Hierarchical modulation

— the transmission of two independent DVB-T multiplexes on a single frequency

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Hierarchical modulation – a variant of the digital terrestrial television standard, DVB-T – has received relatively little attention to date in the planning processes. It enables the transmission of two independent DVB-T multiplexes on a single TV frequency channel, with different transmission qualities (high priority and low priority). The high-priority multiplex can be used, in particular, for portable indoor and mobile reception.

On the basis of specific examples, this article shows that hierarchical modulation can be a worthwhile alternative to non-hierarchical modulation.

In the DVB standard for digital terrestrial television (DVB-T) [1], hierarchical modulation is designated [2] as an alternative to the "conventional" modulation methods specified (QPSK, 16-QAM and 64-QAM). With the use of hierarchical modulation (HM), two autonomous DVB-T multiplexes can be transmitted on a single TV frequency channel. Up until now, relatively little attention has been paid to HM, possibly on account of the greater complexity of the DVB-T planning – due to an additional degree of freedom being available when choosing the transmission parameters.

This article provides an outline description of hierarchical modulation and, on the basis of several examples, demonstrates the possibilities offered by this transmission method. It discusses (i) the benefits and drawbacks of HM for portable, mobile and stationary reception from a single transmitter, (ii) the opportunities that are provided by HM for local and wide-scale DVB-T services and (iii) the impact of HM on self-interference in single-frequency networks (SFNs).

1. Principles of DVB-T and hierarchical modulation

1.1. Parameters of DVB-T

The DVB-T standard (Digital Video Broadcasting – Terrestrial) defines a method for transmitting MPEG-2 encoded TV signals, adapted to the specific features of the terrestrial transmission channel (e.g. multipath reception). Its basis is the modulation technology COFDM (Coded Orthogonal Frequency Division Multiplex) which uses thousands of narrow-band frequency carriers that are orthogonal to each other [3].

Several parameters can be chosen for a DVB-T transmission channel:

❑ **The code rate**

This is the ratio of the data rate of the *useful* bits, to the overall data rate: typical values are 1/2, 2/3, 3/4, 5/6 and 7/8). The greater the chosen code rate, the higher the available *effective* data rate but the worse the error protection and, consequently, the lower the coverage radius and/or the service coverage quality.

❍ **The method of carrier modulation**

Three methods of modulation are currently used: **QPSK** [1], **16-QAM** [2] and **64-QAM** [3]. In the case of the higher-level methods, the useful data rate is greater but the transmission is more susceptible to interference (because the separation between the permissible states in the phase space is smaller). Consequently, the coverage radius is smaller.

❍ **The length of the guard interval**

The guard interval extends the duration of each transmitted symbol – in order to guarantee a safety interval for the subsequent symbol. The ratio of the guard interval to the total interval for each symbol is typically 1/4, 1/8, 1/16 or 1/32. The longer the guard interval (tending towards 1/4), the less the interference due to multipath propagation and the weaker the inherent interference (self interference) when employing multiple transmitters in a single frequency network (SFN). However, the number of useful bits that can be transmitted are fewer.

❍ **The number of carriers**

There are currently two modes: **2k** (with 1705 carriers) and **8k** (6817 carriers).

❍ **Hierarchical or non-hierarchical modulation**

If hierarchical modulation is chosen, it is necessary to allocate a value to the modulation parameter "α". Typical values are: $\alpha = 1$ (uniform modulation) and $\alpha = 2$ or 4 (non-uniform modulation).

1.2. Principle of hierarchical modulation

The principle of hierarchical modulation will be explained here using 64-QAM as an example. *Fig. 1* shows the constellation diagram of 64-QAM. Each permissible digital state is represented by a yellow dot in the complex plane (amplitude, phase). Because 8 x 8 different states are defined, 64 possible values of 6 bits can thus be transmitted. The diagram shows the assignment of the binary data values to the permissable states (as defined in the DVB-T specification).

[In the case of 16-QAM, there are only 4 x 4 different states (and 4 transmitted bits) while, in the case of 4-PSK, there are 2 x 2 states (and just 2 transmitted bits).]

In hierarchical modulation, the possible states are interpreted differently than in the non-hierarchical case. The location of a state within its quadrant is regarded as *special* information in HM. The other special information used in HM is the number of the quadrant in which the state is located (1, 2, 3 or 4). In this way, two separate data streams can be made available for transmission. Formally, we are still dealing with 64-QAM but, in the hierarchical interpretation, it is viewed as the combination of 16-QAM and 4-PSK modulation. This is referred to as "**4-PSK in 64-QAM**". The bit-rates of the two partial streams together yield the bit-rate of a 64-QAM stream. *Fig. 2* shows how, in the case of hierarchical
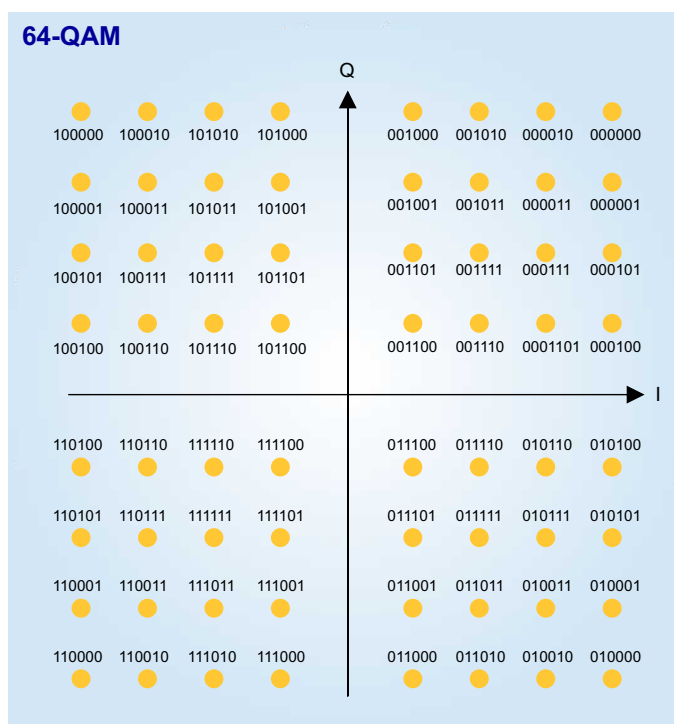

Figure 1
Constellation chart for 64-QAM modulation
(with $\alpha = 2$ for hierarchical modulation)

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1. Quadrature Phase Shift Keying, referred to in this article as **4-PSK** but also known as 4-QAM.

2. Quadrature Amplitude Modulation using two 4-step orthogonal input signals.

3. Quadrature Amplitude Modulation using two 8-step orthogonal input signals.
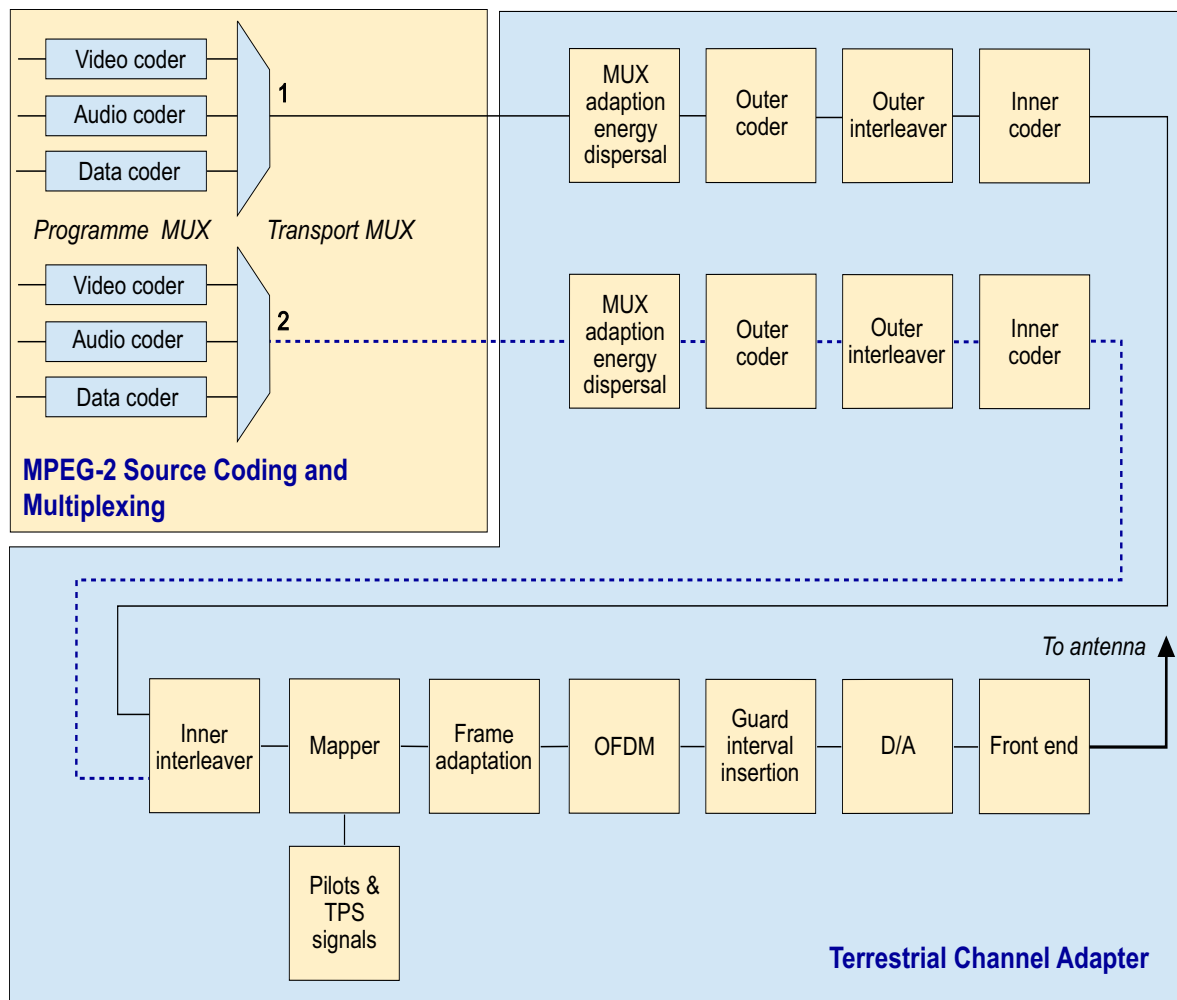
Figure 2
Block diagram of a DVB-T system with hierarchical modulation

modulation (for which the dotted-line blocks have been added), the input comprises two completely separate MPEG-2 transport streams. After combining at the inner interleaver, the composite stream is sent on its way to the transmitting antenna.

It can thus be seen that hierarchical modulation allows two data streams – each having *different* transmission performance – to be made available within a *single* TV frequency channel.

A comparison between 4-PSK in 64-QAM (hierarchical modulation) and 64-QAM (non-hierarchical modulation) is appropriate here. The separation of the states in the 64-QAM scheme shown in *Fig. 1* does not change if the states within a block are interpreted as possible states of a 16-step modulation scheme. For that reason, the noise sensitivity is only slightly (and insignificantly) greater in the case of hierarchical modulation, compared to 64-QAM, on account of the slightly lower encoding gain of the error protection. On the other hand, the noise sensitivity of the 4-PSK data stream in the HM realisation is substantially lower than that of the 64-QAM data stream of non-hierarchical (and also hierarchical) modulation. This is because the affiliation of two-bit information to a quadrant is less likely to become disturbed. If any constellation state does get disturbed (i.e. mixed up with another arbitrary state in the same quadrant), the quadrant information is still correct.

In addition to obtaining two independent data streams in hierarchical modulation, the data stream with the lower data rate is less susceptible to noise than it would be in a non-HM scheme. At the same time, the HM data stream with the higher data rate is not noticeably less robust than an equivalent data stream in a non-HM realisation. The total data rate of the two HM streams is identical to that of a non-HM scheme. The *net* data rate will however be slightly lower because twice the MPEG-TS overhead is incurred in the case of hierarchical modulation, on account of the two multiplexes.

1.3. High- and Low-priority streams

As outlined above, the data streams of hierarchical modulation vary in their susceptibility to noise. In other words, the service coverage areas differ in size. The better-protected data stream is referred to as the **High-Priority** (HP) stream; the other one is referred to as the **Low-Priority** (LP) stream. Compared with non-hierarchical modulation, the HM data stream with the lower data rate can be used to supply a larger coverage area, whereas the coverage area of the data stream with the higher data rate is only insignificantly smaller than for the corresponding non-HM variant. This subdivision alone can be of practical benefit.

It is possible to enlarge the coverage area of the HP stream even further by changing the modulation parameter α at the expense of the robustness of the LP stream. This is the case for the constellation shown in *Fig. 1*. Here, the neighbouring dots which are located in adjoining quadrants have twice the spatial separation of those neighbours located within a single quadrant (modulation parameter $\alpha = 2$), i.e. they can be less easily confused when reception is impaired by noise. In *Fig 1*, the first two bits indicate the quadrant. Consequently, these bits are more reliably transmitted than the other four. With $\alpha = 4$, the protection of the two leading bits would be even better. On the other hand, the reliability of the differentiation between the states decreases in the course of decoding, on account of the reduction in the separation of the states within a quadrant. In each case, the enhanced protection for the first two bits is at the expense of the remaining four bits. When $\alpha = 4$, the separation between the protection levels is correspondingly greater than for $\alpha = 2$.

The bits of the HP stream can additionally be transmitted with a greater error protection than those of the LP stream, i.e. with a lower code rate (e.g. 1/2 or 2/3). This might be necessary, e.g. for mobile reception *(see Section 2.3.)*. Using these error-protection techniques, the HP stream may require a considerably lower C/N (carrier-to-noise) ratio in order to achieve the same bit error ratio (BER) as the LP stream. This is shown in *Fig. 3*.
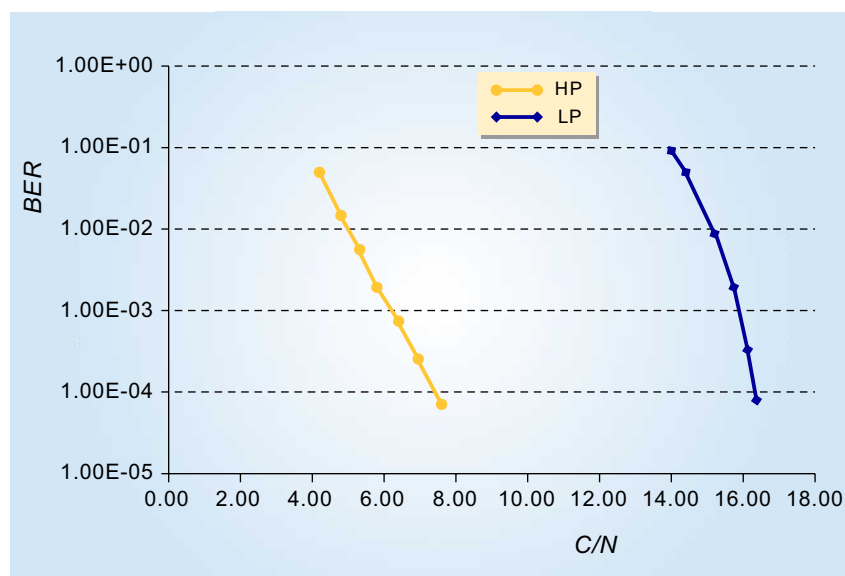

Figure 3
System behaviour for low- and high-priority streams, in the case of hierarchical modulation
(α = 2; high priority = 4-PSK with code rate 2/3; low priority = 16 QAM with code rate 3/4)

Thus, three parameters are required to describe a hierarchical modulation scheme: α, and the code rates for the HP and LP streams.

1.4. The benefits of hierarchical modulation

Originally in the development of the DVB specification, careful consideration was given to using the principle of hierarchical modulation, in order to deal with a fundamental problem of digital transmission – the abrupt breakdown in reception below a critical field strength level. If, in the case of MPEG source encoding, a coarse and a fine resolution were to be divided up into two data streams (SNR scalability) then, with appropriate hierarchical modulation, the reception would not fail at a single stroke when the field strength diminished at the reception location. Instead, the resolution of the source encoding would initially decrease by one stage.

This possibility was not actually used in the DVB-T standard because it would have increased the hardware costs of the source decoder in the receiver and would not have been compatible with standard MPEG decoder chips.

However, the transmission-side application of the HM principle is incorporated in the DVB-T standard. Here, the variable robustness of constellations is used for the transmission of different programme multiplexes with unequal priority (high priority, low priority) over one frequency channel. *Figs. 4* and *5* show the relevant alternatives which the DVB-T standard thus provides: 4-PSK and 16-QAM via two separate TV channels (in the case of non-hierarchical modulation) or 4-PSK in 64-QAM via one single channel (in the case of hierarchical modulation).

Figure 4
4-PSK and 16-QAM separated over two TV channels using non-hierarchical modulation

As illustrated above, in the case of hierarchical modulation, the coverage areas for the two programme multiplexes are of different sizes – for $\alpha = 1$ (uniform modulation) – owing to the different susceptibility to noise of the two streams. In the LP case, the coverage is roughly as large as in the non-HM case, but is even larger in the HP case. The HP coverage area can be further enlarged at the expense of the LP area, by choosing appropriate values for α if this is desired.

Of course, different-sized coverage areas are not always desirable for the programme multiplexes broadcast by a transmitter. But should this really be a fundamental objection against using hierarchical modulation? Keep in mind that even without hierarchical modulation, different sized coverage areas are inevitable because the radius depends on the power constraints at any considered frequency. (Because of national and international frequency co-ordination, in most cases DVB-T multiplexes cannot be operated on different channels with the same transmission power). Coverage areas also depend on the selected method of modulation and on the code rate. It is therefore advisable to verify, in each specific case, whether hierarchical modulation would be a better alternative under the existing constraints.

Figure 5
4-PSK in 64-QAM over one TV channel using hierarchical modulation

1.5.   Definition of comparison criteria

How can we gauge whether hierarchical or non-hierarchical modulation is the right choice for a specific application? With hierarchical modulation, two MPEG multiplexes with a differing data rate and differing robustness (i.e. coverage radius) can be broadcast on one TV frequency channel. A shortage of transmission channels is therefore an argument in favour of hierarchical modulation. Whether differently sized coverage areas are acceptable or even desirable depends on the individual case.
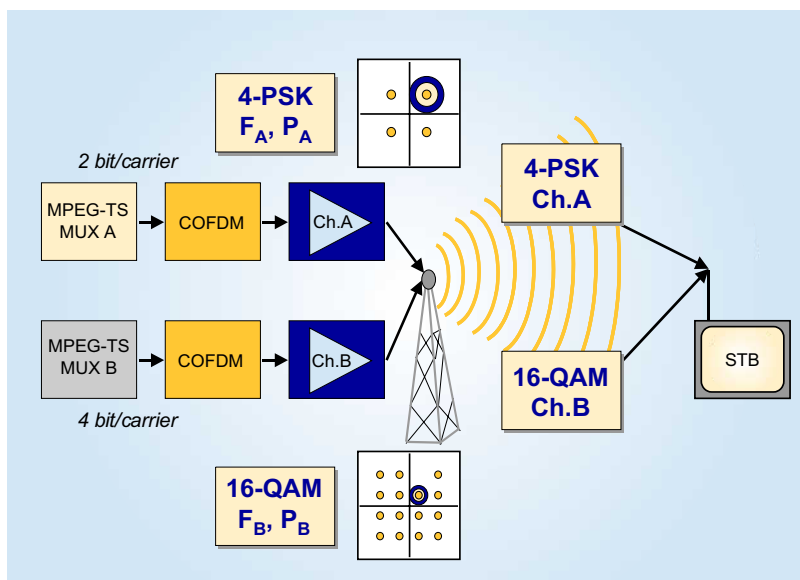
In the following paragraphs, the coverage areas for various different HM alternatives are compared with the most important variant of non-hierarchical modulation (16-QAM, code rate: 2/3) which will be used in Germany. For that purpose, universally usable benchmarks are essential when making comparisons.

One benchmark used here pertains to the population:

Data Supply Capability = Supplied Population * Data Rate [User * Mbit/s]

In accordance with this criterion, the maximum traffic volume is attained when all accessible users retrieve all the transmitted data.

The second benchmark is related to the coverage area:

Data Area Supply Capability = Supplied Area * Data Rate [km² * Mbit/s]

In accordance with this, the maximum traffic volume occurs when all transmitted data are retrieved by each unit of the covered area.

In the case of hierarchical modulation, the contributions of the HP and LP data streams have to be added. The results of a comparison using these two benchmarks naturally depend on the geographical and demographic circumstances.

2. Example cases of hierarchical modulation

2.1. Service coverage by a single transmitter

For this investigation, coverage provided by the Alexanderplatz transmitter in Berlin (on channel 27) was assessed over a square-shaped region of side length 120 km. A transmission power of 150 kW was assumed.

Three different implementations of hierarchical modulation were compared with the non-HM scheme: 16-QAM, code rate 2/3. The size of the coverage areas depends on the C/N ratio which has to be achieved in order not to exceed a certain bit error rate. The DVB-T specification assumes a bit error rate of $2*10^{-4}$ in accordance with the Viterbi decoder [4]. C/N ratios based on simulations can be found in tables in the DVB-T specification. In this context, a distinction must be drawn between the C/N ratio for indoor reception using a directional rooftop aerial (Rice channel) and portable indoor reception using a small omnidirectional telescopic or rod antenna (Rayleigh channel). *Table 1* shows the theoretical values which are detailed in the DVB-T specification for the cases considered here.

For planning in accordance with the Chester Conference [5] [4], implementation losses of 3 - 4 dB were assumed. Subsequent measurements performed by the IRT have demonstrated that these values are rather optimistic. However, it did not seem advisable to simply employ the IRT's measured values for the supply calculations. Rather, in the case of the reference, the planned value agreed at Chester was retained while, for the three HM cases considered, the *difference* between the measured values for the HM and the non-HM cases was added as shown in the following expression:

$$\text{C/N}_{\text{hierarchical}} = \text{C/N}_{\text{non-hierarchical (Chester)}} + \left\{ \text{C/N}_{\text{hierarchical (measured)}} - \text{C/N}_{\text{non-hierarchical (measured)}} \right\}$$

Accordingly, the differences between the measured values as stated in *Table 2* were to be added to the planned values of the reference. Thus, the results of the analysis demonstrate what has changed in the HM case, relative to the non-HM reference, and they retain their information value even if the reference value is changed for the non-hierarchical case.

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4. Block and convolution encoding is used in the case of DVB-T. In order to "de-convolute", a Viterbi decoder is used in the receiver.

5. In 1997, a European conference of postal and telecommunications administrations (CEPT) was held in Chester, England, and it adopted a convention for the conversion of analogue television to DVB-T.

Table 1
C/N ratios necessary for reception in the analysed non-hierarchical and hierarchical modulation cases
(theoretical values are in accordance with the DVB-T specification, without implementation losses)

	Modulation	Code rate	Hierarchical (4-PSK in 64-QAM)	α	Priority	C/N (dB) reception using roof antenna	C/N (dB) portable indoor reception
Reference	16-QAM	2/3	no			11.6	14.2
Case 1	64-QAM	2/3	yes	1	HP		14.8
	64-QAM	2/3	yes	1	LP	17.6	19.4
Case 2	64-QAM	2/3	yes	2	HP		11.7
	64-QAM	2/3	yes	2	LP	19.5	21.7
Case 3	64-QAM	1/2	yes	2	HP		11.4
	64-QAM	1/2	yes	2	LP	14.9	16.4

Table 2
Differences between the C/N ratios required for reception and the corresponding values of the reference
(non-hierarchical, 16-QAM, code rate: 2/3)

	Modulation (hierarchical)	Code rate	α	Priority	C/N (dB) reception using roof antenna	C/N (dB) portable indoor reception
Case 1	64-QAM	2/3	1	HP		+ 0
	64-QAM	2/3	1	LP	+ 9	+ 8
Case 2	64-QAM	2/3	2	HP		- 3
	64-QAM	2/3	2	LP	+ 11	+ 11
Case 3	64-QAM	1/2	2	HP		- 5
	64-QAM	1/2	2	LP	+ 6	+ 5

Table 3
Coverage of the area considered (location probability: 95 %)

		Area	Population
Reference: 16-QAM, R = 2/3 **D = 13.27 Mbit/s**	**Portable indoor**	51 %	90 %
Case 1: **4-PSK in 64-QAM** **α = 1, R_{HP} = 2/3, R_{LP} = 2/3** **D_{HP} = 6.64 Mbit/s** **D_{LP+HP} = 19.91 Mbit/s**	**HP portable indoor**	51 %	90 %
	LP portable indoor	29 %	84 %
	LP stationary	95 %	99 %
Case 2: **4-PSK in 64-QAM** **α = 2, R_{HP} = 2/3, R_{LP} = 2/3** **D_{HP} = 6.64 Mbit/s** **D_{LP+HP} = 19.91 Mbit/s**	**HP portable indoor**	61 %	92 %
	LP portable indoor	22 %	79 %
	LP stationary	94 %	99 %
Case 3: **4-PSK in 64-QAM** **α = 2, R_{HP} = 1/2, R_{LP} = 1/2** **D_{HP} = 4.98 Mbit/s** **D_{LP+HP} = 14.93 Mbit/s**	**HP portable indoor**	67 %	94 %
	LP portable indoor	37 %	86 %
	LP stationary	96 %	99 %

The coverage areas are shown in *Fig. 6*, while *Table 3* gives an overview of the service coverage achieved in each case.

High-res GIF (850 KB)

Reference:
16-QAM
R = 2/3
13.3 Mbit/s

Portable Indoor

Stationary

Case 1:
4-PSK in 64-QAM
$\alpha = 1$
R_{HP} = 2/3 R_{LP} = 2/3
D_{HP} = 6.64 Mbit/s D_{LP+HP} = 19.91 Mbit/s

HP Portable Indoor   LP Portable Indoor   LP Stationary

Case 2:
4-PSK in 64-QAM
$\alpha = 2$
R_{HP} = 2/3 R_{LP} = 2/3
D_{HP} = 6.64 Mbit/s D_{LP+HP} = 19.91 Mbit/s

Case 3:
4-PSK in 64-QAM
$\alpha = 2$
R_{HP} = 1/2 R_{LP} = 1/2
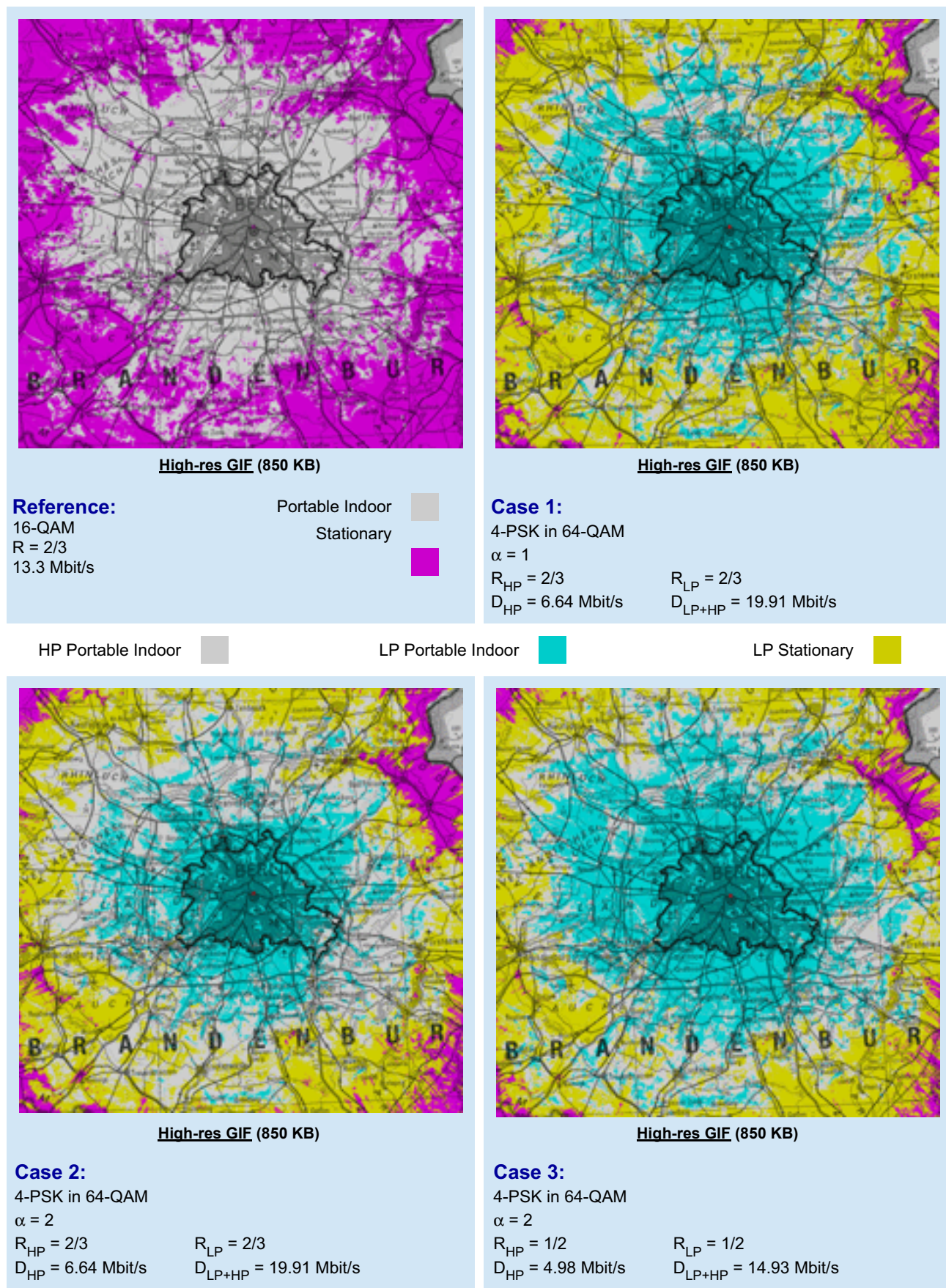D_{HP} = 4.98 Mbit/s D_{LP+HP} = 14.93 Mbit/s

Figure 6
Coverage by the Alexanderplatz transmitter: reference (16-QAM), hierarchical modulation and 64-QAM cases

A brief summary, drawn from these three tables, is as follows:

Case 1: For the HP multiplex, the portable indoor reception is unaltered because the C/N ratio has remained the same. By contrast, however, the covered area is significantly smaller for the LP multiplex because the necessary C/N ratio is 8 dB higher.

Case 2: If α is changed from 1 to 2, the difference between the HP and LP coverage areas increases. The HP area is now larger than the reference area (-3 dB) and the LP area is considerably smaller (+11 dB).

Case 3: If the code rate for HP and LP is also reduced, i.e. the error protection is increased, then both coverage areas increase in size. For HP, the effect is smaller than for LP (2 dB less in one case, 6 dB in the other) so that the coverage area sizes again draw closer together. Nonetheless, the data rate is lower than in the first two cases.

In all three cases, the population having stationary reception is completely covered by the LP multiplex.

On account of the differing data rates of the MPEG-2 multiplexes under consideration (reference, HP and LP), these findings on their own do not support a conclusion on which is the best alternative. However, from the coverage data in *Table 3*, it is now possible to deduce the coverage capability according to the criterion given in *Section 1.5*. The total area is 14,400 km², the modulation is hierarchical (4-PSK in 64-QAM), coverage is provided by the Alexanderplatz transmitter for both non-hierarchical and hierarchical modulation, and the total population covered is 4,774,402.

That yields – for the reference case:

Data Supply Capability

= Supplied population ∗ data rate [users ∗ Mbit/s]

= 0.90 ∗ 4,774,402 ∗ 13.27 [users ∗ Mbit/s]

= 57,020,683 [users ∗ Mbit/s]

Fig. 7 provides an overview of the findings. It can be seen that all the cases of hierarchical modulation yield higher overall supply capability than the reference. The largest increase in the data supply capability with respect to the population is 43 % in *Case 1*. For comparison purposes, the supply capability was also calculated in the case of non-hierarchical modulation for 4-PSK and 64-QAM with a code rate of 2/3 (*Fig. 8* shows the coverage areas). For this purpose, as in the case of the calculations for hierarchical modulation, the measured deviations between the C/N values required for reception and the theoretical values were considered.

With 4-PSK, a considerably lower supply capability is obtained than with the reference 16-QAM. With 64-QAM, the Data Area Supply Capability is roughly 6 % lower than in the case of the reference. However, the Data Supply Capability with respect to the population is 42 % greater, thus nearly as high as in *Case 1* of hierarchical modulation.
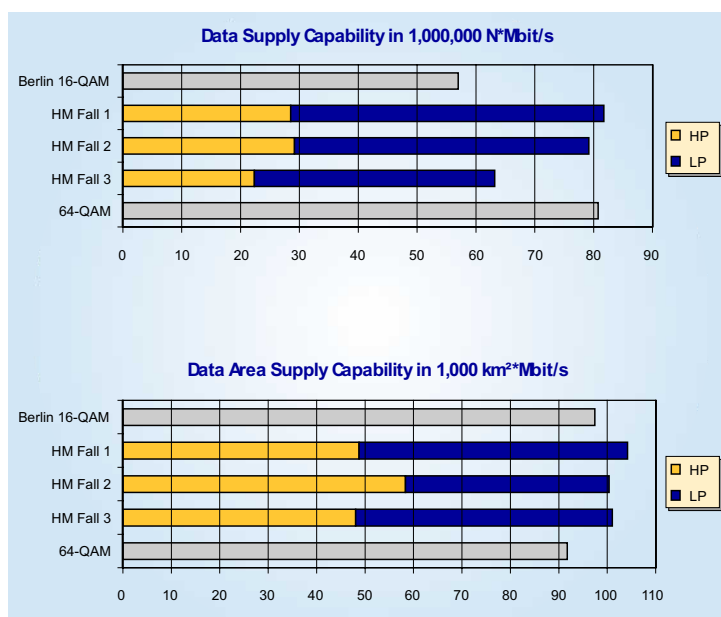

Figure 7
Supply capability for the reference (16-QAM), hierarchical modulation and 64-QAM schemes

2.2. *Single-frequency network (SFN) having strong self interference*

As an example of an SFN, the coverage area provided by 18 transmitters of the national TV station ZDF in northern Germany, using channel 40, was considered. According to the Chester Agreement of 1997, the
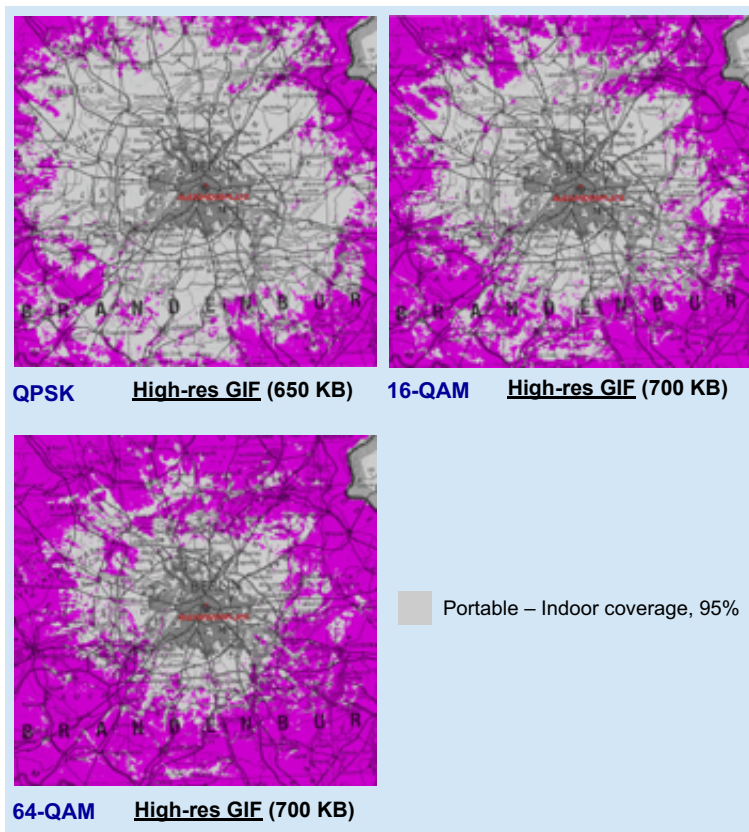
QPSK   <u>High-res GIF</u> **(650 KB)**   **16-QAM**   <u>High-res GIF</u> **(700 KB)**

Portable – Indoor coverage, 95%

64-QAM   <u>High-res GIF</u> **(700 KB)**

Figure 8
Variations of non-hierarchical modulation with code rate 2/3

<u>High-res GIF</u> **(700 KB)**

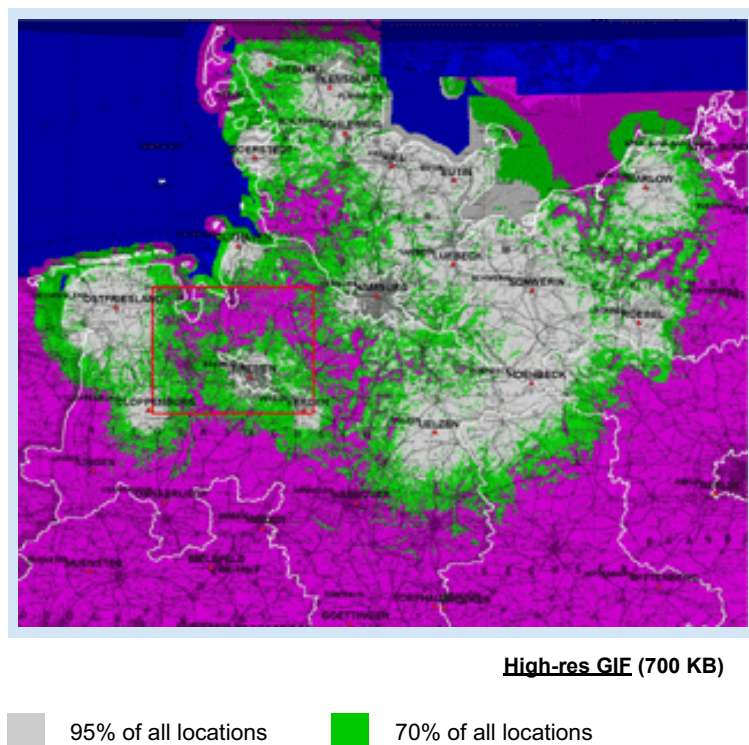95% of all locations   70% of all locations

Figure 9
Portable indoor coverage by an SFN of 18 transmitters with 16-QAM modulation, code rate 2/3.
Noise interference for 5% of the time.

power of each transmitter was reduced by 7 dB. Again the reference was 16-QAM modulation with a code rate of 2/3. *Case 3* as described in *Section 2.1.* was assumed to be the hierarchical modulation case (4-PSK in 64-QAM, with $\alpha = 2$, $R_{HP} = 1/2$ and $R_{LP} = 1/2$). *Fig. 9* shows the coverage provided by the reference system. The red frame contains large areas that are not covered because of self-interference problems (the corresponding coverage provided by an MFN network demonstrates this).

Table 4 shows the calculated coverage probabilities, within the red frame only. *Fig. 10* indicates the data supply capabilities deduced from these. The overall area of the test rectangle is 8,058 km² and it contains a population of 1,863,838.

In this case too, the data supply capabilities compared with the non-hierarchical reference are improved on account of the hierarchical modulation.

2.3. Mobile reception of the HP stream

In a field trial performed in Munich in 1999, the IRT tested mobile reception of the HP multiplex in the case of hierarchical modulation using 4-PSK in 64-QAM, $\alpha = 1$, $R_{HP} = 1/2$ and $R_{LP} = 2/3$. This mode is a variation of *Case 1* from *Section 2.1.* with more robust transmission of the HP multiplex (code rate 1/2 instead of 2/3). With three different first-generation receivers (BBC, ITIS and NTL / DMV), mobile reception was assessed for the 8k-FFT case which, at that time, was regarded as extremely critical for mobile reception. *Fig. 11* shows the minimum field strengths required for reception, according to this analysis.

The overall representation is for outdoor reception. A, B and C denote the three receivers tested. Horizontal lines indicate the minimum field strengths in the case of non-mobile reception for LP and HP. As a result of the greater interference sensitivity, the minimum field strengths for the LP multiplex are, depending on the receiver, up to 14 dB above those for the HP multiplex. The

Table 4
Service coverage of the area considered (location probability: 95 %)

			Area	Population
Reference	16-QAM R = 2/3 D = 13,27 Mbit/s	Portable Indoor	17 %	39 %
Case 3	4-PSK in 64-QAM α = 2, R_{HP} = 1/2, R_{LP} = 1/2 D_{HP} = 4.98 Mbit/s D_{LP+HP} = 14.93 Mbit/s	HP Portable Indoor (95 % of the locations)	42 %	57 %
		LP Portable Indoor (95 % of the locations)	7 %	29 %

interesting possibility for mobile reception is the HP multiplex. The chart indicates for the three receivers how the minimum field strength for HP reception increases with increasing speed. In the case of high speeds (100 - 150 km/h), it reaches the value which is necessary for stationary reception of the LP multiplex. In other words: at high speeds, the coverage area for mobile reception of HP is roughly the same as the coverage area for portable outdoor reception of LP. In this context, it is essential to know that the receivers used were not optimized for mobile reception and the maximum speed for the 16-QAM reference, accord-
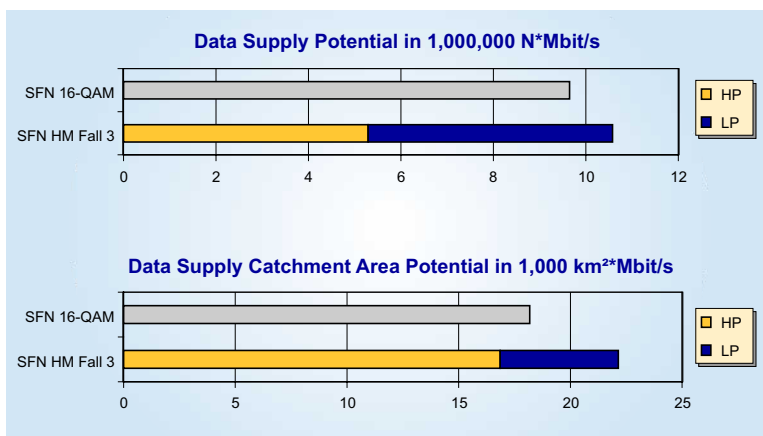
Figure 10
(Upper) **Data Supply Capability and** *(lower)* **Data Area Supply Capability – for "reference" and "higher modulation (Case 3)"**

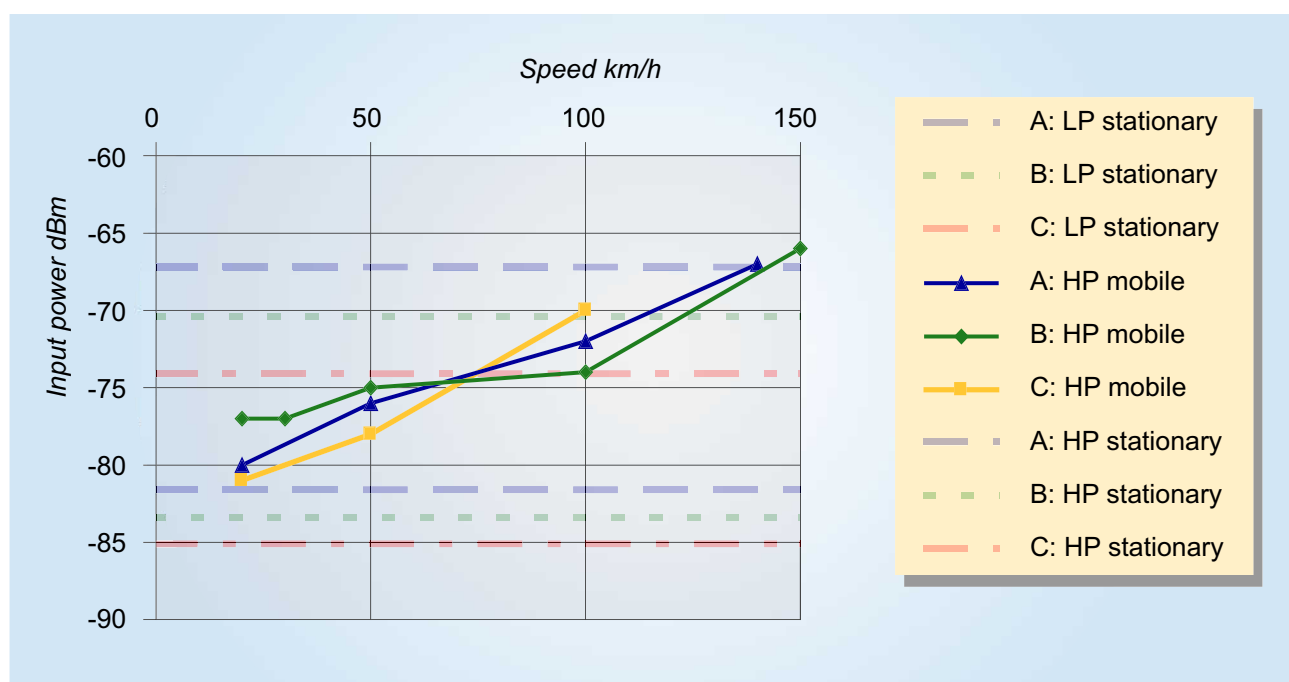**Figure 11**
Minimum field strength depending on driving velocity in the case of mobile reception of the HP multiplex of hierarchical modulation

Abbreviations

4-PSK	4-state Phase Shift Keying *(see QPSK)*	**ISO**	International Organization for Standardization
BER	Bit-Error Ratio	**LP**	Low-Priority
C/N	Carrier-to-Noise ratio	**MPEG**	(ISO/IEC) Moving Picture Experts Group
COFDM	Coded Orthogonal Frequency Division Multiplex	**MUX**	Multiplex / multiplexer
D/A	Digital-to-Analogue	**OFDM**	Orthogonal Frequency Division Multiplex
DVB	Digital Video Broadcasting	**QAM**	Quadrature Amplitude Modulation
DVB-T	DVB - Terrestrial	**QPSK**	Quadrature (Quaternary) Phase-Shift Keying
HM	(DVB-T) Hierarchical Modulation	**SFN**	Single-Frequency Network
HP	High-Priority	**SNR**	Signal-to-Noise Ratio
IEC	International Electrotechnical Commission	**STB**	Set-Top Box
		TS	(MPEG) Transport Stream

ing to measurements made by the IRT at that time, was only approx. 55 km/h in the 8k mode (broadcasting via channel 43).

3.   Applications of hierarchical modulation

Using specific examples, it has been demonstrated here that hierarchical modulation enables greater overall data supply capability than non-hierarchical modulation. However, HM should only be used if it fulfils the broadcasters' existing service requirements. For example, using the HP multiplex to broadcast major programmes (such as the German national TV programmes ARD, ZDF ...) and the LP multiplex to broadcast supplementary programmes (such as Eins MuXx, ZDF INFObox, ARD online) is quite conceivable. The HP programmes can be received on portable and mobile equipment all over the rural surrounding areas. The LP transmissions are suitable for stationary reception in rural areas and portable reception in the higher populated areas or in the proximity of the transmitter, respectively. The higher data rate of the LP stream can also be used to accommodate more programmes in the multiplex or, in the future, to broadcast HDTV programmes for displaying on high-resolution screens.

4.   Conclusions

The conclusion is that, in certain realistic cases, hierarchical modulation can represent a better alternative than non-HM. It provides two autonomous multiplexes (HP and LP) over a single TV frequency channel. The total data rate (HP + LP) of 4-PSK in 64-QAM is higher than in the case of non-hierarchical modulation using 16-QAM (the reference system). A portion of the HP data rate can be used in particular for portable indoor and mobile reception. With this arrangement, very flexible service coverage concepts can be developed for future requirements.

To ensure that hierarchical modulation actually becomes available to digital terrestrial broadcasters as a future option, the receiver industry should incorporate the relevant parameters of the DVB-T standard in their firmware from the very outset (presently, it is less thoroughly considered in some aspects of the receivers' control software / firmware). Furthermore, the transmitter industry in general should follow the lead of several manufacturers by making hierarchical modulation available as an option for their transmitters.

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