Coverage aspects of digital terrestrial television broadcasting

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The specification for digital terrestrial television, DVB-T, offers a wide range of potential applications: single transmitter and single-frequency networks, prohibited channel operation, portable reception, hierarchical transmission, etc. The network operator can select technical parameters such as the number of OFDM carriers, the length of guard interval, the degree of error protection and the modulation method. The last two parameters in particular allow the operator to reach a compromise between the number of programmes carried and their transmission reliability. This raises the question of which results, with regard to coverage, need to be achieved in each case.

The main applications have been studied at the IRT using Monte Carlo simulations of regular network situations. The results are documented here in the form of predictions for the coverage probabilities. The reasons for the choice of parameters for the terrestrial specification are dealt with specifically. Ways to restrict the basically very wide choice of system states (modes) can also be derived from these simulations.

1. Introduction

The intention is to make terrestrial broadcasting of television programmes a more attractive proposition to meet competition from cable and satellite transmission. The new specification for digital terrestrial television, DVB-T [1], will make it possible to provide television services which can hold their own, even when digital transmission via satellite and cable is introduced.

The chief advantages of terrestrial broadcasting are to be found in regional and local services (pictures, sound and data). A further plus point for digital systems is the marked improvement in portable reception when ordinary antennas are used. It is also possible with digital systems to transmit within a standard (7 or 8 MHz) television channel either (i) more programmes concurrently or (ii) programmes with a higher image resolution (EDTV, HDTV).

As far as coverage planning is concerned, there are important advantages in the design of the transmitter network structure and the energy balance. An important aspect in this respect is the possibility of using single-frequency networks (SFNs) combined with the possible use of "gap-fillers" (local relay transmitters) on the same carrier frequency in regions where the service is poor. With a digital system it is also possible to use domestic gap-fillers, at the same transmission frequency as the main transmitter, inside houses or flats where the signal attenuation is frequently high, in order to supply adequate field strengths for portable appliances.

2. Digital terrestrial television broadcasting

Because of their high data-rate (ITU-R Recommendation BT.601 [2] specifies a rate of 216 Mbit/s in the studio), digital video signals can only be transmitted via existing television channels after the data-rate has been effectively reduced. The MPEG-2 source-coding method envisaged for DVB achieves a data-rate of 5-6 Mbit/s for digital video signals of a quality at least comparable with PAL. This data-rate is assumed for a standard-definition programme (SDTV) although an adequate image quality (comparable to that of the VHS tape format) could be achieved with lower data-rates, depending on the picture content; higher data-rates (8-11 Mbit/s) are also of interest for highly-critical image presentations (e.g. sport).

There are still bottlenecks with the available transmission channels for DVB-T, despite the large data reduction achieved by source coding. The frequency resources in the VHF and UHF ranges are already largely exhausted by analogue services (e.g. in Germany alone, there are currently 578 analogue television transmitters and 8707 gap-fillers). The situation is exacerbated by the fact that the introduction of DVB-T will generate instant demand for several digital television programmes or additional multimedia services.

A transmission method for digital video signals with a high spectral efficiency is therefore required which, at the same time, has a high resistance to the many different types of interference on the channel (e.g. interference due to multipath reception, signal interference from other radio or broadcasting services, high signal attenuation in the case of portable reception in buildings, etc.).

In the development and definition phase of the DVB-T specification, the advantages of the COFDM transmission method [3][4] outweighed those of single-carrier methods in terms of broadcasting requirements (as was also the case with DAB). The crucial factor in favour of COFDM is the ability to set up single-frequency networks which offer network planners a higher network efficiency. However, a digital system also allows greater planning leeway for regional broadcasting services in the existing transmitter network (e.g. possible use of prohibited channels such as adjacent and image channels) because, with an appropriate choice of parameters, networks can also be planned with lower signal-to-noise ratios.

3. Coverage probability

The abrupt degradation of a DVB system at the coverage periphery makes it easy to establish whether or not reception is possible at a location. A single location can be deemed to be covered if the required signal-to-noise ratio is achieved for 99 % of the time. On the other hand, it is not practicable to demand a similar coverage for all locations in a "sub-area" (e.g. 100 m x 100 m). The coverage criterion for a sub-area is also influenced by the extent to which the signal-to-noise ratio varies as a function of the location ("log-normal fading" component). A high probability of interference-free reception within a particular sub-area results in high costs for the network operator (higher transmission power, additional main transmitters and gap-fillers). In an initial approach by the EBU, the coverage was described as "good" if at least 95 % of the sub-area is served for 99 % of the time and as "acceptable" if at least 70 % of the sub-area is served for 99 % of the time [5].

Another quantity of interest for the planning of DVB-T is the global coverage probability within the target service area, which is derived from the coverage probability of all the sub-areas contained within the target area.

Abbreviations	
agl	Above ground level
C/I	Carrier-to-interference ratio
C/N	Carrier-to-noise ratio
CCETT	Centre Commun d'Etudes de Télédiffusion et de Télécommunications (France)
COFDM	Coded orthogonal frequency division multiplex
DLR	Deutsche Forschungsanstalt für Luftund Raumfahrt (German aerospace research establishment)
DVB	Digital Video Broadcasting
EDTV	Enhanced (extended) definition television
FFT	Fast Fourier transform
HDTV	High-definition television
MPEG	Moving Picture Experts Group
OFDM	Orthogonal frequency division multiplex
PSK	Phase shift keying
QAM	Quadradure amplitude modulation
SDTV	Standard-definition television
SFN	Single-frequency network

4. Reception situations

A distinction is drawn between two particular reception conditions for digital terrestrial television broadcasting: stationary and portable reception. In both cases, typical conditions found in practice are assumed, not the worst conditions; for example, it is assumed that the position of an antenna can be optimized over a range of ± 50 cm.

A directional antenna 10 m above ground level (agl) is assumed for stationary reception. For portable reception, a non-directional antenna on top of or inside the equipment – positioned 1.5 m above the ground or above floor level – is assumed. The least favourable case, on the ground floor of a building, is generally considered separately.

The data in the DVB-T specification which relates to the efficiency of the system are based on simulation results using a Rayleigh channel model for portable reception (omnidirectional reception in a multipath channel) and a Rice channel model for stationary reception with a directional antenna. In the latter case, a Rice factor of K = 10 dB is applied, i.e. the received field strength of the direct signal is 10 dB higher than that of all the reflected signal components. The DVB-T specification thus uses known values for the theoretically required signal-to-noise ratio for various operating modes. However, during coverage analyses an implementation loss of at least 3-4 dB must be expected.

5. Simulation model for coverage analyzes

The IRT's contribution to the DVB-T system specification included an assessment of the coverage probabilities which result when different system parameters are applied. For this purpose, a simulation model was created to analyze coverage, thus allowing a fundamental study to be made of reception conditions in an SFN. The results described in this article do not therefore refer to a specific planning study of DVB-T.

The propagation of a broadcast signal from a single transmitter to a receiving location is considered as a statistical process, which takes account of the various propagation conditions that have to be considered at a specific distance from the transmitter. The parameters for this statistical process are based on the ITU-R propagation curves [6] which represent the results of numerous field measurements. An average unevenness has been applied as the parameter for the topology (e.g.

50 m); in other words, the actual terrain of the coverage areas is not taken into account. It is thus possible to simulate the main reception situations with a "Monte Carlo" simulation (explicit study of random events). First and foremost, this allows the fundamental characteristics of the new technology to be identified, whereas practical use calls for the planning of coverage for specific cases. Simulations such as these are based on propagation models whose parameters are not clearly established. The influence of critical propagation parameters therefore have to be taken into account. In the case of single-frequency networks, the statistical propagation processes from all the active transmitters are superimposed.

The fading component at a specific distance from the transmitter exhibits a log-normal distribution. When investigating the coverage probabilities by means of Monte Carlo simulations, the basic standard deviation (σ) for the fading component must be selected carefully. The use of a mean variation of σ = 9.5 dB is recommended for the planning of analogue services in the UHF range. However, propagation measurements with digital signals in a bandwidth of 1.5-8 MHz show a significantly lower variation (e.g. 5 dB) in the *measured* field strengths across the location [7][8]. This means that the value on which local planning calculations are based could also be lower. The variation of the field strength *prediction error* also plays a crucial role in the calculation of coverage probabilities in an SFN. This quantity also has a log-normal distribution but, with an average value of 14 dB, is significantly higher [9] than the variation measured in an area, because it is highly dependent on the terrain. In the IRT studies, as described in this article, a value for σ of approximately 9 dB was applied, taking into account both these quantities, i.e. the measured variation of the field strength and the variation of the field strength prediction error.

The signals from different transmitters in a single-frequency network arrive at the receiving location with different delays, to form a sum signal which is a function of the individual path delay differences. The signal components which are within the guard interval make a constructive contribution to the signal-to-noise ratio (C/N) or signal-to-interference ratio (C/I) which can be determined in the case of COFDM simply by adding the powers of the signal components. All signal components received outside the guard interval disturb the usable signal, an effect known as the *inherent interference* of a single-frequency network. The impact of inherent interference on the coverage probability depends on the amplitude of

all the signal components involved and the length of time they exceed the guard interval.

The computation model used for evaluating interference by signal components outside the guard interval was the one on which the planning for DAB was also based [10]. However, more recent studies by RAI [11] indicate that this is too optimistic for DVB-T. In contrast to DAB, a channel estimate for the coherent demodulation is required for DVB-T which is impaired by echoes outside the guard interval, especially with 64-QAM. This is, however, of lesser importance for the comparative studies of the DVB-T system variants presented in this article, whereas the absolute results will require further investigation.

The ITU-R propagation curves for 1 % of the time must be used for the most distant transmitters in a single-frequency network; they must thus be considered as interfering transmitters [12]. In the local area around an SFN transmitter, the curves for 50 % of the time have to be taken into account because this corresponds to the less favourable reception conditions. However, in view of the relatively small distances to the nearest transmitter in an SFN (which results in little difference between the propagation curves for 50 % and 99 %

of the time), the curves for 1 % of the time can be used for all transmitters in an SFN.

## 6. Transmitter networks studied

Two transmitter network structures are of particular interest with regard to local and regional DVB-T services:

− an extensive SFN with a large number of transmitters;

− a minimal SFN with only two transmitters, which is also applicable to the reception situation when gap-filling transmitters are used.

The SFN on which the results presented here are based covers an area of about 400 km x 240 km (*Fig. 1*). It comprises 33 transmitters arranged in a regular structure, with a transmitter spacing of 60 km which corresponds to the average spacing between transmitters of present-day TV networks.

All transmitters broadcast the signal synchronously at the same power. A standard transmitter height of 150 m agl is selected, and the height of the receiving antenna is taken as 10 m agl for

Figure 1
Structure of the analyzed regular SFN: 33 transmitters with an interspacing of 60 km.

= Self-interfering SFN transmitter
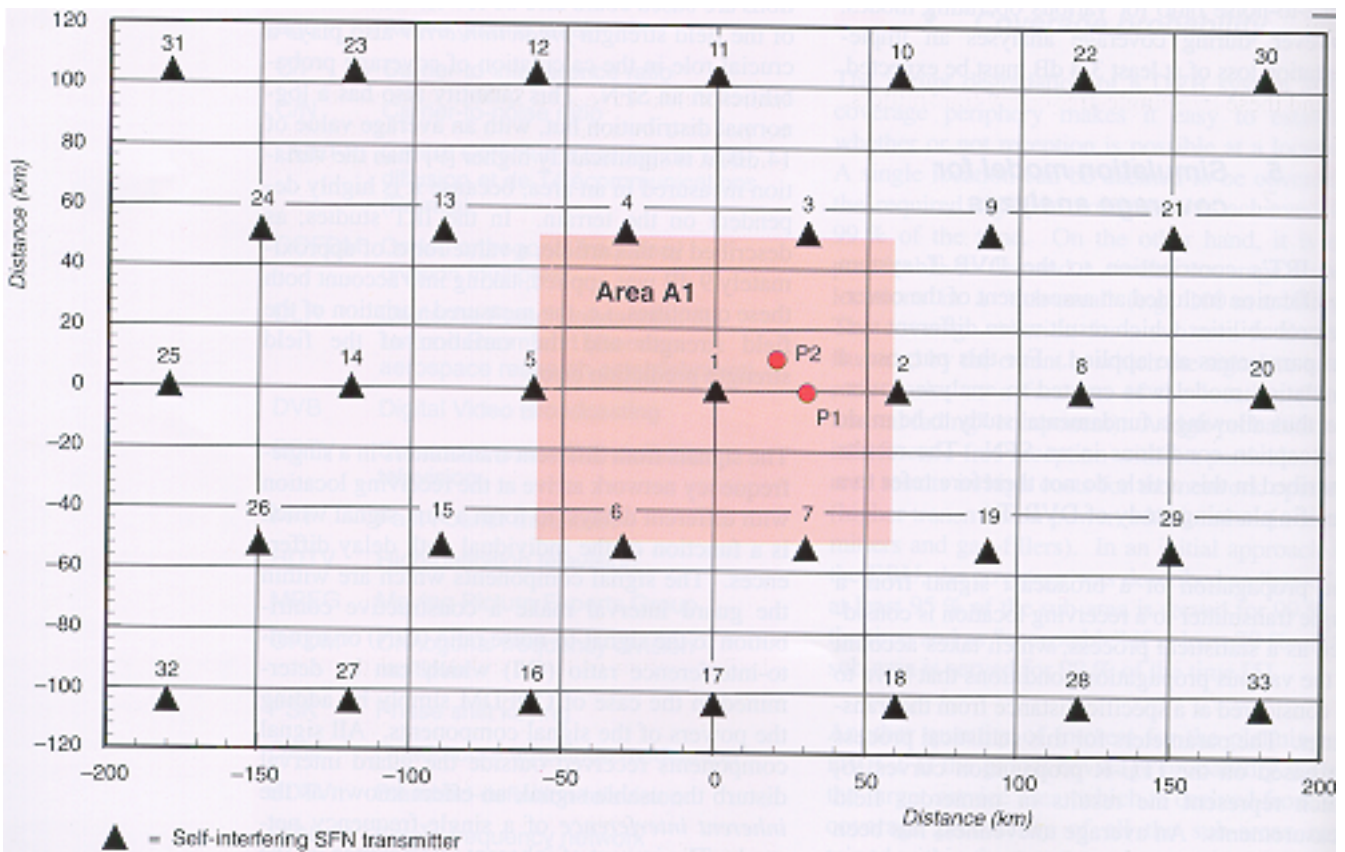
Duration of guard interval (T_g) at the useful symbol time (T_u) of:				Resulting transmission capacity (%) at the useful symbol time of:	
T_u = 896 μs		T_u = 224 μs		T_u = 896 μs	T_u = 224 μs
1/4	224 μs			100 %	
1/8	112 μs			111 %	
1/16	56 μs	1/4	56 μs	118 %	100 %
1/32	28 μs	1/8	28 μs	122 %	111 %
		1/16	14 μs		118 %
		1/32	7 μs		122 %

Table 1
Flexible settings of the DVB-T guard interval.

directional reception [13] and 2 m for omni-directional (portable) reception. The coverage probabilities were investigated for both direction-al and omnidirectional reception in a rectangular area (area A1), measuring 60 x 52 km, which is representative of a large-area SFN. In order to save computing time, reception conditions at a point (P2) – about 25 km from one of the trans-mitters – was also considered as an alternative because experience has shown that the results obtained there correspond approximately to the area average within the network.

The minimal SFN considered in the IRT studies consists of just two transmitters, spaced 60 km apart, which emit identical power from the same antenna height. The coordinates (in km) of the two transmitters are: Transmitter 1: (0, 0); Trans-mitter 2: (60, 0). The coverage probabilities for directional and omnidirectional reception were analysed in a rectangular area, 150 km by 60 km, around these two single-frequency transmitters.

7. Influence of the DVB-T transmission parameters

The DVB-T specification has been formulated so flexibly that ideal parameters for transmission can be selected for each different application, be it a specific source data-rate (e.g. SDTV or HDTV) or a specific transmission reliability (error protection or modulation for portable or stationary recep-tion), a particular transmitter network structure (single-transmitter or SFN) or compliance with different signal-to-noise ratios. This allows the best possible use to be made of frequency re-sources when introducing DVB-T.

8. Length of the guard interval

The standardization bodies working on DVB-T in Europe called for the option of using SFNs so that frequency resources could be used efficiently. The COFDM modulation scheme was therefore

based on 8K-FFT which allows a guard interval of T_g = 224 μs at 25 % overhead and an effective symbol time of T_u = 896 μs. This means that the permissible signal delay times are outside the sig-nal delay between adjacent transmitters, when these are situated less than 67 km apart.

Choosing a large guard interval costs transmission capacity (e.g. 25 %). Also, the cost of the hard-ware at the receiving end is increased because of the large OFDM symbol times (8K-FFT). Com-promise solutions for the length of the guard inter-val are either (i) at the expense of frequency econ-omy from the network planning aspect (low coverage probabilities in the SFN) or (ii) at the ex-pense of transmission efficiency (low data-rate).

A long guard interval will not be necessary for all coverage concepts of a future digital terrestrial tele-vision system. Local or regional services can be implemented with considerably shorter guard intervals than large-area SFNs. Whereas it might be possible to achieve an increase in frequency economy with a large guard interval in an SFN, a reduction in transmission efficiency by the amount of the guard interval would have to be accepted for local services with conventional network planning.

The DVB-T specification therefore makes provi-sion, firstly, for different lengths of the guard inter-val (1/4, 1/8, 1/16 and 1/32 of the effective symbol time) and, secondly, for two different symbol times T_u = 896 μs and T_u = 224 μs (*Table 1*). The shorter symbol time means that there is a correspondingly smaller number of carriers and that a 2K-FFT sys-tem is used instead of 8K-FFT. The DVB-T speci-fication thus allows for six different values for the guard interval in the range from 7 to 224 μs.

Flexible setting of the guard interval provides a means of optimizing the transmission efficiency according to the network structure. Although the frequency efficiency is reduced as the guard inter-val increases, this case basically only arises when very high frequency economy is achieved through the use of a large-area SFN.

9. Influence of the guard interval on coverage probability

In a wide-area SFN, the coverage probabilities decrease when a shorter guard interval is applied (see *Fig. 2*). Of the four guard intervals provided for in the DVB-T 8K-FTT specification, three of them (28, 112 and 224 µs) are shown on this graph, as well as two non-specified cases (0 and 448 µs) for illustration purposes. These results indicate clearly that the longest guard interval selected for the DVB-T 8K system (i.e. 224 µs) was a compromise in order to keep the symbol overhead within acceptable limits (25% of the active symbol time, 896 µs). *Fig. 2* shows that the 8K system provides even better coverage probability if the guard interval is set to 448 µs: despite the higher symbol overhead (50% in this case), there may exist some applications of very large SFNs where the frequency efficiency is still superior to that of conventionally-planned networks.

Fig. 2 also shows that the relatively large active symbol time of the 8K-FFT system (896 µs) results in a certain coverage probability even with no guard interval. This is due to the fact that the interfering echoes largely decay within the first quarter of the symbol.

In a 2K-FFT system, signal delays that exceed the guard interval are very much more conspicuous due to the considerably shorter usable symbol time of 224 µs. The signal delays occurring in the wide-area SFN considered here, which has a transmitter spacing of 60 km, are significantly higher than 56 µs. Consequently, increasing the guard interval from 1/32 to 1/4 of the symbol time results in hardly any positive effect (*Fig. 3*). In that case, a coverage of 90 % of the locations would only be possible for a single-programme service based on 4-PSK.

10. Comparison of coverage probabilities in a two-transmitter SFN

Assuming that DVB-T will concentrate particularly on local and regional services, it becomes necessary to decide whether an 8K-FFT system is only required in large single-frequency networks or whether an 8K-FFT system and a guard interval of 1/4 would also provide coverage advantages for small transmitter networks. For this purpose, the IRT studied an SFN with just two transmitters spaced 60 km apart and with the same antenna height, radiating the same transmission power.

The coverage probabilities were investigated for directional and omnidirectional reception in a rectangular area, 150 km by 60 km, around the two single-frequency transmitters. The result obtained across the area indicates that the influence of inherent interference of the transmitters in the 8K system is more than 17 dB lower than in the

Figure 2
8K-FFT system with a useful symbol time of 896 µs: influence of the length of guard interval; directional receiving antenna.
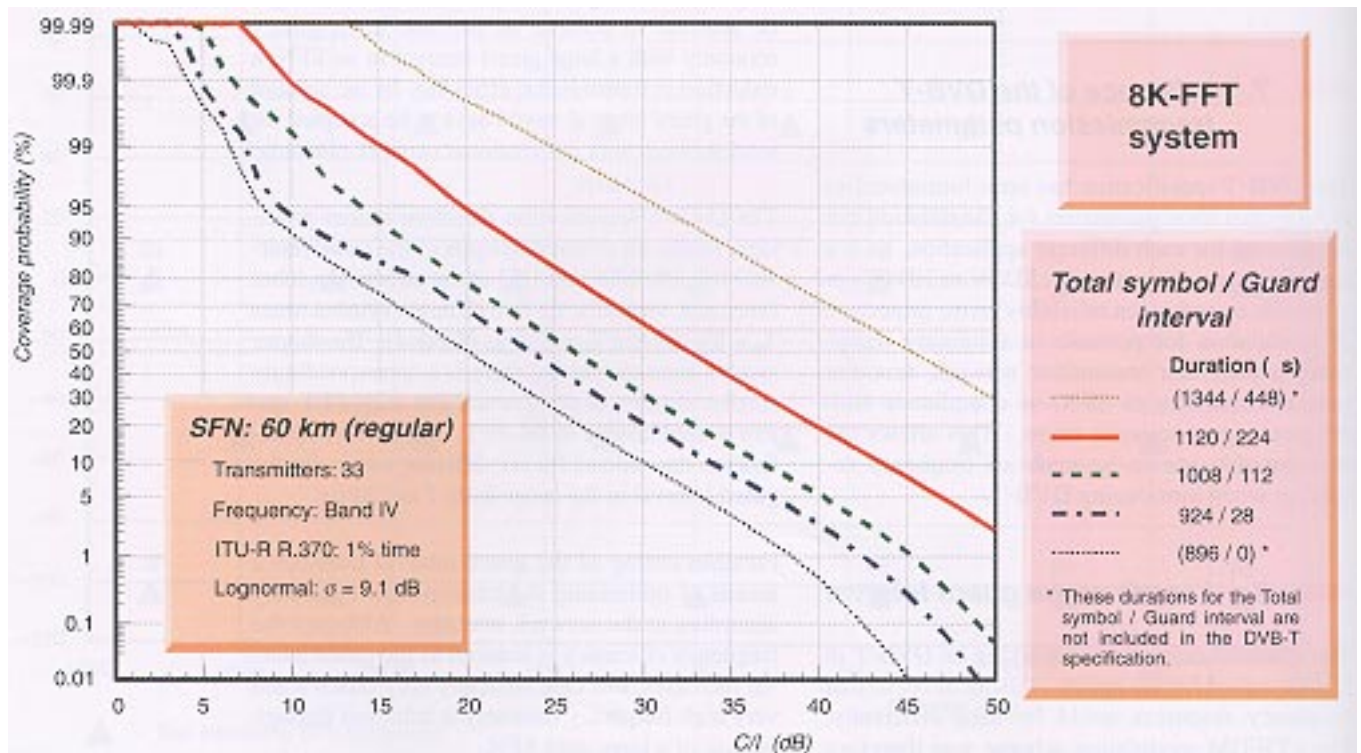
case of the 2K system. *Fig. 4* shows the coverage probabilities across the receiving location when a signal with four television programmes is broadcast (equivalent to a C/I of 23 dB for a 64-QAM system). One half of the reception area, which is symmetrical for 30 km, is shown and the results for the 2K and 8K systems are compared.

The results for the 2K-FFT system shown in *Fig. 4 (upper)* indicate that considerable impairment of signals is to be expected with omnidirectional reception, especially between the two transmitters where slight path delay differences occur. With directional reception, the attenuation at the rear of the receiving antenna can noticeably reduce the effect of the interfering signal. However, an exceptionally steep drop in the coverage probability can be seen in the area outside the two transmitters, in the case of both omnidirectional and directional reception. The results for 8K-FFT in *Fig. 4 (lower)* illustrate the clear superiority of the 8K system, also – or particularly – in a small SFN such as the one used in the IRT simulation.
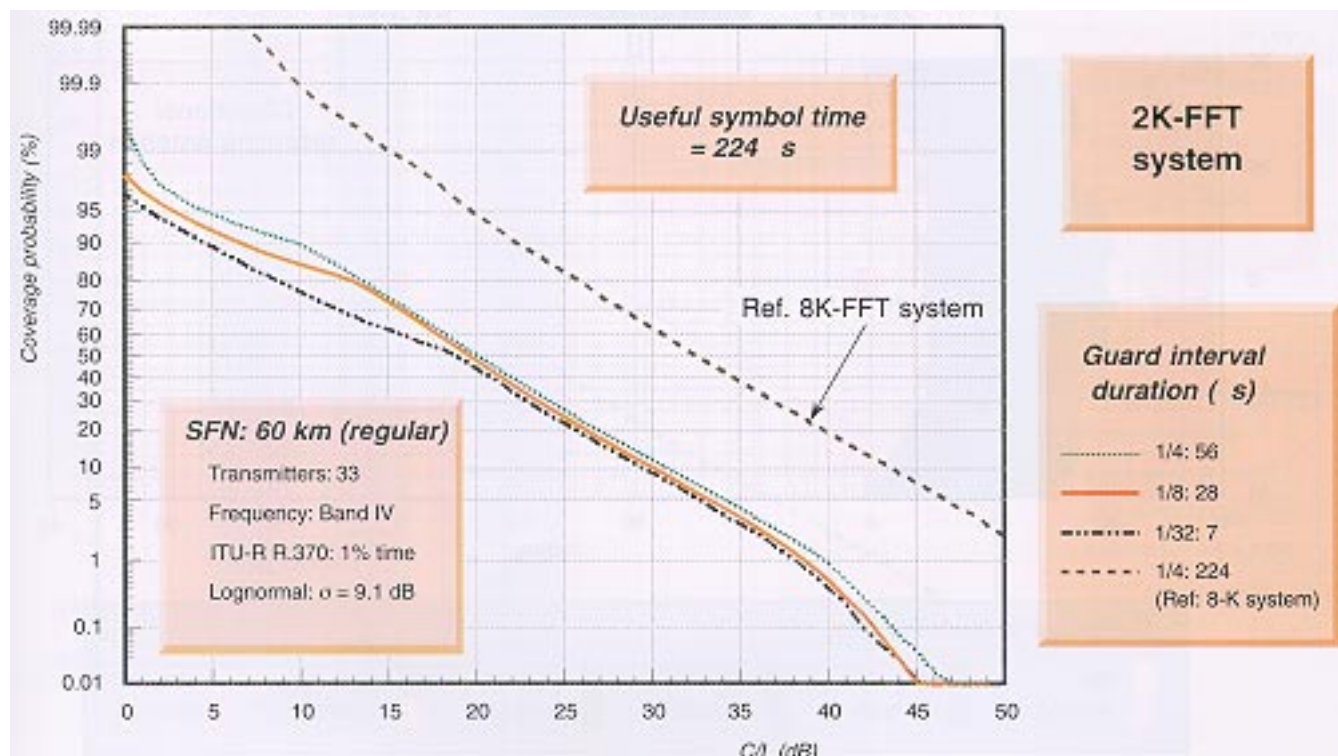
▬ 11. *Modulation parameters*

Provision is made in the DVB-T specification for three different phase/amplitude constellations, 64-QAM, 16-QAM and 4-PSK , in order to meet the different requirements in terms of spectral efficiency and the reliability of the broadcast service. The reduction in the data-rate by a factor of
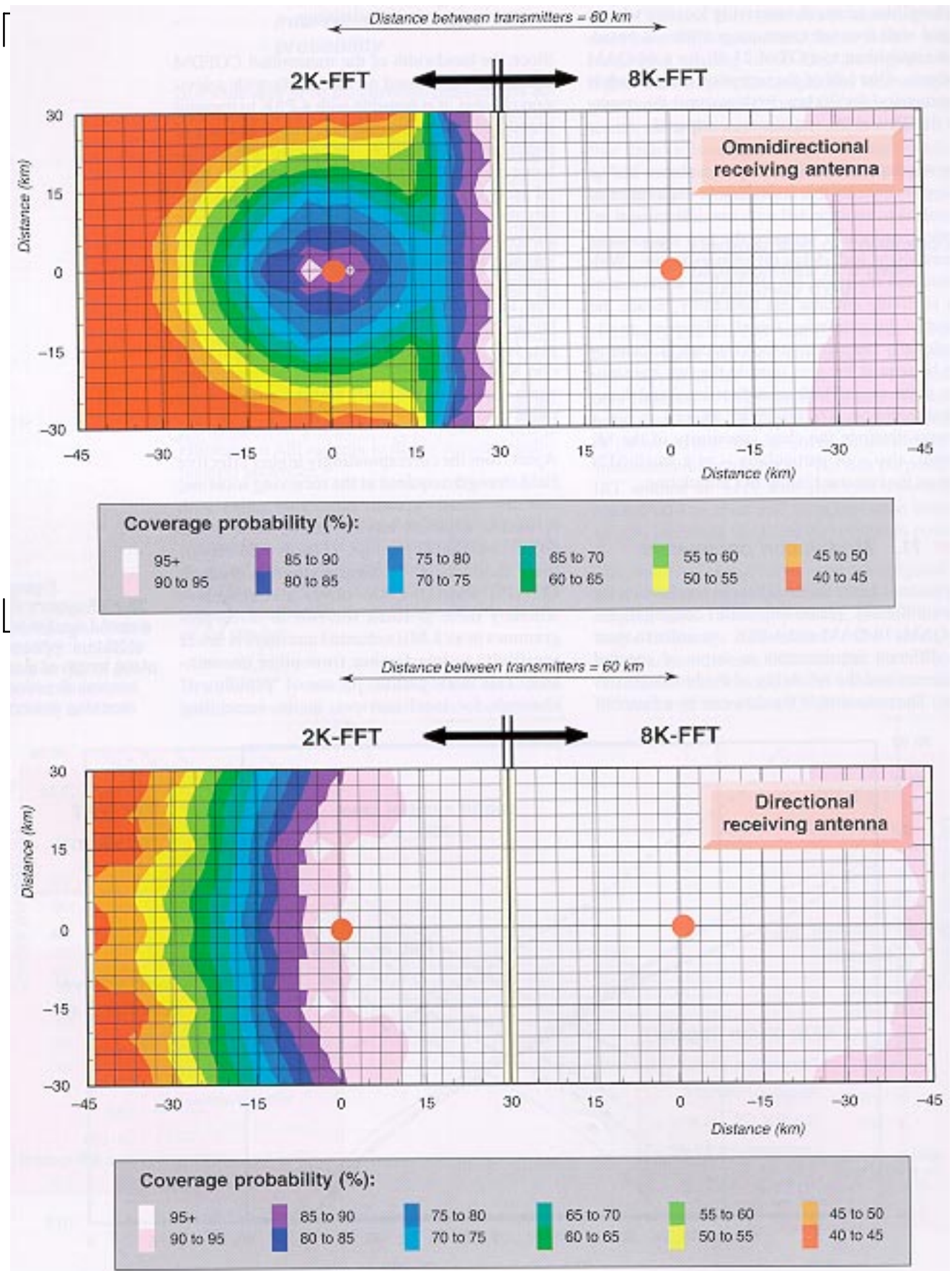
about 2 from stage to stage is matched by a simultaneous increase in the reliability.

Since the bandwidth of the transmitted COFDM signal has been based on an 8 MHz-wide television channel, it is possible with 4-PSK to transmit exactly one digital programme with a data-rate of approximately 7 Mbit/s. This means that an analogue television service can be replaced by a digital service, thereby allowing a considerable improvement in the reception conditions for portable receivers. Conversion to a digital terrestrial television system becomes even more attractive as the number of programmes offered increases in relation to the analogue services. This speaks in favour of using 64-QAM with which, for example, four programmes can be accommodated in one 8 MHz channel. This form of modulation again requires significantly higher signal-to-noise ratios than 4-PSK.

Apart from the correspondingly higher effective field strength required at the receiving location, this also means greater protection ratios with respect to adjacent services in the same or the adjacent frequency range. The availability of these channels is, however, extremely limited. COFDM with 16-QAM offers a compromise whereby there is room for two to three programmes in an 8 MHz channel and there is lower sensitivity to interference from other transmitters. This mode permits the use of "prohibited" channels for local services, at the same time

Figure 3
2K-FFT system with a useful symbol time of 224 µs: influence of the length of guard interval; directional receiving antenna.

Distance between transmitters = 60 km

2K-FFT ← | → **8K-FFT**

Omnidirectional receiving antenna

Coverage probability (%):

95+	85 to 90	75 to 80
90 to 95	80 to 85	70 to 75

65 to 70	55 to 60	45 to 50
60 to 65	50 to 55	40 to 45

Distance between transmitters = 60 km

2K-FFT ← | → **8K-FFT**

Directional receiving antenna

Coverage probability (%):

95+	85 to 90	75 to 80
90 to 95	80 to 85	70 to 75

65 to 70	55 to 60	45 to 50
60 to 65	50 to 55	40 to 45

allowing the conventional planning of a DVB-T transmitter network with less stringent requirements in terms of the protection ratio.

Fig. 5 shows the coverage probability at point P2 of the single-frequency network under consideration (COFDM with 896 μs effective symbol time and 224 μs guard interval) for both stationary and portable reception. Ranges for C/I values are marked in which one, two or four programmes, each at approximately 6 Mbit/s, can be received depending on the modulation method, or more programmes if the source data-rate and/ or error protection is reduced. *Fig. 5* shows that about 90 % of locations can be supplied with four or more programmes (64-QAM) in the case of directional reception (unbroken curve). On the other hand, only about two programmes (16-QAM) can be broadcast for portable reception with an omnidirectional antenna if 90 % of the locations are to be served (broken curve). For portable reception of four programmes, the coverage probability is reduced to as little as 25 % (in the C/I range, 25-28 dB).

12. Hierarchical modes

When COFDM carriers are modulated with 4-PSK, the information (2 bits each) is transmitted in the phase quadrant. With 16- or 64-QAM, an additional 2 or 4 bits are transmitted in each phase quadrant, by spacing possible amplitudes and phase values closer together. An obvious solution is therefore to organize the modulation in two steps. In the first step, the phase quadrant is selected on the basis of two bits of a (channel-encoded) datastream, *HP* ("high priority"). Then the momentary phase and amplitude constellation is formed inside the preselected quadrant, depending on the 2 or 4 remaining bits of another (channel-encoded) datastream, *LP* ("low priority"). This form of modulation, known as *hierarchical modulation*, enables 4-PSK to be integrated in the constellation diagram of a 16- or 64-QAM system. *Fig. 6* shows the case for 16-QAM. The *HP* datastream can be demodulated independently by a single evaluation of the quadrant used.

The separate transmission of the two datastreams, *HP* and *LP,* each with their own error protection, means that transmission of the integrated 4-PSK is less susceptible to interference than is the case with non-hierarchical 16- or 64-QAM. It also results in a higher coverage probability for the *HP* datastream, which is advantageous for a broadcasting system geared to portable reception. However, a slightly higher signal-to-noise ratio is required for the *LP* datastream compared with normal 16- or 64-QAM, because for the purposes of error correction the
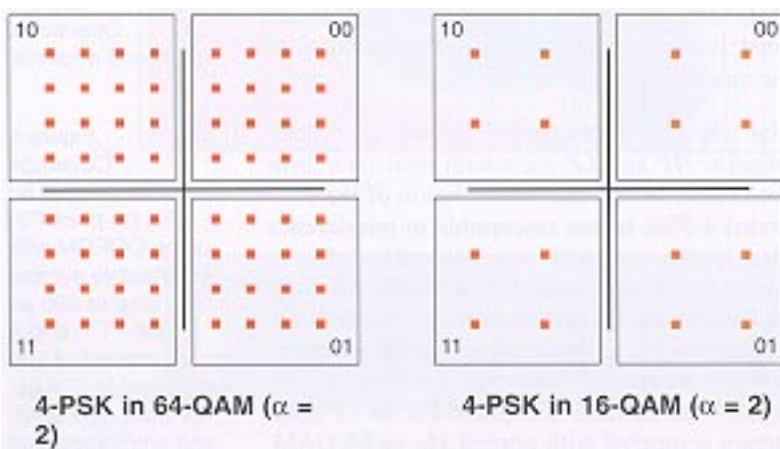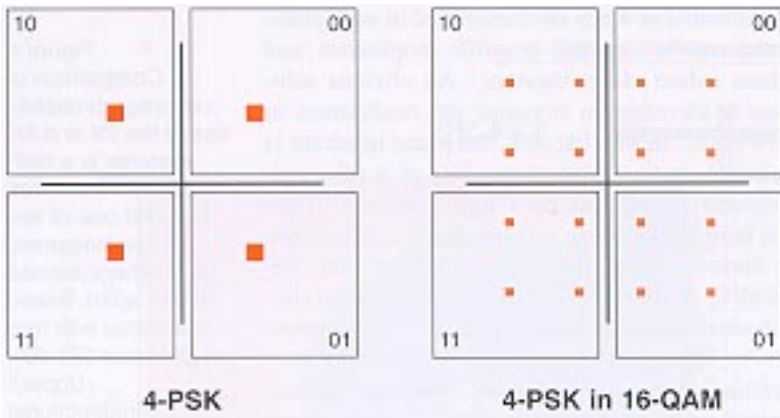
Figure 5
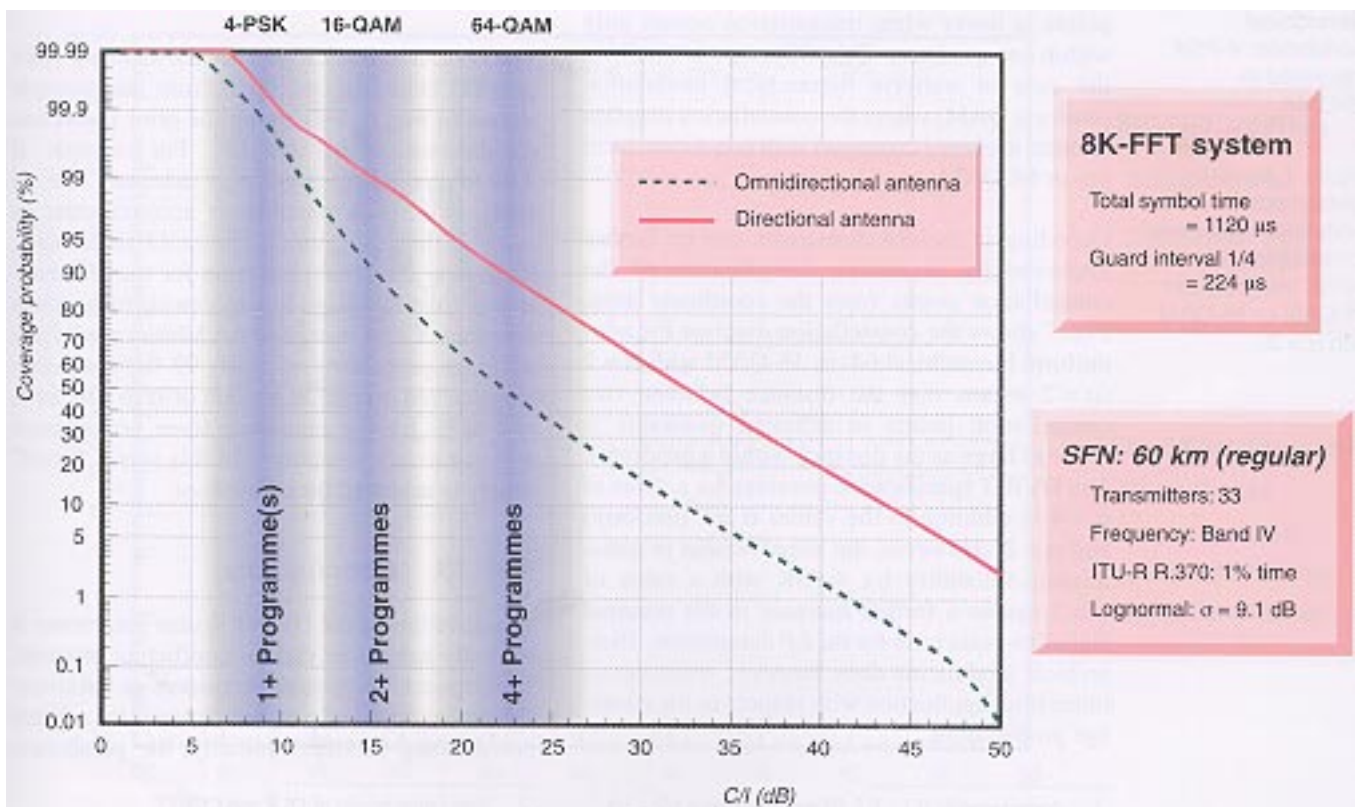
Figure 6 *(upper)* Hierarchical modulation: 4-PSK integrated in 16-QAM.

Figure 7 *(lower)* Hierarchical modulation: Improved constellation for 4-PSK integrated in 64-QAM or 16-QAM with α = 2.

mean distance between successive constellation points is lower when transmission occurs only within one quadrant. This difference is small[1] in the case of uniform hierarchical modulation (uniform QAM) where the constellation diagram remains unaltered compared with non-hierarchical 16- or 64-QAM.

Decoding of the *HP* datastream can be further improved by increasing the distance of the constellation points from the coordinate axes. *Fig. 7* shows the constellation diagram for non-uniform hierarchical 64- or 16-QAM with α = 2 (α = 2 means that the distance between two constellation points in different quadrants is twice as large as the distance within a quadrant). The DVB-T specification provides for a value of α = 4 in addition to the values α = 1 (uniform) and α = 2. However, the improvement in transmission reliability for 4-PSK with a value of α > 1 causes a further increase in the required signal-to-noise ratio for the *LP* datastream. Hierarchical modulation does, however, represent an interesting application with respect to the coverage probabilities.

Fig. 8 shows the coverage probabilities in an SFN with additional examples of hierarchical and non-hierarchical modulation. These are based on the required signal-to-noise ratios[2] for portable and stationary reception which are given in the DVB-T specification. This example shows 4-PSK in a 64-QAM system. The same error protection with a code rate R = 2/3 is used for both datastreams, *LP* and *HP*, so the ratio of the data-rates between *LP* and *HP* is exactly 2 to 1. With the guard interval of 1/4 considered here, this gives a data-rate of 6.6 Mbit/s for the *HP* datastream.

The coverage probability for the three programmes with non-hierarchical modulation is about 65 % for portable reception and about 98 % for stationary reception. The coverage probability for the *LP* datastream is reduced only minimally with hierarchical transmission where α = 1, whereas it is significantly higher for the *HP* datastream (90 % for portable reception). This means that the coverage probability for a service which can be received portably (*HP*: 90 %) is approaching the values for the services intended for stationary reception (*LP*: 98 %). In the case where α = 2, a value of 98 % is produced for services intended for portable reception, compared with 95 % for services intended for stationary reception. In other words, owing to hierarchical modulation, the coverage probability for at least one programme can be increased significantly and there may even be no loss in practice for the *LP* datastreams.

The DVB-T specification also allows many other possible combinations, apart from the example shown in *Fig. 8*, by varying the error protection for datastreams *HP* and *LP*. For example, if 4.98 Mbit/s-per-programme is adequate for an application, it is possible to accommodate as many as three programmes in the *LP* datastream. Increasing the error protection for the *HP* datastream from R = 2/3 to R = 1/2 (owing to the lower data-rate of 4.98 instead of 6.6 Mbit/s) results in a coverage probability of nearly 99 % for a portably-received service at a value of α as low as 1, and 96 % for the remaining three programmes with stationary reception. In this way a "good" supply is achieved for all services.

13. Conclusions

The definition of the DVB-T system parameters is naturally subject to various conflicting interests. The impact of the system parameters on the coverage probability is of particular interest for a future broadcasting service. Initially, the parameters

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1. Approximately 0.1 – 0.5 dB with code rates 1/2 – 3/4.

2. Simulation results of DLR and CCETT.

required for a system specification and their relative effects on the coverage will be of greater interest than the results for a concrete application with a real transmitter network and real signal-to-noise conditions (a task that must be performed by network planners).

The study of the DVB-T coverage aspects presented in this article has been based on the use of a single-frequency network. This is because, in Germany, there is great interest in the use of SFNs for reasons of frequency and power economy. The results are also fundamentally transferable to other network structures. More precise results about system behaviour, which are important for the actual planning of DVB-T services, are expected to be obtained from the European ACTS project "VALIDATE" which will also verify the DVB-T specification in laboratory and field tests.

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Figure 8
Comparison of the coverage probabilities in an SFN with hierarchical and non-hierarchical modulation: COFDM, 4-PSK in 64-QAM, R = 2/3, effective symbol time 896 µs, guard interval 1/4, directional and omnidirectional receiving antennas.
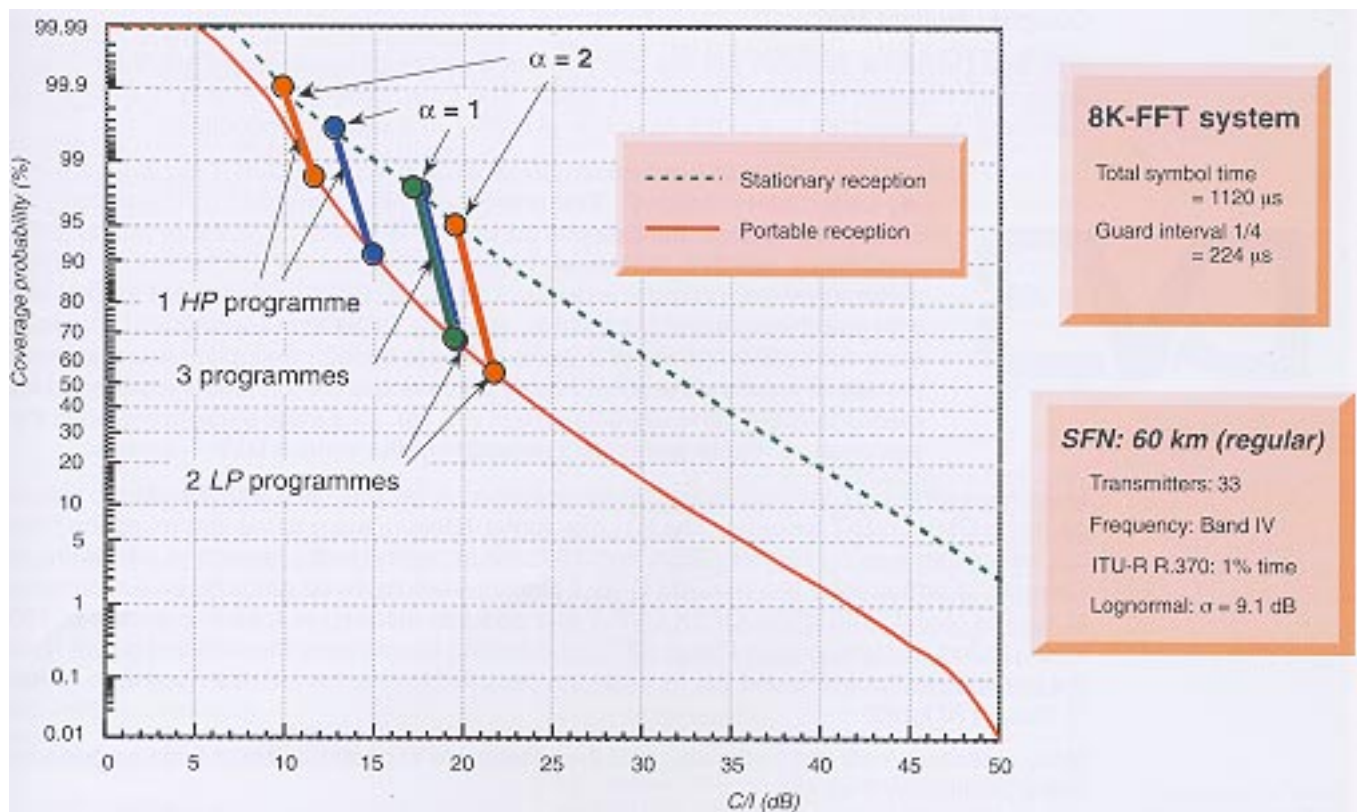
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Dr Chris Weck graduated in Electronic Engineering from the Technical University of Berlin in 1986 and joined the "Systems for Sound and Data Transmission" section of the IRT in Munich. First, he worked on channel coding for digital audio broadcasting with regard to subjective criteria. In the framework of the Eureka-147 DAB Project, he was involved in the system specification and contributed especially to the definition of the unequal error protection scheme.

Since 1993, Chris Weck has participated in various national and European projects dealing with the development and specification of digital terrestrial television (e.g. HDTV, RACE dTTb, DVB task forces). He has been engaged in the field of channel coding and modulation, and also in the coverage aspects of SFNs. In the ACTS Project VALIDATE (verification and launch of the DVB-T specification), he is currently Chairman of the "Field Tests" Task Force.

In 1996, Chris Weck obtained a Ph.D. from the Technical University of Berlin, in the field of source-adaptive channel coding for digital audio broadcasting.

Mobile DVB-T – important results

Cologne, January 1997.

RTL and Deutsche Telekom AG are carrying out a series of trials using DVB-T compliant equipment supplied by the UK company, DMV. The trials, covering the area of Cologne in Germany, are designed to test the reception of DVB-T in a variety of conditions.

Initial results have been extremely promising, with the DVB-T system performing better than predicted. The preliminary tests consisted of transmitting 2k DVB-T signals from the Cologne transmitter of Deutsche Telekom with an ERP (equivalent radiated power) of 1 kW on Channel 40. A variety of DVB-T parameters were chosen including QPSK, 16-QAM and 64-QAM modulation with guard intervals of 1/4 and 1/8. Both the QPSK and 16-QAM FEC (forward error correction) options of 2/3 and 3/4 were tested. Reception was based on the use of an omnidirectional set-top antenna and a short antenna designed for mobile telecommunications reception in a car. The initial trials investigated the stationary, portable and mobile reception of the various DVB-T signals.

Most interesting were the results for mobile reception. A car was fitted with the set-top antenna and a DMV DVB-T receiver. The RTL/Deutsche Telekom team found that reception from the transmitter was perfect for QPSK and 16-QAM at normal traffic speeds in the centre of Cologne. Furthermore, the 16-QAM DVB-T signals were received perfectly on a motorway at speeds of up to 140 km/h. QPSK DVB-T was perfectly received at speeds in excess of 170 km/h. In fact, according to Dr Paech (RTL), the limiting factors were the received power from the transmitter, the traffic and the fact that the car used for the trials had a maximum speed of about 170 km/h!

More extensive trials are underway, and the results are expected to be at least as good as these preliminary findings.