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REPORT FROM AD-HOC GROUP B/CAI-FM24 TO B/MDT & FM PT24 ON SPECTRUM REQUIREMENTS FOR DVB-T IMPLEMENTATION

THIS TECHNICAL REPORT SUPERSEDES
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Executive summary

The report presented hereafter by B/CAI-FM24 to B/MDT and to FM PT24 is the result of the theoretical studies on the amount of spectrum required in the all-digital future to provide digital television coverage throughout Europe for a set of representative coverage requirements. These studies allow different scenarios to be compared.

The Group B/CAI-FM24 has been working for about one year and has used the experience of broadcasters who are now implementing the DVB-T networks as well as that of experts in theoretical network planning. The Group started its work by analysing the numerous possibilities that the DVB-T standard offers compared to analogue transmissions and therefore the many different possibilities for providing different types of coverage. It became obvious that the task was very complex. It is **multi-criteria** due to the large choice of DVB-T variants and also **multi-parameter**[1] due to the many possible network configurations that can be used.

As a consequence, the studies were limited to a sub-set of the criteria that were being proposed for use or are already in use in different countries, but extended to permit the examination of a wide range of planning parameters. These were considered to be representative options and are described in ***Chapter 1 of Part 1***. The planning criteria and parameters used for the theoretical calculations are given in ***Chapter 2 of Part 1*** The description of the theoretical planning methods and the calculation procedures used to obtain the results presented in these report are given in ***Chapter 3 of Part 1***.

The results of the calculations of the number of RF channels needed to provide coverage for one multiplex are given for MFN and for SFN network structures in ***Annex C of Part 1*** and in ***Annex D of Part 1***, respectively. The results are presented in two ways. Firstly in terms of the "numbers of channels" and secondly, in terms of "equivalent number of channels" needed to provide a given data capacity. The comparison with different DVB-T variants can be easily made using the concept of ‘’equivalent number of channels’’.

The provision of complete coverage, where at least one specific television multiplex is receivable at any location, is described as 100% pixel coverage. The term "percentage pixel coverage[2]" has been introduced to allow investigation of the number of channels needed for less than complete coverage. This parameter is useful when making calculations for less than complete coverage, for instance where the coverage is restricted to areas around to each transmitter site. It may be of particular interest where only certain areas are intended to be covered, i. e. in the case of portable indoor antenna reception.

Chapters 4 and 5 of Part 1 analyse the results and explain the influence of the criteria and parameters on the variation of the number of channels needed for one coverage.

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[1] In this report, it is considered that the planning criteria are the minimum signal levels and the protection ratios and that the planning parameters are the inter-transmitter distances, the transmitting antenna heights and the type of reception (although the last of these items also includes criteria elements).

[2] The term ‘’pixel’’ has also been defined for other situations. It is usually a small discrete element of an image or picture. Here, it is a constituent of the coverage of the quasi-infinite area.

The results of the studies presented in the report are **theoretical** and assume the ideal case of a quasi-infinite area where the population is distributed evenly. They do not take into account country boundaries or any subdivision of the country into regions. Furthermore, it is assumed that analogue transmissions have been switched off and that the spectrum is available.

Part 2 of this report summarises the impact of real-world considerations on the theoretical number of channels needed. In this respect, it must be realised that there may be considerable differences between the real-world and the results obtained from the theoretical studies. A comparison between the theoretical results and the studies made by some countries clearly demonstrate the strong influence on the choice of criteria and parameters.

Part 3 gives a summary of national studies in progress to illustrate the influences of the criteria and the parameters on the technical results which have been found according to the selected configurations.

As a summary conclusion of the work presented hereafter, the group would like to highlight:

- it must be recognised that this is a multidimensional subject requiring inputs from many parties;
- the results are given for a wide choice of network configurations;
- the final choice must be made on a country-by-country basis as each country may have different requirements to those of its neighbours;
- that there is no single and universal solution;
- further work is required to study mobile reception and hierarchical variants and to investigate further the impact of real-world considerations;
- digital television will use less spectrum than analogue television to carry the same number of programmes under the same conditions.

The Group has decided to publish its results to date, as these could help countries wishing to introduce DVB-T get a better idea of what might be achieved and the amount of spectrum required.

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Introduction: Presentation of the work of the B/CAI-FM24 Ad-hoc Group

I.1 The B/CAI-FM24 Group

The B/CAI-FM24 Group was created by the EBU Group B/CAI[3] (Chairman Nigel Laflin) and by the CEPT FM PT24 Group (Chairman Jan Doeven).

I.2 The mandate

The mandate given to the B/CAI - FM24 Group was:

1. To investigate the amount of spectrum required to provide digital television coverage throughout Europe for a set of representative coverage requirements.

2. To identify, in the coverage proposals derived in item (1), if there may be unused spectrum in individual countries.

3. To present progress reports and the results of any studies undertaken to EBU Group B/CAI (i. e. B/MDT now) and to CEPT FM PT24.

I.3 The participants

18 participants attended the meetings. The members of the group were:

Jean-Jacques Guitot, Project Manager (ANFR, France); Jiri Vostruha (CTU/Testcom, Czech Republic); Cenek Pavelka (CTU/Testcom, Czech Republic); Jörn Andersen (DR, Denmark); Philippe Debreux (GRF/TDF, France); Patricia Martigne (ANFR, France); Walid Sami (CSA, France); Roland Brugger (ARD/ZDF/IRT, Germany); Ute Rolly (DT, Germany); Juraj Oravec (VUS, Slovakia); Peter Vercoe-Rogers (RTE, Ireland); Mats Ek (SVT/Teracom, Sweden), Phil Marsden (BBC, United Kingdom); Olivier Blondeau (FT/TDF, France); Benoist Guillard (FT, France); Darko Ratkaj (ERO, Denmark); Ken Hunt[4] (EBU, Switzerland) and Elena Puigrefagut, Secretary (EBU, Switzerland)

I.4 The meetings and the working method

The group has held seven meetings (up to January 2001) and the report was prepared from the members' contributions and the calculations provided by the members and by Mr Ken Hunt. Some of the latter calculations have been re-used by members.

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[3] Chester Agreement Implementation Group, B/CAI, and now called B/MDT, Migration to Digital Television.

[4] Initially as Secretary and later as EBU representative.

Part 1: Theoretical aspects

Given that the studies on the number of channels required for a complete coverage of DVB-T are of a theoretical nature, and that no channel allocation is attempted, the availability of any specific part of the spectrum is of no importance. The only information required concerns the frequency bands to be used, so that the appropriate propagation models can be used.

For the purpose of the studies undertaken and the results presented in this report, it is assumed that the broadcasting spectrum has been freed from analogue television which is assumed to have been switched off. This means that the results obtained apply only to the all-digital future and, in particular, not to any mixed analogue and digital situation.

Chapter 1: Key elements

In DVB-T planning there are many more parameters to be considered than in analogue planning. The key elements to be considered in the exercise of DVB-T planning are listed below Some comments, extracted from the contributions provided for the studies, are given with some of these key elements in order to illustrate them briefly.

This chapter is in the form of definitions of terms used in the subsequent sections. The complete definitions of most of these key elements can be found in the relevant documents such as ETSI standard ETS 300-744, EBU document "Terrestrial Digital Television Planning and Implementation Considerations" (BPN 005), The Chester 1997 Multilateral Coordination Agreement relating to Technical Criteria, Coordination Principles and Procedures for the introduction of terrestrial Digital Video broadcasting (DVB-T) (Chester, 25 July 1997) and the ERC/EBU Report on “Planning and Introduction of Terrestrial Digital Television (DVB-T) in Europe” (Izmir, December 1997).

1.1 DVB-T variants

The DVB-T standard allows for different levels of modulation and different code rates to be used to trade bit rate versus ruggedness. The system also makes allowance for two level hierarchical channel coding and modulation, including uniform and multi resolution constellations. However, a sub-set of DVB-T variants is needed to explore the influence of the particular system variant on the number of channels needed without requiring an excessive amount of computation time or an excessive amount of examination of the results obtained.

Some variants were selected as representative of the much larger set of all variants. This sub-set was chosen to avoid too many options that would need to be displayed. The non-hierarchical variants were chosen as being typical of some expressed requirements and are close to others; for example, it is to be expected that channel requirements for a variant with a code rate of 2/3 will be similar to those for a variant with a code rate of 3/4, for the same modulation.

No specific choice has yet been made for a hierarchical variant and it is also not yet clear how the planning for such a variant might need to be undertaken. For example, should the planning be made for the more sensitive or the less sensitive component and how should the results for the other component be interpreted or displayed? This matter will need further study.

It is important to note that the lowest number of RF channels needed may not correspond to the use of a system variant with the highest data capacity. This aspect of the overall problem has been given considerable attention by the group but its implications may require further study by administrations as it relates to the total channel requirement for a given data capacity. In order to avoid confusion with regard to this subject, this report indicates clearly whether any particular result is being expressed in terms of “number of channels per multiplex” or “number of channels for a given data capacity”.

1.1.1 V1: QPSK, 2/3

This variant provides a low data capacity of only 6 to 8 Mb/s but it does provide a very rugged service.

Networks using QPSK may be of particular value in urban areas for services to pedestrians and vehicles.

It is not yet clear if there is a real demand (either now or in the future) for this type of network.

1.1.2 V2: 16QAM, 2/3

The data capacity is moderate at 13 Mb/s to 16 Mb/s and this variant may be of interest for providing reasonably rugged services to medium or densely populated areas.

1.1.3 V3: 64QAM, 2/3

This variant has a high data capacity, 20 Mb/s to 24 Mb/s but does not provide rugged services and is particularly sensitive to self-interference effects in a large area SFNs.
This is the most commonly used DVB-T variant used so far. It can be used in multi frequency networks (MFNs) using the shortest guard interval (implemented in UK, planned in France), and in SFNs using a large guard interval (examples are the implementation in Spain and the plans for the Netherlands).

1.1.4 V4: Hierarchical variant

Hierarchical DVB-T system variants mean that the MPEG 2 bit stream is divided into two parts, the High Priority stream and the Low Priority stream. The high priority stream is the rugged part of the hierarchical system and uses QPSK modulation and an appropriate code rate to provide the necessary protection against noise and interference. Because of the type of modulation, the data capacity is low (about 5 to 6 Mb/s). However, the C/I ratio is worse than that for a non-hierarchical QPSK system although the data capacity is the same as that of a QPSK system of the same code rate.

The low priority stream is the more fragile part of the hierarchical system and may be either 16QAM or 64QAM. Not much consideration has been given to a low priority stream using 16QAM because the data capacity of the low priority stream is about the same as that of the high priority stream. A low priority stream using 64QAM provides about twice the capacity of the high priority QPSK stream. Its exact capacity relative to that of the high priority stream depends on the relative code rate is of the two streams.

The hierarchical system variants could be used in several ways. One example would be for a combination of fixed and mobile services in the same area, where the high priority stream gives robust mobile coverage and the low priority stream provides fixed antenna reception. This may be done by using, for example, the mode QPSK in 64QAM. At the moment it seems too early to make a choice of any particular hierarchical system variant. More theoretical results and practical experiments on the use of hierarchical modes are required.

1.2 Guard interval

OFDM, used in DVB-T, due to its multi-carrier nature exhibits relatively long symbol periods. This long symbol period provides a degree of protection against inter-symbol interference caused by multipath propagation. This protection can, however, be greatly enhanced by use of a guard interval. The guard interval is a cyclic extension of the symbol, in simplistic term a section of the start of the symbol is simply added to the end of the symbol. The guard intervals for the 2k and 8k system are given in Table 1 in § 2.1.1 *Table 1: System criteria of DVB-T.*

1.3 Reception conditions

Although four types of reception conditions are recognised, only two of them (fixed and portable indoor) have received detailed attention so far. There has also been considerable discussion of mobile reception, but few detailed results for the proposed new receivers and receiving antennas are generally available and this has limited the number of studies which it has been possible to undertake.

1.3.1 Fixed antenna reception

Fixed antenna reception *- is defined in the Chester 97 Agreement as reception where a directional receiving antenna mounted at roof level is used. In calculating the field strength for fixed antenna reception a receiving antenna height of 10 m above ground level is considered to be representative.*

Reception with a fixed roof-level antenna makes it possible to implement a network with large inter-transmitter distances (with a common multiplex or with separate multiplexes from each transmitter) without requiring very high-transmitted power.

In the case of an SFN, there is an upper bound for the coverage which is caused by self-interference effects. This bound depends on the guard interval and on the system variant. This is of particular importance in the case where a country has a requirement for a very high data capacity which can only be met by choosing a small guard interval as this leads to the result that large area SFNs are unlikely to be useful.

1.3.2 Portable indoor antenna reception

Portable antenna reception - *is defined in the Chester 97 Agreement as:*

- *Class A (outdoor[5]) being reception where a portable receiver with an attached or built-in antenna is used outdoors at no less than 1.5 m above ground level.*
- *Class B (ground floor, indoor) being reception where a portable receiver with an attached or built-in antenna is used indoors at no less than 1.5 m above floor level in rooms:*
    - *on the ground floor;*
    - *with a window in an external wall.*

Portable indoor reception at the first or higher floors will be regarded as class B reception with signal level corrections applied, but indoor ground floor reception is likely to be the most common case.

Furthermore, in both categories A and B, above, it is assumed that:

- *optimal receiving conditions will be found by moving the antenna up to 0.5 metre in any direction;*
- *the portable receiver is not moved during reception and large objects near the receiver are also not moved;*
- *extreme cases, such as reception in completely shielded rooms, are disregarded;*
- *it is assumed that the receiving antenna is non-directional.*

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[5] For information only, not used in this report.

The interest in portable indoor antenna reception is increasing and this makes it all the more important to provide an in-depth examination of the coverage possibilities.

1.3.3 Mobile reception

Mobile reception[6] **-** *is defined as being the reception of a DVB-T signal while in motion, using a non-directional receiving antenna situated at no less than 1.5 metres above ground level.*

Mobile reception is still under study and there is clear interest in some areas. In this document, explanations are given for this type of reception in § 2.2.4.2 *Mobile reception*.

1.4 Type of networks

The network can be implemented as an MFN, as an SFN or as a hybrid network consisting of MFNs and SFNs. The type of network implemented will depend on the availability of frequencies, the type of coverage required, and the number of multiplexes to be provided. Definitions of the MFN and SFN, along with additional information about each are given hereafter.

1.4.1 Multi Frequency Network

In a multi frequency network (MFN), each transmitter operates independently (using a different RF channel) and has its own coverage area. The same RF channel is re-used only in regions separated by a relatively large distance, to avoid harmful co-channel interference.

There is considerable interest in MFNs in some countries. They can provide large area coverage. The individual transmitters may carry different multiplexes and can thus allow for regional or local programming. In addition, MFNs can be designed to reproduce, approximately, the coverage of the existing analogue networks and this may be of importance when it is considered necessary to maintain an existing coverage pattern for political or commercial reasons. It also has to be noted that MFNs may be of particular interest during the transition period of co-existence of analogue and digital services. This has increased the attention which they have received so far.

1.4.2 Single Frequency Network

In a single frequency network (SFN), all transmitters of a network use the same channel. They possess a common coverage area and cannot operate independently. They require a high degree of synchronicity:

- the emitted signals from different transmitters must be identical in content;
- signal emissions must take place at the same time (or with precisely controlled delays);
- the RF carriers must comply with stringent frequency precision requirements.

The same RF channel is re-used only by networks separated by a relatively large distance, to avoid harmful co-channel interference.

Several types of SFN can be envisaged and some examples are given below. The present studies are intended to provide the channel requirements for all of these types. This is achieved by allowing for a very wide range of coverage area width[7].

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[6] As given by Motivate AC318/DR/006/P/a1.

[7] In this document, the terms width and diameter are used interchangeably for SFNs.

Types of SFN

National SFN
It seems that a real national network using the same frequency (SFN) will be difficult to achieve in any but the smaller countries because of self-interference effects, unless a low data capacity variant were to be adopted.

Regional SFN
It is assumed that a medium or small SFN corresponds in Europe to a cultural or administrative region of up to 200 km width. The sizes of the European regions are very different from one country to another, even for countries of comparable size. Clearly there is also a major impact from the size of the country and any internal linguistic or cultural considerations.

Local area SFN
Such SFNs are assumed to be needed to provide for local programme coverage.

In addition, SFN gap-fillers can be used to improve or complete the coverage of a network.

1.4.3 Mixed MFN-SFN environments

The mixed MFN-SFN scenario could correspond to different approaches.

Some countries have an interest in having an MFN, which consists of higher power main stations, this does not provide complete coverage. Lower power relay stations (gap fillers or in-house repeaters) complete the coverage using the same frequency as the associated main station. Some other countries have chosen an MFN structure for transmitting a national multiplex and an SFN structure for transmitting a regional multiplex.

In other cases, this type of hybrid network scenario could arise from different approaches in adjacent countries (e.g. an MFN approach in one country and an SFN one in the other). It would be dependent on the actual situation - real country boundaries and real transmitter locations.

1.5 Coverage

1.5.1 Percentage of time

Digital television planning is based on 99 % time protection against interference. In view of the very rapid transition from satisfactory reception to no reception at all which is displayed by digital systems, the need to protect DVB-T against interference for 99 % of the time seems to be a self-evident.

1.5.2 Percentage of locations covered and percentage of pixels covered

Percentage of locations covered within a small area and percentage of pixels covered are two different concepts and great care has to be taken to avoid equating the ‘’small area’’ with the definition of pixel given in this report.

In BPN 005 and in the Chester Agreement, the percentage of locations covered within a small area (the location probability) has been one of the parameters used to determine the minimum field strength necessary to provide the required DVB-T coverage, and is a familiar concept. Both of the above documents assume full coverage of the area covered by the network, i.e. 100% pixel coverage.

It is, however, possible to plan for less than 100% pixel coverage, in other words less than full coverage of this area. The percentage of pixel coverage parameter, which was not used in either of the above documents, has been introduced since their publication. It is necessary to define this new parameter and to highlight the differences between it and the percentage of locations parameter.

1.5.2.1 Percentage of locations covered

In the use of this parameter the following assumptions are made:

- the area covered by the network is divided into a large number of small areas, about 100m by 100m;
- in each of these small areas, the distribution of field strength with location has a log-normal distribution with a standard deviation usually taken to be 5.5 dB, for outdoor reception. For indoor antenna reception, the standard deviation is larger (see §2.2.1 *Propagation characteristics*).

Thus 50% of the locations will have a field strength less than the median field strength and the other 50% of locations will have a field strength greater than the median. Digital systems (including DVB-T) exhibit an abrupt failure as the C/N ratio falls to the threshold value. If satisfactory reception is required at a large percentage of the locations within each small area, the minimum field strength needed for reception must be exceeded at this large percentage of locations. It is usual to plan for the minimum field strength to be exceeded at 70% or 95% of locations within each small area. This is achieved by adding to the minimum field strength a correction factor. This consists of the standard deviation of field strength with location (in dB) multiplied by the appropriate figure for the percentage of locations to be covered, taken from the log-normal distribution curve. This calculation has been used in BPN 005 and in the Chester Agreement where the 95% criterion is defined as “good” reception and the 70% criterion is defined as “satisfactory” reception.

It must be noted that when discussing the influence of the choice of criteria and parameters on the number of channels needed to provide a given level of coverage, the specified percentage of locations covered is for a location at the edge of the coverage area. Locations closer to the transmitter will, in general have a higher percentage of locations covered.

It is not yet clear what the location coverage requirements will be for mobile television.

1.5.2.2 Percentage of pixels covered

The concept of ‘’percentage of pixels covered” can be outlined as follows: *“The provision of complete coverage, where the signal from at least one transmitter is receivable at any location, is described as 100% pixel coverage”.*

In BPN 005 and in the Chester Agreement, it has been assumed that 100% of pixels are covered i.e. the network provides complete coverage. Subsequent to the publication of these two documents, investigations have been made on coverage percentages of less than 100%, i.e. networks that do not provide complete area coverage. However, within each pixel, there is still the variation of field strength with location described above.

It has to be clear that this part of the study is intended to represent a long-term coverage strategy. Studies, which demonstrate that only limited coverage can be achieved with, specified planning parameters may have a very different aim, for example to show that some parameter combinations are not of interest to a particular country.

MFN

The percentage of pixel coverage parameter which can have different values (examples for 50 to 100%, see Figure 1a, 1b and 1c) has been included to allow the theoretical exploration of channel requirements as a function of the amount of the area, which is intended to be covered. In these figures, the contours are drawn for a given percentage of locations covered.

If all locations are able to receive the signal from at least one transmitter then the pixel coverage is said to be 100 %. Pixel coverage values lower than 100 % represent the case where ‘’islands’’ of coverage exist. For this theoretical study, the value of 100% pixel coverage is taken to be the coverage of each of the individual circles shown in Figure 1a, with no account being taken of the effect of any of the coverage overlaps shown.

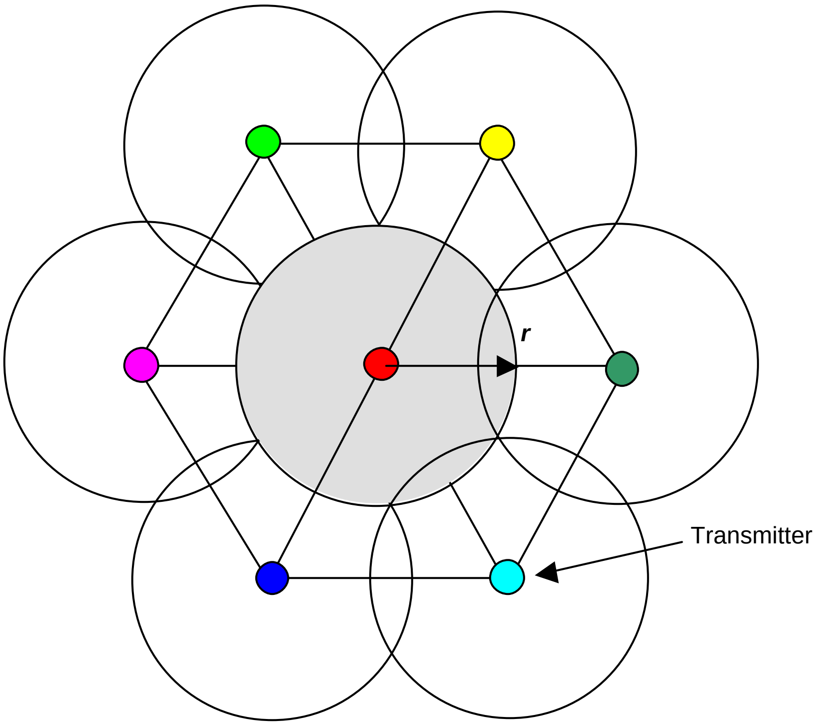
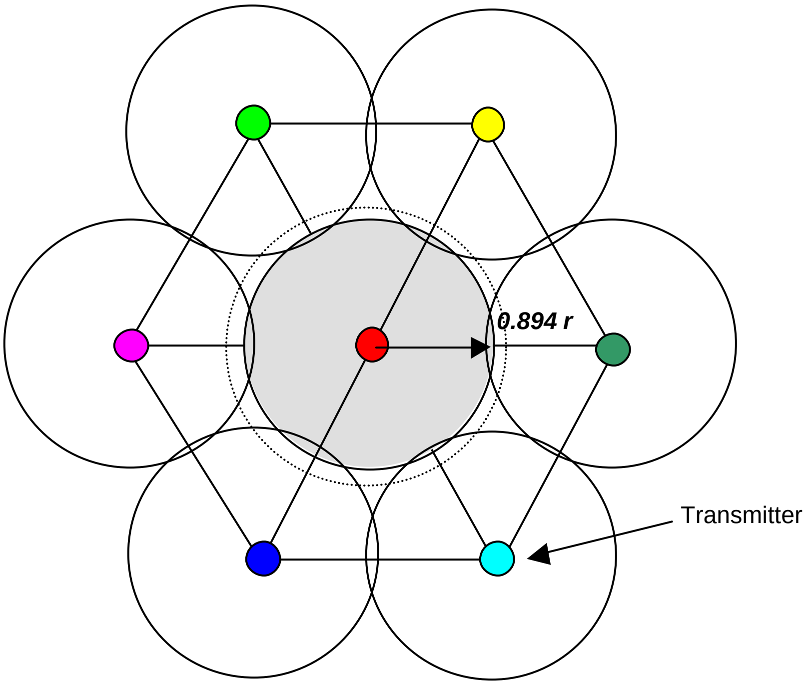
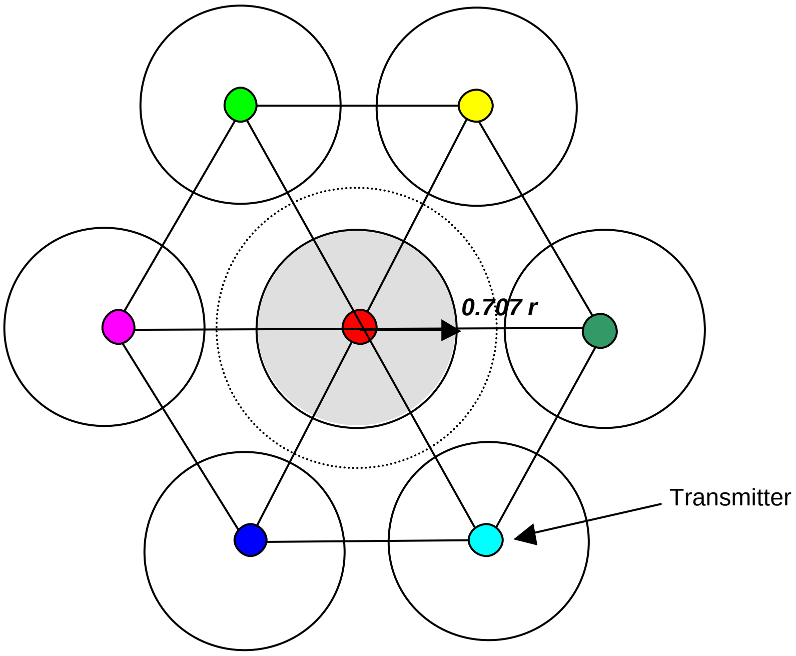


Figure 1a: 100% pixels covered, coverage radius = *r.*



The “dashed” circle corresponds to 100% pixels covered.

Figure 1b: 80% pixels covered, coverage radius = $r\sqrt{0.8}$



The “dashed” circle corresponds to 100% pixels covered.

Figure 1c: 50% pixels covered, coverage radius = $r\sqrt{0.5}$

SFN

100 % pixel coverage of the theoretical semi-infinite area can be made by several SFNs using different frequencies. This corresponds to the previous MFN exercise with the exception that the transmitters forming each SFN are distributed throughout the circle. In the case where significantly less than 100 % pixel coverage is required (SFN islands), it may be possible to use the same frequency throughout the theoretical semi-infinite area.

1.6 Networks

A wide range of networks has been identified to allow the exploration of all of the likely parameter combinations (and a number of unlikely ones, which are included primarily to assist in the establishment of a complete parameter set). Part 2 identifies some cases as being impractical and such results are discussed only briefly in the remainder of Part 1.

1.6.1 Transmitter separation distances in MFN

The range of transmitter separation distances in MFNs used in the studies is 10 km to 250 km. This allows all probable networks to be investigated.

1.6.2 Width of areas to be covered by individual SFNs

The range of width of areas to be covered in SFNs used in the studies is 20 km to 400 km. This allows all probable networks to be investigated.

1.6.3 Open or closed SFN configurations

An SFN comprise of stations using non-directional transmitting antennas is called an 'Open SFN'. An SFN made of stations using directional transmitting antennas, radiating primarily into the SFN and situated along the periphery of the coverage area is called a 'Closed SFN'.

Closed SFN configurations are likely to offer the better usage of the spectrum but may be difficult to realise in practice because of the demands on the transmitting antenna patterns. Studies made so far by IRT have concentrated on closed configurations. Some studies have been undertaken by the EBU to evaluate the impact of using an open network, but only for the case of fixed antenna reception. Some studies will also be made to evaluate the advantages which may be offered by different closed configurations (containing fewer transmitters) which may be more appropriate for SFNs with smaller coverage widths.

In practice, in the case of extended networks, there may be little difference in the channel requirements for open and closed networks.

1.6.4 Transmitting antenna effective height

The range of effective transmitting antenna heights used in the studies is 37.5 m to 1200 m. This allows all probable networks to be investigated.

1.7 Frequency bands

It is expected that the UHF band(s) will be used for terrestrial digital television in all countries and the initial studies have been concentrated here. Further studies will be needed to determine the impact of using the VHF band.

1.7.1 UHF (Bands IV and V)

While the initial studies have concentrated on a frequency near the centre of the UHF band (600 MHz), there could be some differences across the whole frequency range. This remains to be investigated, although it is to be noted that the recommendation ITU-R P.370-7 does not distinguish between frequencies in the range 450 to 1000 MHz.

1.7.2 VHF (Band III)

Although only a few channels are available, there is considerable interest in the use of this band in some countries for DVB-T. This band is used by T-DAB in some countries and is planned for use in most other CEPT countries.

1.8 Number of multiplexes

This initial study investigates the amount of spectrum required for a single multiplex or a given data capacity throughout a large area which may contain a number of countries. Later studies will investigate the impact of the choice of different scenarios in different countries and will thus need to consider more than one multiplex.

Chapter 2: Criteria and parameters used in theoretical planning exercises

2.1 System criteria for DVB-T

2.1.1 General on DVB-T

The DVB-T system offers a large variety of variants in order to accommodate the system to the various targets that may be aimed at with regard to data capacity, reception mode, network configurations or size of service area. The criteria that are relevant for planning are given in Table 1.

FFT	2k or 8k
Modulation	QPSK, 16QAM, 64QAM
Code rate	1/2, 2/3, 3/4, 5/6, 7/8
Useful symbol length T_U	224µs for 2k mode or 896µs for 8k mode
Length of guard interval	1/4, 1/8, 1/16, 1/32 of the symbol length T_U

Table 1: System criteria of DVB-T.

Table 2 gives an overview of the non-hierarchical DVB-T variants with the net bit rates available and the theoretical C/N values. The C/N figures in this Table assume perfect channel estimation and do not include a receiver implementation margin. Due to the lack of information about consumer tuner and integrated receiver/decoder (IRD) characteristics it is not yet possible to characterise DVB-T receivers precisely. Nevertheless, on the basis of the available theoretical and laboratory test results, typical system implementation losses have been agreed for use within CEPT 3 dB for a 2D-channel estimation or for CD3 and 3.5 dB for a 1D-channel estimation[8].

2.1.2 Subset of system criteria used in planning exercise

A subset of DVB-T variants has been selected from the set given in §2.1.1. This subset is:

- system variant V1: QPSK, 2/3;
- system variant V2: 16QAM, 2/3;
- system variant V3: 64QAM, 2/3;

for 2k and 8k and all guard interval lengths.

Calculation results are only given for these DVB-T variants. However results for other modes can be extrapolated (for the same or similar C/N values). In some of the studies performed, results for other variants were available.

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[8] ''ERC/EBU Report on Planning and Introduction of Terrestrial Digital Television (DVB-T) in Europe, Izmir, December 1997'', page A1-7.

			Required C/N for BER=2 . 10^{-4} after Viterbi (quasi error-free after Reed-Solomon)			Net bit rate (Mb/s)			
System	**Modulation**	**Code Rate**	**Gaussian Channel**	**Ricean Channel (F_1)**	**Rayleigh channel (P_1)**	**D/T_U =1/4**	**D/T_U =1/8**	**D/T_U =1/16**	**D/T_U =1/32**
A1	QPSK	1/2	3.1	3.6	5.4	4.98	5.53	5.85	6.03
A2	QPSK	2/3	4.9	5.7	8.4	6.64	7.37	7.81	8.04
A3	QPSK	3/4	5.9	6.8	10.7	7.46	8.29	8.78	9.05
A5	QPSK	5/6	6.9	8.0	13.1	8.29	9.22	9.76	10.05
A7	QPSK	7/8	7.7	8.7	16.3	8.71	9.68	10.25	10.56
B1	16QAM	1/2	8.8	9.6	11.2	9.95	11.06	11.71	12.06
B2	16QAM	2/3	11.1	11.6	14.2	13.27	14.75	15.61	16.09
B3	16QAM	3/4	12.5	13.0	16.7	14.93	16.59	17.56	18.10
B5	16QAM	5/6	13.5	14.4	19.3	16.59	18.43	19.52	20.11
B7	16QAM	7/8	13.9	15.0	22.8	17.42	19.35	20.49	21.11
C1	64QAM	1/2	14.4	14.7	16.0	14.93	16.59	17.56	18.10
C2	64QAM	2/3	16.5	17.1	19.3	19.91	22.12	23.42	24.13
C3	64QAM	3/4	18.0	18.6	21.7	22.39	24.88	26.35	27.14
C5	64QAM	5/6	19.3	20.0	25.3	24.88	27.65	29.27	30.16
C7	64QAM	7/8	20.1	21.0	27.9	26.13	29.03	30.74	31.67

Note: Quasi error-free means less than one uncorrected error event per hour, corresponding to BER = 10^{-11} at the input of the MPEG-2 demultiplexer.

Table 2: Required C/N for non-hierarchical transmission (8 MHz version) to achieve a BER = 2 **.** 10^{-4} after the Viterbi decoder for all combinations of coding rates and modulation types. The net bit rates after the Reed-Solomon decoder are also listed.

2.2 Technical criteria and planning parameters used in theoretical studies

The technical criteria for the planning and co-ordination of DVB-T networks have been provided by the DVB-T planning meeting Chester 1997. These include the system criteria such as signal-to-noise ratio C/N, protection ratios and minimum field strengths as well as the field strength propagation model and the definition of the reception modes. The present studies use the values given there apart from very few exceptions, which will be mentioned.

2.2.1 Propagation characteristics

For the field strength predictions, the statistical propagation model of ITU-R P.370-7 is used. The parameters of the model are given in Table 3.

Propagation model	Rec. ITU-R P.370-7
Parameter Δh	50 m
Standard deviation of outdoor field strength distribution	5.5 dB
Time percentage for wanted signal	50%
Time percentage for unwanted signal	1%
Correction for 10m -> 1.5 m receiving antenna height	- 12 dB

Table 3: Parameters of the propagation model.

The figures for the building penetration loss, which is necessary for indoor antenna reception calculations, are given in Table 4.

Frequency band	UHF	VHF
Building penetration loss [dB]	7	8
Standard deviation of the building penetration loss [dB]	6	3

Table 4: Values of building penetration loss.

2.2.2 Reception modes

Two reception modes have been studied in detail with respect to spectrum requirements, fixed roof-level and portable indoor. They are given in Table 5 and described in more detail in §1.3 *Reception conditions*.

System	Reception mode	Channel characteristics	Comment
DVB-T	Fixed roof-level	Ricean	Reception at roof level, multipath channel with one dominant component
DVB-T	Portable indoor at ground floor	Rayleigh	Reception at 1.5 m a.g.l., multipath channel building penetration loss

Table 5: Reception modes for DVB-T.

Spectrum requirements for mobile reception and possibly portable outdoor reception will have to be studied at a later stage.

2.2.3 Target percentage coverage

The coverage targets for time, locations and pixels are key elements of planning as described in Chapter 1 of Part 1. The following figures were used in the studies:

- percentage time: 50 % of time for the wanted signal and 1 % of time for the unwanted signal (this is close to a 99 % time protection);
- percentage locations: 70, 95% location coverage;
- percentage pixels covered: 50, 60, 70, 80, 90, 100% of nominal coverage area.

2.2.4 C/N and minimum field strength requirements

2.2.4.1 Fixed roof-level and portable indoor antenna reception

The signal-to-noise ratios for the selected DVB-T variants are given in table 6.

Modulation	Code rate	C/N [dB] fixed roof-level antenna reception (*)	C/N [dB] portable indoor antenna reception (*)
QPSK	2/3	8.7	11.4
16QAM	2/3	14.6	17.2
64QAM	2/3	20.1	22.3

*(*for some of the SFN studies a 0.5 dB lower C/N value was used)*

Table 6: Signal-to-noise ratio C/N for the various DVB-T variants.

The minimum median field strength values applicable for the reception modes and the DVB-T system variants are given in Table 7. (In practice, most of the studies were made for a frequency of 600 MHz). The values for Band III are provided for reference only as no detailed studies have yet been carried out for this band.

Variant	Fixed roof-level antenna reception			Portable indoor antenna reception		
	Band III	Band IV	Band V	Band III	Band IV	Band V
QPSK, 2/3	36.7	41.5	45.7	65.4	75.4	79.4
16QAM, 2/3	42.6	47.6	51.6	71.2	81.2	85.2
64QAM, 2/3	48.1	53.1	57.1	76.3	86.3	90.3

Table 7: Minimum median field strengths for DVB-T in band III (200 MHz), band IV (500 MHz) and band V (800 MHz) and for 95% location coverage.

The minimum median field strength values refer to 10 m a.g.l. Thus they allow a direct application of the ITU-R P.370-7 curves.

2.2.4.2 Mobile reception

Mobile reception has not been studied until now with respect to its spectrum requirement. C/N figures for mobile reception for “TYPICAL RURAL” and “TYPICAL URBAN” profiles have been studied (MOTIVATE reference receiver). It is considered that such values should be regarded as very preliminary and large improvements are expected to be achieved with receivers particularly designed for mobile reception (diversity receiving antennas, advanced channel estimation, etc.). It is thought that C/N figures for mobile reception will become comparable to the portable outdoor reception figures and it is likely that such values will be used in further studies.

2.2.5 Transmitter and network characteristics

The e.r.p. of the transmitter is not essential in these theoretical studies since they are dealing with interference-limited situations where noise has only a limited effect. However it has to be noted that, in real network implementations, e.r.p. restrictions need to be taken into account, although such restrictions may change with time.

In order to provide information about the power levels necessary to reach an interference limited situation, Figures A1, A2 and A3 in Annex A of Part 1 show the minimum powers for some MFN cases as an example.

Chapter 3: Theoretical planning methods

Terrestrial digital television services can be planned using assignments and/or allotments. The 1961 Stockholm Plan was an assignment plan, whereas the 1995 Wiesbaden T-DAB Plan was an allotment plan with procedures for converting the allotments into assignments.

The theoretical planning exercises described in this chapter study the variation of the number of channels per multiplex required to provide different levels of coverage as certain parameters are changed. (See also §4.4.1 *RF channels needed per multiplex and data capacity*). These parameters include the effective transmitting antenna height, the system variant, distance between transmitters (in an MFN) or between co-channel allotment areas (in an SFN). MFN and SFN exercises use regular networks of transmitters with uniform characteristics (equal effective antenna heights, standardised horizontal radiation patterns, equal e.r.p.s, etc.) and a statistical propagation model (ITU-R P.370-7).

3.1 Assignments and/or allotments

3.1.1 Assignments

An assignment defines the location and characteristics of an individual transmitter. In the past, terrestrial television planning in Europe has been based on assignments. European broadcasters have gained much experience in assignment planning, particularly since some of the planning methods of the ST61 conference are still applied to analogue television planning, although the criteria have been extended to allow for the introduction of colour and of stereo sound.

3.1.2 Allotments

The primary purpose of allotment planning is to provide a group of administrations the right to use specified frequencies or channels without the need for detailed knowledge of the assignments which would be used in practice.

The only parameters available in allotment planning are a definition of the area to be covered and the channel to be used. Thus it is normally only necessary to specify the signal levels radiated towards the outside of the allotment.

A convenient method for doing this is to define a reference transmitter (for MFN planning) or a reference network (for SFN planning). Such a reference source may be considered as situated at any point, or at specified points on the boundary of the allotment. The potential interference created by such a reference source may readily be calculated by means of agreed propagation prediction methods.

After the allotment has been agreed, it must be converted into one or more assignments in order that a service may be provided.

3.2 Lattice planning

In broadcasting, lattice planning is generally understood to be the development of geometrical regular lattices having linear channel distributions. However, in the case of digital television, it is normally assumed that the effects of interference other than co-channel can be neglected. The lattice based theoretical studies described below therefore take no account of the absolute channel distribution.

3.2.1 MFN case

The basic idea of lattice based theoretical MFN studies is that the planning area under consideration can be represented as a semi-infinite plane covered by a network of equally spaced transmitters. This arrangement implies that the transmitter sites form equilateral triangles with each transmitter on a different channel (Figure 2). A similar set of transmitters, with larger spacing, represents the sources of co-channel interference (Figure 3) and is the basic geometric structure which is used by the different calculation methods. (Strictly speaking, the sites do not need to form equilateral triangles, but this is a convenient starting point for the studies.)

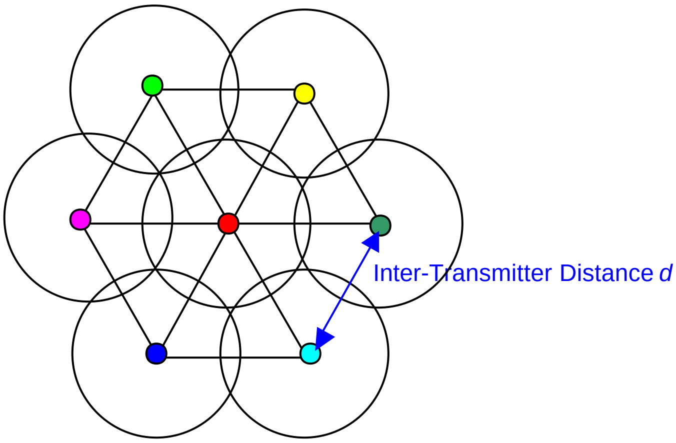


Figure 2: Hexagonal structure of MFN coverage showing inter-transmitter distance.

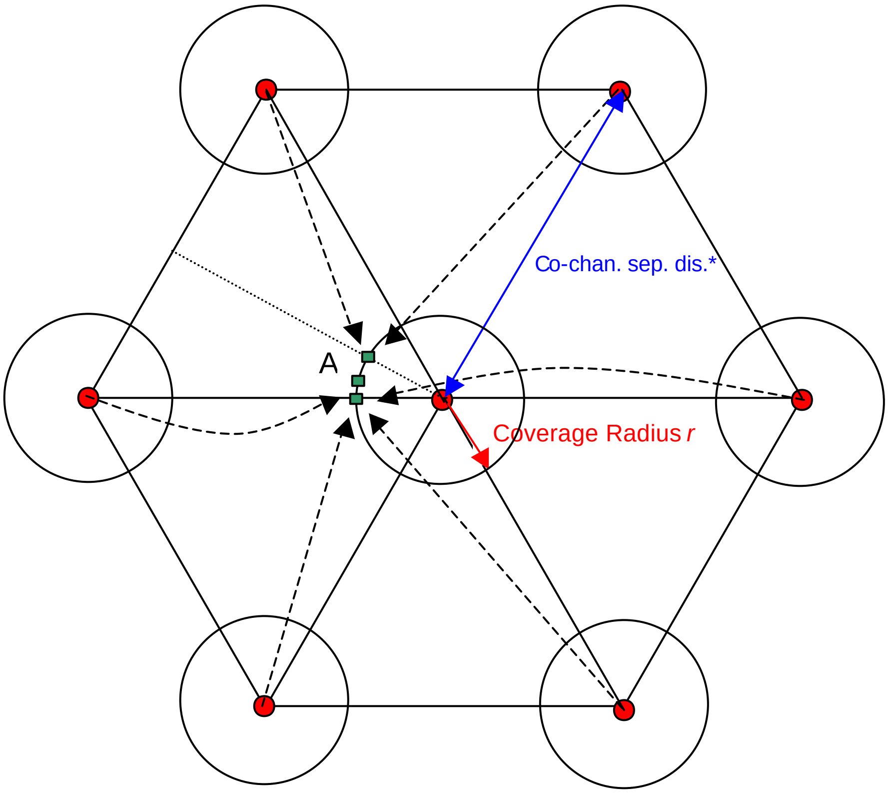


Figure 3: Multiple co-channel interference at points A.

(* co-channel separation distance)

3.2.2 SFN case

Similar ideas can be used for theoretical SFN studies; the primary difference is that the basic unit providing coverage is a group of transmitters acting as an SFN, rather than a single transmitter. The other major difference is that it is the spacing between individual co-frequency SFNs which determines the spectrum requirement, rather than the spacing between the sites of co-frequency transmitters.

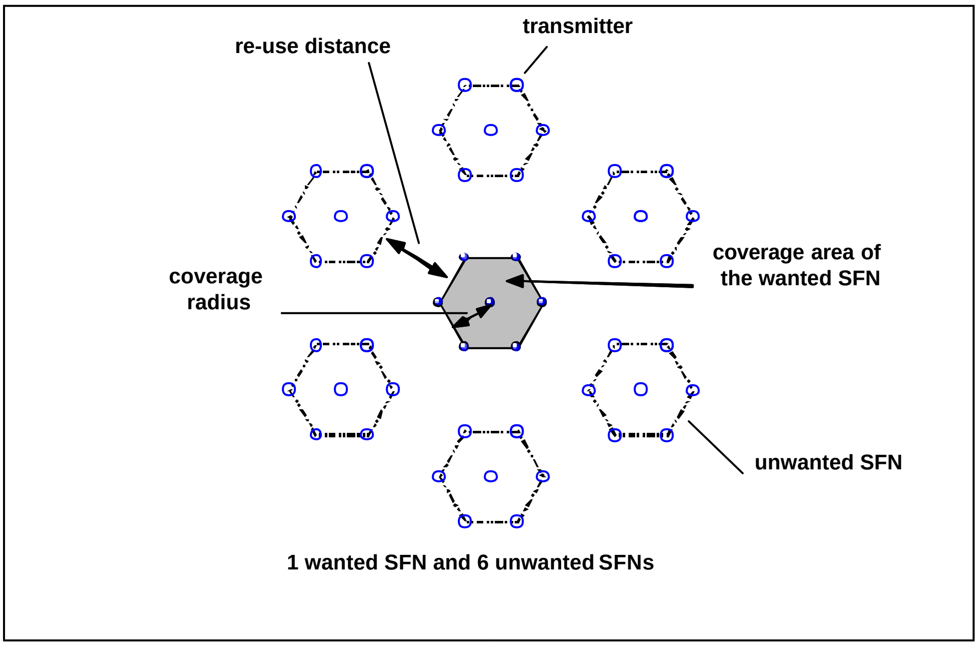


Figure 4: A model of SFN configuration.

3.3 Description of calculation procedures

The following paragraphs give the description of the calculation procedures used to provide the spectrum requirements results given in this report.

3.3.1 Description of a calculation procedure for MFN

One possible calculation procedure is thus:

1 Set up the input parameters:

- 1.1. Reception mode (including receive antenna characteristics if fixed antenna reception);
- 1.2. System variant;
- 1.3. Minimum required C/N for system (from 1.1 and 1.2) with 3 dB implementation margin added. This value is also used for the minimum required C/I;
- 1.4. Minimum required location percentage;
- 1.5. Standard deviation with location, s_w, dependent upon 1.1;
- 1.6. Minimum median equivalent field strength at 10 m (from 1.1, 1.3, 1.4 and 1.5);
- 1.7. Percentage of the maximum coverage (percentage pixels), *p;*
- 1.8. Distance between transmitters, *d* in MFN (Figure 2);

1.9. Effective antenna height of transmitter.

2 Calculate the service radius, *r* from 1.7 and 1.8.

$$\frac{d}{\sqrt{3}} \bullet \sqrt{\frac{p}{100}}$$

3 Calculate e.r.p. required to give the minimum median equivalent field strength for 50% time at 10 m at distance *r* (noise limited coverage) from 1.6 and 1.9.

4 Set up network of transmitters in Figure 2 using the transmitting antenna height given in 1.9 and the e.r.p. given in 3.

5 Calculate an initial value for the reuse distance.

6 Iteration loop:

6.1. for each of the test points A in Figure 2:

6.1.1 calculate the field strength from each of the interfering transmitters for 1% time, using the e.r.p. from step 3 and the antenna height from step 1.9;

6.1.2 calculate the cumulative interfering field strength. For example, using the k-LNM, obtain the median and standard deviation values, $\bar{f}$ and σ_i, of the set of interfering field strengths;

6.1.3 calculate the protection margin (PM). For example using the k-LNM,

$$PM = wanted - (\bar{f} + CI + q\sqrt{(s_W^2 + s_I^2)})$$

Using $\bar{f}$ and σ_I from step 6.1.2

CI is the value of C/I from step 1.3

σ_w from step 1.5

wanted is the signal level from step 1.6

q is the inverse cumulative distribution function corresponding to the required location percentage in step 1.4. For example q = 1.645 for 95% locations and 0.524 for 70% locations. (See Annex B of Part 1 for equations to derive the value of q for other percentages);

6.2. select the smallest value of PM from step 6.1.3;

6.3. If PM < 0, increase D

PM > 0, reduce D

7 Repeat iteration loop until the absolute value of PM < 0.3 dB (or some similar value).

3.3.2 Description of calculation procedure for SFN

One possible calculation procedure referring to the SFN approach described in §3.2.2 could be:

1 Set up the input parameters:
1.1 – 1.8 as in §3.3.1

2 Evaluate the re-use distance for the SFN.

To evaluate the re-use distance, six interfering (regular) SFNs are symmetrically situated around the wanted (regular) SFN, as depicted in Figure 4. They are uniformly shifted towards the wanted SFN until the coverage probability at some location within the wanted SFN falls below the chosen minimum required location percentage. The distance when this happens defines the re-use distance. The resulting re-use distance is assumed to be approximately the same for all SFN diameters.

3 Choose the diameter of the SFN;

4 Evaluate the number of channels needed.

The number of channels needed is calculated by means of an EBU model. The input parameters of the model are the re-use distance and the SFN diameter from 2 and 3. It is to be noted that the use of this model gives channel numbers which are rounded upwards to the nearest “rhombic number“. This rounding process has not been applied to the results of the MFN studies and thus the two sets of results may only be compared to a limited extent.

3.4 Monte Carlo method

The Monte Carlo method is particularly useful for making calculations in cases where it is necessary to evaluate the impact of random variations in one or more of the contributing components. It thus has a direct application in the calculation of coverage, especially where there are multiple wanted or interfering signals, or where there are both, as it is then necessary to consider the effect of multiple randomly varying signal levels.

The Monte Carlo method may be applied to the calculation of coverage by dividing the area concerned into a large number of sub-areas. For each of these sub-areas, a calculation of the 50% location signal level value at the centre of the sub-area is made using, for example ITU-R P.370-7. A large number of samples is then examined by using a random number generator to provide the field strength differences equivalent to the random distribution experienced in a real-world situation. The statistics of this set of samples may then be examined in order to find, say, the signal levels corresponding to 95% or 70% of locations, and thus determine whether a given percentage of locations may be considered served or not. It is necessary to use a large number of samples to ensure that the statistics from them can be regarded as accurate. The result is that a relatively large amount of computation time is required and it is this element which make the Monte Carlo method unattractive for general use as part of any large scale planning exercise.

Where there are multiple wanted or interfering signals, the samples are generated independently for each contributor and summed using the power sum method, modified if necessary to take account of signal arrival times. The overall statistics are then determined using the results of the summation process.

Chapter 4: Results of theoretical planning exercises

4.1 Introduction

Theoretical, lattice-based studies provide a powerful means for evaluating the impact of varying the planning parameters for a television service, or any other service requiring widespread coverage. However the primary constraint that must be applied is to note that the results obtained from such studies do not give absolute values for the spectrum requirement. However, they give the change in the relative values when specific parameters are varied.

The results presented here are extracted from several studies, given in the list of references included in Part 3.

4.2 Types of study

Studies have been carried out for two different network concepts. These are Multi Frequency Networks (MFNs) and Single Frequency Networks (SFNs). In both cases, the planning parameters have been varied over a wide range and it must be noted that some of the combinations of parameters are unlikely to be feasible in practice. However, they were included in order to make the studies cover a very large range of possible planning scenarios, rather than being confined to specific examples, which could be regarded as being representative of the needs of a specific a given country.

The presence of national boundaries will have the effect of increasing the spectrum needed, not only near the boundaries themselves, but also at some distance from the boundaries because of the resultant distortion of the lattice. Similarly, the use of "real" transmitting sites in place of the theoretical (ideal) lattice locations will increase the spectrum needed. The impact of "real" terrain is more difficult to judge in a theoretical manner. In some cases, there will be an increase in the spectrum requirement; in other cases there could be a reduction. (See also Part 2).

Answers on the points raised in the previous paragraph can only be given when further studies have been undertaken, based on examples of real networks. The reason that the theoretical studies have been undertaken first is that a much wider range of parameters can be examined in a reasonable time frame than would be possible if the studies were based only on real networks. In any case, the existing networks do not represent the full range of parameters already agreed for study.

4.3 Results

4.3.1 MFN case

Theoretical studies have been undertaken by CSA, RTE and EBU. The results were reasonably similar, although not identical as somewhat different assumptions were made during the calculation processes. It is to be expected that the results will approach one another as the processes are refined and more elements are taken into account. For illustration, curves giving results for many configurations are given in Annex C of Part 1.

4.3.2 SFN case

Theoretical studies have been undertaken by IRT and EBU. The latter were only for fixed antenna reception in an open network and the results were comparable to the results obtained by IRT for closed networks. The results quoted here correspond only to 100% pixel coverage and 95% location coverage and use "closed network" configurations. These basic examples deal with the cases where coverage of large areas is provided by different sizes of SFN.

The discussion about SFNs is given for fixed roof-level antenna reception and for portable indoor antenna reception. It is noted that fixed roof-level antenna reception is possible but considering that the most interest is for portable indoor antenna reception, most studies for SFN have been made for portable indoor antenna reception. For illustration, curves giving results for many configurations are given in Annex D of Part 1.

4.4 Discussion of results

The objective of this exercise is to determine the number of channels necessary for the realisation of a service or set of services. Reader must be reminded that this is a theoretical exercise and gives values for an ideal situation.

The exercise is complex, using criteria specific to standard (non-hierarchical) DVB-T variants and parameters suitable for planning. At a first level, it is easy to compare different scenarios for one type of network configuration, either MFN or SFN on the basis of the number of channels needed for one multiplex, a concept derived directly from ideas based on analogue planning. Indeed, this was the original intention of much of the study. However, it was realised that it would then be necessary for administrations to perform additional tasks in order to convert such results into the total amount of spectrum needed to carry a given number of services using specific system variants. So, at a second level, it was considered useful to make additional comparisons taking account of the total data-rate which could be carried in a number of RF channels. A specific example is given for the purposes of illustration. For theses comparisons it is calculated the total number of channels needed to transmit a given data-rate; it is called the “**equivalent number of channels**”.

4.4.1 RF channels needed per multiplex and data capacity

Many of the earlier discussions, which have taken place about the amount of spectrum required, relate to the number of RF channels needed per multiplex. However, this is only part of the equation. The other part is the data capacity of the multiplex carried in each channel. This data capacity also needs further consideration. For example, 64QAM code rate 2/3 can provide a data capacity in two channels of about 48 Mb/s if used with a low value of guard interval (for example 1/32 of the active symbol period). With two channels, 16QAM can provide a data capacity of about 32 Mb/s and three channels are needed to provide a data capacity of 48 Mb/s. This observation can provide a simple (even if only approximate) method for considering the number of channels needed to provide a given data capacity.

The three (primary) system variants selected by B/CAI-FM24 as the basis for spectrum requirement investigations are QPSK rate 2/3, 16QAM rate 2/3 and 64QAM rate 2/3. For any given guard interval ratio (however, the same value for all of the three system variants), these have data capacities in the ratios 1:2:3.

Thus, results can be presented in terms of “equivalent number of channels’’ needed by multiplying:

- by 3 the number of RF channels per multiplex for QPSK;
- by 1.5 the number of RF channels per multiplex for 16QAM;
- by 1 the number of RF channels per multiplex for 64QAM.

In this way a direct comparison may be made of the number of channels which would be needed to provide a given spectrum capacity, bearing in mind that is not possible to provide a “half channel” or any fraction of a channel. The theoretical number of channels calculated must be rounded to the next higher integer.

It must be remembered that this is a theoretical process designed only to permit a comparison between the RF channel requirements for different system variants when these are being used to provide a given data capacity. The “equivalent number of channels” does not represent any absolute amount of spectrum.

Some typical examples of such comparisons are given in Figures C1 to C8 to be found in Annex C of Part 1. These results show clearly that in order to provide for a given data capacity, similar numbers of channels are needed for 64QAM and 16QAM and rather more channels are needed for QPSK.

It may be more difficult to think in terms of number of channels for a given data capacity than it is to think in terms of channels per multiplex. However, it must be noted that the former approach is much more closely related to the amount of spectrum needed to provide a specific service. The concept of ‘number of channels per multiplex’ is clearly derived simply from the concepts used for analogue planning and may not, ultimately, prove very useful when planning for the all-digital future.

To illustrate the concept of equivalent channel requirements, an example could be where 18 channels (144 MHz) are made available to provide a data capacity of 48 Mb/s with a specified coverage target (say, fixed antenna, 95% location, 100% pixel coverage). The transmissions could use either:

three 16QAM multiplexes each using 6 RF channels; or,
two 64QAM multiplexes each using 9 RF channels .

4.4.2 Discussion on the influence of criteria and parameters

The theoretical studies (semi-infinite area, entire spectrum available) show that a minimum of 3 to 4 channels would be needed for complete coverage for one multiplex.

- For an MFN, this would be possible with small distances between transmitters (less than 20 km), the use of QPSK and a uniform antenna height of between 150 m and 300 m.

- For an SFN, this would be possible with highly symmetrical hexagonal coverage areas, which clearly cannot be achieved in the real-world taking into account: terrain, country boundaries, cultural areas, etc.

It would not be possible to apply these constraints in most European countries.

It is thus necessary to analyse the whole set of parameters before limiting on the studies to those sets of parameters which give realistic solutions.

However, within these sets of realistic solutions, all operators in the various countries will not necessarily choose the same criteria, nor the same parameters. It is thus necessary to discuss a range of solutions.

In order to simplify the discussion of the results, some of the calculated values for parameters such as transmitting antenna heights of 1200 m, 600 m and 37,5 m have been discarded. The discussions are concentrated on two typical values 150 m and 300 m of effective antenna height, with some attention also being given to a value of 75m.

In the discussion, the reader would be helped by the studying the curves relative to different cases which are given in the Annexes C (for MFN) and D (for SFN) of this Part 1.

4.4.2.1 MFN – fixed roof-level antenna reception

This coverage option can be used inside a theoretical lattice to provide a medium to large coverage radius from a single transmitter with a large effective antenna height. The theoretical calculations do not take into account country boundaries nor regionalisation within a country. See Part 2 for the impact of real-world considerations.

In general terms, for transmitting antenna effective height values of 150 and 300 m, the distance separation between transmitters in the range 50 to 100 km has little effect on the number of channels needed, except in the case of QPSK.

However, dense networks with short inter-transmitter distances could be envisaged in a real-world lattice planning. In these cases, the use of low effective antenna heights (75 m or less) may be advantageous.

a) The distance between transmitters

See Figures C1 and C2.

Through the example of fixed antenna reception, 95% locations covered, 100 % pixels covered, and main station effective antenna heights of 150 and 300 m, it can be seen that the number of channels is nearly constant for distances between transmitters from 50 to 100 km.

For this example, the most relevant results are given in Table 8:

MFN - Fixed antenna reception 95 % locations, 100% pixel, distance between transmitters 50 - 100 km				
Effective Antenna Height	Number of channels		Equivalent number of channels	
	64QAM	16QAM	64QAM	16QAM
150 m	9	6	9	9
300 m	6	4	6	6

Table 8: Case of fixed antenna reception, 95% locations, 100% pixels covered for MFN.

In terms of equivalent number of channels (See §4.4.1), the two options 64QAM and 16QAM need the about same number (i.e. 9 channels for 150 m of effective antenna height and 6 channels for 300 m), while QPSK would need about 12 and 9 channels, respectively.

b) The effective antenna height

See Figures C1 and C2.

In any given example, effective heights of antennas are constant throughout the theoretical network. It seems realistic to take effective heights of 150 to 300 m for the main transmitters of the national networks. The change of effective antenna height from 300 m to 150 m increases the number of channels by 2 to 3 depending on the sensitivity of the DVB-T variant.

c) Modulation

See Figures C13a and C13b.

In terms of the number of channels needed to provide for one multiplex, the least sensitive modulation QPSK needs fewer channels for the wanted coverage than either 16QAM or 64QAM. But it provides for a lower data capacity than more sensitive modulations such as 64QAM. To have a proper comparison of the DVB-T variants, the comparison has to be made through the equivalent number of channels. See Table 8.

d) Percentage of pixels covered

See Figures C9 and C10.

For the distance between transmitters in the range 50 to 100 km, each decrease in the pixel coverage by 10% lowers the theoretical channel requirement by about one channel. Thus, a 64QAM, 150 m of antenna height with 50% pixels will require 5 channels, 7 per 70%, 8 per 90% and 9 to 100%. It must be noted that this simple explanation applies only to the specific set of results quoted here.

The impact of real-world considerations takes into account the percentage of pixel coverage and this topic is discussed in Part 2.

4.4.2.2 MFN – Portable indoor antenna reception

a) The distance between transmitters

See Figures C5 and C6.

For this example of portable indoor antenna reception, 70% locations covered, 100 % pixels covered, and main station effective antenna height between 150 and 300 m, the most relevant results are given in Table 9.

The maximum e.r.p. of a transmitter limits the distance of the area coverage for portable indoor receiver. A distance of 10 to 60 km between transmitters must be taken into account if practicable radiated powers are to be used and realistic coverages are to be achieved. See Annex A of Part 1.

MFN - Portable indoor antenna reception 70 % locations, 100% pixels, Distance between transmitters 10 - 60 km						
Effective Antenna Height	Number of channels			Equivalent number of channels		
	64QAM	16QAM	QPSK	64QAM	16QAM	QPSK
150 m	15 to 18	10 to 13	6 to 9	15 to 18	15 to 20	18 to 27
300 m	24 to 12	16 to 9	11 to 6	24 to 12	24 to 14	33 to 18

Table 9: Case of portable indoor antenna reception 70 % locations, 100 % pixels for MFN.

b) The effective antenna height

See Figures C5 and C6.

As noted above, it is necessary to restrict the range of transmitter separation distances in the case of portable indoor antenna reception if excessive radiated power requirements are to be avoided. The range of powers needed without such restrictions can be seen in the curves in Annex A of Part 1. It must be noted that for inter-transmitter distances of greater than about 50 km, 150 m effective antenna height requires less channels than 300 m effective antenna height.

c) Modulation

See Figures C14a and C14b.

In terms of the number of channels needed to provide for one multiplex, the least sensitive modulation QPSK needs fewer channels than either 16QAM or 64QAM. However, it provides for a lower data capacity than more sensitive modulations such as 64QAM. To have a proper comparison of the DVB-T variants, the comparison has to be made through the equivalent number of channels. See Table 9.

d) Percentage of locations covered

While it has been considered that 95% location coverage is essential for fixed antenna reception, partly because there is usually no possibility to optimise the position of a fixed receiving antenna, it may be considered that the provision of 70% location coverage is sufficient for portable indoor antenna reception. Comparison of Figures C3, C4, C5 and C6 shows that this can lead to a significant reduction in the number of channels needed.

However, if a network of several multiplexes is required, care must be taken to ensure that the receiving antenna does not have to be moved when changing from one multiplex to another. This may require the percentage of locations covered to be greater than 70%.

e) Percentage of pixels covered

See Figures C11, C12, C7 and C8.

A decrease in the percentage pixel coverage makes it possible to decrease the number of channels significantly. For example, it is possible to provide for portable indoor antenna reception in a network intended for fixed antenna reception if it is accepted that there is a significant reduction in the percentage pixel coverage. In this case, portable indoor antenna reception is possible close to the transmitters and difficult further away.
As an example see in Table 10 the case of 70 % of pixel coverage.

MFN - Portable indoor antenna reception 70 % locations, 70% pixels, Distance between transmitters 10 - 60 km						
Effective Antenna Height	Number of channels			Equivalent number of channels		
	64QAM	16QAM	QPSK	64QAM	16QAM	QPSK
150 m	10 to 13	7 to 9	10 to 6	10 to 13	11 to 14	30 to 18
300 m	21 to 8	13 to 6	9 to 4	21 to 8	20 to 9	27 to 12

Table 10: Case of portable indoor antenna reception 70 % locations, 70 % pixels for MFN.

In conclusion, portable indoor antenna reception in an MFN requires a large number of channels and it does not seem realistic to provide national coverage. That does not mean to say that there is no possibility of portable indoor antenna reception close to the transmitters. However, it is possible inside a coverage designed for fixed antenna reception to increase the field strength and hence the percentage of pixels covered by using SFN gap-fillers.

4.4.2.3 SFN – fixed roof-level and portable indoor antenna reception

1) Width of the service area and re-use distance

The number of channels needed per multiplex varies with the width of the service areas and the re-use distances that are considered in the model.

In practice, the service areas correspond to cultural or administrative areas. Generally, both are common. The width of the service area varies from one country to the other and even inside a country. They are found to be between 50 and 200 km. Larger SFN diameters may exist but will not influence the results significantly except that self-interference effects will limit the use of more sensitive modulations in large networks.

The re-use distances have effect on the number of channels needed according to the diameter of the service area of the SFN. Typically, re-use distances from 40 to 120 km can be considered. According to these values, by using calculations made by the IRT, the assessment of the number of channels needed are found to be between 3 and 16 channels.

It will be noted that the re-use distances increase significantly with the use of higher modulation schemes: for example, from 62 km with QPSK 2/3 to 120 km with 64QAM 2/3 (for portable indoor antenna reception). There is thus a balance to be found between the re-use distance and the data capacity of the modulation scheme to be chosen. A more sensitive modulation scheme needs a larger re-use distance but – on the other hand – offers a higher data capacity. In addition, large SFN areas show better spectrum usage, which is particularly obvious for the sensitive DVB-T variants. However, sensitive DVB-T variants will have self-interference restrictions.

It must be noted that the calculations made for these SFN studies assume that the inter-transmitter distance is 60 km and that the effective antenna height is 300 m.

Results for the most interesting cases are given in Tables 11 and 12:

SFN - Fixed antenna reception, 95% locations, 100% pixels						
Service area diameter	Number of channels			Equivalent number of channels		
	64QAM	16QAM	QPSK	64QAM	16QAM	QPSK
50 km	9	7	4	9	11	12
150 km	3	3	3	3	5	9

Table 11: Case of fixed antenna reception, 95 % of locations, 100 % of pixels for SFN.

The 50 km case gives the lower limit for reasonable SFN areas, where the coverage area of a single transmitter, i.e. the MFN concept, is approached. Therefore the results of the MFN and the SFN approaches should be the same or at least similar for that case. Possible differences arise from the use of different models and, in particular, from the use of integer (for SFN) or continuous (for MFN) channel requirement functions.

SFN - Portable indoor antenna reception, 95% locations, 100% pixels						
Service area diameter	Number of channel			Equivalent number of channels		
	64QAM	16QAM	QPSK	64QAM	16QAM	QPSK
50 km	16	12	7	16	18	21
150 km	4	4	3	4	6	9

Table 12: Case of portable indoor antenna reception, 95% locations, 100 % pixels covered for SFN.

It should be noted that the results of the present SFN study are obtained for idealised network and service area configurations: closed SFNs, with ideal transmitting antenna patterns for the outer transmitters, highly symmetrical coverage areas etc. A careful interpretation of the results has to be made when extrapolating to real-world planning cases.

2) Modulation

The number of channels for different modulation schemes varies according to the respective re-use distances. For an SFN with 50 km in diameter the QPSK 2/3 variant will require 7 channels, the 16QAM 2/3 variant will require 12 channels and the 64QAM 2/3 variant will require 16 channels for the case of portable indoor antenna reception. For fixed roof-level antenna reception, the same SFN would need 4 channels for QPSK 2/3, 7 channels for 16QAM 2/3 and 9 channels for 64QAM 2/3.

For larger SFNs, e.g. of 100 km diameter, 16QAM 2/3 will require 7 channels for a portable indoor antenna reception, which is 5 channels less than for the case of an SFN of 50 km diameter.

3) Percentage of locations covered

All transmitters of an SFN contribute to the coverage of the service area and no transmitter can be treated separately. In the study it is assumed that the density, the powers and the effective antenna heights of the SFN transmitters are arranged such that all of the intended service area is covered. Therefore distance between transmitters and effective antenna height are not explicit parameters of the model.

It is noted that the percentage of locations covered for a given power varies from one modulation to another. Good coverage will be obtained with less with a QPSK 2/3 variant than with a 64QAM 2/3 variant. However, this is a general feature of all network modes.

4) Percentage of pixels covered

In each example in Annex D of Part 1, 100% pixel coverage is considered. As for the MFN case, reduction of the pixel coverage reduces the number of channels needed.

4.4.2.4 Mixed MFN and SFN.

No calculations have yet been made of combinations of an MFN and an SFN. Such a combination could occur for the case of one type of network being used in one country and the other in a neighbouring country. In this case, calculations will need to be based on real transmitter locations and take real country boundaries into account.

A combination of MFN and SFN could also be used within a single country, where a main station MFN is used to provide a major part of the coverage. Relay stations are then provided to complete the coverage by re-using the same channel as the relevant main station. This case could be simulated by choosing a medium to low percentage pixel coverage for the main station in the MFN and then adding small stations on an SFN basis to increase the overall pixel coverage. This may be interesting as a means for reducing the total spectrum requirement and also the e.r.p.s of the main station while also providing a high percentage of pixel coverage. (It may also be interesting as part of a transition philosophy where the lower power stations are not added until some or all of the existing analogue stations are removed).

4.4.2.5 Comparison between MFN and SFN.

The following Table 13 contains figures for MFN and SFN configurations for portable indoor antenna reception. It should be noted that this is a theoretical case and that the configurations of the two networks, MFN and SFN, are not equivalent. The comparison is given here to complete the discussion.

The figures given in this table show that while it is possible to make a comparison between the channel requirements for SFN and MFN, such a comparison is only valid for a limited area and case by case basis, which was not the purpose of this study.

Portable indoor antenna reception 95% locations, 100% pixels, distance between transmitters 10 - 60 km.				
	Number of channels needed		Equivalent number of channels	
	64QAM	16QAM	64QAM	16QAM
MFN (150 m effective antenna height)	49-38	28-31	49-38	42-47
MFN (300 m effective antenna height)	60-25	40-19	60-25	60-29
SFN (50 km diameter, 300 m effective antenna height)	16	12	16	18

Table 13: Comparison of number of channels needed and equivalent number of channels for SFN and MFN Portable indoor antenna reception, 95 % locations and 100% pixels covered.

Table 14 below contains values of the number of channels needed for MFN and SFN for the case of fixed antenna reception. The number of channels obtained in this example shows that it could be difficult to make a choice between the two configurations. Other criteria and parameters also enter into account, as do the details of the calculation process. However, the following comparison could be useful for administrations to analyse an example of mixed MFN-SFN on each side of a regional or national country boundary.

Fixed reception 95% locations, 100% pixels, distance between transmitters 15 - 50 km.				
	Number of channels needed		Equivalent number of channels	
	64QAM	16QAM	64QAM	16QAM
MFN (150 m effective antenna height)	7 to 9	4 to 5	7 to 9	6 to 8
MFN (300 m effective antenna height)	7 to 6	4	7 to 6	6
SFN (50 km diameter, 300 m effective antenna height)	9	7	9	11

Table 14: Comparison of number of channels needed and equivalent number of channels for SFN and MFN fixed roof-level antenna reception, 95 % locations and 100% pixels.

In conclusion, it is, in general, impossible to make direct comparison between SFN and MFN solutions in terms of channels due to the complexity of the scenario. The frequency planners must compare the two network configurations, MFN and SFN, by means of specific calculations taking into account the criteria and parameters chosen and the actual assumptions of the area to be covered.

Chapter 5: Summary of the results

The discussions of the theoretical results give indications about the influences of criteria and parameters on the number of channels (or the equivalent number of channels) needed for a complete coverage of one multiplex.

Tables 8 to 14 in §4.4 *Discussion of results* show that the SFN mode could appear to require less spectrum than an MFN choice. It is important not to forget that the results are given for the ideal case. In particular, it is considered that population is evenly distributed (which is not true) and that the studies do not take into account country boundaries or any subdivision of the country into regions. Part 2 summarises in two pages the impact of real-world considerations which are sometimes far from the models (even if some countries fall completely in one of the models) and will distort the theoretical results.

As is said in §4.4.2.6 *Comparison between MFN and SFN*, it is impossible to make useful comparisons between MFNs and SFNs in terms of number of channels needed due to the complexity of the scenarios. Frequency planners must compare the two configurations mode MFN and SFN by specific calculation taking into account the criteria and parameters chosen and actual assumptions of the area to be covered.

For many reasons countries may adopt different configurations of networks MFN, SFN or mixed MFN-SFN and may adopt different DVB-T variants, probably mainly 64QAM and 16QAM, but QPSK and hierarchical variants cannot be excluded. Each choice can be justified by the particular needs of each country or network operator.

The curves which give the "equivalent number of channels" needed to provide a given level of coverage should be examined. This examination will show which of the DVB-T system variants needs the lowest number of channels to provide a specified data capacity – an important factor in any comparison of variants. However, it must be remembered that the "equivalent number of channels" concept is an artificial one and does not represent any absolute quantity of spectrum. Furthermore, the whole process is a theoretical one based on a semi-infinite plane populated by a uniform lattice of transmitters.

To illustrate this comparison, a simple example would be where 18 channels are made available to provide a data capacity of 48 Mb/s with a specific target (say, fixed antennas, 95% location, 100% pixel coverage). The transmissions could use either:

> three 16QAM multiplexes each using 6 RF channels; or,
> two 64QAM multiplexes each using 9 RF channels.

Each solution presents advantages or disadvantages depending on different national points of view.

The same illustration could be made for an example of SFN planning (fixed reception, 95%, 100% pixel coverage) with 50 km service area width (example of Table 11) which needs 9 channels to transmit a multiplex of 64QAM or 7 channels to transmit a multiplex of 16QAM. Referring to the "equivalent channel requirements to carry the same data capacity", the figures would be 9 channel (72 MHz) for 64QAM and 11 channels (88 MHz) for 16QAM. However, considerable care is needed with this example because of the distorting effect of rounding the number of channels needed upwards to a rhombic number.

No comparison of results between MFN and SFN is given here for portable indoor coverage. While it may be possible to make such a comparison, the results given in §4.4.2.6 *Comparison between MFN and SFN* show that the choice of parameters have a great influence on the number of channels needed. Thus the comparison is only valid for a limited area and case-by-case basis, which was not the purpose of this study.

These examples indicate that it is necessary to take the figures cautiously.

It must be noted that the spectrum requirements shown are minimum theoretical values and it is likely that somewhat higher values will be needed in most practical situations, especially in areas near to common national boundaries. It must also be noted that the MFN calculation process is subject to some rounding effects and no account should be taken of small differences between adjacent values, either on a single curve or between curves. In addition, the MFN calculations have taken no account of the use of integer numbers of channels nor of any specific distribution of channels to transmitters and these two effects are both likely to lead to some increases in the number of channels needed.

Annex A of Part 1: E.r.p. requirements for MFN

The curves in this Annex show the minimum radiated power, e.r.p., which is needed to achieve the minimum median wanted signal levels at the edge of any given MFN coverage area. The power level needed depends on the criteria and parameters used for each planning exercise. It can be seen that the power levels needed for fixed antenna reception may be regarded as reasonable, at least for effective transmitting antenna heights of 150 m or more. However, the values needed for portable indoor antenna reception are unrealistic in a number of cases. This can be either because it is not possible to achieve the values shown or because the resulting signal levels could pose significant health hazards, or EMC problems, at locations near to the transmitting sites. It can be seen that the radiated power levels for 70% location coverage and portable indoor antenna reception are significantly lower than those required for 100% location coverage and portable indoor antenna reception.

The following figures are included in this Annex:

Figure A1: Radiated power needed for fixed antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, pixel coverage: 100%.
Parameter: H_{eff}.

Figure A2: Radiated power needed for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, pixel coverage: 100%.
Parameter: H_{eff}.

Figure A3: Radiated power needed for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, pixel coverage: 70%.
Parameter: H_{eff}.

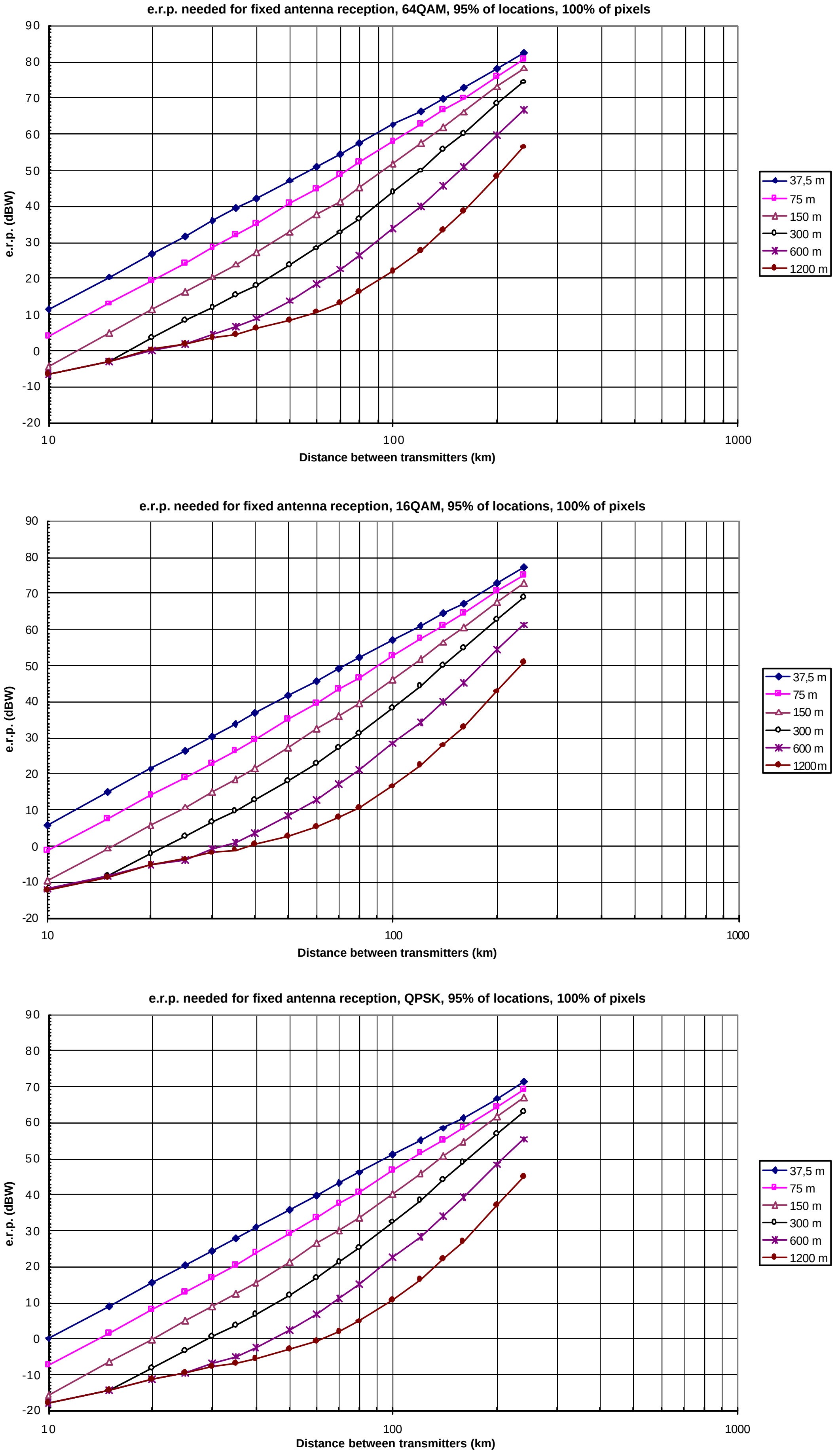


Figure A1: Radiated power needed for fixed antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, pixel coverage: 100%.
Parameter: H_{eff}.

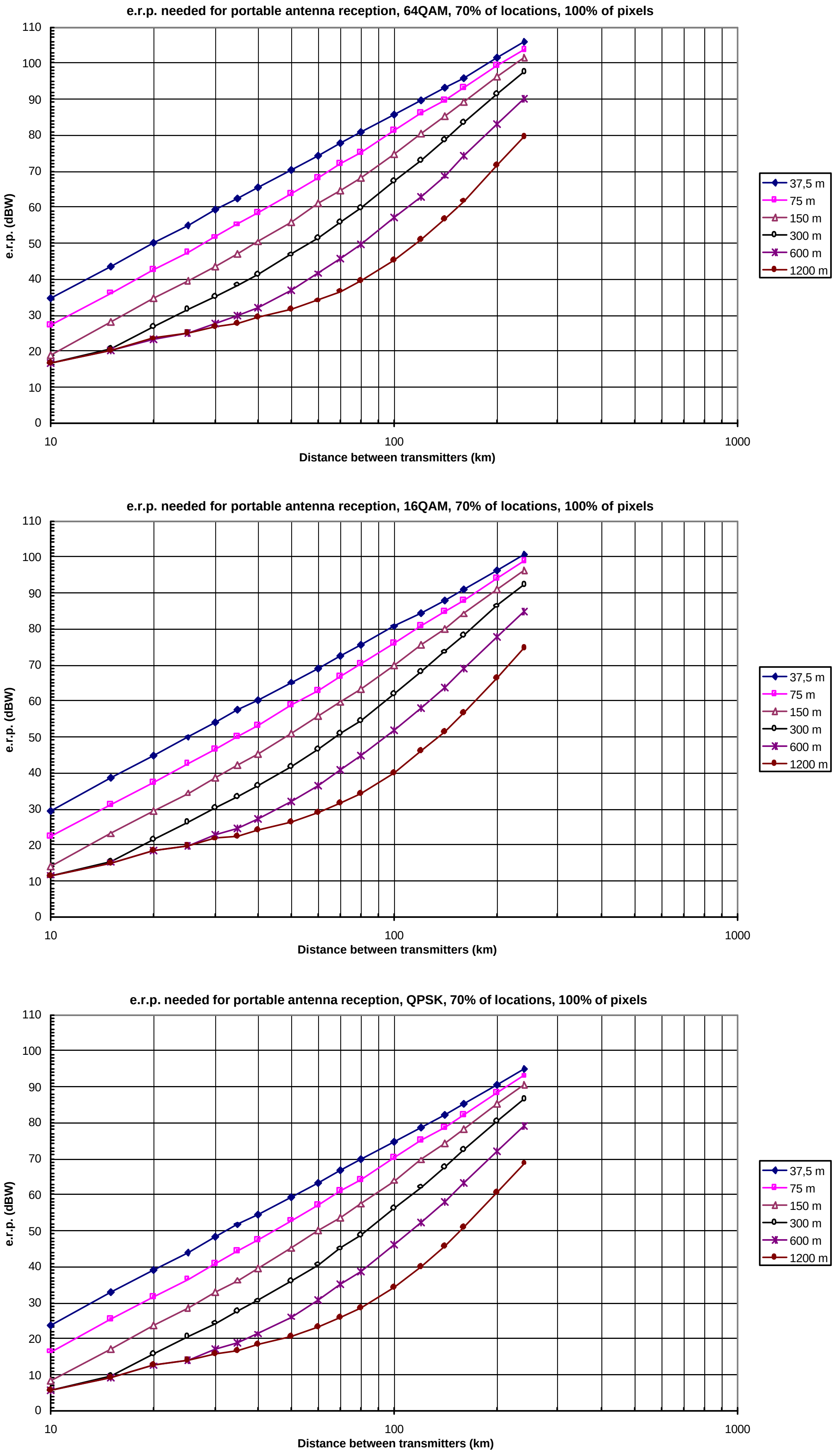


Figure A2: Radiated power needed for portable indoor antenna reception, using 64QAM, 16QAM or QPSK. Location probability: 70%, pixel coverage: 100%. Parameter: H $_{\text{eff}}$.

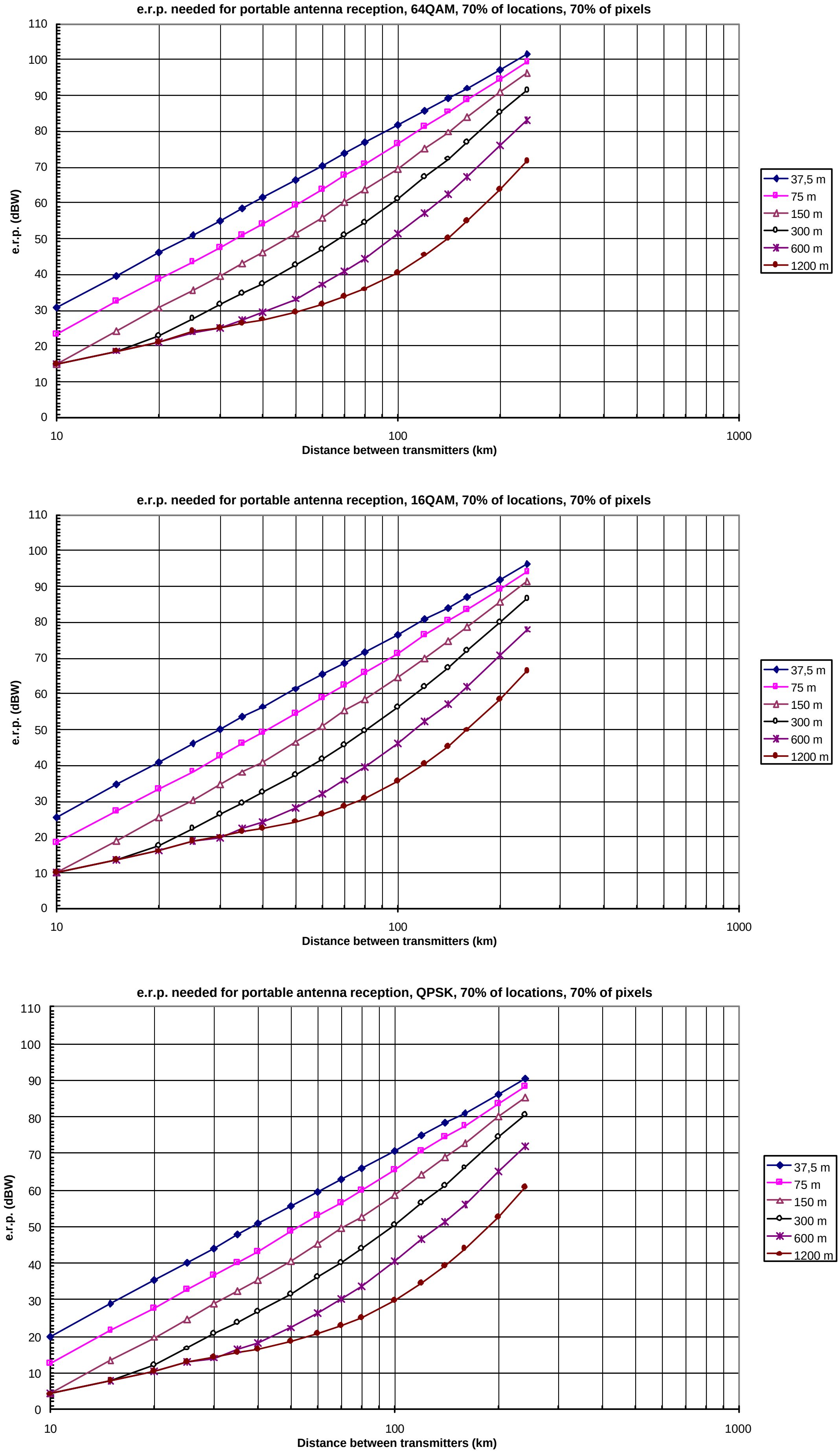


Figure A3: Radiated power needed for portable indoor antenna reception, using 64QAM, 16QAM or QPSK. Location probability: 70%, pixel coverage: 70%.
Parameter: H $_{\text{eff}}$.

Annex B of Part 1: Distribution function q

The cumulative distribution function

$$p(x) = \frac{1}{\sqrt{2p}} \int_{-\infty}^{x} e^{\frac{-t^2}{2}} dt$$

gives the total (cumulative) probability, p, that the value x of a continuous random variable, with a Gaussian distribution[*], is not exceeded in a trial with a large number or random events.

The <u>inverse</u> cumulative distribution function

$$x(p) = I(p)$$

gives the value, x, of the random variable which will not be exceeded, with probability p, in a trial with a large number of random events. The expression for *I(p)* cannot be expressed in a closed form. It can be approximated with the following equations:

1) if $0 < p \leq 0.5$, then

$$I(p) = -\left[t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right]$$

with $t = \left[\ln(\frac{1}{p^2}) \right]^{\frac{1}{2}}$

and $c_0 = 2.515517$ $d_1 = 1.432788$
$c_1 = 0.802\,853$ $d_2 = 0.189269$
$c_2 = 0.010328$ $d_3 = 0.001308$

2) if $0.5 < p > 1$, then

$$I(p) = S - \frac{c_0 + c_1 S + c_2 S^2}{1 + d_1 S + d_2 S^2 + d_3 S^3}$$

with $S = \left[\ln\left(\frac{1}{1-p} \right)^2 \right]^{\frac{1}{2}}$

and c_0, c_1, c_2, d_1, d_2, d_3 as in case 1).

---

[*] The Gaussian distribution in question is normalised to have a standard deviation equal to 1.

Using the formulas one can establish the following table of conversions:

p	x
0.00	- ∞
0.01	-2.32692
0.05	-1.64476
0.10	-1.18147
0.15	-1.04637
0.20	-0.84161
0.25	-0.67453
0.30	-0.52443
0.35	-0.38527
0.40	-0.25338
0.45	-0.12570
0.50	0.0
0.55	0.12570
0.60	0.25338
0.65	0.38527
0.70	0.52443
0.75	0.67453
0.80	0.84161
0.85	1.04637
0.90	1.18147
0.95	1.64476
0.99	2.32692
1.00	+ ∞

Annex C of Part 1: Number of channels needed for a MFN

The results of the theoretical calculations of the number of channels needed for an MFN are included in the following figures:

Figure C1: Number of channels needed for coverage with 1 multiplex,
for fixed antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 95%, pixel coverage: 100%.
Parameter: $H_{eff.}$

Figure C2: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for fixed antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, pixel coverage: 100%.
Parameter: $H_{eff.}$

Figure C3: Number of channels needed for coverage with 1 multiplex,
for portable indoor antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 95%, pixel coverage: 100%.
Parameter: $H_{eff.}$

Figure C4: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, pixel coverage: 100%.
Parameter: $H_{eff.}$

Figure C5: Number of channels needed for coverage with 1 multiplex,
for portable indoor antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 70%, pixel coverage: 100%.
Parameter: $H_{eff.}$

Figure C6: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s),
for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, pixel coverage: 100%.
Parameter: $H_{eff.}$

Figure C7: Number of channels needed for coverage with 1 multiplex,
for portable indoor antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 70%, pixel coverage: 70%.
Parameter: $H_{ef.}$

Figure C8: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, pixel coverage: 70%.
Parameter: $H_{eff.}$

Figure C9: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for fixed antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, H_{eff}: 150 m.
Parameter: Percentage of pixels covered.

Figure C10: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for fixed antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, H_{eff}: 300 m.
Parameter: Percentage of pixels covered.

Figure C11: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, H_{eff}: 150 m.
Parameter: Percentage of pixels covered.

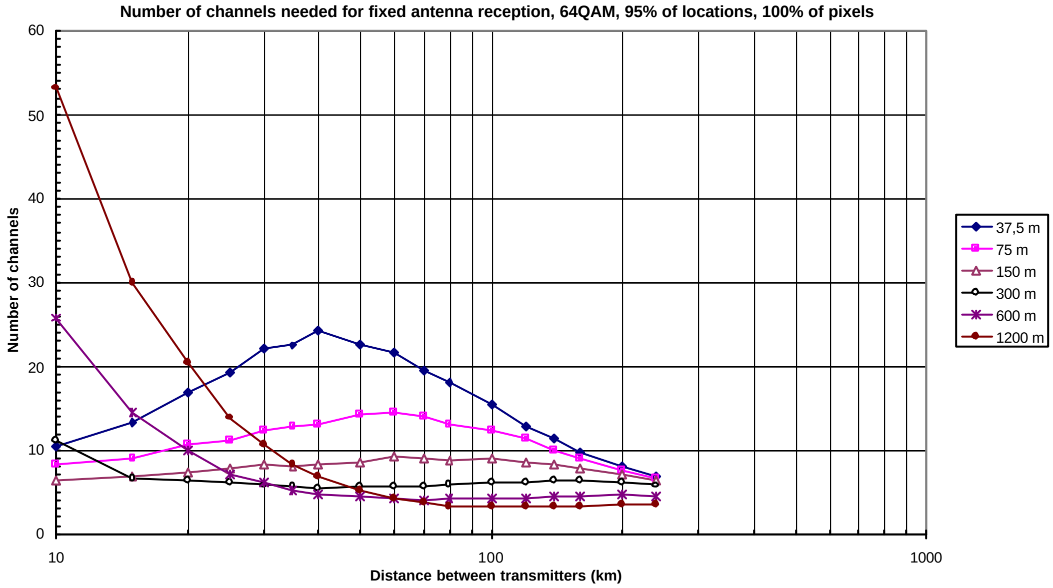
Figure C12: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, H_{eff}: 300 m.
Parameter: Percentage of pixels covered.

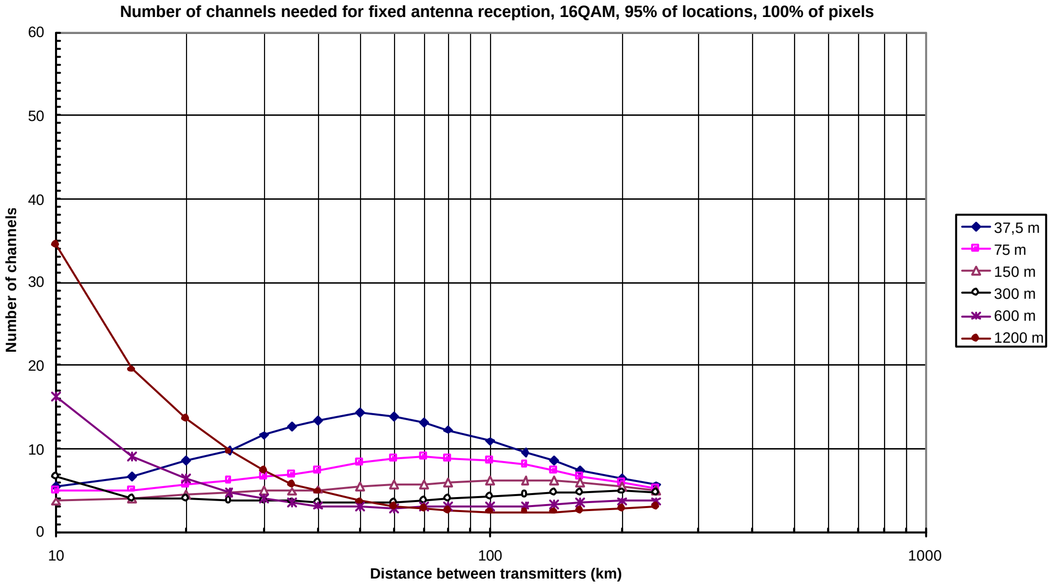
Figure C13a: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for fixed antenna reception.
Location probability: 95%, pixel coverage: 100%, H_{eff}: 150 m.
Parameter: Modulation type.

Figure C13b: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for fixed antenna reception.
Location probability: 95%, pixel coverage: 100%, H_{eff}: 300 m.
Parameter: Modulation type.

Figure C14a: Equivalent number of channels needed for coverage with the same data capacity
20-24 Mb/s), for portable antenna reception.
location probability: 70%, pixel coverage: 70%, H_{eff}: 150 m.
Parameter: Modulation type.

Figure C14b: Equivalent number of channels needed for coverage with the same data capacity
(20-24 Mb/s), for portable indoor antenna reception.
Location probability: 70%, pixel coverage: 70%, H_{eff}: 300 m.
Parameter: Modulation type.





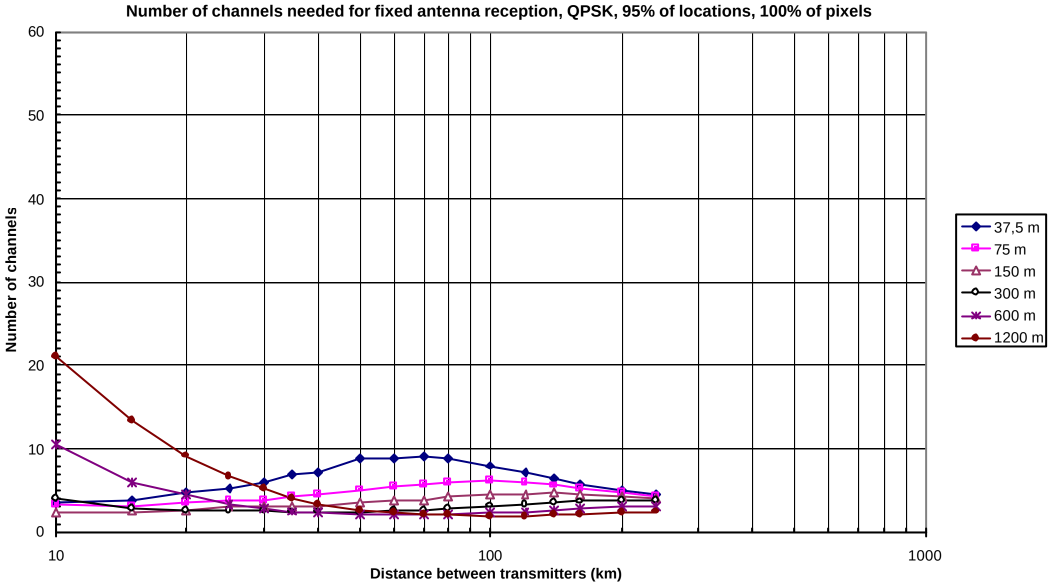


Figure C1: Number of channels needed for coverage with 1 multiplex,
for fixed antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 95%, pixel coverage: 100%.
Parameter: H_{eff}.

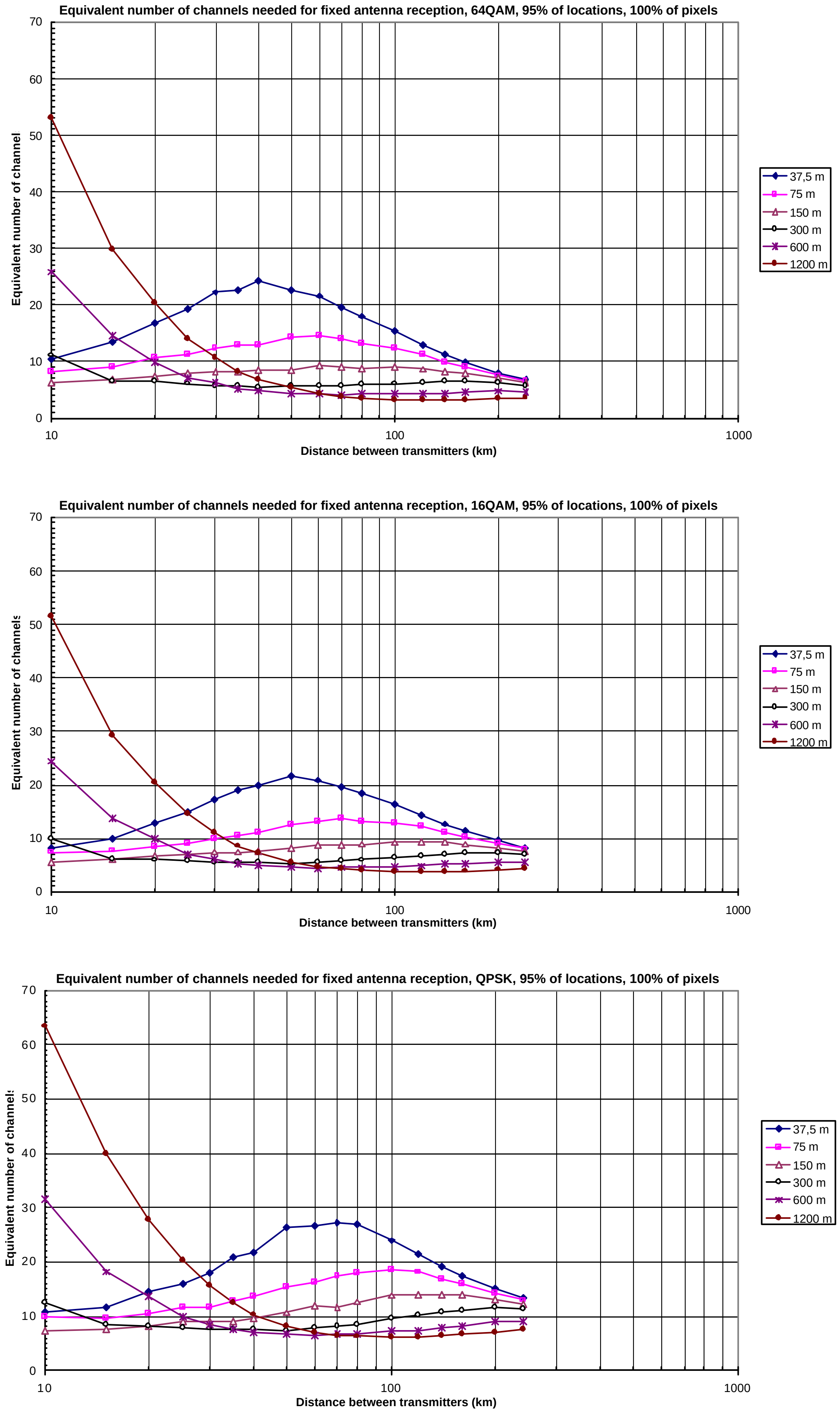
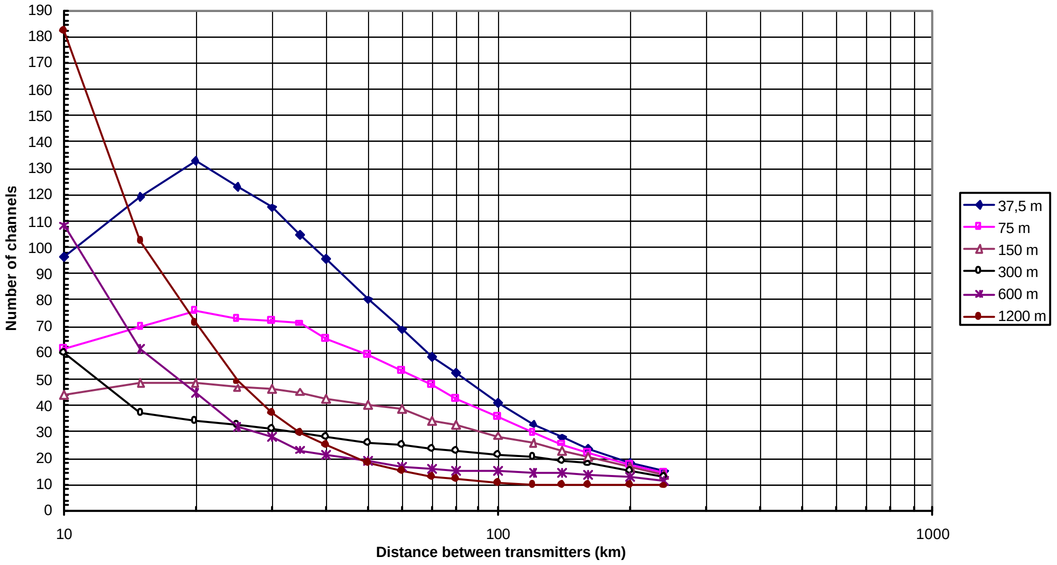
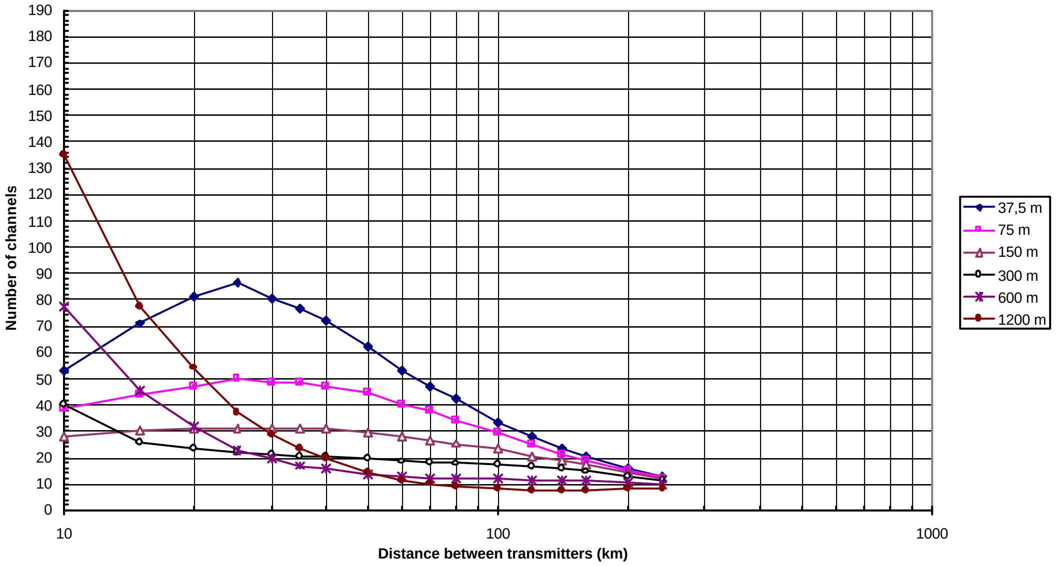


Figure C2: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for fixed antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, pixel coverage: 100%.
Parameter: H_{eff}.

Number of channels needed for portable antenna reception, 64QAM, 95% of locations, 100% of pixels



Number of channels needed for portable antenna reception, 16QAM, 95% of locations, 100% of pixels



Number of channels needed for portable antenna reception, QPSK, 95% of locations, 100% of pixels

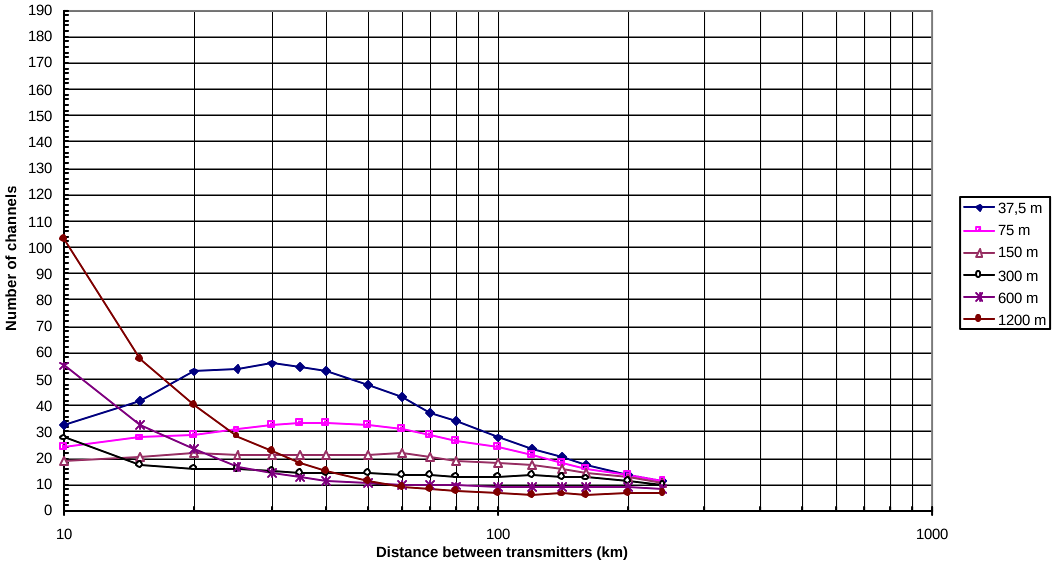
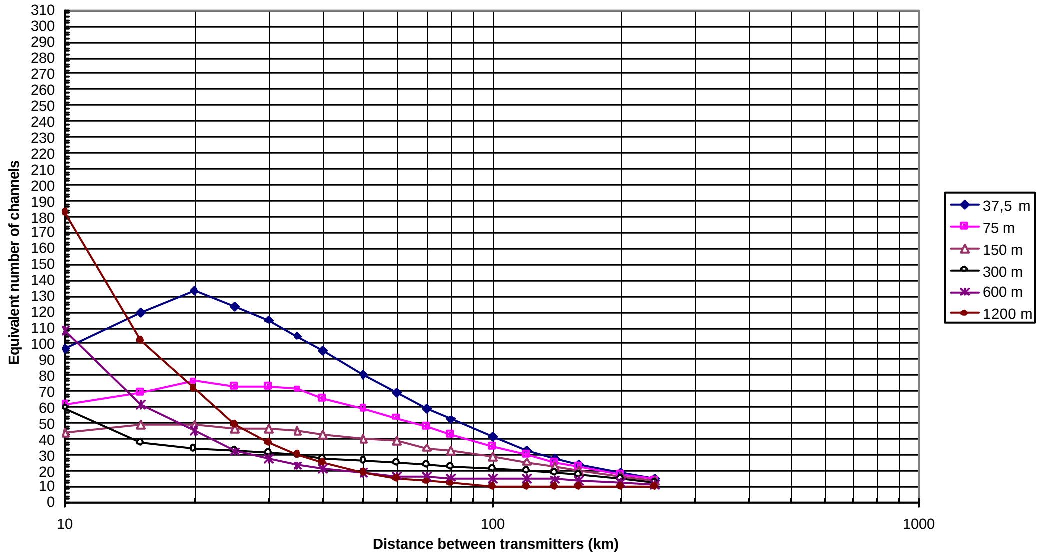
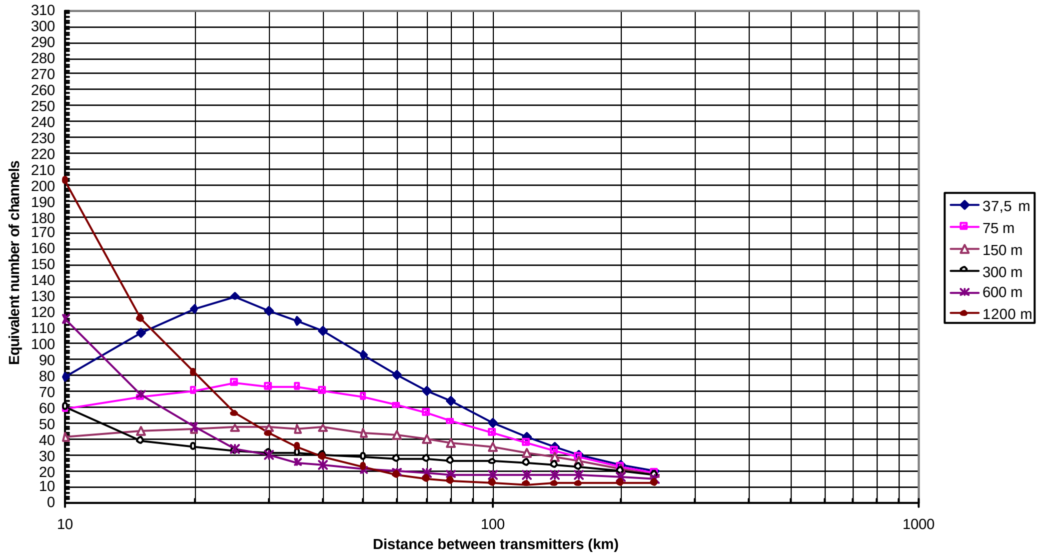


Figure C3: Number of channels needed for coverage with 1 multiplex, for portable indoor antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 95%, pixel coverage: 100%.
Parameter: H_{eff}.

Equivalent number of channels needed for portable antenna reception,
64QAM, 95% of locations, 100% of pixels



Equivalent number of channels needed for portable antenna reception,
16QAM, 95% of locations, 100% of pixels



Equivalent number of channels needed for portable antenna reception,
QPSK, 95% of locations, 100% of pixels

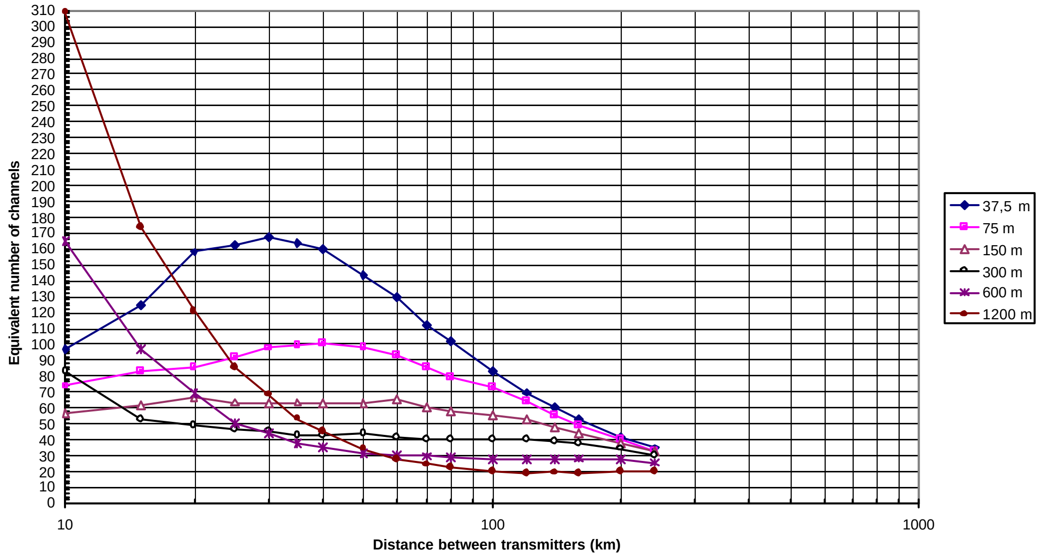
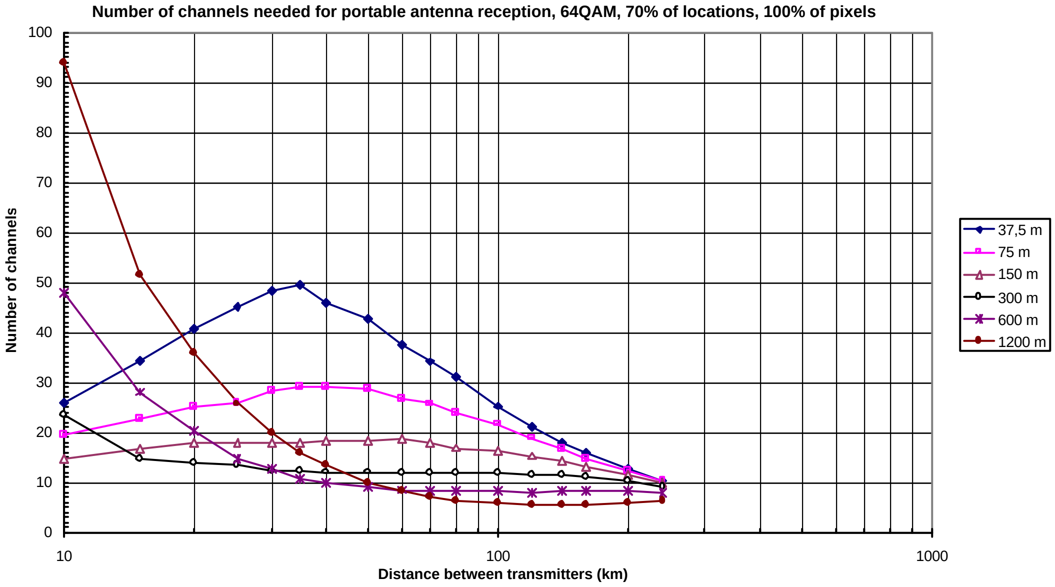
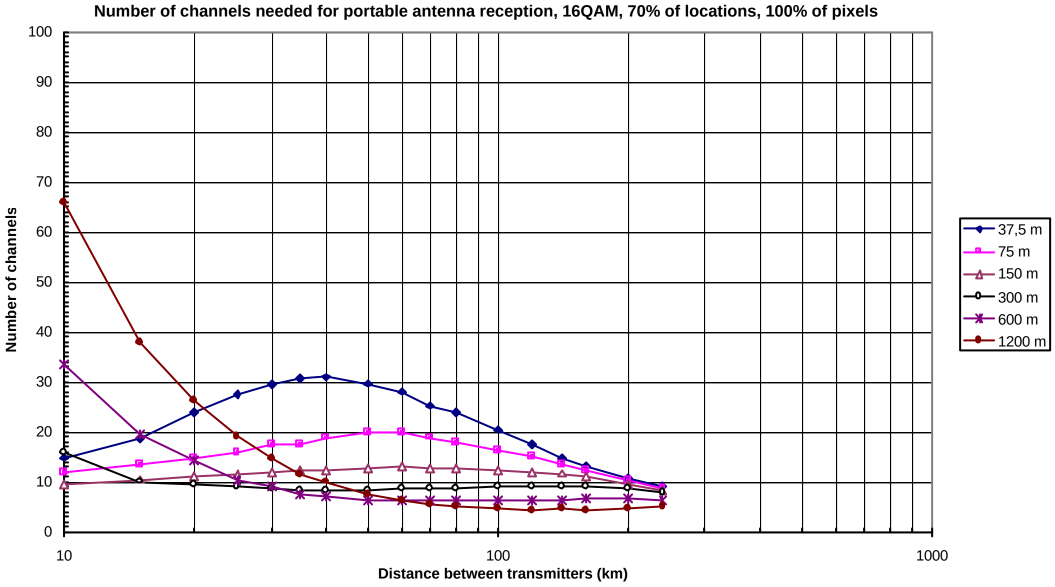


Figure C4: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, pixel coverage: 100%.
Parameter: H_{eff}.





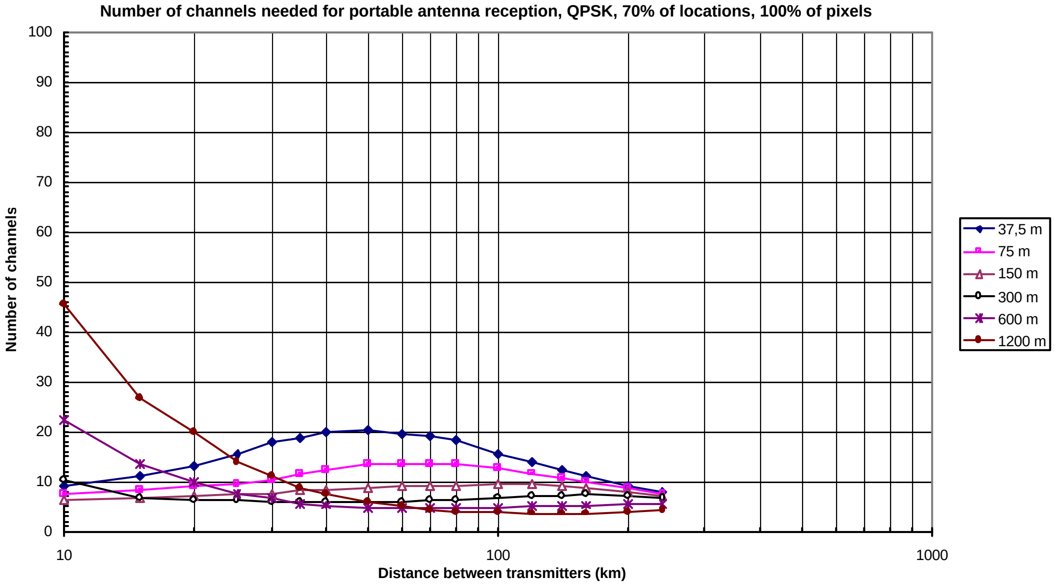
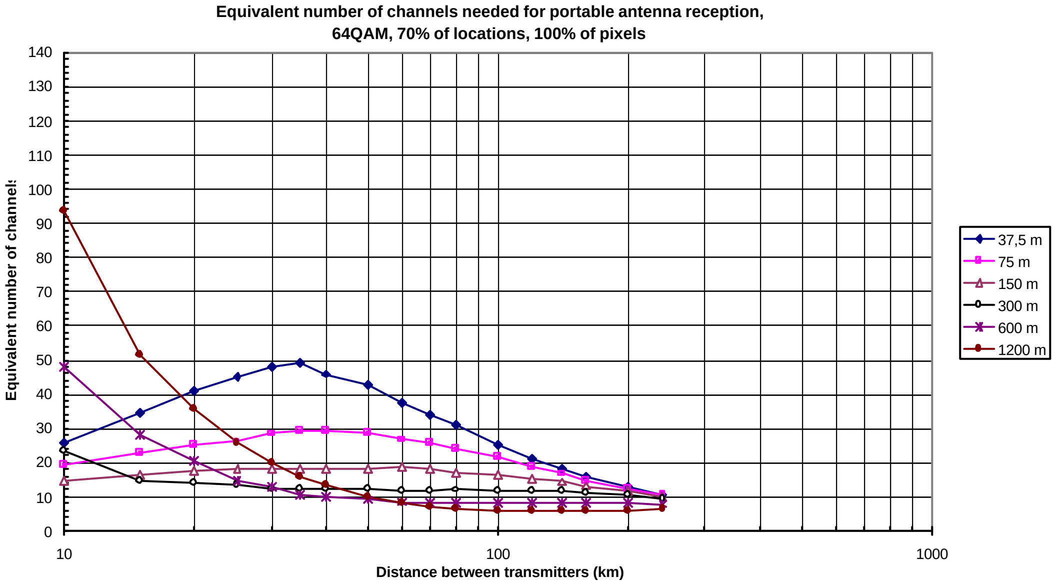
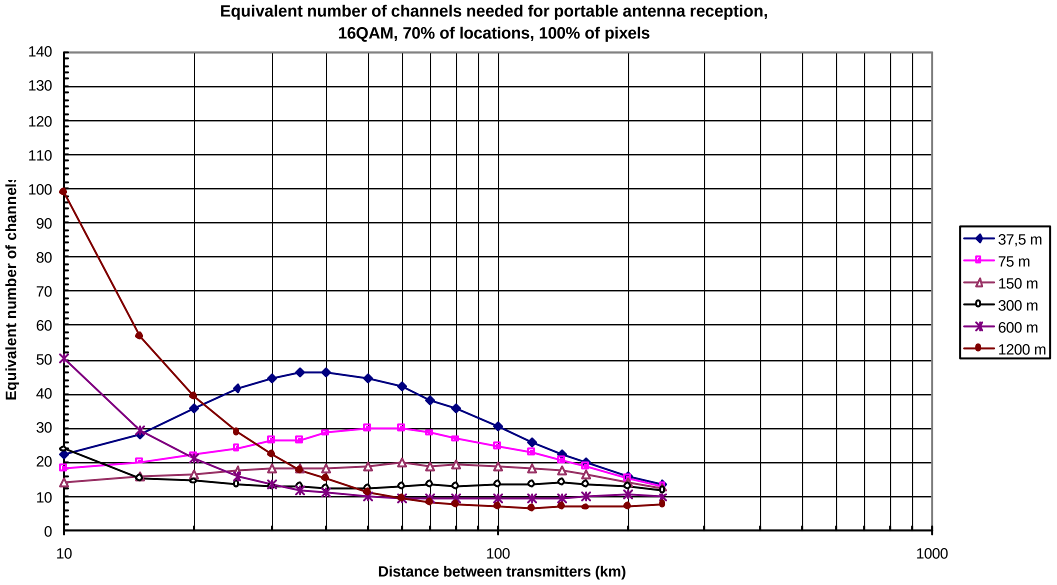


Figure C5: Number of channels needed for coverage with 1 multiplex,
for portable indoor antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 70%, pixel coverage: 100%.
Parameter: H_{eff}.





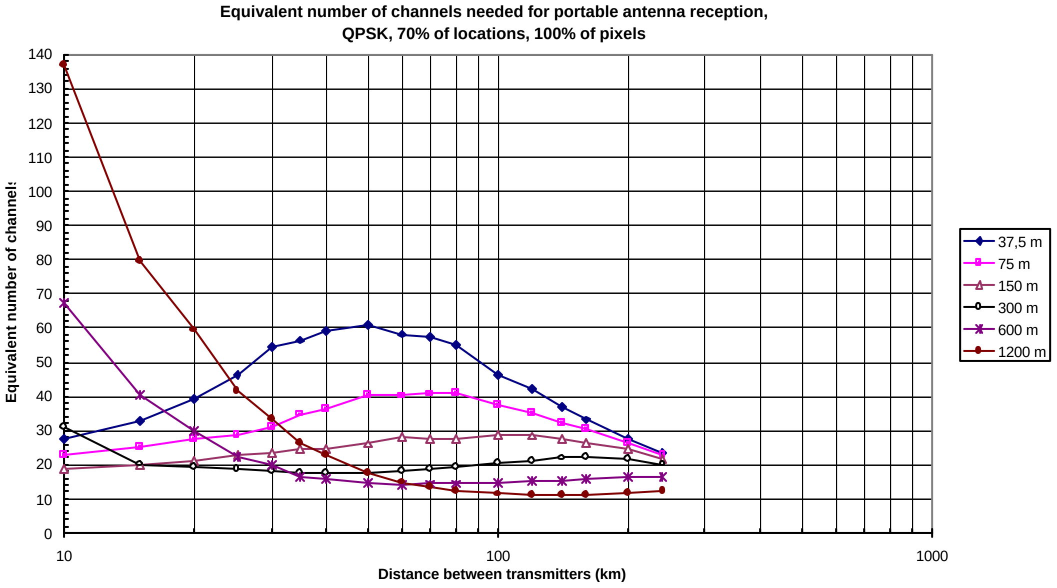
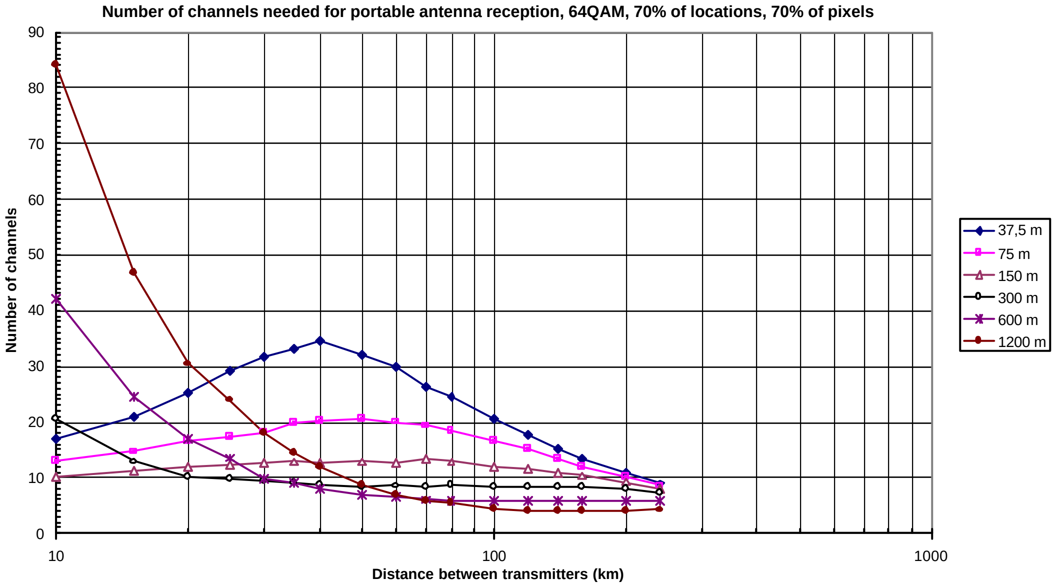
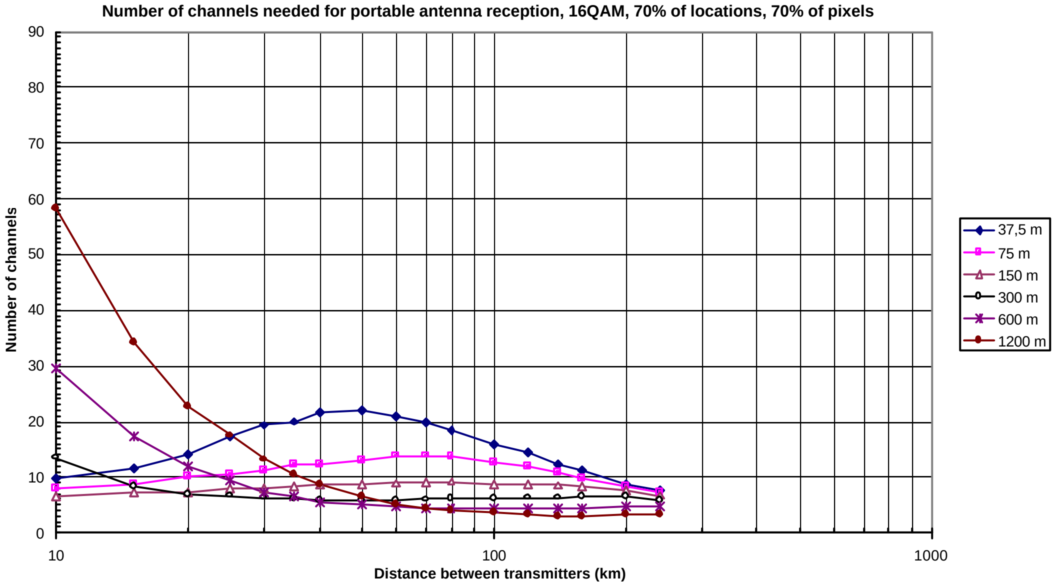


Figure C6: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, pixel coverage: 100%.
Parameter: H_{eff}.





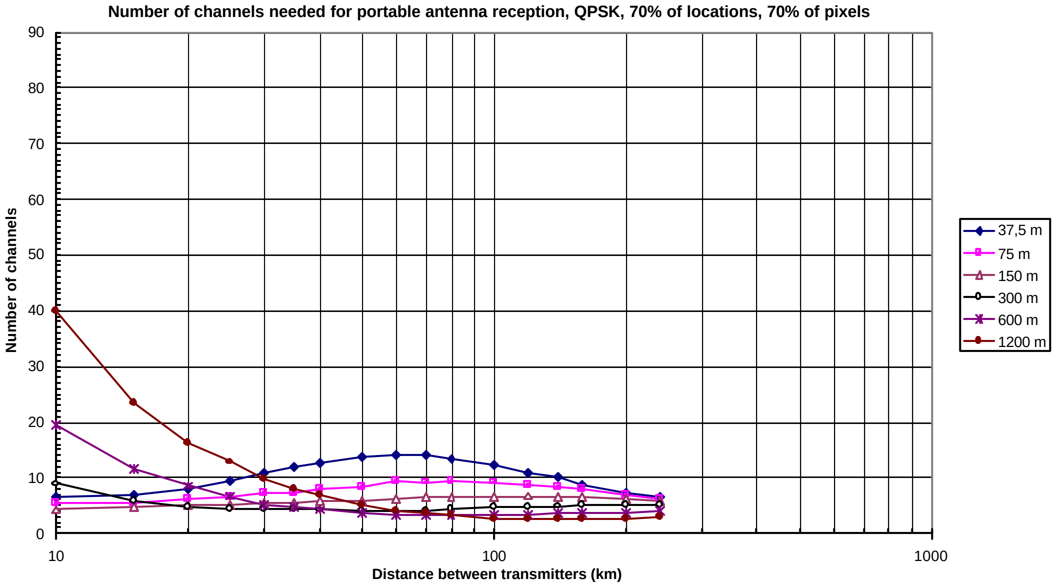


Figure C7: Number of channels needed for coverage with 1 multiplex, for portable indoor antenna reception, using 64QAM, 16QAM or QPSK, giving different data capacities.
Location probability: 70%, pixel coverage: 70%.
Parameter: H_{eff}.

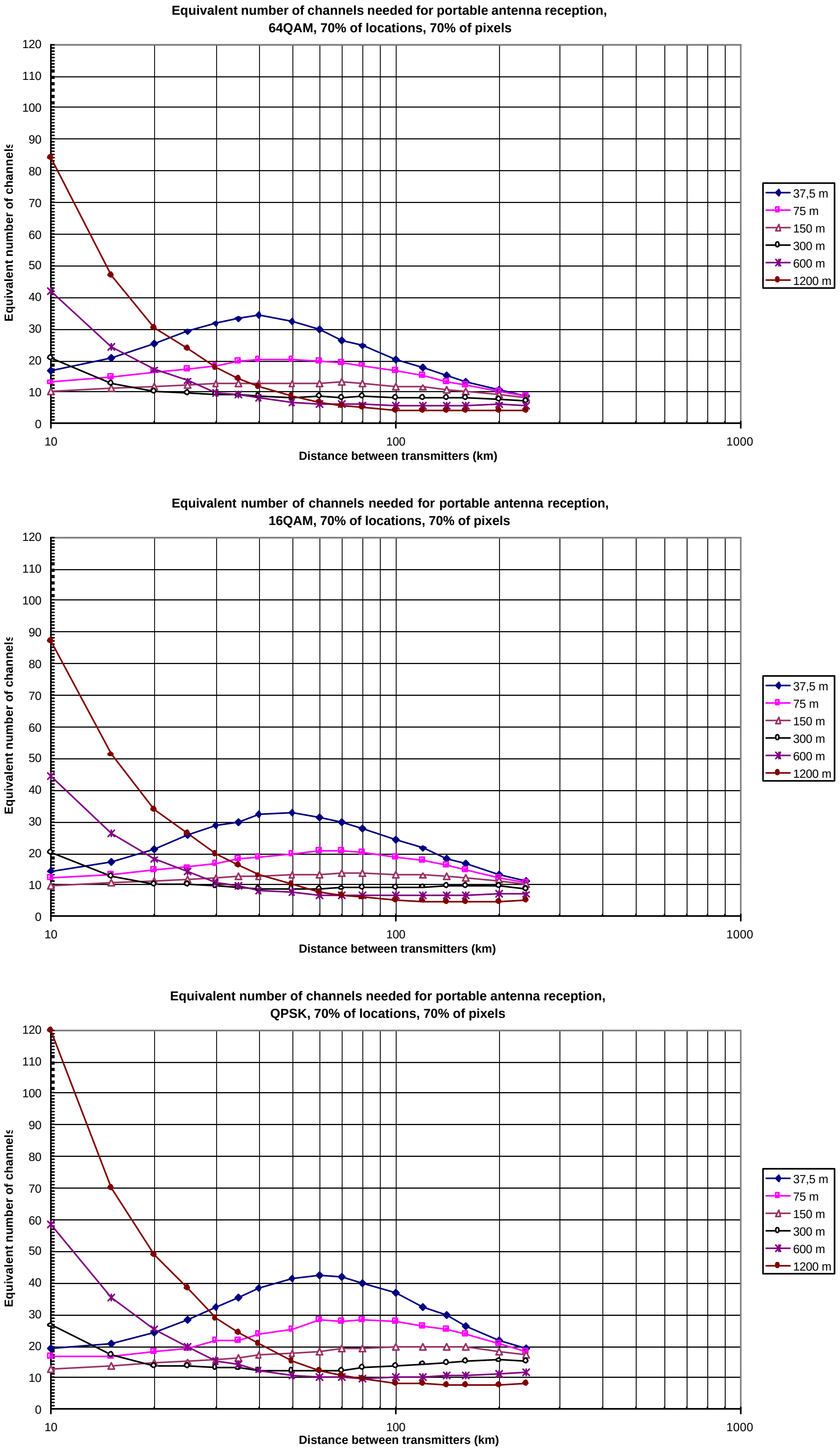
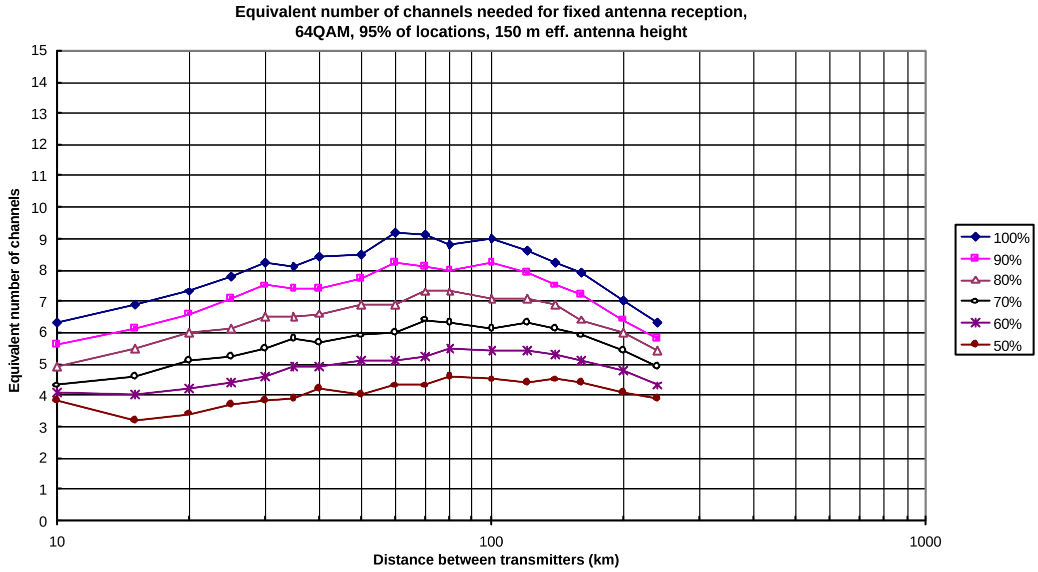
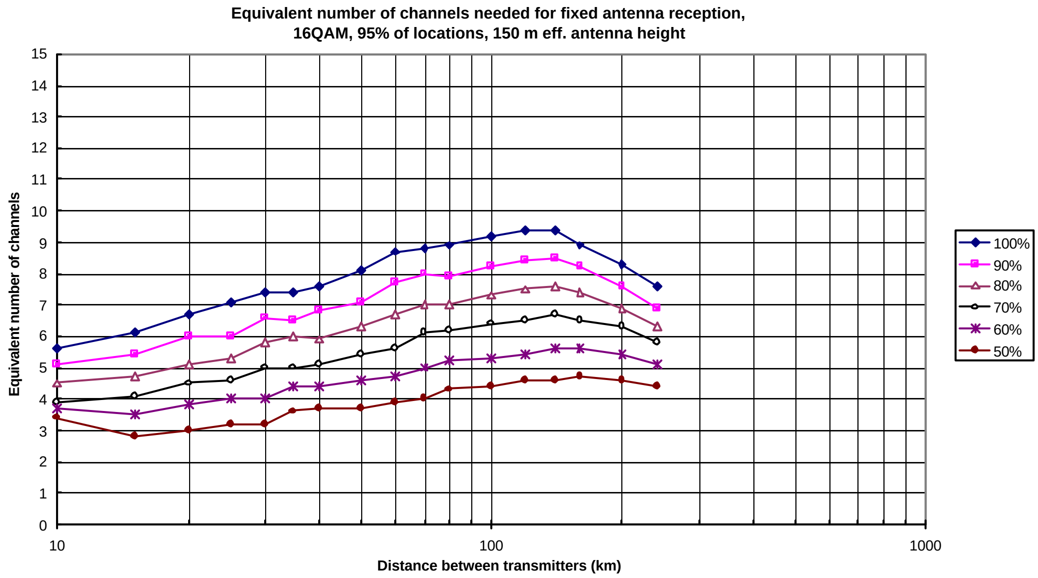


Figure C8: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, pixel coverage: 70%.
Parameter: H_{eff}.





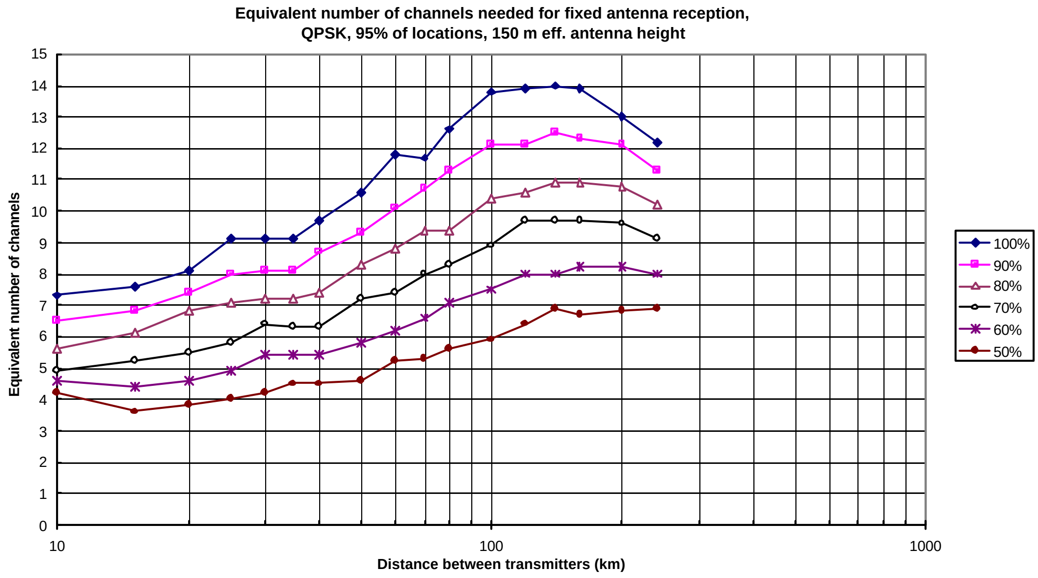


Figure C9: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for fixed antenna reception, using 64QAM, 16QAM or QPSK. Location probability: 95%, H_{eff}: 150 m. Parameter: Percentage of pixels covered.

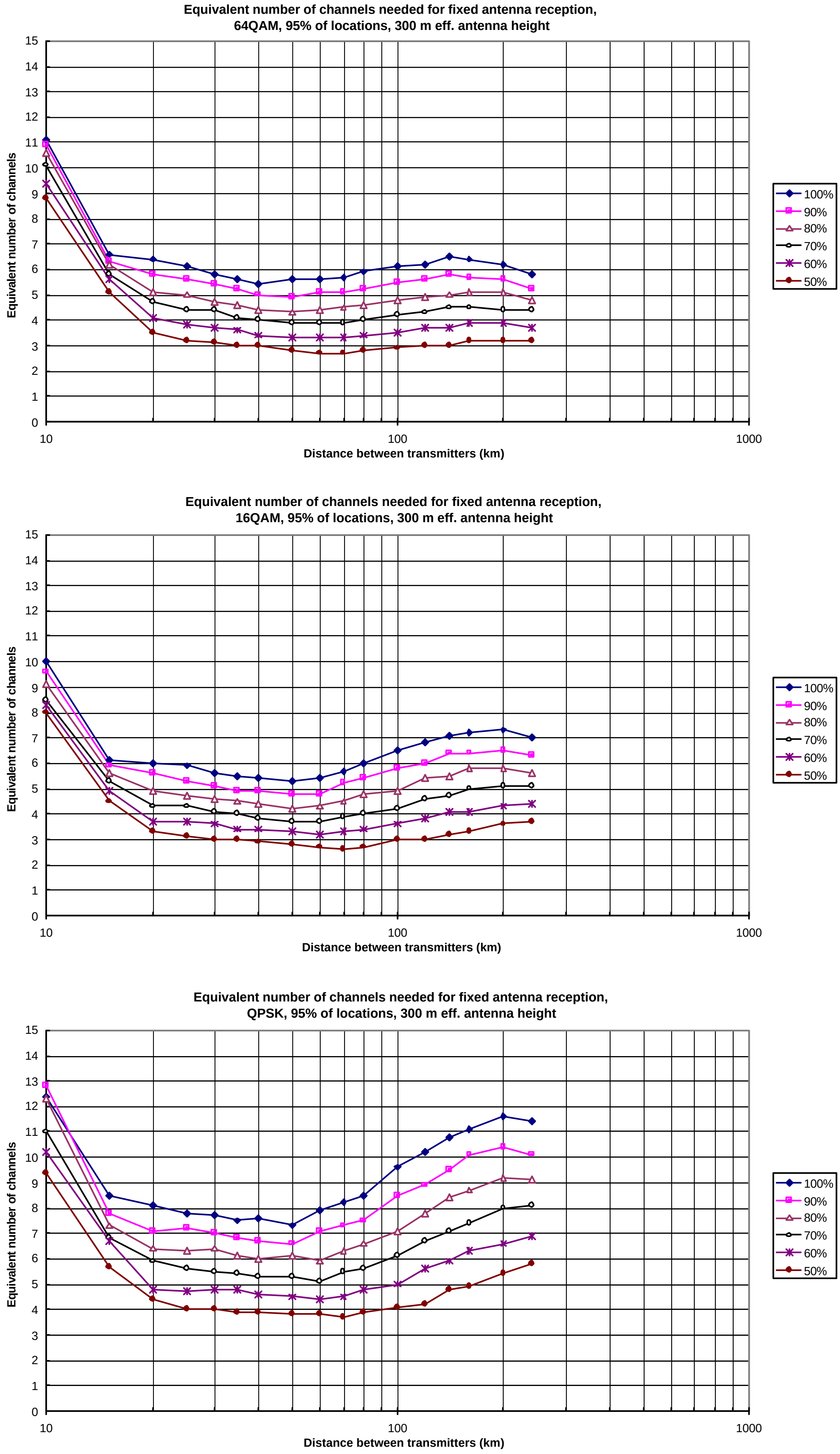
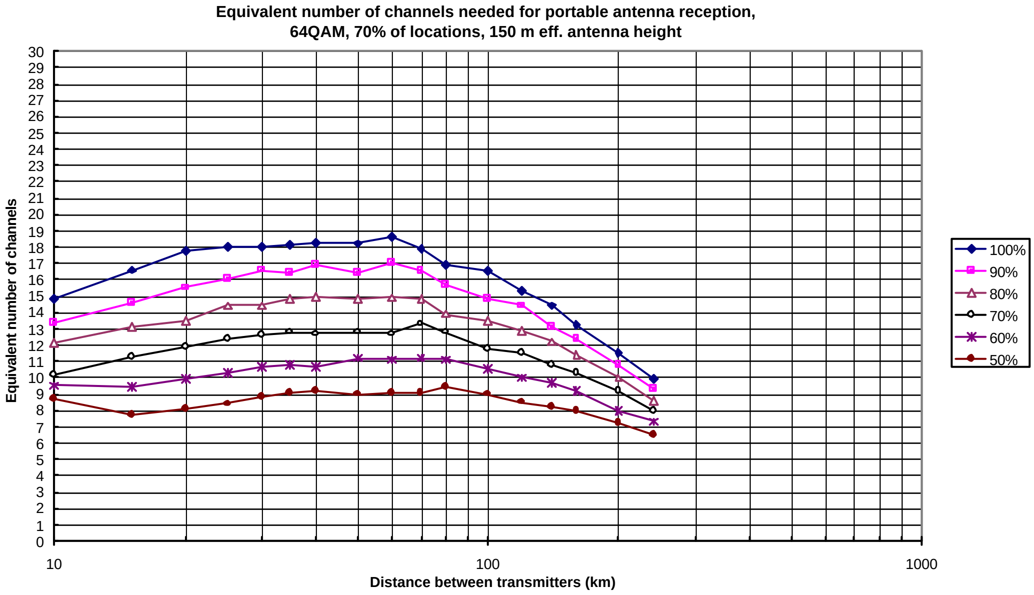
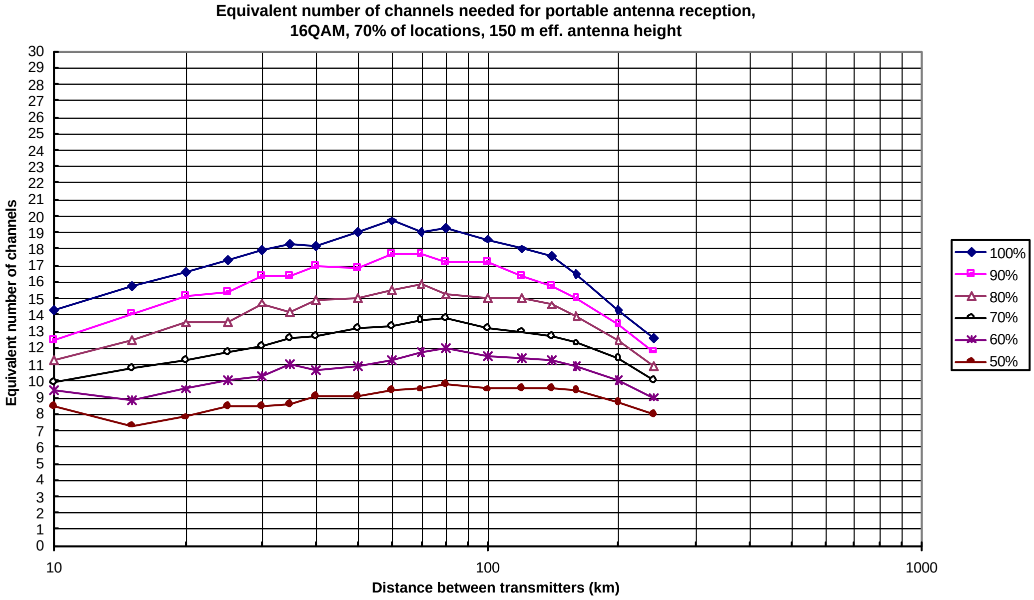


Figure C10: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for fixed antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 95%, H_{eff}: 300 m.
Parameter: Percentage of pixels covered.





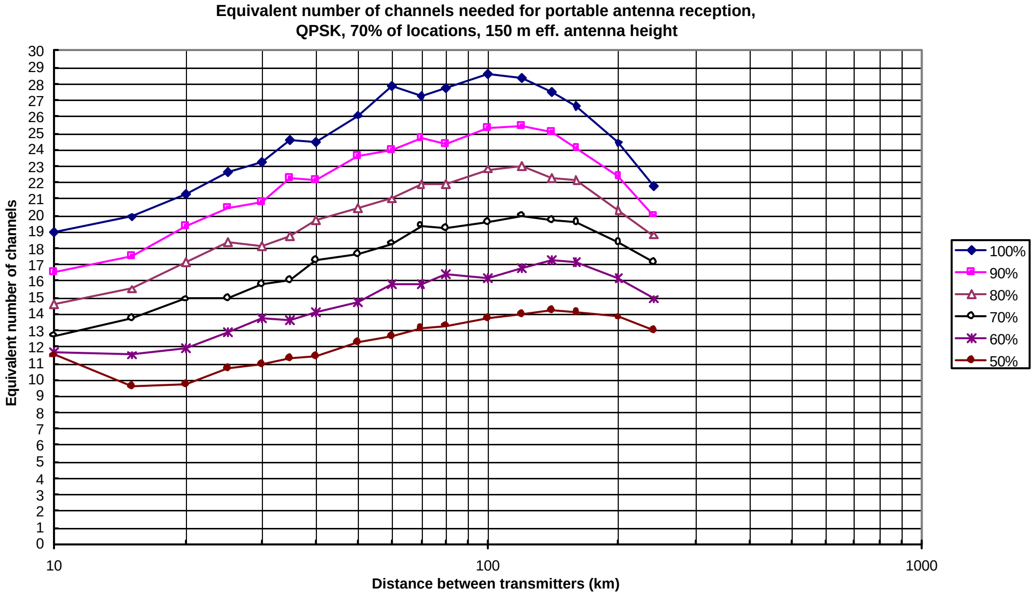


Figure C11: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, H_{eff}: 150 m.
Parameter: Percentage of pixels covered.

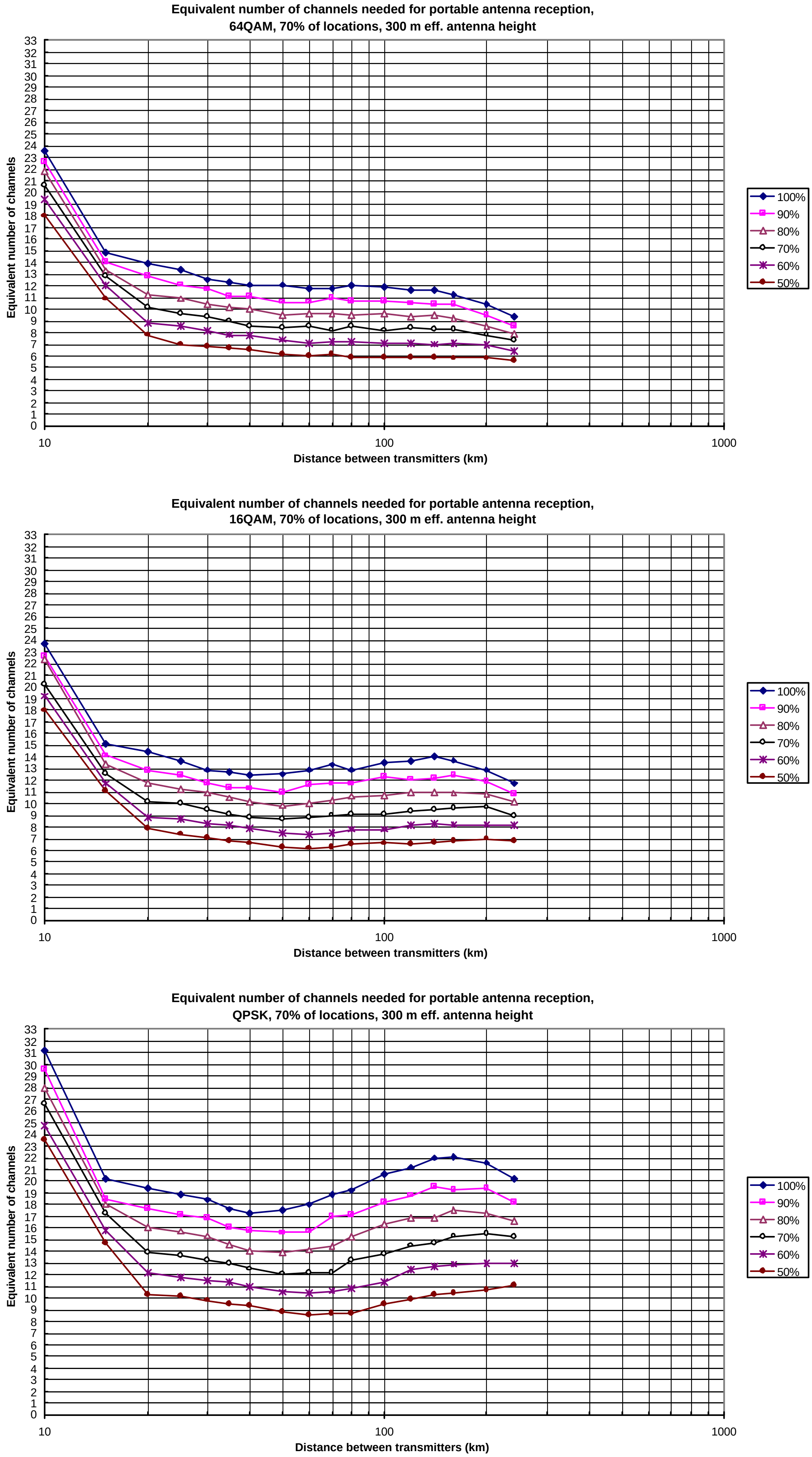


Figure C12: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for portable indoor antenna reception, using 64QAM, 16QAM or QPSK.
Location probability: 70%, H_{eff}: 300 m.
Parameter: Percentage of pixels covered.

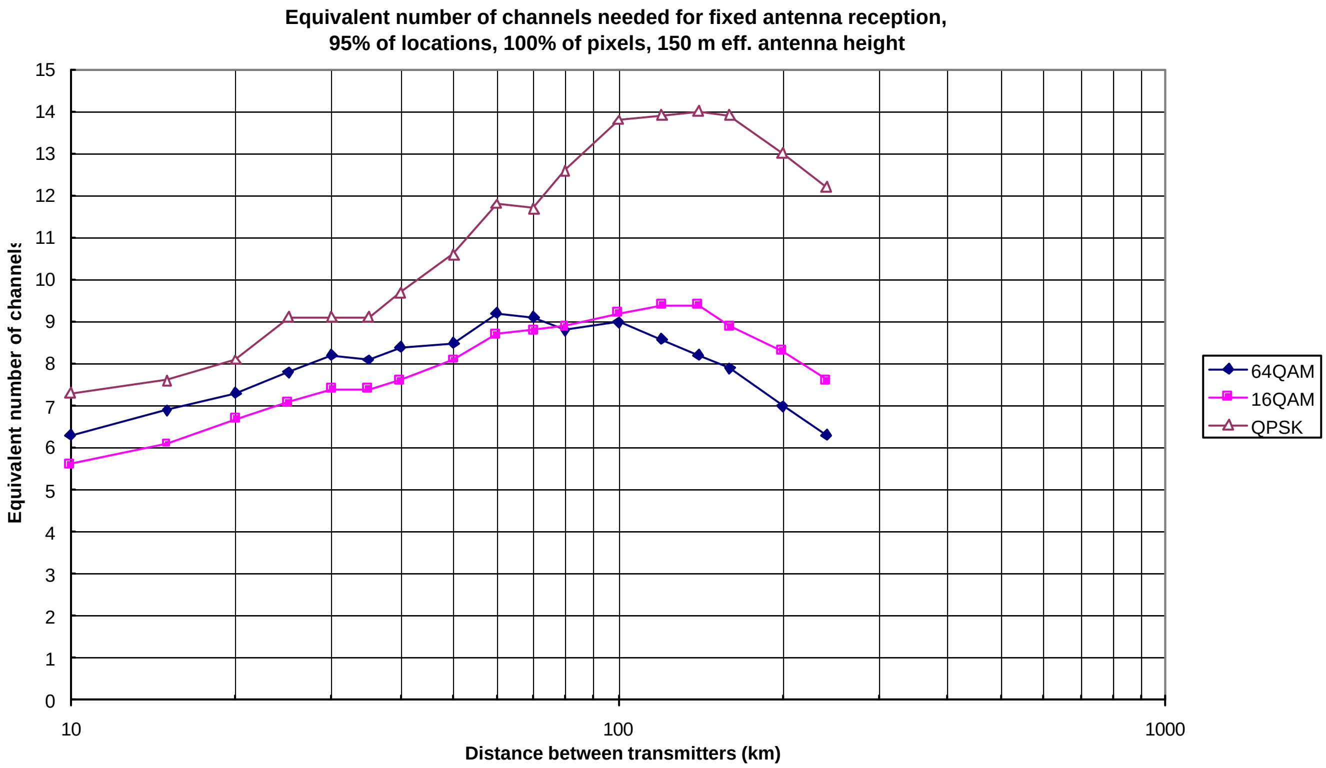


Figure C13a: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for fixed antenna reception.
Location probability: 95%, pixel coverage: 100%, H_{eff}: 150 m.
Parameter: Modulation type.

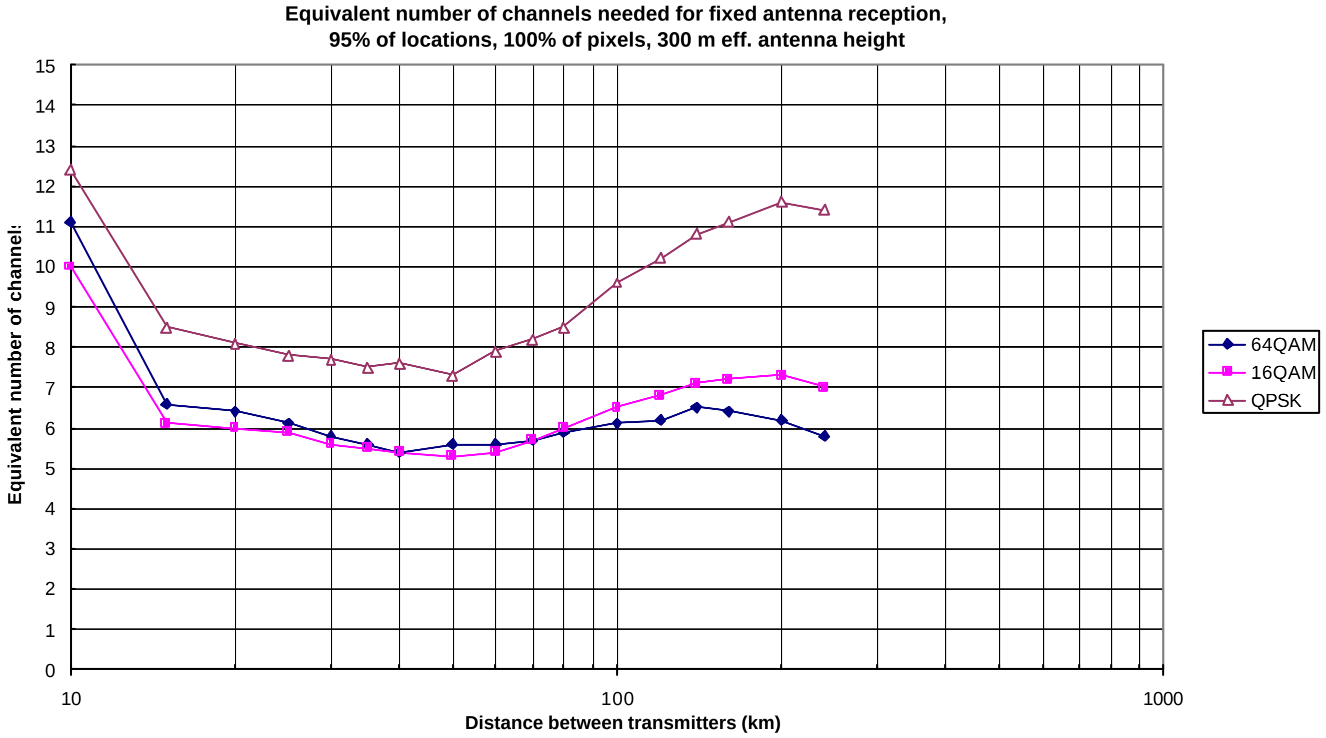


Figure C13b: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for fixed antenna reception.
Location probability: 95%, pixel coverage: 100%, H_{eff}: 300 m.
Parameter: Modulation type.

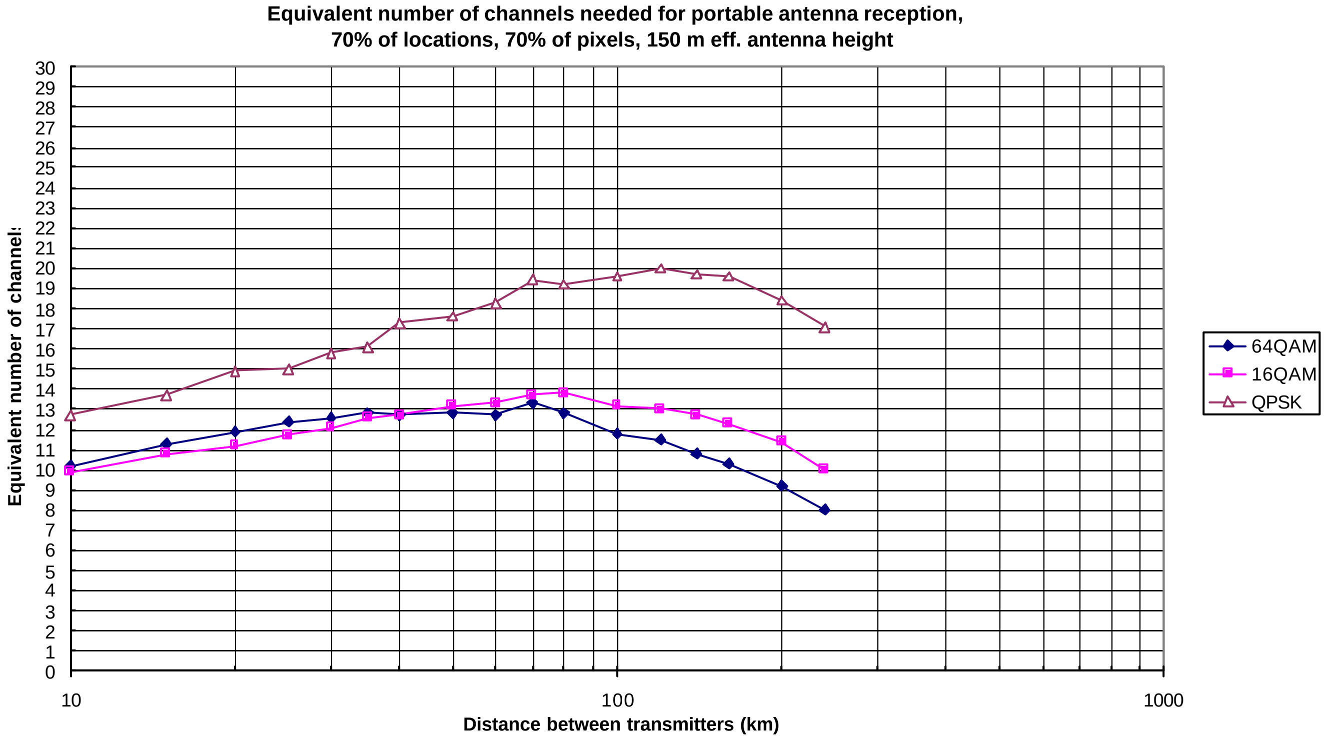


Figure C14a: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for portable antenna reception.
Location probability: 70%, pixel coverage: 70%, H_{eff}: 150 m.
Parameter: Modulation type.

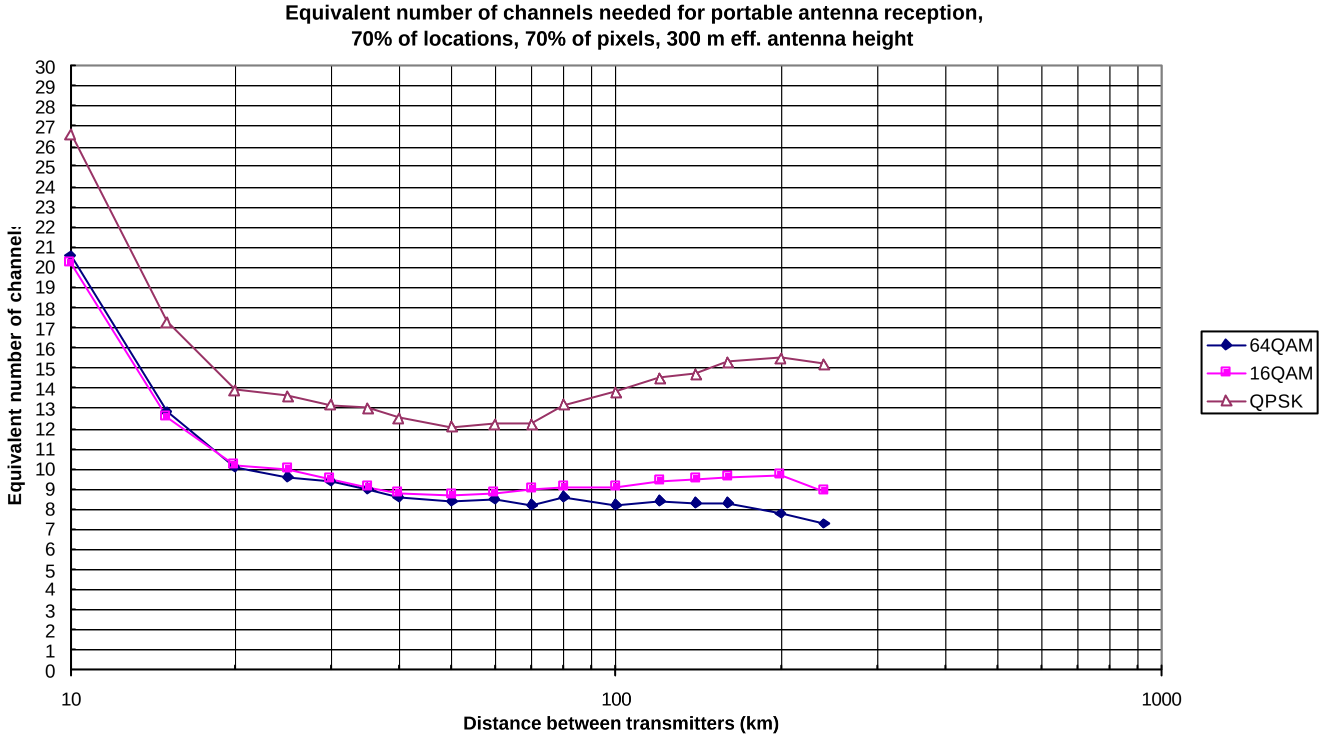


Figure C14b: Equivalent number of channels needed for coverage with the same data capacity (20-24 Mb/s), for portable indoor antenna reception.
Location probability: 70%, pixel coverage: 70%, H_{eff}: 300 m.
Parameter: Modulation type.

Annex D of Part 1: Number of channels needed for a SFN

In order to evaluate the theoretical spectrum requirement of the DVB-T variants, assumptions have to be made regarding the structure of the service areas. Firstly it is assumed that full area coverage is intended, i.e. the whole area under consideration is covered by service areas. Secondly it is assumed that all of the service areas have equal size and equal, hexagonal shape. Together with the re-use distance approach, these assumptions form a simple model that allows for a spectrum requirement analysis. The model is described in more detail in §3.2.2 *Lattice planning, case SFN* and §3.3.2 *Description of calculation procedure for SFN*. The relevant parameters of the model are the diameter of an individual service area and the re-use distance which depends on the system variant, network configuration and reception mode under consideration. From these two parameters a model function can be derived that serves for the determination of the spectrum requirement of the investigated configuration. It is shown in Figure D1.

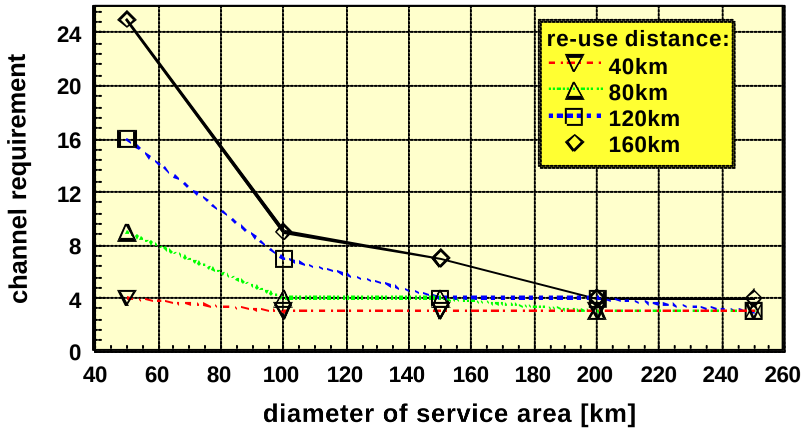


Figure D1: Model function for the evaluation of the channel requirement.

Clearly, the assumption of equal-sized, hexagonal service areas is an idealisation, that will hardly be found in reality and that biases the results. As an example, in the most advantageous case - with nearly vanishing re-use distance - the model yields a spectrum requirement of 3 channels for a full area coverage, whereas in general at least 4 channels are needed. However, the aim of the present investigation is not to find absolute values for the spectrum requirement of particular configurations, rather it is to be found in the possibility to compare the various system variants, reception modes and network configurations. However, the theoretical investigations give a lower bound for the spectrum requirement of the considered configuration.

All of the following figures give the results in terms of channel requirement per multiplex.

It must be also noted that the calculations made for this SFN study assume that the inter-transmitter distance is 60 km and that the effective antenna height is 300 m.

Figures D2 to D5 show for the chosen DVB-T system variants and the three reception modes the channel requirements for various diameters of the service areas. For convenience, different scaling of the x-axis has been chosen in the figures.

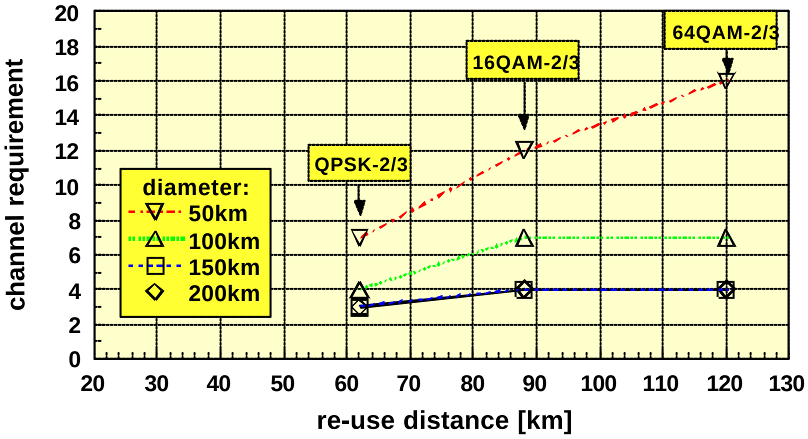


Figure D2: Channel requirement for various system variants and for portable indoor antenna reception.

As may be expected, the channel requirement increases with a higher sensitivity of the DVB-T variant and with a more demanding reception mode. For example, for a service area diameter of 100 km QPSK 2/3 has a spectrum requirement of 4 channels and 64QAM 2/3 has a spectrum requirement of 7 channels, i.e. about twice the channels. A large increase of spectrum requirement is found for all variants when service areas with small diameters are involved. The curves then approach the values that can be found for multiple frequency networks.

The differences found for the various reception modes are remarkable, too. When changing from fixed roof-level reception to portable indoor antenna reception, doubling of the required spectrum is to be expected.

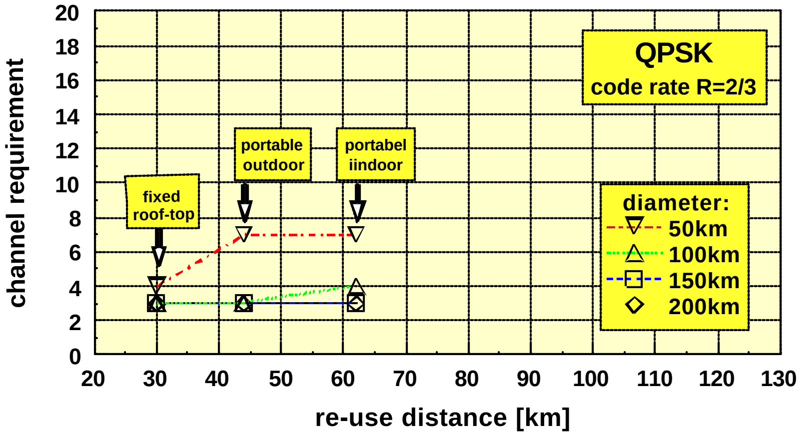


Figure D3: Channel requirement of variant QPSK 2/3 for various reception modes.

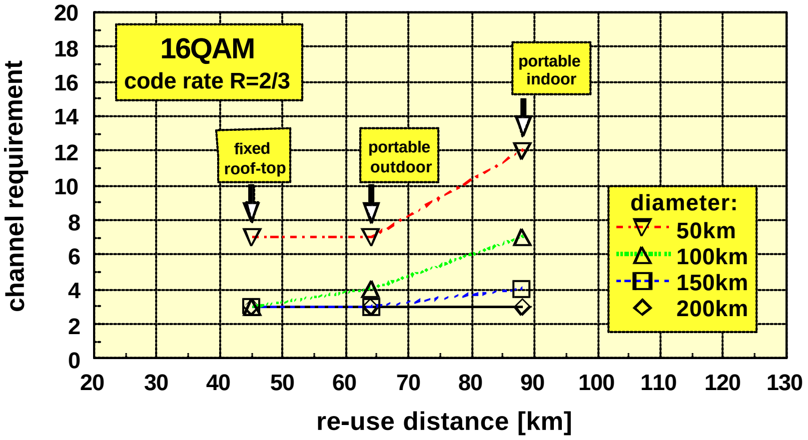


Figure D4: Channel requirement of variant 16QAM 2/3 for various reception modes.

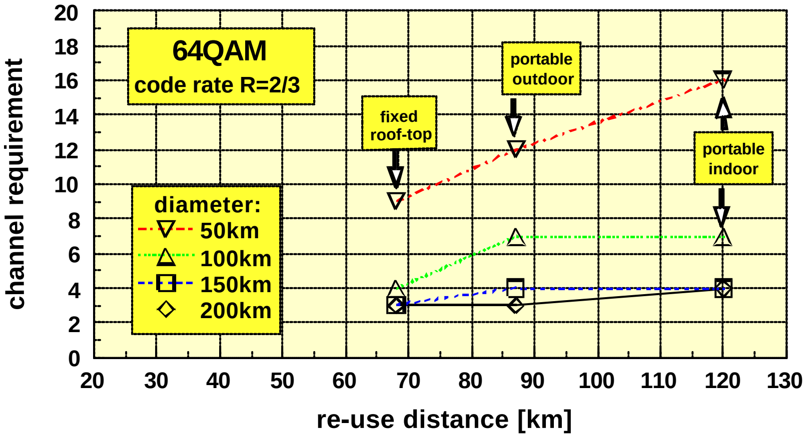


Figure D5: Channel requirement of variant 64QAM 2/3 for various reception modes.

For service areas with large diameters - 200 km or more -, for all system variants, the calculations indicate that 3 or 4 channels per multiplex are needed. When compared to real scenarios, with service areas that are irregular in shape and size, it turns out that the average diameters of the theoretical service areas have to be identified with the diameters of the smaller service areas of a real scenario and with the 'critical' linear extensions of irregularly shaped service areas. This means that more than 3 channels will be needed in practice.

Part 2: Impact of real-world considerations

The theoretical studies carried out in this document give an indication of the number of channels per multiplex and the equivalent number of channels needed for different sets of criteria and parameters. This part of the report shows the impact which the real-world could have on these results. It is very important to note that the real-world is much more complex than the simplified models used during the theoretical planning exercises. Most of the additional complications will manifest themselves as a need for a larger amount of spectrum if an equivalent degree of coverage is to be achieved in practice as that achieved in the theoretical exercises. If this additional spectrum cannot be provided then there will be coverage losses. However, because an OFDM system is being used, it may be possible to recover some of these losses by the provision of additional relay stations which use the same channel as their parent stations. This is true for networks based on either MFNs or SFNs, although it will be necessary to study carefully the impact on other co-channel stations, especially in areas near to national boundaries.

1 Parameters and calculation methods

1.1 Receiver related parameters

- The use of low noise pre-amplifiers (for fixed antenna reception) or an improvement in the noise figure of receivers can potentially increase the service area of a transmitter. However the effect of interference on the lower level signals then being used will be more limiting, especially for small percentages of time. The impact of these factors on the results of theoretical studies is not expected to be large.
- Diversity receivers have being investigated in MOTIVATE for mobile use. If these receivers are successful the same technology could be used to enhance portable indoor antenna reception by reducing the required C/N although this will not necessarily have any effect on the limitations caused by interference and these are usually by far more important than limitations caused by noise.
- Theoretical SFN studies assume that the receivers have a suitable synchronisation strategy. In reality different types of receivers will be available. This may have an impact on the quality of coverage.

1.2 Transmitter antenna characteristics

- The theoretical results do not take into account the influence of national boundaries. Particularly in the case of contiguous small countries, such boundaries will have the effect of increasing the number of channels needed.
- For the MFN case, the theoretical studies assume that a non-directional transmitting antennas are used. In reality, many transmitting antennas are directional and use some degree of beam tilt. These factors could be of help in real planning, especially in solving problems along borders of regions or countries.

1.3 Propagation considerations

- The theoretical networks have been constructed with uniform effective antenna heights. In reality networks will consist of transmitters with a wide range of effective antenna heights. This will have an effect on the number of channels needed, but this can only be quantified in a study of real transmitter networks.

- Rec. ITU-R P.370-7 has been used in the theoretical studies. In practice it is probable that most countries will use a terrain based method to plan their networks and to co-ordinate on a bi- or multi-lateral basis with their neighbours. Taking into account terrain shielding effects (if any) could reduce the effect of co-channel interference and thereby reduce the separation distances between co-channel stations. On the other hand there will be cases where terrain based coverage calculation methods will increase these separation distances.
- Theoretical studies are based on land paths only. Sea paths and mixed land/sea paths will undoubtedly increase the co-channel separation distances and therefore the number of channels needed.

2 Type of network

- Theoretical studies assume that a single type of network (MFN or SFN) is used throughout the planning area. It is probable that a mixture of network types is used by neighbouring countries or even in the same country. Further studies are planned to evaluate the impact that this could have on the amount of spectrum needed.
- In this theoretical study it is found that 9 channels are needed to provide fixed antenna reception for 95% of locations and 100 % of pixels using 64QAM 2/3, using a set of realistic planning parameters. However in the practical planning carried out in, for example, UK and Sweden less than 9 channels per multiplex have been used. One reason may be that these networks provide coverage in less than 100 % of the pixels, which reduces the required spectrum. Another reason may be that, in some cases, the location coverage is less than 95%. In the example of Sweden, the main transmitters cover approximately 90 % of the pixels with a location coverage of 95 %. In order to increase the pixel coverage (and population coverage) additional fill in stations are used. This reduces the spectrum requirements compared to the case where only main transmitters are used to cover 100 % of the area (100% of the pixels). If additional fill in stations can be implemented as SFN gap fillers, they will then have very little impact on the overall spectrum required for the network.

3 Reception mode and system variants

- Theoretical studies have assumed that the same mode of reception and the same system variant is used throughout the planning area. Indications are that neighbouring countries are using, or propose to use, different modes of reception and system variants. e.g. mainly fixed (64QAM, 2/3) in the UK, fixed/portable (64QAM, 2/3) in France, portable/mobile (16QAM, 2/3) in Germany and portable indoor (16QAM, 2/3) in Netherlands. Due to this the interference considerations across the borders are not uniform. The impact of this needs to be investigated.

4 Physical limitations

- Some of the studies have shown that for portable indoor antenna reception, in particular, some combinations of the complete set of planning parameters under investigation in this theoretical study lead to completely impractical requirements, especially as regards the e.r.p. which can exceed 1 MW; in many countries, EMC limits would also be exceeded for some combinations of parameters.

5 Constraints related to the transition period

The theoretical studies assume that the necessary spectrum is available for planning and that no existing transmitters need to be taken into account (the ''clean sheet'' approach). However, this is unlikely to be the case as during the transition period:

- the problem of “first come, first served” may arise in spite of Chester 97. Countries starting early may have a better position at the foreseen DVB-T planning conference;

- there may be an inequality between different countries, early adopters unwilling to change their networks because of economic, technical and customer related costs;
- if a ‘’clean sheet’’ planning is not possible the spectrum efficiency may decrease compared to the theoretical models; the result of this could be:
  - in order to provide a given level of service more spectrum will be used than would otherwise be needed;
  - in a given amount of spectrum fewer services will be provided.

6 Band III

- Theoretical studies for Band III will need to take into account sharing between DVB-T and T-DAB.

7 Conclusion

- Additional studies will be required to evaluate the possible impact of real-world considerations on the relationship between the amount of spectrum needed and the coverage which can be achieved. Such studies should take account of the current locations of transmitting sites and allow for the possibility that additional sites will be needed. However, it will not, in general, be possible to evaluate any coverage improvements, which could result from the use of such additional sites as their locations, and their transmitting parameters will not be known. Studies based on the real-world will thus have a more limited scope than theoretical studies, but can be expected to provide considerable information about the limitations caused by some of the well-known features, such as country and regional boundaries. Such studies will be needed in order to provide more information for the forthcoming planning conference.

Part 3: Summary of national studies

A number of administrations have already started working on defining the framework for the implementation of digital television and the associated analogue switch-off (the all-digital future).

Even at this early stage, requirements differ from country to country, as they depend on the current development of TV services within each country (proportion between terrestrial, satellite, and cable coverage for example).

At this time (December 2000), information from 19 countries on DVB-T planning is available, some more detailed than others. This gives a general idea of the scenarios chosen for the introduction of DVB-T, such as:

- the date of the proposed analogue switch-off: ranging from 2006 to 2015 (Germany, Spain, Finland, UK, Netherlands, Hungary, Ireland, Sweden, Slovakia);
- the number of multiplexes expected at the launch of the services: from 2 to 6 (Belgium, Germany, Denmark, Spain, France, Finland, UK, Netherlands, Hungary, Italy, Ireland, Lithuania, Norway, Portugal, Sweden, Slovenia).

As for the type of network, it appears that none of these countries plans to have a nationwide SFN (depending on the definition of "national"), mainly because of technical difficulties (self interference and the availability of a specific channel throughout the country). Most of them will rather use a mixed MFN/SFN configuration, with SFNs ranging from gap-fillers to local or regional SFNs.

Concerning reception targets, whereas some countries favour the fixed antenna reception, with possibly portable indoor antenna reception in urban areas at the launch of the DVB-T, some others prefer to focus on full portable indoor antenna reception. There is also increasing interest in mobile reception.

As an example, in Germany the long-term aim is to provide portable indoor antenna reception with a high location probability and possibly mobile reception for the whole population. The all-digital scenario is currently based on SFN planning for all regions with 6 to 8 multiplexes, using an 8k system and 16QAM 2/3. To secure a good frequency economy and to avoid self-interference problems SFNs with a diameter of 150 km to 200 km are envisaged.

France will launch DVB-T by providing 6 multiplexes combining MFNs with SFN gap-fillers. Fixed antenna reception generally and portable indoor antenna reception in urban areas will be provided. In this context, an urban area consists of a town, its suburbs and the surrounding commuter belt. There are 361 such areas, representing 30% of the surface of France and 75% of its population.

Sweden has launched DVB-T using 4 multiplexes mainly to supply fixed antenna reception. The network is mainly planned as an MFN, but there are a few examples where adjacent main stations are configured as regional SFNs. In order to improve portable indoor antenna reception in urban areas additional SFN gap-fillers are also installed.

In UK, 6 multiplexes using MFN with predominantly fixed antenna reception are now in operation.