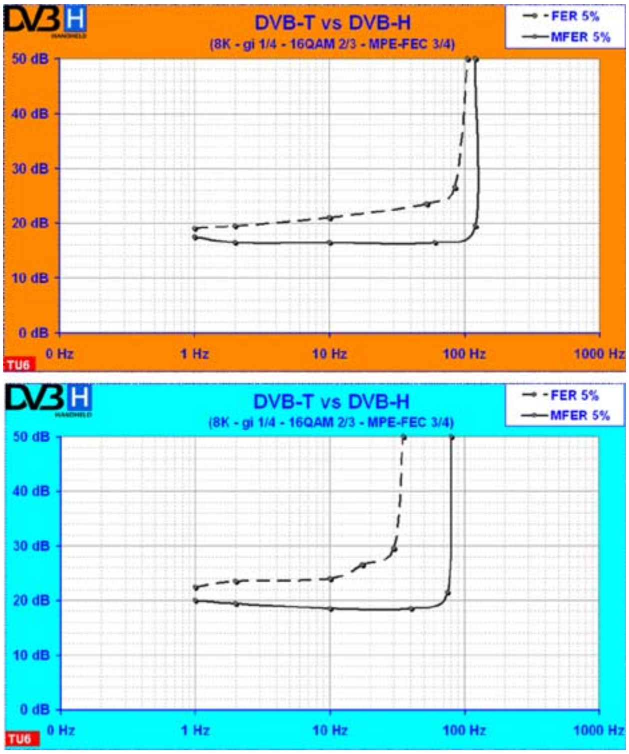


Fig. 10. DVB-H gains in 16QAM 2/3.

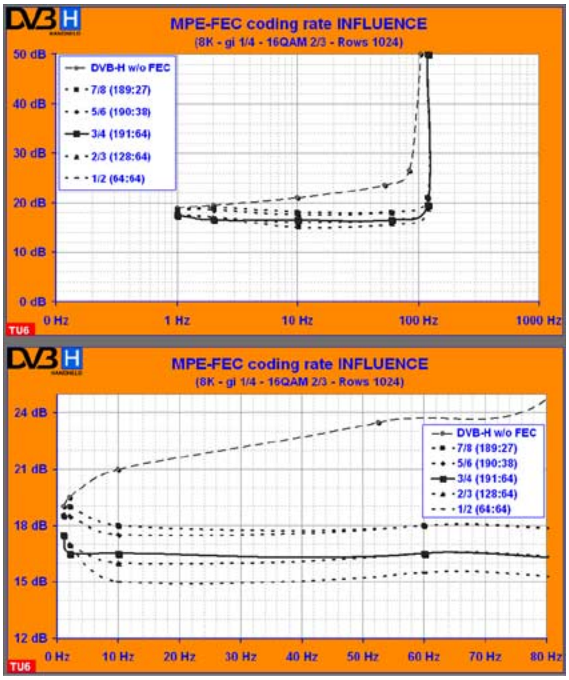


Fig. 11. MPE-FEC coding rate influence in 16QAM 2/3.

the "speed gain" is more appreciable with this modulation scheme.

Tests using 8K mode with QPSK 2/3 and 16QAM 1/2 confirmed these results, showing that MPE-FEC allows the DVB-H transmission system to use TS bitrates of 5 to 14 Mb/s from 500 km/h (Band III) to 130 km/h (Band IV).

This DVB-H performance resembles the C/N and maximum speed improvement observed with antenna diversity reception.

b) MPE-FEC coding rate influence: To study the effects of the MPE-FEC coding rate, the weak coded constellation (i.e., 16QAM 2/3) has been used and the various MPE-FEC coding rate listed in Table 6 (T2 label) have been experienced. Results are shown in Fig. 11.

The "zoom" presented in the second graph highlights the tremendous effect of the MPE-FEC on the C/N (i.e., 5–6 dB).

In pedestrian situations (f_D below 10 Hz) the progressive effect of the virtual time interleaver can be observed, which gradually allows to reach the improved C/N.

In mobile situations, the C/N gain is already effective with the lowest coding rate 7/8 (i.e., 12.5% overhead) and it nicely increases proportionally with larger coding rates, to reach up to 9 dB gain for coding rate 1/2 (i.e., 50% overhead).

For all coding rates, the maximum speed remains outstandingly around a Doppler frequency of 120 Hz which corresponds to a speed range of 160 km/h @ 800 MHz (upper part of Band V) to 650 km/h @ 200 MHz (lower part of Band III).

c) Transmission mode influence: With the DVB-H extension, the DVB-T standard allows the use of three transmission modes involving 2K, 4K, or 8K subcarriers. These three modes allow one to broadcast strictly the same bitrate range but, due to the orthogonal organization of the frequency division multiplex (i.e., OFDM), provide three tradeoffs between ICS (i.e., room for Doppler spread) and guard interval duration (i.e., maximum echo delay tolerance and, consequently, maximum transmission cell size).

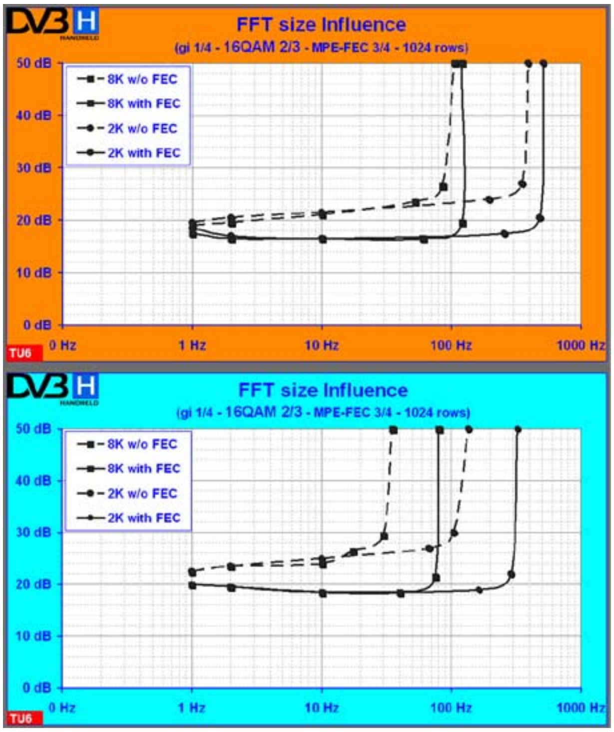


Fig. 12. Transmission mode influence in 16QAM 2/3.

Even if performance measurements have not been realized in the 4K transmission mode, two receivers have been tested in 2K and 8K transmissions, as shown in Fig. 12.

Fig. 12 shows clearly that the C/N gain and the Doppler acceptance gain provided by the MPE-FEC remains available whatever the transmission mode. Moreover, the maximum speed remains in strict relation with the ICS implemented: the 2K mode is obviously four times more Doppler resilient than the 8K mode.

This confirmed that the DVB-H 4K mode would have intermediate characteristics between 2K and 8K; which will be very appreciated to enlarge the 2K transmission cell size while maintaining receiving capabilities at very high speed, for services targeting high-speed trains for instance.

3) Field Trials Results: In order to verify on the fields the DVB-H performances, a 600-W ERP transmitter using QPSK 1/2 and 16QAM 2/3 constellations in 8K with guard interval 1/4, has been used to cover the city of Metz with the same DVB-H services organization as the ones experienced in the laboratory.

A wide range of field measurements has been done in various receiving situation: pedestrian outdoor (in city downtown), mobile (in car traveling the city center and the highway in suburb), and pedestrian indoor (within the research center of Télédiffusion de France).

Each field trial session captured up to 3000 measurement points, sampling the experienced C/N and received RF power level every second while assessing the FER and MFER criteria.

The achieved results do give indications on the MPE-FEC improvements, which were in line with the laboratory measurements.

Unfortunately, in the field, receivers suffer simultaneously from slow shadowing fading (produced by the environment) and fast Rayleigh fading (coming from the mobile channel); accordingly, field trial results cannot be straightforwardly compared with the laboratory measurements. However, improvements of the order of 5–6 dB in C/N and even more were observed and the flatness of the C/N requirement down to pedestrian speeds, either for indoor or outdoor reception was confirmed.

The DVB-H validation task force report [7] provides exhaustive data on the results summarized here. Also, on the basis of the laboratory and field tests a reference receiver for network planning purposes has been published in DVB-H implementation guidelines [8].

VI. DVB-H NETWORKS

A. *The IPDC-System*

A typical application for DVB-H is IP datacasting service to handheld terminals like mobile phones. Fig. 13 shows a full IPDC system with the various components and elements included. First the service system is used to produce the various IP streams (like video streams) to the network. They are then distributed over the multicast intranet to the IP encapsulators, which will output the DVB-H TS with time slicing and MPE-FEC included. This TS is then distributed to the DVB-T/H transmitters of the broadcasting network. The IP Datacast (IPDC) system may include other functions via cellular networks like General Packet Radio Service (GPRS) or Universal Mobile Telecommunications System (UMTS).

B. *Broadcasting Spectrum*

DVB-H is intended to use the same broadcasting spectrum, which DVB-T is currently using. The physical layer of DVB-H is in fact DVB-T and therefore there is a full spectrum compatibility with other DVB-T services.

DVB-H can be introduced either in a dedicated DVB-H network or by sharing an existing DVB-T multiplex between DVB-H and DVB-T services. When the final selection of the DVB-H concept was made, the capability to share a multiplex with DVB-T was indeed one of the decisive factors, as it was seen that this would enhance the commercial introduction possibilities of the service in the crowded UHF broadcasting spectrum. Technically almost any DVB-T frequency allotment or assignment can be used also for DVB-H; the only limitations come from interoperability with GSM900 cellular transmitter in the DVB-H terminal. If simultaneous operation is required, the frequencies below about 700–750 MHz are favored.

For broadcasters DVB-H can be seen just as a new means to provide broadcast services for a new, interesting group of customers, namely, the mobile phone users. If this is seen as interesting enough, spectrum will be available. It is in any case expected that the situation will be more relaxed after the analog TV services will start to close. It should also be noted that DVB-H is very spectrum efficient when compared with the traditional TV-services. One 8-MHz channel can deliver 30–50 video streaming services to the small screen

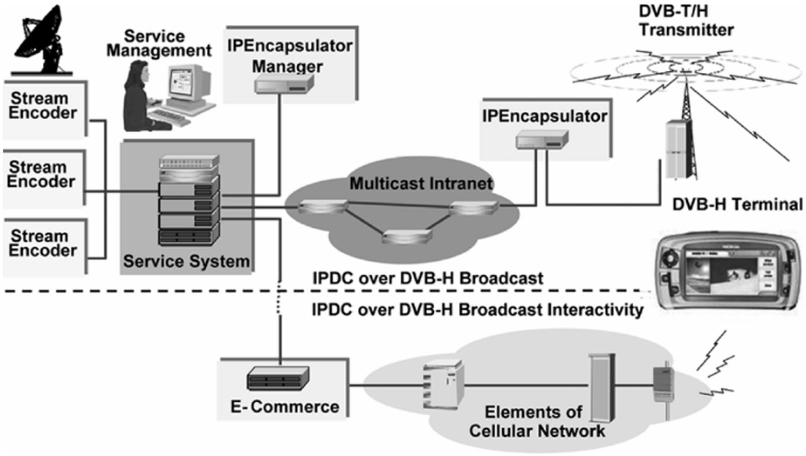


Fig. 13. A typical IPDC-system.

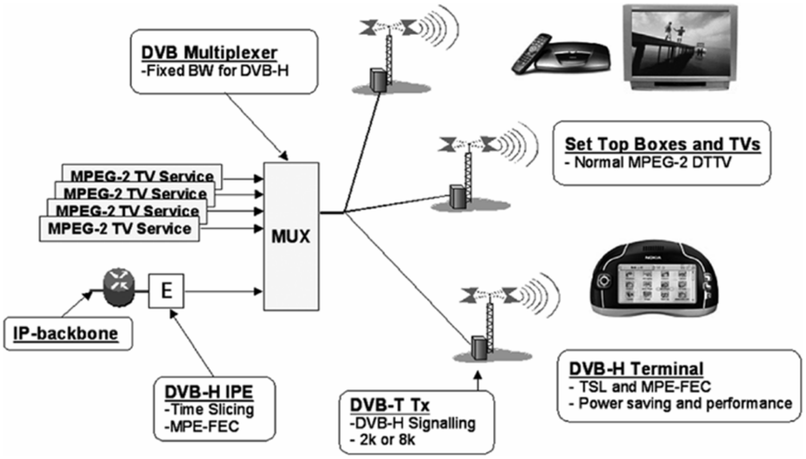


Fig. 14. Sharing a network with DVB-T by multiplexing.

terminals. This is ten times more than standard-definition TV (SDTV) with MPEG-2 or 20 times more than high-definition TV (HDTV) with AVC.

C. Sharing with DVB-T

A shared network could look like the one in Fig. 14. There a network of DVB-T transmitters is serving both DVB-H and DVB-T terminals. The existing DVB-T network has to be, however, designed for portable indoor reception so that it can provide high enough field strength for the hand-held terminals inside the wanted service area. The only required modification in the transmitters is an update so that the DVB-H signaling bits and Cell ID bits are added to the TPS information of the transmitter.

The actual sharing is done at the multiplex level. DVB-H offers a full flexibility to select the wanted portion of the multiplex to DVB-H services. The key DVB-H component in the network is the IP-encapsulator, where the MPE of IP data, time slicing, and MPE-FEC are implemented.

Another possibility to share the network is to use the DVB-T hierarchical modulation. In that case the MPEG-2 and DVB-H IP services will have their own independent TS inputs in the DVB-T transmitters. The DVB-H services would use the high-priority part, which would offer increased robustness over the low-priority input, which is then used for the normal digital TV services.

D. Dedicated DVB-H Networks

When a full multiplex can be reserved for DVB-H, the freedom in planning is increased. If needed, now it is possible to select the new 4k mode or in-depth interleavers introduced in the latest DVB-T standard for DVB-H. A dedicated DVB-H network is shown in Fig. 15.

A typical network is composed of several SFN areas, each using its own frequency allotment. The maximum size of one SFN area depends on the FFT size, guard interval, and geographical properties in the network, but can typically be in the order of tens of kilometers. Each SFN area has probably several GPS-synchronized transmitters supported by a number of on-channel repeaters to cover some smaller holes. As the required field strength in a DVB-H network is fairly high and the allowed total interfering power from an allotment is limited by the coordinated plan, the number of synchronized main transmitters should be higher and the transmitter powers and antenna heights lower than in a traditional DVB-T network. The network can be called dense SFN. Obviously the cost of the network is higher than

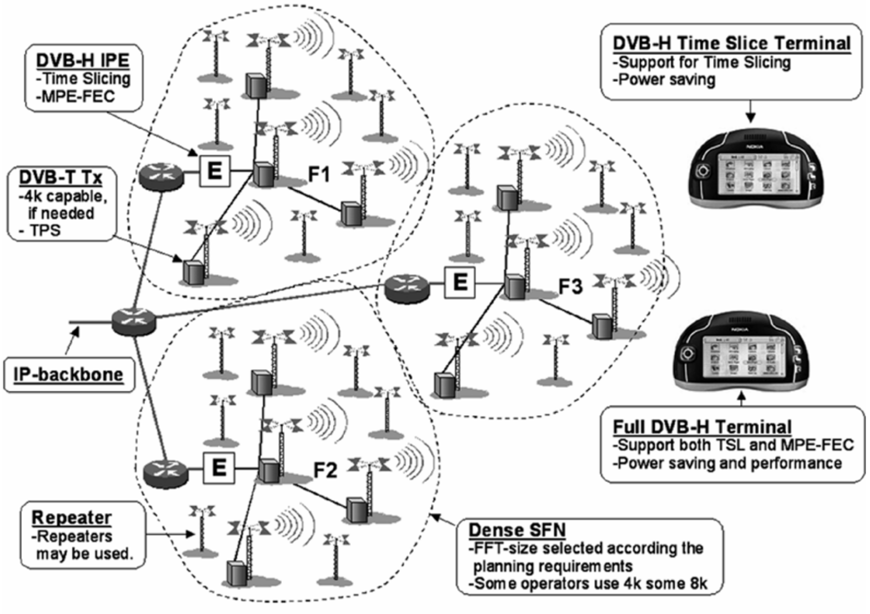


Fig. 15. A dedicated DVB-H network.

in conventional DVB-T network, but also the number of services in one multiplex is ten times higher.

E. Network Dimensioning

Independent of the actual network construction, several planning parameters have to be understood in detail so that the required planning field strength can be calculated. The following examples will demonstrate the process, which starts from the receiver characteristics. Adding the noise figure F and the required C/N to the noise floor of the 7.61-MHz-wide channel gives the receiver sensitivity in certain channel conditions. In decibels this leads to

$$P_{RX\,\min}[\text{dBm}] = -105.2\text{ dBm} + F + \frac{C}{N}. \tag{2}$$

For planning purposed these may be obtained from a reference receiver defined in the DVB-H implementation guidelines. For example, if F is 5 dB and for QPSK CR $= 1/2$ the required C/N in a portable channel is 6.4 dB (assuming 2.5-dB implementation loss), the sensitivity becomes $-$ 93.8 dBm.

The next important parameter is the terminal antenna gain G_a. This is needed so that the minimum field strength $E_{\min}$ can be calculated by

$$E_{\min} = \sqrt{4\pi\eta\frac{P_{RX\,\min}}{G_a}} \cdot \frac{f}{c} \tag{3}$$

where $\eta = 120\pi\Omega$.

Assuming an integrated antenna in a small hand-held terminal like a mobile phone, the antenna gain in UHF frequencies will be low. DVB-H implementation guidelines and draft ITU Recommendation 1368 give gains between $-$ 5 dBi (862 MHz) and $-$ 10 dBi (470 MHz). Taking the $-$ 7-dBi figure at 700 MHz, we can calculate the minimum field strength for our example case as

$$\begin{aligned} E_{\min} &= P_{RX\,\min}[\text{dBm}] - G_a[\text{dB}] + 77.2 + 20\log_{10} f[\text{MHz}] \\ &= -93.8 + 7 + 77.2 + 20\log_{10} 700 \\ &= 47.3\text{ dB}\mu\text{V/m} \end{aligned} \tag{4}$$

When planning for indoor reception, this is the minimum field strength indoors where the terminal still works. The network planner, however, wants to know what is the required planning field strength outside. As the field strength is a random variable, with lognormal distribution, the planner has to consider this slow fading effect and decide what is the coverage location probability target. In the broadcasting world, the location coverage is normally defined at the edge of the coverage area and can for indoor reception be, for example, 90%, meaning that the field strength is high enough in 90% of the locations at the edge of the service area, giving roughly 97% location coverage over the whole cell. To calculate the needed margin over the median field strength (which would give 50% coverage), we need to know the standard deviation (STD) of the signal. The normal value used with broadcasting signals in the UHF band is 5.5 dB. This has originally been derived with fairly large planning grid, like 500 m × 500 m squares, and when more precise tools with planning grid of 10 m × 10 m are used, a lower value may be realistic.

This will give the signal distribution outside, but we still have to consider the effects of the building penetration loss. This is one of the most difficult parameters to model, and when we measure it in the field, we see a large variation of values inside a single building and even higher variation with different type of buildings. The distribution is considered to be again lognormal and can be characterized by a mean value and STD. The total signal STD inside the building can be

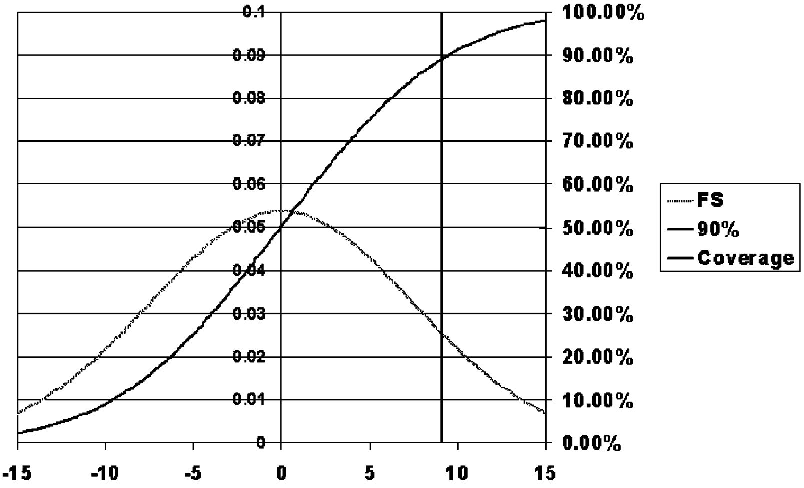


Fig. 16. Log normal field strength distribution and cumulative distribution.

Table 7
Link Budget Calculation

Rx Link Budget **F=700 MHz**			**Urban Indoor Rayleigh Channel**
Parameter		**Unit**	**Value**
Noise Floor	PN=kTB	dBm	-105.2
Rx Noise Figure	F	dB	5.0
C/N QPSK 1/2	C/N	dB	6.4
Rx sensitivity	Prx min	dBm	-93.8
Rx antenna gain	Grx	dB	-7.0
Isotropic power	Pi	dBm	-86.8
Location variation	Llv	dB	10.3
Building loss	LB	dB	11.0
Minimum power outside	Pmin	dBm	-65.5
Minimum field strength outside	Emin	dBμV/m	68.7

calculated as a square sum of the STD of the signal outside and STD of the building penetration loss, giving

$$\sigma_{\text{tot}} = \sqrt{\sigma_s^2 + \sigma_{\text{bpl}}^2} \qquad (5)$$

where σ_{tot} is the total STD, σ_{s} is the STD of the signal outside, and σ_{bpl} is the STD of the building penetration loss.

Using this total STD, the required location variation margin can be calculated by using the cumulative distribution of the field strength. If we assume σ_{bpl} to be 6 dB, we get σ_{tot} equal to 8.1 dB, which gives a 10.3-dB location correction margin, as shown in Fig. 16.

Assuming 11-dB mean value for building penetration loss [8, ch. 11.2.2.2] we can calculate a sample link budget, which is shown in Table 7.

This calculation gives the required planning field strength at street level (1.5 m). Sometimes we want to predict the field strength at 10-m height, and then the height loss has to be considered. It is dependent on the environment (urban, suburban, rural) and frequency. Values varying between 11 and 24 dB can be found in the DVB-H implementation guidelines.

F. Pilot Networks

Technical trials and pilot projects have been two important elements in the development of DVB-H network concepts. They are aimed at speeding up the verification process for the standards and at testing the technical feasibility of various network equipment and terminals. More importantly, because of these pilots and trials, valuable experience has been gained regarding how the end users are adopting the new services and how they are consuming them. The pilots also play a role in the ongoing spectrum planning process by demonstrating the importance of hand held reception for the Regional Radio Conference. DVB-H pilot networks have been operational in Berlin, Germany; Helsinki, Finland; Turku, Finland; Pittsburgh, PA; and Oxford, U.K. Several others are in the planning stage at the time of this writing (winter 2005). Currently there already exist several DVB-H chips available on the market and several others have been announced. Prototype receivers for the pilots and H-transmitter equipment have existed already over a year.

VII. CONCLUSION

The new DVB-H standard, while in no way changing the current digital TV business models for fixed reception, could provide new business possibilities for a variety of players from broadcast and cellular operators to chip and equipment manufacturers. The standard has exhibited proven performance in the laboratory and field tests where the additional error correction and virtual interleaver have shown their efficiency. The power saving given by time slicing makes digital broadcast reception in handheld terminals practical reality. The new system has been well received by various operators, both broadcast and telecom. Several pilot networks are running in various parts of the world and commercialization in the form of chips and user terminals takes place by several manufacturers.

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REFERENCES

[1] *Digital video broadcasting (DVB); transmission system for handheld terminals (DVB-H)*, ETSI EN 302 304 V1.1.1 (2004-11), European Telecommunications Standards Institute.

[2] *Digital video broadcasting (DVB); DVB specification for data broadcasting*, ETSI EN 301 192 V1.4.1 (2004-11), European Telecommunications Standards Institute.

[3] *Digital video broadcasting (DVB); Specification for service information (SI) in DVB systems*, ETSI EN 300 468 V1.6.1 (2004-11), European Telecommunications Standards Institute.

[4] *Digital video broadcasting (DVB); framing structure, channel coding and modulation for digital terrestrial television*, ETSI EN 300 744 V1.5.1 (2004-11), European Telecommunications Standards Institute.

[5] *Digital video broadcasting (DVB); DVB mega-frame for single frequency network (SFN) synchronization*, ETSI TS 101 191 V1.4.1 (2004-06), European Telecommunications Standards Institute.

[6] COST207 (under the direction of M. Failly), “Digital land mobile radio communications (final report),” Commission of the European Communities, Directorate General Telecommunications, Information Industries and Innovation, 1989, pp. 135–147.

[7] *Digital video broadcasting (DVB); transmission to handheld terminals (DVB-H); validation task force report VTF*, ETSI TR 102 401 V1.1.1 (2005-04), European Telecommunications Standards Institute.

[8] *Digital video broadcasting (DVB); DVB-H implementation guidelines*, ETSI TR 102 377 V1.1.1 (2005-02), European Telecommunications Standards Institute.

[9] U. Ladebusch and C. Liss, “Terrestrial DVB (DVB-T): A broadcast technology or stationary portable and mobile use,” *Proc. IEEE* vol. 94, no. 1, pp. 183–193, Jan. 2006.

[10] U. Reimers, “DVB—The family of international standards for digital video broadcasting,” *Proc. IEEE* vol. 94, no. 1, pp. 173–182, Jan. 2006.

[11] ——, *DVB—The Family of International Standards for Digital Video Broadcasting*, 2nd ed. Berlin, Germany: Springer, 2005, 408 pp..

Gerard Faria graduated from the Technical University of Paris VI, France, in 1978.

He is the Executive Director and cofounder of TeamCast in Rennes, France. Founding the ITIS company in 1988, he managed the ITIS R&D engineers team, conceived most of the company’s DAB and DVB products, and participated in major European Collaborative Research projects working on digital radio and digital TV broadcasting systems (VALIDATE, MOTIVATE, iTTi, Witness, MCP, IM4DTTV). In 2003, he founded a new company, TeamCast, aiming to be the preferred partner of the broadcast actors for digital broadcasting technologies. He is the company’s representative for international conferences, technical seminars and international forums driving the digital audio broadcasting and DVB technologies. Recently, he wrote the DVB-H physical layer standard and coordinated the DVB-H Validation Task Force.

Jukka A. Henriksson (Senior Member, IEEE) was born in Turku, Finland, in 1946. He received the Dipl. Eng. degree in electronics engineering (telecommunications) and the Lic. Tech and the Dr. Tech degrees (with honors) from Helsinki University of Technology, Espoo, Finland, in 1970, 1980, and 1985, respectively.

He joined the Communications Laboratory, Helsinki University of Technology, in 1969, where he worked as an Assistant Teacher and from 1973 as a Laboratory Engineer. In 1984 he moved to Nokia Telecommunications, Helsinki, and since 1986 he has worked in the Nokia Research Center as Research Fellow. In the DVB organization he has chaired the *ad hoc* group TM-H defining the DVB-H standard. He holds nearly 20 patents and patent applications. His current main interests lie within digital broadcasting, propagation, and modulation.

Dr. Henriksson is a member of the Finnish Society of Electronics Engineers (EIS) and Knight of the Order of the Lion of Finland. In 1990, he received the Nokia Award for achievements in digital communications.

Erik Stare was born in Väddö, Sweden, in 1959. He received the M.S.E.E. degree from the Royal Institute of Technology (KTH), Stockholm, Sweden, with in 1984.

He joined Ericsson in 1984 and worked as a sales engineer with transmission equipment for the North African market. In 1987 he joined Swedish Telecom (now TeliaSonera) and worked with R&D related to HDTV and digital terrestrial TV. He participated in the Eureka95 project as well as in various EBU and ITU groups related to HDTV and digital terrestrial TV. He was the project leader of the Scandinavian HD-DIVINE project, which performed the world’s first demonstration of a digital terrestrial HDTV system using OFDM technology at the International Broadcasting Convention (IBC) in 1992. Since 1992, he has worked at Teracom, Sundbyberg, Sweden, mainly with R&D related to digital terrestrial TV in general, DVB-T technology, mobile reception of DVB-T, hybrid networks using DVB-T and telecom systems, and most recently DVB-H and IP datacast. He participated in the joint dTTb/HDTVT/HD-DIVINE task force (TFSC), which developed the DVB-T system. In the DVB organization, he chaired the *ad hoc* group, which developed the DVB-SFN specification for synchronization of single-frequency networks and has also participated in a number of other DVB groups, e.g., the Technical Module, DTTV-SA, the commercial and technical *ad hoc* groups for DVB-H, and the technical CBMS group. He has participated in the EU-funded R&D projects ACTS-VALIDATE, ACTS-MOTIVATE, and IST-MCP. He holds one patent and one patent application. His current main interests lie within IP Datacast over DVB-H.

Mr. Stare is a member of the Swedish Society of Electrical and Computer Engineers (SER).

Pekka Talmola was born in Turku, Finland, in 1962. He received the Dipl. Eng. degree in electronics engineering and the Lic. Tech. degree from Helsinki University of Technology, Espoo, Finland in 1986 and 1994 respectively.

He joined Lohja Consumer Electronics in 1985, where he worked as a Design Engineer in the area of satellite TV. The company became part of Nokia Consumer Electronics in 1992 and he continued to work as a Senior Engineer in various TV projects. In 1996 he moved to Nokia Multimedia Network Terminals and started to work with digital TV-systems as R&D Group Manager. In 2000 he moved to Nokia Ventures Organization, where he worked in the development of mobile TV technology like DVB-H. Since 2005 he has worked in Nokia Rich Media/Industry Affairs, Turku, as a Senior Technology Manager in the area of standardization. In the European Information, Communications and Consumer Electronics Technology Industry Association (EICTA) organization, he has chaired the MBRAI-group, which has developed standards for the mobile and portable DVB-T/H terminals. He holds about ten patents and patent applications. His current main interests lie within mobile digital broadcasting, spectrum issues, and network planning.

Mr. Talmola is a member of the Finnish Society of Electronics Engineers (EIS).