EBU
OPERATING EUROVISION AND EURORADIO

TR 029

DVB-T2 SINGLE FREQUENCY NETWORKS AND SPECTRUM EFFICIENCY

STATUS: VERSION 1

TECHNICAL REPORT

Geneva
November 2014

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Contents

DVB-T2 Single Frequency Networks and Spectrum Efficiency

Keywords: Digital Terrestrial Broadcasting, DTT, Single Frequency Network, SFN

1. Introduction

The increasing popularity of, and demand for wireless communications is placing greater pressure on the radio frequency spectrum. In light of these circumstances, broadcasters, along with other stakeholders, may need to review how they currently make use of the frequency bands they have been allocated and whether or not they may be able to do so more effectively.

In the context of traditional High-Tower-High-Power (HTHP) broadcasting, the introduction of new technologies such as DVB-T2 will be a big step towards greater efficiencies that will enable service enhancements such as the migration to HD television. However, it is often suggested that in order to drive even greater gains, these developments could be combined with further measures such as wider area SFNs and Low-Tower-Low-Power networks (LTLP), which could ultimately be more spectrally efficient.

Although these suggestions are in principle good ideas from a technical viewpoint, their benefits are often unquantified, and their practicalities are not well known, which can make coming to an informed decision about their benefits difficult. The aim of this report is to shed more light on the subject by presenting and summarising a number of theoretical and 'real world' case studies in order to see whether and how their potential benefits may be realised in practice, and how they could be used to fulfil broadcasters' requirements such as regionality, throughput and coverage. Particular emphasis has been placed on television broadcasting via DVB-T/T2 with some reference to DAB/DAB+, but it should be noted that the general principles covered in the report could be applied more widely to other systems.

A number of key aspects of networks and transmission systems have been considered. The potential for SFNs to provide even greater benefit than they presently do has been investigated by considering whether they could be extended over arbitrarily large areas, both in principal and for practical scenarios. The concept of Layer Spectrum Efficiency (LSE), a clearer definition of spectrum efficiency, has been applied in order to compare and contrast different combinations of network topology and transmission technology. HTHP and LTLP networks have then been assessed on this basis in order to compare their relative merits. Different network configurations ranging from national SFNs to regional SFNs and MFNs have also been considered to see how they could fulfil broadcasters' requirements for various receiving environments including, fixed, portable and mobile.

The structure of the report is as follows:

After the introductory part in **§ 1**, **§ 2** provides a basic overview of SFNs and some essential background. It provides a short introduction to the concept of SFNs and discusses some aspects of coverage assessment in broadcast networks as well as how to establish suitable parameters when planning an SFN. This section is brief since the principles of DVB-T2 SFN planning are the same as for T-DAB and DVB-T, and are now well established. Other EBU documents **[TR 021, TR 022]** extensively describe the principles of T-DAB and DVB-T, and should be referred to for further information. The report **[TR 024]** on principles of SFN planning covers most of the basic characteristics of SFN while **[TR 016]** gives a short overview of benefits and drawbacks of SFN. Technical details of DVB-T2 regarding network and frequency planning, and in particular differences to DVB-T, can be found in the EBU DVB-T2 report **[EBU Tech 3348]**.

§ 3 describes broadcasters' requirements ranging from the efficient delivery of regional or editorial content to other high-level commercial requirements that underpin broadcasters' business models. These are separate from purely technical considerations and must be taken into account in the network and frequency planning process.

§ § 4, **5** and **6** are the core sections of the report related to DVB-T2 SFN and spectral efficiency. **§ 4** describes the possibilities to extend DVB-T2 SFN to cover areas larger than was possible with DVB-T, but also elaborates on the constraints that remain. A mixture of theoretical and practical case studies has been used to illustrate the salient points. Also a comparison with an MFN approach has been performed in order to draw out the benefits of each. The practical case studies highlight the constraints that are imposed on technical network and frequency planning by editorial and commercial requirements.

In **§ 5** a more theoretical view is taken regarding the performance of DVB-T2 networks. It is demonstrated that the spectral efficiency DVB-T2 is not a fixed value but depends very much on the chosen type and size of the network as well as the intended reception mode. Beyond that, Spectrum Layer Efficiency, a generalized approach to the assessment of spectrum usage is applied. Also the aspect of frequency re-use distances is discussed.

§ 6 deals with an alternative approach for the network topology of DVB-T2 implementations. A comparison is performed between classical broadcast network topologies and cellular network topologies well known from mobile networks.

Finally, **§ 7** collects studies related to a further focus of the report: Particular aspects of DVB-T2 parameter choice, SFN design and operation. It contains contributions on the relevance of sea propagation in the design of SFNs, on static time delay and guard interval optimization of SFNs, on distribution networks for SFNs and on the inclusion of DVB-T2-Lite in a DVB-T2 multiplex.

§ 8 summarizes the main findings of the report.

The Annexes to this report contains material which has been used for the findings and conclusions of the main sections of the report and which has been published and discussed in the EBU project groups SMR-EDP and SMR-BNP. These documents are internal EBU documents and therefore not publicly available. The purpose of these annexes is to make them available to all readers.

The Annexes comprise the following:

A1: A theoretical study on maximum achievable data rates for large DVB-T2 SFN areas (EBU Doc. SMR-BNP 002rev1)

A2: A case study on large DVB-T2 SFN in Denmark (EBU Doc. SMR-EDP199)

A3: A case study on DVB-T2 service areas in Sweden (EBU Doc. SMR-EDP260)

A4: A case study on DVB-T2 MFN vs. SFN in the UK (EBU Doc. SMR-EDP261)

A5: A case study on national DVB-T SFN in Italy. This document also contains material on sea propagation and measurement techniques how to identify individual transmitter signals in an SFN environment (EBU Doc. SMR-BNP 088)

A6: A study on re-use distances of DVB-T2 networks (EBU Doc. SMR-BNP 033)

2. Background and SFN basics

2.1 Service areas

Broadcast networks are designed to provide coverage over given, pre-defined geographical areas, commonly called service areas. The size of these can vary significantly - they could be as large as an entire country or as small as a single town, and in general they fall into the three main categories of national, regional and local areas. Invariably, service areas are defined by a mixture of political, editorial, economic and practical considerations.

In most cases service areas are large enough to require multiple transmitters to provide the desired coverage, and broadcast networks are normally planned to match these as closely as is practicable.

2.2 Definition of single frequency networks

Digital broadcast systems such as DVB-T/T2 and T-DAB introduced the potential to use Single Frequency Networks (SFN). In these the same frequency is assigned to all transmitters in a given network that covers all, or part of a service area. For the systems mentioned, harmful intra-SFN interference is avoided by COFDM modulation on which they are based.

SFNs have now been widely deployed, and have been in operation for many years. They require a different planning approach to Multiple Frequency Networks (MFN) in which each transmitter would be assigned a different frequency to its neighbours in order to avoid undue interference between them.

Relative to MFNs, SFNs have a number of benefits, but these are associated with some drawbacks. The most significant of these aspects are briefly discussed below.

2.3 Benefits of single frequency networks

The obvious benefit of SFNs is the potential to improve the utilisation of the spectrum, i.e. to increase the spectral efficiency of the network. In many circumstances the use of an SFN may enable a coverage area, or part thereof, to be covered by a single frequency, rather than multiple frequencies. This is a clear benefit and forms a major subject of this report.

SFNs also introduce flexibility into network design - the ability to deploy SFNs, MFNs or a mixture of the two introduces a greater number of options for network planning, allowing the most suitable solution to be selected for the circumstances at hand.

Network gain, particularly relevant to mobile and portable networks, is another well-known benefit. These receiving environments are characterised by a Rayleigh channel whereby heavy multipath leads to a channel response with a number of deep ripples across the pass-band. Typically an SFN would introduce multiple transmissions from multiple sites, meaning that many locations would often be served by more than one transmitter. This property introduces a level of signal diversity not present in MFNs, a property that would often improve reception. The presence of several transmitters, each transmitting the same signal on the same frequency, from different directions as seen by the receiver, decreases the variability of the signal’s field strength from one location to another. For example, if one source is shadowed, others may be easily receivable, and the field strength variation of a single transmitter normally seen due to the presence of obstacles in the propagation path could thereby be reduced. Compared with an MFN, this effect would create a more homogeneous field strength distribution, and more certainty that a signal would be receivable at a particular location. It is one of the two main contributors to network gain.

The second main factor in network gain is the ability of the receiver to make use of the power in each of the multiple signals received from the other SFN transmitters. Signals that arrive within the guard interval can be combined to increase the power of the received signal. This effect is again most beneficial for Rayleigh channels whereby the increase in total received power would outweigh the effects of additional multipath which would have little detrimental impact on an already distorted signal.

SFNs also have the ability to make spectrum planning more effective. They enable allotment planning which can simplify the technical aspects of the frequency coordination process as the detail of the transmission network does not need to be known in advance - it can be determined later in the planning phase, or even during or after implementation. However, overall there is no reduction in network planning effort because work is simply shifted from the coordination phase to later in the network lifecycle. Although the total planning effort for MFNs and SFNs would be similar, SFNs may offer greater flexibility.

SFN allotments also allow network coverage to be progressively modified or improved by adding further transmitters without the need for re-planning frequency use or additional frequency coordination as long as the constraints of the frequency plan are respected. This would make it easier to improve the coverage quality step by step, as for example when enhancing coverage from fixed rooftop reception to portable reception.

2.4 Requirements and limitations of single frequency networks

In order to operate successfully, SFNs must avoid self-interference. They achieve this by sacrificing part of the signal‘s throughput to the guard interval, or cyclic prefix. Subsequently, SFNs cannot usually achieve the same throughput in an individual multiplex as would be possible in an otherwise equivalent MFN. This point is a key consideration of SFNs and is studied in more detail in **§ 4**.

Furthermore, transmitters within an SFN cannot operate independently - the content that they transmit must be identical, and the time at which they transmit it must be precisely controlled. Signals transmitted from the stations within an SFN must:

- have precise time synchronisation (which may purposefully introduce a tightly controlled delay relative to one another),
- be coherent in frequency (within a few Hz),
- have identical and synchronised content over the entire multiplex.

These requirements introduce complexity into the network. For example, additional equipment is needed in order to ensure that the above conditions are met and maintained. Apart from increasing costs, operational complexities are also increased as precise control over transmissions needs to be maintained at all times. Although usually these additional requirements and complexities pose no significant impediment to SFN deployment, they would need to be considered increasingly carefully as the number of transmitters within an SFN increases. For example, networks involving many hundreds of sites would need to consider these factors in greater detail. These aspects are further detailed in ITU-R Report BT.2253 **[BT 2253]**.

The requirement for identical and synchronised content means that any regional or local programmes within an SFN would be transmitted over the entire area it covers. The carriage of local content within a wide area SFN could mean that it would be available in areas where it may not be heavily used. In practice it is often more efficient to limit the size of SFNs to the particular area in which the content is required.

2.5 SFN service area terminology

In order to aid discussion in the remainder of the report it is helpful to introduce some broad classifications for the types of areas that SFNs may need to cover. Broadly, the report refers to SFNs in the following ways.

Geometrical - SFNs in this context refer to the physical or geographical size of the coverage area. They could be defined as small, medium, large, very large, or, more quantitatively, having a diameter of broadly 30 km, 150 km, 300 km or even larger.

Geo-political - SFNs in this context are defined in a more generalised manner with reference to the geopolitical boundaries they are intended to cover (e.g. national, regional or local). Under this definition SFNs of the same nominal classification can have significant variation in size, or coverage area - for example Luxembourg, a country, is smaller than many of the Länder (regions) in Germany.

Structural - SFNs in this context relate to the coverage provided by a particular transmitter infrastructure, or network. For instance it may be practical to continue to us an existing MFN transmitter network structure, so for example, a main station and its relays could operate in a regional or local SFN. Alternatively, countries may wish to use a dense or distributed transmitter network for a large area SFN. Coverage is then mainly set by the particular transmitter network configuration.

The remaining part of this section deals with several aspects related to coverage criteria and to the determination of planning parameters for SFNs.

2.6 Coverage criteria

2.6.1 Reception modes

DTT services are usually planned for three different reception modes: fixed, portable (outdoor/indoor) and mobile, with additional differentiation possible within these categories. For network planning the intended reception mode is perhaps the major planning criterion. It determines the network topology, in particular the transmitter density, and the power (or link) budget of the transmitters. A brief description of these reception modes is provided below.

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

Portable reception is defined as the reception at rest (stationary reception) or at very low speed (walking speed). Although reception in this mode will, in practice, take place under a great variety of conditions (outdoor, indoor, ground floor and upper floors), it is usually characterised by two broad classes: portable outdoor and portable indoor.

Mobile reception is defined as the reception by a receiver in motion with an antenna situated at no less than 1.5 m above ground level. The speed of the receiver can range from walking pace to that of a car driven on a motorway. High-speed trains, buses and other vehicles could also be considered in this mode, and may be a reception target in some instances.

Moreover, in planning, a distinction is made between portable reception with an external (dipole) antenna and an antenna integrated in a handheld device. The difference between portable reception and handheld portable reception lies in the different antenna gains which are assumed for the two reception modes.

A more detailed description of the different reception modes and their characterization by planning parameters can be found in **[EBU Tech 3348]**.

2.6.2 Pixel coverage, area coverage, population coverage

In this section some aspects of the definition of coverage are considered. Firstly, when describing coverage, a principal distinction is to be made as to whether the intended coverage target is to be based on the area or the population served. As population is not distributed homogenously across an area there may be large differences between the covered area and the covered population for a given network. This distinction should therefore be taken into account when coverage figures are compared so that population coverage is not inadvertently compared with, for example, area coverage.

The calculation of coverage, whether it be population or area based, may also be carried out in two main ways: cut-off and proportional.

For the cut-off method the entire population or area of a pixel (a small area of, e.g., 100 m x 100 m) is regarded as served if the predicted probability of coverage exceeds a specified threshold. If however, the predicted probability does not exceed the specified threshold none of the population or area are considered to be served. Typical values for this threshold range from 70% to 95% for fixed and portable reception and 99% for mobile reception. As an example, if the threshold is 70% and the predicted probability of coverage in this pixel is 84% and the population is 200 houses, then the population served using a cut-off method is 200. If in the same pixel we had the same threshold (70%) but the predicted coverage probability was 68%, the population served with the cut-off method would be 0 households.

If the coverage assessment was area based the entire area of the pixel may be considered covered if the specified threshold was reached, and entirely uncovered if the coverage probability was lower than the threshold. The full coverage would be determined by summing together all households, or areas where pixels are served to at least the cut-off threshold.

Broadcasters normally apply this method to describe area or population coverage.

The proportional method is an alternative approach. In this method the predicted probability of coverage of a pixel determines the proportion of the population in that pixel or the area of the pixel that are served. For example, where a pixel with 200 houses is served with a predicted probability of coverage of 84%, 168 households would be considered served. With this method only a proportion of the pixel is considered to be covered whereas the cut-off method would consider it entirely served if the threshold was met. A similar approach could be applied to area where that was the metric to be used. The full coverage is then determined by summing together the proportion of each pixel, either population or area, corresponding to the coverage probability in each.

2.6.3 Full area vs. partial coverage

A further relevant distinction when considering coverage is as to whether it is intended to cover the full area of a country or region, or only parts of it. For example it may be necessary to cover only metropolitan areas. Typically these would not be adjacent - they are usually separated by some distance. If they are separated by more than the re-use distance then the number of required frequencies can be significantly reduced as it would be possible to re-use the same frequency for all or many of the local areas - even if different content is provided to each of these. Therefore, a partial non-contiguous coverage paradigm always has a lower spectrum requirement than full area coverage where adjacent service areas have to use different frequencies in order to avoid undue interference.

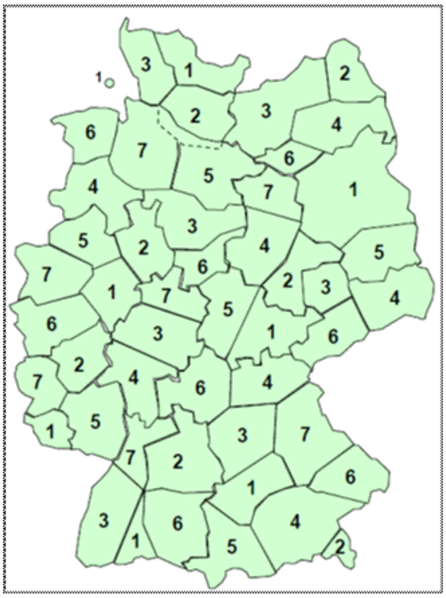

Figure 1a: Example of full area coverage using 7 channels

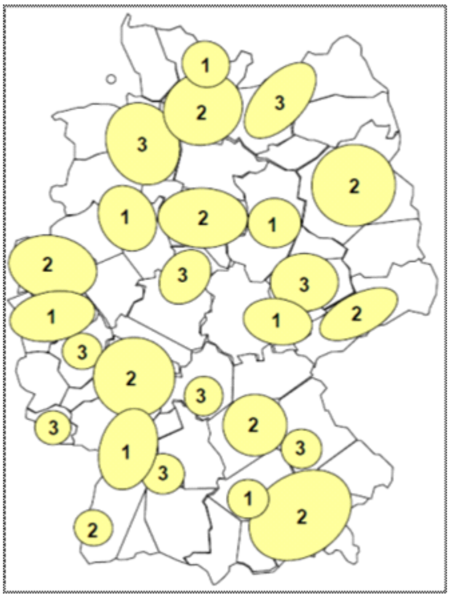

Figure 1b: Example of metropolitan area coverage using 3 channels

Examples are given in **Figures 1a** and **1b** where fictional coverage scenarios for Germany are sketched. **Figure 1a** represents full area coverage and **Figure 1b** metropolitan area coverage. A hypothetical channel assignment is indicated in the figures with channels 1 to 7 for the full area case and channels 1 to 3 for the metropolitan case. The example shows that for the case of full area coverage a higher number of channels is required in order to avoid undue interference between co-channel service areas. In the example a separation distance (re-use distance) of about 120 km is assumed.

Closely related is the planning consideration to cover a full area on an incomplete basis, i.e. it may be sufficient to cover a certain, but nonetheless high percentage of the area. For example 80% or 90% area coverage may be adequate where the non-covered locations are distributed throughout the entire area and fall where no coverage is actually required. An example may be where the aim is to cover populated areas such as households, with no need to cover motorways or roads. In this case only parts of the total area would need full coverage. Relative to a full area requirement, this relaxation reduces the number of frequency channels, in particular for MFNs and also in the case of extending SFN areas.

These aspects are considered in more detail in **§ 4**.

2.6.4 Determination of planning parameters

In order to achieve an intended coverage objective by means of an SFN the system and planning parameters must be carefully determined.

In the first instance an appropriate network topology is to be chosen. Two principle approaches are possible: High-Tower-High-Power (HTHP) or Low-Tower-Low-Power (LTLP), with ranges in between. This aspect is discussed in more detail in **§ § 5** and **6** of this report. Normally, for the distribution of broadcast content, an HTHP approach is pragmatic as it would allow existing transmitter site infrastructure to be re-used.

Secondly, the intended coverage target and reception mode are to be defined. These determine the choice of the system parameters such as the modulation scheme, code rate, guard interval, pilot pattern etc., and ultimately lead to the throughput (Mbit/s) the system could deliver. A sample of typical scenarios with their associated parameter sets are described in section 5 of **[EBU Tech 3348]**.

Finally link budgets for the service area are to be determined in order to tune the transmitter characteristics and to assess the coverage of the network. A detailed description of the components of and the methodology to calculate link budgets can be found in Annex 1 of **[EBU Tech 3348]**.

2.7 Layer definition

In this report, as for many countries, a layer is considered as the set of frequency channels, together with their associated service areas, which can be used to provide full national or partial nationwide coverage, or a substantial part thereof, for a multiplex.

3. Broadcasters' requirements

3.1 Editorial requirements

Broadcasters have different needs that influence the size of their service areas. They may include, for example:

- Commercial requirements: the service itself can contain programs intended for an entire nation, a region or a local area. Additionally it may be necessary to break down larger areas into smaller ones - for example, even when programs are national there may still be a requirement to insert local or regional advertisements.
- Demographic requirements: there may be a need to provide a service in a particular area, due to cultural and language variations, or areas of a particular group of people. Broadcasts in minority languages are an example.
- Regulatory requirements: permission by authorities and regulators may specify the area where it should be possible to receive the program(s), often these areas are defined on the basis of commercial or demographical borders (as given in the two first points).
- Social Requirements: often the regulatory requirements above will consider the social objectives of a broadcast service, particularly in the case of public service broadcasters where a key aim is to minimize the risk of social exclusion by providing easy access to high quality free-to-air coverage for all viewers, listeners or consumers of the service.

Due to its diversity, the actual size of broadcast service areas varies significantly throughout Europe. In terrestrial broadcasting a national service area may cover a whole country with a large number of transmitters, while in some countries only a few transmitters may be needed to provide national coverage. The requirement for regional and local content also varies, depending on the requirements of the country, region or area in question.

The introduction of digital broadcast systems has increased the number of transmitted programs, many of which are often delivered on a commercial basis. In several cases this has led to a greater requirement to insert local or regional advertisements and even regional radio services carried on DTT. While digital broadcast systems have allowed the introduction of wide area SFNs, they do not suit all practical circumstances.

3.2 Coverage requirements

Coverage requirements differ between countries and also depend upon broadcasters' objectives. Furthermore the requirements may be defined by a number of different organisations including, for example, regulatory authorities and broadcasters themselves. For DTT they are often defined in terms of population coverage rather than providing a certain degree of area coverage.

In most countries the coverage requirements are higher for public service broadcasters where they are often obliged to provide close to full population coverage. For example the PSB services in the UK have requirements to cover at least 98.5% of the population and SVT (Swedish television) has an obligation to cover more than 99.8% of the population.

The coverage obligation for commercial broadcasters may be defined by the regulatory authorities, but perhaps more commonly they are based upon market aspects. In Sweden for example the commercial broadcasters require population coverage of 98%.

In many cases it is also fairly easy to reach high population coverage when only using the main transmitters. This is due to the uneven population distribution with population concentrated in a few main cities. Providing coverage for the last few percent will generally require much more effort and will be much more expensive. Coverage requirements can therefore also be set for economic reasons.

Coverage requirements can also be influenced by the reception mode targeted by broadcasters. Some countries aim for portable indoor reception, while others aim for fixed rooftop reception.

3.3 Operational/Network requirements

The nature of broadcasting, particularly for HPHT networks where individual sites cover large numbers of people, often places very high availability targets on transmission networks. Failures in the network may cause break services which may in turn cause in the significant loss of enjoyment for viewers or listeners, especially during peak hours, with the possibility of audiences migrating to competing platforms. For commercial operators funded by advertising, a failure in the network could also lead to financial loss. In order to prevent such events happening, network operators and planners when designing, implementing and operating networks have to be careful to ensure that broadcasters' required service availability can be met.

Compared with MFNs, SFN networks bring additional parameters into play when considering aspects of network reliability, both in terms of equipment and network planning.

To operate correctly, SFNs require tight control of frequency and time; the Global Positioning System (GPS) being typically used to provide both a stable frequency and time reference against which network timing synchronisation can be managed. Failure of the timing in any part of the network or a drift in the frequency of a transmitter can result in significant interference, the source of which can be difficult, and time consuming, to track down, particularly in SFNs.

In a national MFN, whilst parts of an area may be subject to interference occurring due to anomalous propagation conditions, it is unlikely that all frequencies in all areas will be affected - frequency diversity in an MFN mitigates to an extent the interference and where it occurs at any given time. In a large SFN, such as a national SFN, such frequency diversity does not exist and as a consequence interference, when it occurs, at a given point in time, may affect much larger areas than would be affected in an MFN during the same propagation event. As such in SFN, if care is not taken when planning in assessing interference, network coverage problems may occur particularly if sea paths are involved.

As such not only does redundancy need to be factored in to key components associated with network synchronization, but network planning must factor in time variability of signals, particularly over sea paths, see **§ 7.2**.

4. DVB-T2 and Single Frequency Networks

4.1 Overview

DVB-T2 has, relative to its predecessor DVB-T, introduced significantly more freedom with respect to SFN planning and implementation. In particular the increased guard interval durations that DVB-T2 offers allow the maximum practical size of SFN to be extended while maintaining high throughputs (or conversely the throughput of existing SFNs to be increased while maintaining coverage). The extent to which DVB-T2 can be used to introduce new, or modify existing SFNs is discussed here, along with some of the practical considerations that would be involved in so doing.

In the first instance the maximum possible extent of an SFN is of interest, i.e. is there any limit to the geographical area that an SFN may cover? In principle SFN areas may be arbitrarily large, but in practice a number of technical and non-technical factors limit their useful size.

Self-interference places the main constraint on the size of an SFN. In broad terms an SFN will contain coverage holes if any two transmitters within it are separated by distances exceeding the guard interval (more exactly: the distance which the signal travels during the guard interval period). Up to a limit, it is possible to overcome this interference and regain the coverage by increasing the signal's guard interval, or by improving its robustness. However, doing either of these will reduce the network's throughput, and it becomes necessary to trade off coverage against throughput in order to find the most satisfactory combination of the two.

Alternatively, increasing the number of sites within the network in order to reduce the inter-site distance (ISD) would overcome self-interference without reducing coverage or capacity. However, this option could be very costly, and is largely ruled out in instances where the pragmatic approach of re-using existing infrastructure is opted for.

These factors combine in most practical instances to limit the extent to which SFNs are deployed.

Additional non-technical factors also limit their size - editorial or commercial regions play an important role in determining their dimensions, as described in **§ 3**.

In order to see how these factors would affect SFNs in practice, several studies have been undertaken and are summarised in this section:

- A theoretical study by IRT based on regular hexagonal networks investigates the maximum data rate a DVB-T2 multiplex may achieve for portable/mobile reception for large, and very large service areas (the meaning of 'large' and 'very large' is explained further below).
- Another case study completed by Progira and DR (Danish Broadcasting Corporation) investigates the potential for national SFNs based on practical circumstances in Denmark. It also highlights the benefit that DVB-T2 may bring to an existing DVB-T based network.
- A further study for Sweden by Teracom investigates the appropriate size of SFNs with regard to existing infrastructure requirements.
- Two further studies, by BBC/Arqiva, based on the UK compare the coverage and throughput that DVB-T2 may achieve with various modes in different HTHP network configurations such as MFNs, regional SFNs and national SFNs.
- A sixth study for Italy by Rai Way describes the deployment of a national DVB-T SFN and the coverage that can be achieved thereby.
- A seventh study by Arqiva describes an SFN planning exercise with limited spectrum resources in the UK.

§ § 4.2 to **4.8** give a short introduction and summary of these studies, whereas **§ 4.9** presents a synopsis and draws the general conclusions from them. The full studies, which are not yet publicly available, are incorporated into this report as annexes.

4.2 Theoretical study on maximum achievable data rates for large DVB-T2 SFN areas

In a study by IRT **[BNP 002]** (see **Annex A1**), theoretical hexagonal networks have been used in conjunction with the ITU Rec. P.1546 propagation model to examine the limitations and capabilities of large DVB-T2 based SFNs. Two cases, a large SFN with dimensions of 360 km x 360 km and a very large SFN (720 km x 720 km), have been analysed in order to find the modes that would, for 100% area coverage, provide the maximum achievable data rate for mobile, portable and fixed reception.

In the model an inter-transmitter distance of 60 km was assumed. All transmitters in the SFN are assigned the same characteristics: omnidirectional antenna, effective antenna height of 300 m and an ERP of 100 kW.

Additionally the trade-off between area covered and increasing data rate is discussed. Although the large SFN is already quite extensive, due to additional interference beyond the guard interval, the introduction of further transmitters to extend the SFN size affects the performance of the network and impairs reception. This characteristic is closely related to a further trade-off between a higher data rate and a lower reception quality, which is also examined. With an increasing data rate the percentage of the covered area decreases. For instance, in the large SFN, 100% coverage with 20.1 Mbit/s for mobile reception could be achievable, whereas an increase in the data rate to 22.4 Mbit/s would cover only 52% of the area to the required location probability - the rest (48%) would fall below this limit (but would still be above 95% coverage probability) [1].

The less demanding parameters for portable reception, as compared to mobile, allow for higher data rates; for instance, for the large SFN up to 30 Mbit/s would be possible. This is a significant difference which is mainly due to the assumption of a 5 dB allowance for Doppler degradation (which may be conservative) that has been made for mobile reception.

Nevertheless it has been found that even for the large SFN, and also for the very large SFN, a guard interval of 448 µs (GI 1/4 with 16k FFT) would be required. Smaller GIs cannot fulfil the coverage requirements. Only in the case of portable reception, where the modulation is made more robust (64-QAM reduced to 16-QAM), would the smaller guard interval yield acceptable coverage.

Finally, based on a hexagonal network with the size as of 360 km x 360 km, the relationship between signal robustness and minimum required guard interval for networks with various inter-site distances has been analysed. As can be expected, the required guard interval increases as the inter-site distance and the C/N value increase. For example, a DVB-T2 mode with a C/N of 20 dB, operated in an SFN with a typical inter-site distance of 50 km requires a guard interval of at least 425 µs. For a 16k FFT there is only one such guard interval value available which is GI 1/4 (448 µs).

The results may be used as guidance in the initial stages of the network planning process when choosing a DVB-T2 mode for particular coverage scenarios.

4.3 Case study on large DVB-T2 SFNs in Denmark

A study by Progira and DR **[EDP 199]** (see **Annex A2**) aimed at determining whether national SFNs could be a practical method of matching existing near-universal coverage in Denmark. The study considered coverage to directional rooftop antennas from the existing HPHT DTT network for both DVB-T and DVB-T2.

Table 1 shows that the current DTT network in Denmark provides near universal coverage (99.7%

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[1] In this scenario only a small portion of pixels have a location probability between 98.5% and 99%. In order to have 100% of the area covered with the desired C/N value, the requirement for the location probability was lowered from 99% to 98.5%

population) to rooftop antennas. It has some 47 transmitters (18 main stations and 29 lower power, secondary stations) configured mainly in regional SFNs of around 150 to 160 km in diameter, with the occasional MFN. The table also shows the results from coverage predictions for this network with the DVB-T and DVB-T2 modes shown, all of which are practical and could be deployed in real networks.

Table 1: National SFN coverage for various modes in Denmark

	DVB-T Current Network	**DVB-T National SFN**	**DVB-T2 National SFN**	**DVB-T2 National SFN**	**DVB-T2 National SFN**
Mode	DVB-T 64-QAM 2/3 GI 1/4 (224 µs)	DVB-T 64-QAM 2/3 GI 1/4 (224 µs)	DVB-T2 256-QAM 3/5 GI 1/8 (448 µs)	DVB-T2 256-QAM 3/5 GI 19/128 (532 µs)	DVB-T2 64-QAM 3/5 GI 19/128 (532 µs)
C/N	19.5 dB	19.5 dB	19.6 dB	19.6 dB	15.2 dB
Population	99.7%	37.0%	97.0%	97.1%	99%
Capacity	19.9 Mbit/s	19.9 Mbit/s	29.9 Mbit/s	29.4 Mbit/s	21.8 Mbit/s

The following main points were highlighted in the results:

- The maximum guard interval for DVB-T (1/4) would be too short to form a national SFN based on the current network. Widespread self-interference would limit coverage to around 37% of the population. DVB-T2 would therefore be necessary.
- A DVB-T2 based SFN with a 1/8 guard interval (448 µs) would significantly improve coverage, though a shortfall of almost 3% would remain. Despite the doubling of the guard interval, self-interference would still be the limiting factor (the C/N of this mode is similar to the current DVB-T mode, which implies the coverage loss may be attributed to the SFN)
- A further increase in the guard interval to 532 µs would only marginally improve coverage - 0.1% additional population was gained.
- Adoption of a more robust DVB-T2 mode (64-QAM 3/5) with 4.4 dB lower C/N would still not fully regain the coverage - 0.7% of the currently served population would remain without coverage - and importantly the national SFN would only increase throughput by 1.9 Mbit/s, which is not significant.
- For the cases above using DVB-T2, it is however believed that the remaining problems of SFN self-interference could be substantially resolved by introducing static time delays in combination with adjustments of antenna patterns for some of the transmitter sites.

The report made the following general points regarding SFNs:

- National SFNs may make the addition of new, low power transmitters (gap fillers) to the network easier.
- Some network gain may be realised for networks designed to provide mobile or portable reception.
- Regional and local content, an important broadcaster requirement would not be delivered efficiently in a national SFN.
- The throughput of a multiplex configured in an SFN reduces relative to MFNs. This is a direct result of increasing the guard interval to avoid self-interference. Even if it was possible, at least one additional multiplex would be required to recover the lost capacity should DVB-T based MFNs or regional SFNs be converted to national SFNs also based on DVB-T. The overall benefits of this scheme are therefore questionable.

The study incorporated a simplifying assumption that Denmark would have unrestricted use of a single frequency channel, and that it would be free from interference from other countries. In practice this may be an optimistic assumption.

It was also noted that due to the significant number of transmission paths across water (circumstances that increase the potential for self-interference) Denmark may be regarded as a challenging, but nonetheless practical case study. These considerations should be borne in mind when extrapolating the results to other areas.

The study drew the following conclusions:

National SFNs would not be a practical means of delivering near universal coverage with DVB-T due to its limited guard interval duration. DVB-T2 would provide significant improvements, as anticipated, but the study found that a national SFN based on existing network infrastructure, while maintaining sufficient capacity, would still not fully match the coverage of the current regional SFN/MFN network.

It would not be possible to efficiently deliver regional content with a national SFN. Regional SFNs would be better suited for this purpose and may overall remain the most attractive configuration for broadcasters.

4.4 Case study on DVB-T2 service areas in Sweden

A study by Teracom **[EDP 260]** (see **Annex A3**) compares the interference-limited population coverage in Sweden by using two different network configurations: a national SFN and a number of smaller sub-national 'regional' [2] SFNs using a total of four frequency channels. In both cases DVB-T2 was used with the same transmission mode.

In the regional SFN case the maximum distance between any two of the larger stations within each SFN area was kept within the length of the guard interval. However, in some cases there were smaller stations beyond this distance.

The study focussed entirely on Sweden, with no consideration of neighbouring countries, and as such it should not be considered as a proposal but only as an example.

The main findings of the study are as follows:

Covering Sweden with regional SFNs in a 4-frequency network would provide significantly higher interference-limited coverage than a national SFN.

Even if a single frequency was sufficient for Sweden in isolation, neighbouring countries would require separate frequencies of their own. Although not considered in detail, it was estimated that four frequencies might be needed over a wider area in order for other countries to achieve their coverage targets - roughly the same number as would be needed for regional SFNs.

For the same degree of interference-limited coverage, the regional SFN approach, which by virtue of having smaller regions would permit the use of higher capacity/shorter guard interval modes, could lead to a higher total capacity within a set amount of spectrum.

The regional SFN approach also provides far better - although by no means perfect - possibilities for regional programming.

[2] For illustrative purposes hypothetical regions were used with dimensions well matched to the chosen guard interval.

4.5 Practical DVB-T2 based scenarios exploring the interdependence of coverage, capacity, transmission mode and network configuration

4.5.1 Background

A UK based capacity study by Arqiva and the BBC was undertaken with the aim of providing high level guidance as to the throughput and population coverage that DVB-T2 could achieve with various transmission modes in combination with three broad network configurations (MFN, regional SFN and national SFN). The study also considered how the throughput and coverage would vary depending on the amount of spectrum allocated to a multiplex, or layer. In total 360 different combinations, or scenarios, were assessed including 18 different DVB-T2 modes, three different network configurations, and a spectrum allocation ranging from three to six frequency channels per multiplex.

The scope of the study was restricted to the existing HTHP network infrastructure and fixed rooftop reception. In order to simplify the work, many high level assumptions were made (most of which are not set out in this summary), particularly about the transmissions in neighbouring countries. As some assumptions may not accurately reflect their operating conditions, or may not be practical, the results should be treated as indicative, and used to draw only high level conclusions about what may be possible, and although it is believed that the broad conclusions of the work are fairly general, they may not be directly applicable to all countries [3].

The study included real terrain information, and to the extent known, existing antenna systems, transmitted powers, and geographical population distributions.

It must also be pointed out that the study does not constitute any particular proposal for a frequency plan, either within the UK, or further afield. It was simply a research exercise in order to form broad conclusions about what capacity and coverage might be achievable from different network configurations in conjunction with DVB-T2.

The full study is not publicly available, but the methodology and the most relevant results of the work are described briefly below.

4.5.2 Methodology

The study sought to determine the throughput and coverage that could be obtained from a predefined number of frequency channels allocated to a single multiplex, or layer, in one of three network configurations. In total 360 scenarios were considered, each of which were themselves formed from a combination of a sub-scenario and a transmission mode, as set out in **Table 2**. The sub-scenarios consisted of a combination of network configuration (MFN, regional SFN, or national SFN) and a number of frequency channels (3 to 6) assigned to a multiplex. For example, a full scenario may have consisted of four channels being assigned to a multiplex, or layer, configured in a regional SFN whereby a capacity of 34 Mbit/s was available. The population coverage was then calculated. Altogether these full scenarios encompass a wide range of potential network configurations and modes, giving a good indication of what might be achievable under a range of circumstances.

[3] The study was undertaken over a limited area that did not include some well-known hotspot areas where frequency planning is particularly difficult. In these regions in particular the results from this study may need some adaption.

Table 2: Considered sub-scenarios and transmission modes in the study; all 360 combinations were investigated

Sub-Scenario	Transmission Mode
Network Configuration	Constellation Code Rate
MFN	256-QAM 2/3
MFN + Relays SFN	256-QAM 3/5
Regional SFN	64-QAM 5/6
Nations [4] SFN	64-QAM 3/4
National SFN	64-QAM 3/5
	16-QAM 2/3
Frequency Channels per Multiplex	**Guard Interval (μs)**
6	28
5	224
4	448
3	

A bespoke system was created to automatically generate a frequency plan for each sub-scenario (network configuration and channel availability). It assigned to each station a frequency from the pre-determined list of those available, and assumed that the frequencies of stations in the UK and neighbouring countries could be freely changed in order to get the best overall population coverage throughout the planning area. It was further assumed that for each sub-scenario the same network configuration would be used across the entire planning area - for example, in a regional SFN scenario, all countries in the planning area were assumed to adopt regional SFNs comprising the same number of frequency channels. No changes were made to the transmitted powers, or antenna patterns of the stations in any of the scenarios.

The UK coverage for each scenario was calculated based on the existing 80 main stations in the UK and included interference from the main stations of neighbouring countries under pragmatic assumptions based on coordination agreements.

4.5.3 Results

Three charts appear below which summarise the high level results for MFNs, regional SFNs and national SFNs. They are best described by an example in which the aim is to achieve at least 95% coverage. **Figure 2** indicates that the 80 main stations in an MFN would require a minimum of four channels, and around 27 Mbit/s could be achieved from the network. Five channels on the other hand could achieve 34 Mbit/s, while six could achieve 40 Mbit/s. **Figure 3** shows that a regional SFN could achieve the coverage target with three channels, but the capacity would be reduced to around 23 Mbit/s. In this configuration four channels may provide around 35 Mbit/s (more than the MFN), and whereas six channels would provide more coverage in the regional SFN than the MFN, the maximum throughput would be reduced due to the extended guard interval required in the SFN. National SFNs, as shown by **Figure 4**, could achieve around 33 Mbit/s with four channels while reaching the coverage target.

The charts clearly show the inverse relationships between coverage and capacity - increasing one reduces the other. They also show the benefit that using more frequencies can give to both coverage and capacity - both can be increased by using more spectrum. The relationship between guard interval durations, coverage and capacity within SFNs is also highlighted. Increasing the

[4] For the definition of nation see Annex A4.

guard interval can improve coverage, but it reduces capacity.

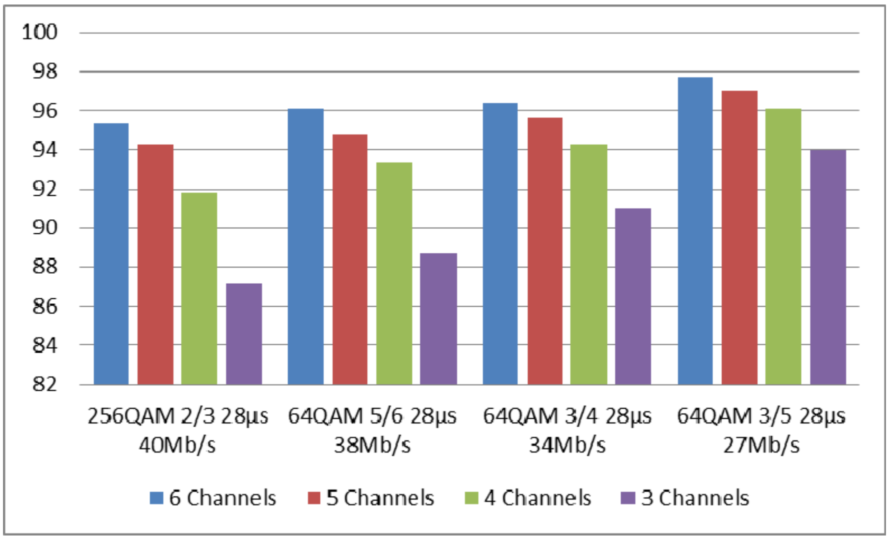


Figure 2: MFN

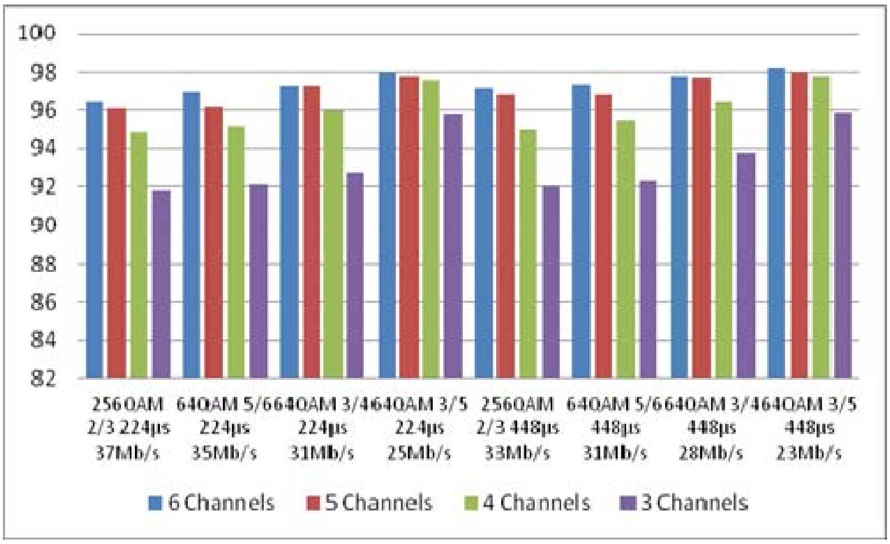


Figure 3: Regional SFN

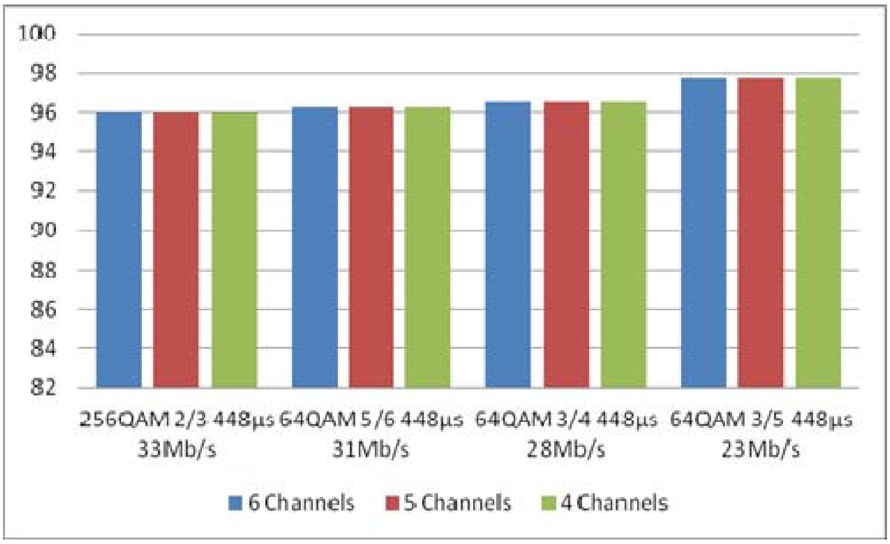


Figure 4: National SFN

4.6 Case study on DVB-T2 MFN vs. SFN in the UK

A study by BBC **[EDP 261]** (see **Annex A4**) incorporates and follows on from the results in **§ 4.5**. It is intended to assess the efficiencies of national SFNs, regional SFNs and MFNs relative to one another. Two methods were used. Method 1 was based on the familiar metric of spectral efficiency measured in bit/s/Hz. Method 2 looked at efficiency in terms of the number of programmes that could be delivered per frequency channel[5] while taking into account the effects of statistical multiplexing and MPEG compression. Both methods were based on the results from **§ 4.5** which determined how many frequency channels would be required to achieve various throughputs in a national network made up either MFNs, regional SFNs or national SFNs.

Method 1 showed that SFNs could be some 25% more efficient than a national MFN, and 10% more efficient than a regional SFN.

Method 2 also shows broadly similar results, though as expected there is some slight variation due to the quantising effect that the carriage of discrete numbers of programmes have on the multiplex capacity (i.e. it is only possible to carry a whole number of programmes on a multiplex - it is not for instance possible to carry half a programme). For a particular program quality this effect can lead to a greater or lesser portion of the total throughput being ‘left over’, and it is more pronounced for high quality HD programmes. Depending on the throughput of a particular multiplex, only three or four HD programmes may be able to be carried within it, which makes the quantising effect more significant. This can have the effect of reducing the efficiency of an SFN as significant ‘left over’ capacity would remain in some instances. For example it may come to pass that introducing three HD channels may nominally leave 2 Mbit/s of multiplex capacity being ‘left over’ which may not be sufficient for another HD programme.

This method also relies on the subjective measure of picture quality which, at first sight, could be perceived to have the potential to change the efficiency conclusions that are drawn from the method 1 analysis. However, this study has looked at various different picture qualities, and although quality does influence the outcome to an extent, it is not sufficient to change the conclusions, except perhaps for the case of very high quality HD pictures in a lower capacity multiplex.

The main factor that influences spectral efficiency is the number of frequency channels required for the different network configurations. The results in **§ 4.5** were used to establish these requirements in the first instance, and they lead to the conclusions above.

A sensitivity analysis was carried out in order to determine how the results may change if additional frequency channels were needed in the various network configurations. Method 1 was used for this assessment and it was found that should each network configuration require an additional channel, relative to an MFN, the efficiency of a national SFN would drop to approximately 20%. Another showed that if MFNs required an additional channel while national SFNs did not, the relative efficiency of an SFN would approach 50% over an MFN.

In all cases it should be noted that the price to pay for the increased efficiency of SFNs would be restrictions on regional and local coverage.

As it would not be efficient to deliver regional content in a national SFN, regional SFNs are a good compromise between an MFN and a full national SFN. Their efficiency generally sits between the two and they would allow regionality to be maintained.

[5] It should be noted that in this study a different definition of spectral efficiency is used from the one applied in §§ 5 & 6.

4.7 National DVB-T SFN deployment in Italy

A report by Rai Way **[BNP 088]** (see **Annex A5**) describes the deployment of a national DVB-T SFN in Italy. The 224 µs maximum guard interval of DVB-T is relatively short compared with the large extent of Italy, which makes this task challenging. Although DVB-T2 does not suffer from this restriction, this Italian example shows what may be achieved and what compromises have to be accepted with an OFDM system based on a HTHP infrastructure and a guard interval restriction to 224 µs.

In 2010 the Italian Authority (AGCOM) delivered the first plan for digital television in which at least 21 national, 13 regional, and other local SFNs have been considered. The adopted GE06 system variant was C2 (64-QAM, FEC 2/3) for UHF and F3 (64-QAM, FEC 3/4) for VHF. With the exception of RAI multiplex 1, all layers have been planned with 1-SFN or 2-SFN, i.e. using one or two channels per multiplex to cover all of Italy. The wanted signals were considered at 50% of the time, whereas the interference signals were considered at 10% of the time for national territory and at 1% of the time for the neighbouring countries [6].

Regarding multiplex 1, RAI was asked to cover the population with the same percentage of the best former analogue network, i.e. 99%. This high percentage cannot be achieved with a national 1-SFN or 2-SFN. Therefore this layer was deployed by using regional SFNs. Furthermore, Rai Way had to reach at least 90% coverage for multiplexes 2 and 3 and 80% for multiplex 4. Multiplexes 2 and 3, deployed as 1-SFN and consisting of 117 transmitters with an ERP higher than 1 kW and another 283 low power transmitters with an ERP of less than 1 kW, reaches the measured coverage of 91.5%.

Annex A5, with the full report, also contains a comprehensive overview of planning and measurement techniques for the deployment of SFNs.

4.8 DVB-T/DVB-T2 planning exercise with limited spectrum resources in the UK

Combined, the main six UK multiplexes use 32 channels, leading to an average-per-multiplex frequency re-use pattern of 5.3. Studies by Arqiva **[Ar 2009, Ar 2011]** investigated whether six channels (31 - 35 and 37), using a re-use pattern of three, would be sufficient to create two national DTT layers (layers 7 and 8) while aligning with existing editorial regions.

Under these more restrictive conditions stations were arranged so that any particular service area had an even number of neighbouring areas, as with this arrangement a three-colour map is possible (i.e. adjacent service areas would not fall co-channel). However, in order to create these conditions some transmitters in particular regions, which would normally be in MFNs, had to be re-configured into SFNs.

It was found that, compared with the main network, where the frequency re-use is higher, the three-channel network would be both coverage and capacity limited - the former being a result of the more frequent re-use pattern, while the latter was due to the increased guard interval necessary to operate some transmitters in SFNs. DVB-T2, it was noted, would offer benefits for both coverage and capacity. It would, in these circumstances, eliminate SFN self-interference, and could, through moving to a more robust mode, improve coverage by sacrificing some of the additional capacity it would introduce relative to DVB-T.

One study **[Ar 2011]** also considered whether a national SFN would be practical (layer 9). With DVB-T it was found that, although quasi-national coverage could be achieved, the capacity of such a network would be impractically low due to the long guard interval requirements. DVB-T2 would,

[6] Rai Way uses different percentages for the interferers depending on the situation (from 1% up to 10%) and on the propagation model adopted.

however offer significant benefits to both coverage and capacity.

Tables 3 and **4** summarise the results of the studies [7].

Table 3: Re-Use 3 Coverage

Mode		Capacity	Layer 7 Coverage (%)	Layer 8 Coverage (%)
DVB-T	8k 64-QAM 2/3 FEC 1/4 GIF	19.9 Mbit/s	89.3	87.2
DVB-T2	32k 256-QAM 2/3 FEC 1/16 GIF	38 Mbit/s	88.1	85.9

Table 4: National SFN coverage

Mode		Capacity	Layer 9 Coverage (%)
DVB-T	8k 64-QAM 2/3 FEC 1/4 GIF	19.9 Mbit/s	84.4
DVB-T2	32k 256-QAM 2/3 FEC 1/8 GIF	35.8 Mbit/s	91.2

Thus, for DVB-T, the findings of Arqiva and Rai Way, described in the previous section, are similar. With a few channels, or even only one, relevant national coverage can be achieved; however, this “saving” of channels has to be paid for by an incomplete coverage which may amount to 10 - 20% lack of covered population being (more or less) uncontrollably distributed across the country.

4.9 Summary and conclusions on SFN studies

The seven studies above variously considered whether it would be possible, practical and efficient to deliver broadcasting services with national or wide area SFNs involving DVB-T and DVB-T2. They were all based on HPHT infrastructure and ranged from a general, flat-earth, hexagonal network analysis to assessment with existing network infrastructure. Even so, a number of common themes were developed and are discussed further below.

In all studies the importance of regional content to broadcasters was emphasised. This leads to the consideration of regional SFNs alongside national SFNs as potential network configurations as the former would retain regionality and would subsequently be a good compromise between full MFNs and national SFNs.

It should be noted that none of the work represents, or forms a proposal for any of the countries involved; purely high-level studies were carried out to further understand network design options.

4.9.1 National SFNs with DVB-T

The study based on Denmark concluded that it would be impractical to cover the entire country with a national DVB-T SFN; the longest available guard interval in DVB-T (1/4 or 224 μs) would be too short to avoid self-interference. It was predicted that coverage of a national DVB-T SFN would be limited to around 40% of the population, much lower than the current near-universal 99.7%, which is currently delivered via a mixture of regional SFNs and the occasional MFN. The further step of adopting a more robust mode was found to be an insufficient mitigating factor to regain the coverage, and it would come with the additional drawback of reducing capacity of a multiplex to below what is currently available.

The Arqiva study found that in the UK both the coverage and capacity of a national DVB-T SFN would fall short of PSB requirements.

[7] It should be noted that the coverage calculations incorporated coordination agreements that, under different conditions might be relaxed, leading to improved coverage. More detail can be found in the reports.

However, the Italy report on the deployment of a national SFN shows that with a larger number of additional low power transmitters a considerable improvement in coverage could be achieved, albeit not to an extent that fulfils public broadcasters' coverage requirements, and often also obligations. The report concludes that this would only be possible with a large number of additional low power transmitters.

4.9.2 National SFNs with DVB-T2

The case studies in Denmark and UK found that DVB-T2 would, as expected, offer significant improvements over DVB-T for national SFNs. However, all the studies recognised that capacity was an important consideration in a network, and that enlarging SFNs to national size would only be possible at the expense of capacity in an individual multiplex. This is confirmed by the theoretical study which shows that for very large SFNs a capacity loss of at least 5% - 15% would be encountered in a multiplex compared to the capacity of a large regional SFN.

The study considering Denmark concluded that it would not be possible to match the full coverage (99.7%) and capacity from the current network infrastructure with a DVB-T2 based national SFN, although network optimization would likely lead to improvements (see **§ 7**).

The study based in Sweden adopted the longest guard interval duration 532 µs (32k, 19/128) and found self-interference, primarily on sea paths, to be the coverage limiting factor. 89.1% population coverage was predicted providing the required 36.7 Mbit/s.

The UK based capacity study considered more robust transmission modes for national SFNs and concluded that around 96% coverage at a 33 Mbit/s throughput may be possible from the core 80 site network, but that four or more frequency channels would be required over the wider planning area including immediate neighbouring countries. At a higher throughput of 35.8 Mbit/s, and with existing coordination agreements, the Arqiva study found that, under around 91% of the population could be covered.

4.9.3 Regional SFNs

All case studies pointed out the benefits of regional SFNs:

- Regionality can, by definition, be maintained.
- Compared with an entire nation, the smaller size of a region is well matched to practical guard intervals. This enables SFN self-interference to be avoided, which improves coverage while allowing a higher payload.
- Over practical planning areas, i.e. those involving many neighbouring countries, regional SFNs may require a similar number of frequency channels as a national SFN, making the efficiency of the two network configurations comparable.

In the Denmark example, the size of the regions were well matched to the length of the guard interval which has the effect of avoiding self-interference - the coverage limiting factor in national SFNs. A similar finding was evident for the hypothetical regions in the Sweden based study and for the Arqiva re-use-3 study.

Inter-regional interference between co-channel regions can also be present, and was predicted in the Sweden study, but it can be substantially eliminated due to the large separation distances between co-channel regions.

4.9.4 Relative spectral efficiencies of MFNs, regional SFNs and national SFNs

All the studies pointed out the following for national SFNs:

- Although a national SFN would require only one frequency channel per country when considered in isolation, four to five would be necessary upon inclusion of neighbouring countries - a similar number as would be required by regional SFNs. In some ‘hot-spot’ areas even more frequency channels may be required.
- Wider area SFNs require a correspondingly longer guard interval in order to overcome self-interference, and therefore offer reduced capacity per multiplex.
- Regional SFNs, due to their restricted size, allow a shorter guard interval and therefore more capacity per multiplex than a national SFN.
- National SFNs would be impractical and inefficient for regional content delivery.

The UK efficiency study compared the spectral efficiency (in Mbit/s/Hz) of the different networks more directly by determining how many frequency channels it would take to provide a particular coverage level in the UK at a given capacity. In general it was found that, over a reasonably wide planning area, for the same coverage regional SFNs would require fewer channels than MFNs, with national SFNs requiring fewer still. However, the offsetting factor being that MFNs would provide more capacity per multiplex than the other two methods with national SFNs providing the least. Comparing the different networks, and the three competing factors of coverage, frequency channels and capacity, it was found that regional SFNs could be some 10% more efficient than an MFN, with national SFNs being some 15% more efficient again. The UK study also compared efficiency in terms of the number of programmes that could be delivered with the different network configurations given the required number of frequency channels. This method incorporated the effects of statistical multiplexing, and picture quality considerations, including SD and HD. In broad terms, this method led to the same conclusions as the standard spectral efficiency method above.

4.9.5 Conclusions

DVB-T would not be practical for national SFNs to meet public service broadcasters’ coverage requirements which in most countries are around 99% (population) coverage.

DVB-T2, with its enhancements over DVB-T, would allow the implementation of wider area SFNs. However, these may not necessarily be arbitrarily large from a practical point of view. The case studies for Denmark and Sweden showed that in those countries, national SFNs may remain impractical, even with the longest possible guard interval available in DVB-T2, particularly if near universal coverage targets are a requirement.

Regional SFNs, as currently operated by broadcasters, offer a good compromise between national SFNs and full MFNs. In these configurations the restricted size of regions (relative to a nation) allows SFN self-interference to be avoided, while at the same time enabling a high payload, and importantly, efficient delivery of regional content.

Although a national SFN may require a single channel in a particular country, consideration of the wider planning area (immediate neighbours at least) implies that four to five frequency channels would be required to avoid interference from one country into another - a similar number of channels as a regional SFN, which may require four to six. This factor combined with the reduced capacity of a national SFN has shown that in some cases (where coverage in the order of 98% may be sufficient) a national SFN may be some 25% more efficient than an MFN with regard to overall spectrum consumption [8], but only around 15% more efficient than regional SFNs. Given that national SFNs would not allow efficient delivery of regional content, regional SFNs are an attractive option for broadcasters with regional delivery requirements.

[8] A more detailed discussion of spectral efficiency and spectrum consumption is given in § 5.

5. Spectral efficiency and spectrum consumption of DVB-T2 networks

5.1 Spectral efficiency and spectrum consumption

§ 4 considered the issue of spectral efficiency of a DVB-T2 network implementation by means of case studies for several countries based on practical considerations.

In this section the spectral efficiency of DVB-T2 is considered in a more theoretical light and the concept of Layer Spectrum Efficiency (LSE) is introduced. This concept is a more generalized way of assessing spectral efficiency which incorporates into a single figure the raw spectrum efficiency of a transmission system as well its re-use distance (a factor that characterizes the distance beyond which a channel may be re-used without causing undue interference - it has a major impact on the overall spectrum consumption of a transmission system). LSE is therefore more holistic than traditional measures of efficiency which are usually based on the performance of a transmission system in isolation (i.e. the performance of the air-interface). LSE more clearly sets out the total amount of spectrum a system would require in order to deliver a set of services, and allows a direct comparison of one system with another while taking into account factors such as the network topology and frequency plans.

Spectrum consumption, together with cost considerations are the major aspects which determine the efficiency of a particular network topology and mode (SFN or MFN).

5.2 Spectral efficiency of DVB-T2

A basic characteristic of a radio transmission system is its spectral efficiency. This is defined as the available data rate per unit frequency, measured in bit/s/Hz. DVB-T2 is specifically designed for the terrestrial distribution of linear broadcast content, and as such it has a high spectral efficiency, in particular for fixed reception. **Table 5** shows this by setting out the spectral efficiency of a range of DVB-T2 modes appropriate for a HTHP network topology. They have been taken from **[EBU Tech 3348]** and are here referred to as scenarios 1 through 8. These are typical modes in operation. Theoretically even higher values of the spectral efficiency are possible.

Table 5: System parameters and spectral efficiencies of several DVB-T2 modes

Scenario	FFT Modulation	Code rate	GI [µs]	Data rate [Mbit/s]	C/N [dB]	Network type	Reception mode	Spectral efficiency [bit/s/Hz]
1	32K-ext 256-QAM	2/3	28	40.2	20.0	MFN	fixed	5.0
2	32K-ext 256-QAM	2/3	448	33.4	21.2	Large SFN	fixed	4.2
3	32k-ext 256-QAM	2/3	224	37.0	20.8	Medium SFN	fixed	4.6
4	16K-ext 64-QAM	2/3	224	26.2	17.9	Medium SFN	portable outdoor / mobile	3.3
5	32K-ext 64-QAM	2/3	448	26.2	17.9	Large SFN	portable outdoor	3.3
6	16K-ext 64-QAM	1/2	448	16.9	15.1	Very large SFN	portable outdoor / mobile	2.1
7	16K-ext 16-QAM	2/3	224	17.5	13.2	Medium SFN	portable indoor	2.2
8	16K-ext 16-QAM	1/2	224	13.1	9.8	Medium SFN	(deep) portable indoor	1.6

5.3 Layer spectrum efficiency of DVB-T2

In § **5.2** only the raw spectral efficiency of the transmission system was considered. In order to address the efficiency question more fully, the total consumption of spectrum needs to be taken into account by incorporating the frequency re-use factor.

Transmission systems, together with their associated network topology are often characterized by the minimum required number of frequency channels to cover a large area, or layer. This is called the frequency re-use figure. This number of channels has to be made available in order to cover the whole layer even if not all channels are used in all locations.

However, in order to realistically assess the spectrum consumption of a transmission system, the frequency re-use figure is a rough metric. For example, in the GE06 plan 6 to 7 channels are required to cover one layer in Europe. But this does not mean that all of these channels are blocked everywhere in the considered area (i.e. that they cannot be used elsewhere in the area). Trivially, one channel is blocked since it is used by the intended service. But, in general, only a fraction of this area is blocked for all the other channels. Thus, there remains a part of the area where the remaining channels may be re-used for other purposes. Therefore, a blocking factor would be a better characterization of the spectrum consumption of a transmission system with its associated network topology than the frequency re-use figure.

In **[BS 2014-1]** an approach is described for defining such a blocking factor. It is called the re-use blocking factor. This factor depends on the system sensitivity, the network topology, the size and shape of the service areas and to a minor extent on the frequency channel distribution of the considered frequency plan. It is thus not a fixed factor of a class of plan implementations but varies slightly from one individual implementation of a frequency plan to the other. Based on these considerations a generalization of the concept of spectral efficiency is introduced which is called Layer Spectrum Efficiency (LSE). It allows for a more holistic assessment of the spectrum needed for a particular scenario to be implemented. The findings of **[BS 2014-1]** are summarized here.

Basically, the LSE value is given by the ratio of Spectral Efficiency to Re-use Blocking Factor (RBF):

$$LayerSpectrumEfficiency = \frac{SpectralEfficiency}{\mathrm{Re}-useBlockingFactor}$$

The larger the re-use blocking factor, the smaller the layer spectrum efficiency; and the larger the spectral efficiency, the larger the layer spectrum efficiency. Since RBF is dimensionless, LSE has the same dimension as the spectral efficiency SE; bit/s/Hz.

The concept of layer spectrum efficiency has been applied to the scenarios listed in § **5.2**. In order to simplify the examples, all scenarios assume full area coverage (100%).

An RBF of 7 is assumed for the MFN approach [9]. For an SFN approach for regional service areas, which requires medium size SFNs, an RBF of 5 is used as calculated in **[BS 2014-1]**. A less regionally oriented approach for the service area would allow for larger SFNs which may be assumed to have an RBF of 4. National service areas, which are even larger and correspond to very large SFN, show an RBF of about 2 as explained in **[BS 2014-1]**.

Table 6 collects these data for the DVB-T2 based scenarios of § **5.2** and gives typical values of the resulting Layer Spectrum Efficiency in the last column.

Two clear trends can be observed. High requirements with regard to regionality (from large SFN to

[9] If the required area coverage is less than 100% smaller RBF could be achieved which is in particular true for MFN where an RBF of 5 might be already achieved with 98 % coverage. However, for the sake of comparability all scenarios assume area coverage of 100%.

medium SFN to MFN, the latter allowing for the highest degree of regionality) have to be paid for by a lower layer spectrum efficiency, and also high requirements with regard to the ease of reception (from fixed to portable outdoor/mobile to portable indoor) have to be paid for by a lower spectrum layer efficiency.

These results fit quite well with findings in **§ 4.5** on building blocks.

Table 6: Layer spectrum efficiency of various DVB-T2 scenarios

Scenario	DVB-T2 Network Type	Reception Mode	Spectral Efficiency SE [bit/s/Hz]	Typical value of the re-use blocking factor RBF	Typical value of the layer spectrum efficiency LSE [bit/s/Hz]
1	MFN	fixed	5.0	7	0.71
2	Large SFN	fixed	4.2	4	1.05
3	Medium SFN	fixed	4.6	5	0.93
4	Medium SFN	portable outdoor / mobile	3.3	5	0.66
5	Large SFN	portable outdoor	3.3	4	0.83
6	Very large SFN	portable outdoor / mobile	2.1	2	1.05
7	Medium SFN	portable indoor	2.2	5	0.44
8	Large SFN	(deep) portable indoor	1.6	4	0.40

5.4 *Re-use distances for DVB-T2 networks*

In order to make an optimum use of the spectrum which is a finite natural source, it is inevitable to re-use the same frequency over different geographical areas. Each of these areas that are covered with a single frequency network is called a service area. To make the repetition of frequency channels possible, a minimum distance –the re-use distance - between the co-channel service areas is vital otherwise there would be an unacceptable degradation in the operation of the co-channel systems. The re-use distance is a metric which plays an important role in the determination of spectrum consumption and is a major component in the evaluation of the re-use blocking factor.

In a study by IRT **[BNP 033]** (see **Annex A6**), the general behaviour of a reference hexagonal network was investigated in the presence of another co-channel reference network. The minimum required distance between operating co-channel service areas was also studied and the relationship between various SFN system parameters and the re-use distance has been set out.

Typical DVB-T2 network implementations have re-use distances between 80 km and 120 - 130 km. A remarkable dependency on the power budget of the network is to be observed. At least a 3 dB power margin above the minimum field strength is required in order to restrict the re-use distances to a reasonable value.

A further interesting finding of the study is that the typical effective antenna heights of the networks have a remarkable influence on the re-use distance. With lower effective antenna heights the re-use distances increase faster with increasing C/N values than with higher effective antenna heights.

The reason for this effect is that at larger distances (beyond the radio horizon) field strengths decrease slower with decreasing effective antenna heights than at smaller distances. Thus, with decreasing antenna heights, the margin between wanted field strengths (coming from smaller distances) and unwanted field strengths (coming from larger distances) decreases, and along with this also the achieved coverage probability. In order to compensate for this a larger re-use distance is required.

Also differences in the re-use distance regarding different reception modes are remarkable. More demanding reception modes require larger re-use distances. **Table 7** gives an example for a particular DVB-T2 mode.

Table 7: Land-path re-use distances of DVB-T2 for different reception modes

64-QAM 3/5, PP1, 1/4 , 16k , data rate = 20.1 Mbit/s (95% location probability)		
Fixed rooftop reception	Portable outdoor reception	Mobile outdoor reception
Re-use distance = 60 km	Re-use distance = 100 km	Re-use distance = 165 km

Moreover, the influence of the inter-site distance of the transmitters in the network on the re-use distance is investigated. As can be expected, with increasing inter-site distance the re-use distance becomes larger. However, this effect is more pronounced for portable reception than for fixed roof-top reception due to the directional character of the receiving antenna in the fixed reception case.

6. Comparison of DVB-T2 network topologies

6.1 LTLP and HTHP broadcast network topologies

It was highlighted in the previous section that the spectrum consumption of a broadcast network is not only a function of the spectral efficiency of the applied transmission system. The envisaged reception mode, the shape of the service areas and the implemented network mode (MFN or SFN) play important roles, too. In this section now, a further crucial, even more influential aspect is addressed: the network topology, i.e. the density and, as derived characteristics, power and antenna height of the transmitters in the network.

Typical broadcast networks are commonly characterised as High-Tower-High-Power (HTHP):

- the main transmitters in the network are usually sparsely distributed across the service area, typically with a distance of 50 to 100 km and
- effective antenna heights of 150 to 1500 m and
- an ERP ranging from 10 kW to 200 kW.

With such a topology relatively few transmitters are required to cover large service areas, and linear content is easily delivered to a mass audience.

As opposed to this, for mobile broadband, cellular or Low-Tower-Low-Power (LTLP) networks are used. These are typically characterized by

- inter site distances (ISD) of less than 1 km to 10 km or more,
- low antenna heights between 10 and 50 m and
- ERPs of a few watts up to around 1 kW.

They are employed to provide bi-directional data traffic, typically speech, non-linear multimedia content, etc. Their topology is generally governed by the radio frequency requirements of the uplink of the user terminals to the base stations and network traffic, or capacity considerations.

LTLP networks could also be used to provide linear broadcast content. Further in this section the results of two studies **[Ny 2014, BS 2014-1]** are summarized which investigate hypothetical LTLP DVB-T2 networks and compare their performance with that of a HTHP network along with the required implementation effort.

6.2 LTLP Broadcast Spectrum Consumption and Implementation Effort

§ 5 emphasised the relevance of the frequency re-use figure and the re-use blocking factor of a network implementation for the assessment of its spectrum consumption. In the study by IRT **[BS 2014-1]** which was already cited in **§ 5** also the impact of the network topology on these quantities is investigated. The results are summarized here.

Generally a frequency channel cannot be efficiently used in adjacent service areas if they required different content because of the mutual interference that would be caused between the two adjacent, dissimilar networks. The potential interference into the neighbouring service area depends very much on the applied network topology. An LTLP network has a much lower interference potential than an HTHP network. Therefore the distance beyond which a channel may be re-used is much smaller in an LTLP approach than in an HTHP approach. Typical re-use distance values for HTHP DVB-T2 networks are between 60 km and 120 km (for land path), whereas for an LTLP network values between 10 and 20 km (for land path) may be realistic.

This difference between LTLP and HTHP networks induces a significant effect with regard to the number of channels that are required to fully cover a large area or territory which consists of several or many individual service areas. The larger the re-use distance, the greater is the number of required channels for a given distribution of service areas before the original channel can be re-used. Therefore the frequency re-use figure and also the re-use blocking factor are increased.

In **Table 8** the case of portable indoor reception is considered. Re-use blocking factor and layer spectrum efficiency of an HTHP DVB-T2 implementation as described in **§ 5** is compared with hypothetical LTLP DVB-T2 implementations. The data of the latter are taken from **[BNP 084]**.

Table 8: Layer spectrum efficiency of HTHP and (hypothetical) LTLP DVB-T2 scenarios

DVB-T2 Network Topology	Network type	Reception mode	Spectral efficiency SE [bit/s/Hz]	Re-use blocking factor RBF	Layer spectrum efficiency LSE [bit/s/Hz]
HTHP	Medium SFN	portable indoor	2.2	5.0	0.44
LTLP	Cellular SFN ISD = 2 km	portable indoor	6.0	1.7	3.53
	Cellular SFN ISD = 5 km	portable indoor	3.5	1.4	2.50

The result shows that the benefit of the LTLP approach is twofold. Firstly, it allows for the use of higher modulation schemes and shorter guard intervals resulting in a higher spectral efficiency of the applied DVB-T2 mode. Secondly, short re-use distances make a quicker re-use of frequencies possible, i.e. smaller re-use blocking factors are achieved. Both effects together result in a much higher layer spectrum efficiency relative to HTHP networks.

It is important to realize that this high efficiency is achieved through the combination of high spectral efficiency and low re-use blocking factor. If one of these components is missing the effect drops. An example is described in **[BS 2014-1]** with the broadcast mode of LTE eMBMS.

The high efficiency of the LTLP approach has to be paid for. The price is a high implementation effort. **[BS 2014-1]** shows that for the example of Germany roughly 90000 base station sites would be required in order to cover 90% of the area of Germany (with an ISD of 2 km). This high number of base station sites does not exist today. The cost of such an implementation and the operational costs are calculated in **[BS 2014-2]**.

6.3 Network topologies and spectrum efficiency for high-tower and low-tower broadcast networks

In a theoretical study made by Progira **[Ny 2014]** different SFN broadcast network topologies and the spectrum efficiency of LTLP and HTHP networks is compared. The study assumes use of SFNs with the DVB-T2 system.

The HTHP network is represented by an SFN using 300 meter antenna height and an ERP of 50 kW. While for the LTLP networks, antenna heights of 50 and 30 m have been studied using an ERP between 50 W and 5 kW. Both the HTHP and the LTLP SFN are assumed to consist of 7 transmitters.

As in the previous study the conclusion is that a reduction of the antenna height and the power in the broadcast network would increase the number of sites required.

According to the results about 108 times more low-tower sites with antennas at 30 m and ERP of 50 W (inter-site distance 10.0 km) would be required to cover the same geographic area as the corresponding high-tower network. Alternatively, about 37 times more sites would be required for networks with antennas at 30 m and ERP of 500 W, and in the case of networks with antennas at 50 m and ERP of 500 W, 23 times more sites would be needed.

The results are summarised in **Table 9**.

Table 9: Site multiplier factor for different LTLP DVB-T2 network topologies

HT/LT	Antenna height (m)	ERP (W)	Inter-site distance (km)	Service area per site (km^2)	Site multiplier factor
HT	300	50000	104	7123	1
LT	50	50	12.8	108	66
LT	50	500	21.6	308	23
LT	50	5000	34.6	790	9
LT	30	50	10.0	66	108
LT	30	500	17.0	191	37
LT	30	5000	27.4	495	14

Applying these results to Sweden, as an illustration, shows that country-wide area coverage would require 63 high-tower sites with antennas at 300 m and ERP of 50 kW versus 4161 low-tower sites with antennas at 30 m and ERP of 50 W, alternatively, 2360 sites with antennas at 30 m and ERP of 500 W. The current DTT network in Sweden consists of 53 HTHP transmitters supplemented by about 500 fill-in transmitters using lower power and lower antenna heights.

Co-channel separation distances are also studied for the different network topologies based upon the assumption of a 3 dB interference margin. As in the previous study referenced in **§ 6.2** co-channel separation distances are largely reduced when using the LTLP network topologies. For example an LTLP SFN network using 30 m antenna height and 50 W ERP has a co-channel re-use distance of about 40 km, which is much lower than the HTHP network (300 m, 50 kW) showing a frequency re-use distance of 195 km.

Shorter co-channel separation distances provide more flexibility in frequency planning but may not always offer increased efficiency in spectrum consumption. The spectrum requirement for a network is strongly related to the size and shape of the wanted broadcast service areas.

In the GE06 Plan many SFNs were planned based upon allotments. Generally the allotment sizes were limited by the length of the guard interval in DVB-T. However, when using the DVB-T2 system there is a possibility to implement larger SFNs, due to the longer guard interval.

The study concluded: Provided that the SFN allotment areas are sufficiently large the spectrum efficiency of HTHP and LTLP networks will be in the same order. However the LTLP network will allow much more flexibility when tailoring the service areas to fit the required broadcast service area.

7. Elements of DVB-T2 parameter choice and SFN design

7.1 Overview

As an OFDM system DVB-T2 is subject to the same network design rules as are other OFDM systems like T-DAB and DVB-T. These are described in detail elsewhere in EBU documents **[TR 021, TR 022, TR 024]** and need not to be repeated here. Furthermore, additional information relating to several design aspects specific to DVB-T2 can be found in **[EBU Tech 3348]**. This section therefore deals only with particular aspects which deserve additional attention. These are sea propagation, static time delay, choice of guard interval, the combination of T2-Base and T2-Lite for mobile reception in a single multiplex and the distribution of multiplex signals to the transmitters. Some of the examples chosen to illustrate these aspects are taken from the planning of DVB-T and T-DAB networks, but the principles apply to DVB-T2 as well.

7.2 Propagation over sea paths

In **§ 4** the particular relevance and limiting character of self-interference in single frequency networks was addressed. In large SFNs, signals beyond the guard interval contribute an interfering component which increases with lengthening delay. In each location of the service area of an SFN this interference component is to be kept below a critical threshold (the system C/(N+I)) in order to avoid a coverage loss due to self-interference.

Signals show time variability; in particular at small time percentages high field strengths may occur due to meteorological phenomena such as tropospheric scatter or ducting. These happen predominantly over sea paths, and are more pronounced in warmer seas than in cold.

The practical relevance of tropospheric scatter and ducting phenomena over sea paths has been well documented, and a practical example occurred in 2012 when self-interference problems in a DVB-T SFN in Portugal were reported. The source of this was found to be long-range, time variable tropospheric propagation interference and was significant enough to warrant a partial re-design of the network where additional frequencies were used to split a large SFN area into several smaller SFN in order to remove the long distance interference.

Typically an upper bound of 1% of time is allowed in broadcast planning for undue interference as this enables a high time reliability for the broadcast signal. This upper bound also applies to self-interference. Depending on the distance between transmitter and receiver the 1% time percentile field strengths can be much higher than the average (50% time) field strengths, and the differences are particularly high for propagation paths over sea. For a proper broadcast network planning it is therefore essential to take these phenomena into account.

The following two examples illustrate this aspect, the first being a coverage planning exercise in the UK, and the second being a practical exercise in identifying self-interference effects which originate from propagation over sea paths.

7.2.1 Effect of sea path propagation - An example in the UK

Later in this report, **§ 7.4** summarises a UK based study concerning the optimisation of the guard interval for wide-area SFNs. In part it considers long distance interference from beyond the guard interval, over land and sea paths. Here, in this section, the sea path aspect is highlighted.

The optimal guard interval can be taken as a measure of the strength of self-interference in the network. Longer guard intervals are required if the self-interfering components of the SFN signals are larger. In the study the optimum guard interval is evaluated for the whole UK as well as for its four constituent nations: Wales, Scotland, Northern Ireland and England.

The study shows that a UK-wide SFN including all four nations would, relative to an England-Scotland SFN, benefit from longer guard intervals, even though the maximum geographical extents of the network would not significantly change, the reason being that the inclusion of Wales and Northern Ireland would introduce more interference from signal paths over sea. These can be significant sources of interference that must be properly taken into account during any network design. The details of the study are described in **§ 7.4**.

7.2.2 Self-interference in a DVB-T SFN due to sea path propagation; an example in Italy

Annex A.5 contains a concrete example of self-interference in a DVB-T SFN due to the particular propagation conditions of signal paths over warm sea. The investigation **[BNP 088]** was performed by Rai Way on an interference case in the northern Adriatic Sea. It was found that an SFN transmitter more than 200 km away was causing interference which could only be explained by the particular propagation characteristics of a warm sea. In order to resolve the problem Rai Way relocated the interfering transmitter, effectively removing the interference from affected areas. The study describes the measurement campaign to identify the interfering transmitter and in particular how this was achieved by attributing individual cell IDs to the SFN transmitters.

7.3 Static time delays

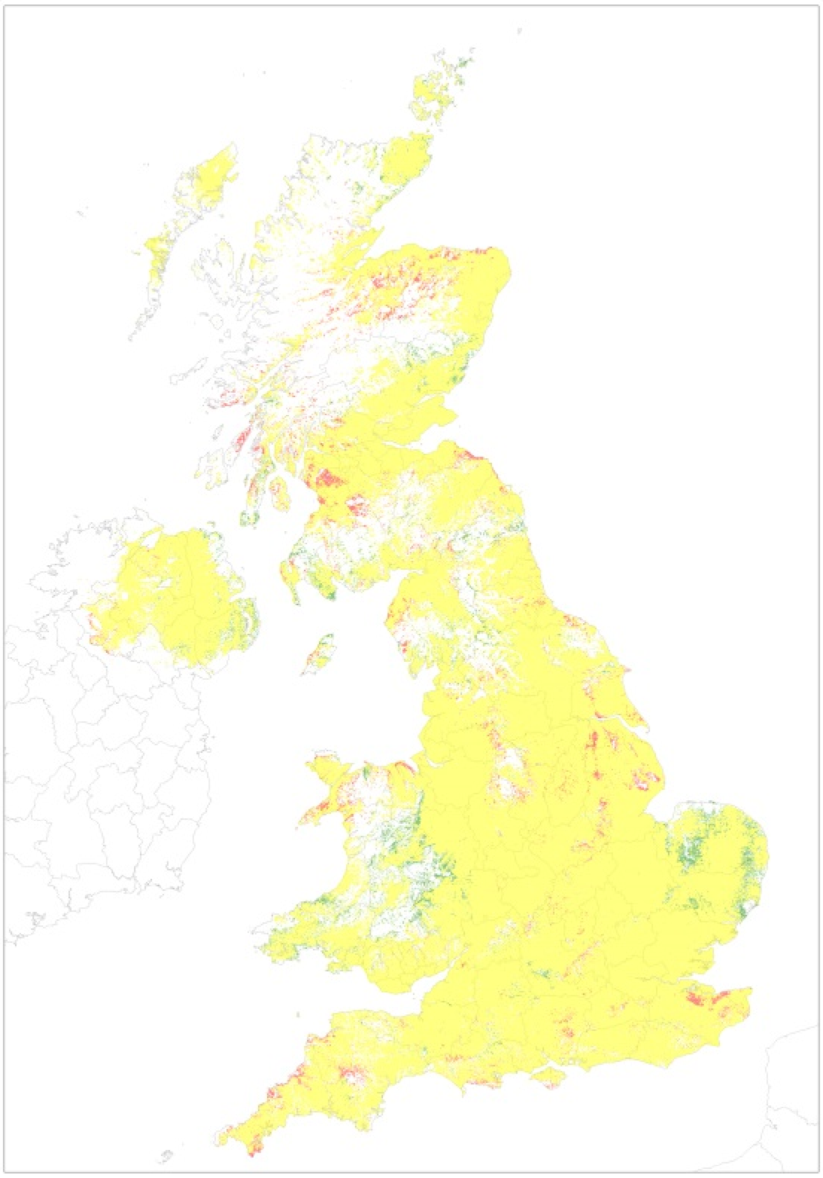
In practical broadcasting networks, transmission sites are often separated by distances beyond the guard interval. These circumstances can lead to self-interference in SFNs, and a subsequent loss of coverage or capacity. Static timing whereby the signals from stations in the network are delayed relative to one another can be used to mitigate this interference. This technique can enable interference to be positioned over unpopulated areas such as the sea, or it may allow it to be moved to areas well served by other transmitters, effectively masking it.

In this section several case studies are described where the optimization of SFN coverage is achieved by the application of static timing, often accompanied by additionally optimizing antenna diagrams and transmitter powers. A detailed description of delay time tuning can be found in **[HL 2009]** (for the case of T-DAB).

7.3.1 Static timing in the UK DAB network

The UK has two DAB networks which operate as national SFNs. Their predicted coverage is shown in **Figure 5** where the coverage of the network with optimised static timing (timed network) is compared with the coverage of the same network with all transmitters set to the same relative delay of 0 µs (untimed network) - all other parameters are identical in the two situations. Yellow shows coverage common to both the timed and untimed networks, red shows coverage only available in the untimed network while green shows coverage available only in the timed network.

It is clear that in some areas the untimed network performs better than the timed network, and vice versa. Overall, the static timing is of benefit as it improves population coverage by almost 1% and coverage to roads by some 4.7%. It is estimated that around 20 to 40 transmitters would otherwise be required to provide this coverage increase.



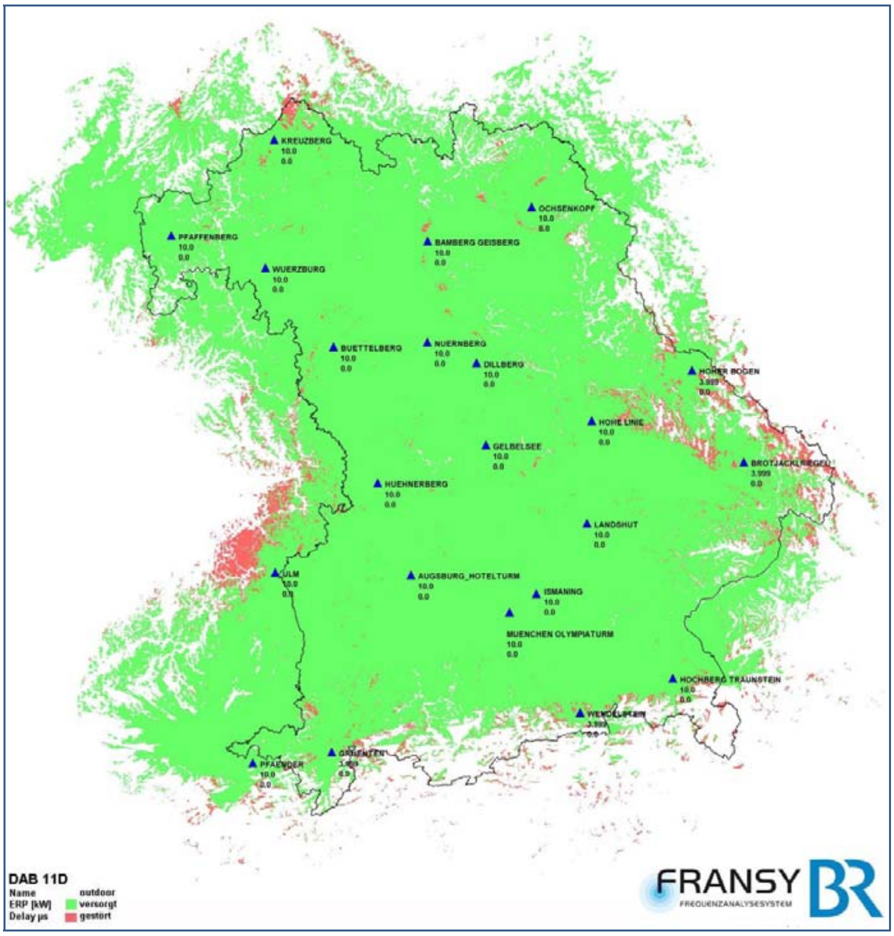
(Yellow: coverage common to both the timed and untimed networks,
Red: coverage only available in the untimed network
Green: coverage available only in the timed network)

Figure 5: The benefits of static timing in the UK T-DAB network

7.3.2 Static timing in the Bavarian DAB+ network

A further example of delay time tuning is given with the DAB+ network in Bavaria. It consists of 22 transmitters, where most of them have individually set transmitter offset delays in order to optimise the coverage. This measure is necessary since the transmitter characteristics with regard to distance from the next transmitter, antenna height or transmitter power, are very heterogeneous. The optimization was performed by Bayerischer Rundfunk (BR).

Figure 6 gives a coverage plot with the transmitter sites and transmitter powers, but without any delay time optimization. Green denotes covered locations for DAB+ mobile reception and red indicates locations where sufficient field strength is available but reception is not possible because of self-interference. The non-optimised network already has very good coverage; however there remain areas of interference, mainly in the fringes.



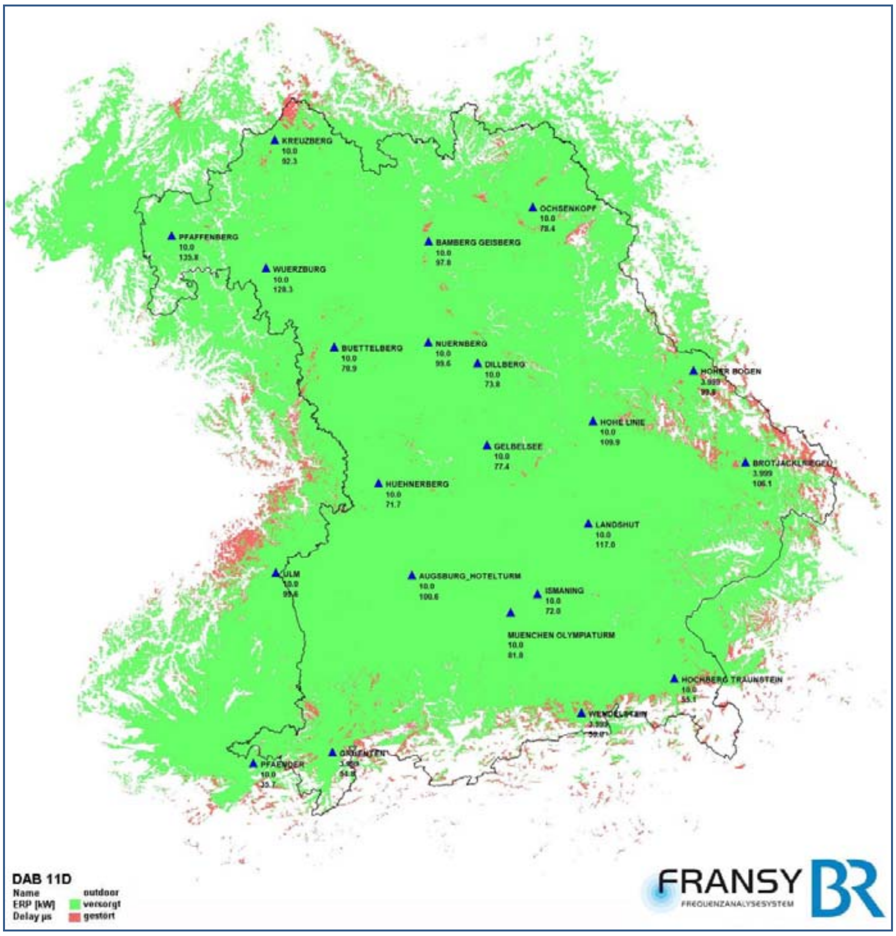
Transmitter sites, transmitter ERP (kW) and the initial static delay (0 µs) are indicated

Figure 6: Coverage of the DAB+ network in Bavaria - without static delay time optimization

These remaining areas of interference could be reduced by a static time delay optimization, as can be seen in **Figure 7**, where the individual delays are indicated in the coverage plot. Still there remain regions where self-interference occurs. This is due to the fact that time delay optimization may be a means to improve a self-interference situation but cannot totally eliminate it.

Figure 8 is a difference plot showing the areas where the delay optimization improved the situation. As compared to the total coverage area these amount to a small percentage which is due to an already well-chosen transmitter topology.

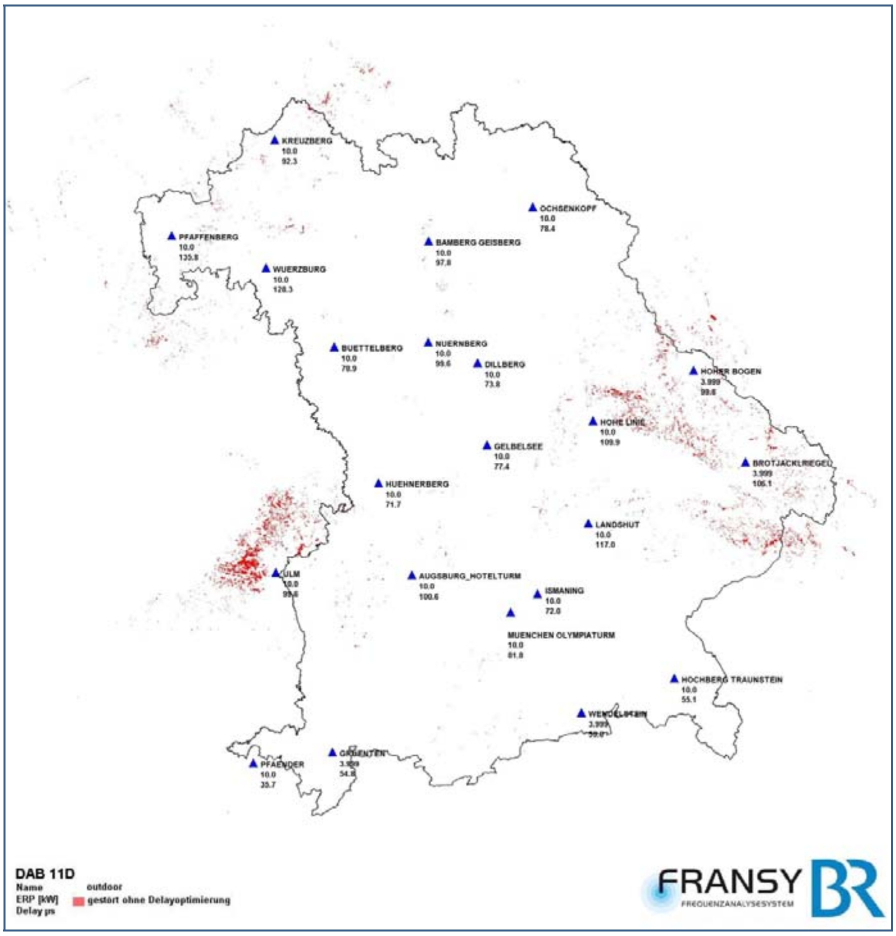
To illustrate how the delay tuning impacts the signal situation, a receiving location was chosen where the reception was improved by the optimization and the time delay spectra were calculated for the two cases - with and without delay optimization. This is shown in **Figure 9**.



Transmitter sites, transmitter ERP (kW) and individual static delays (µs) are indicated

Figure 7: Coverage of the DAB+ network in Bavaria - with static delay time optimization.

The upper delay spectrum represents the signal situation without delay optimization, the lower one with delay optimization. The cyan time region shows the signals within the guard interval. They contribute constructively to the wanted field strength which is indicated by a blue bar. Beyond the guard interval, the orange time region, the signals have both constructive as well as interfering components. The interfering components are indicated by red bars. In order to keep the two components together they are plotted in the same place on the time axis, the smaller component being put in the foreground. Thus both contributions can always be identified and are visible - apart from the case where both components are equal; then only the red interfering bar is visible.



Locations where static delay time optimization improved the coverage

Figure 8: DAB+ network in Bavaria - Difference plot

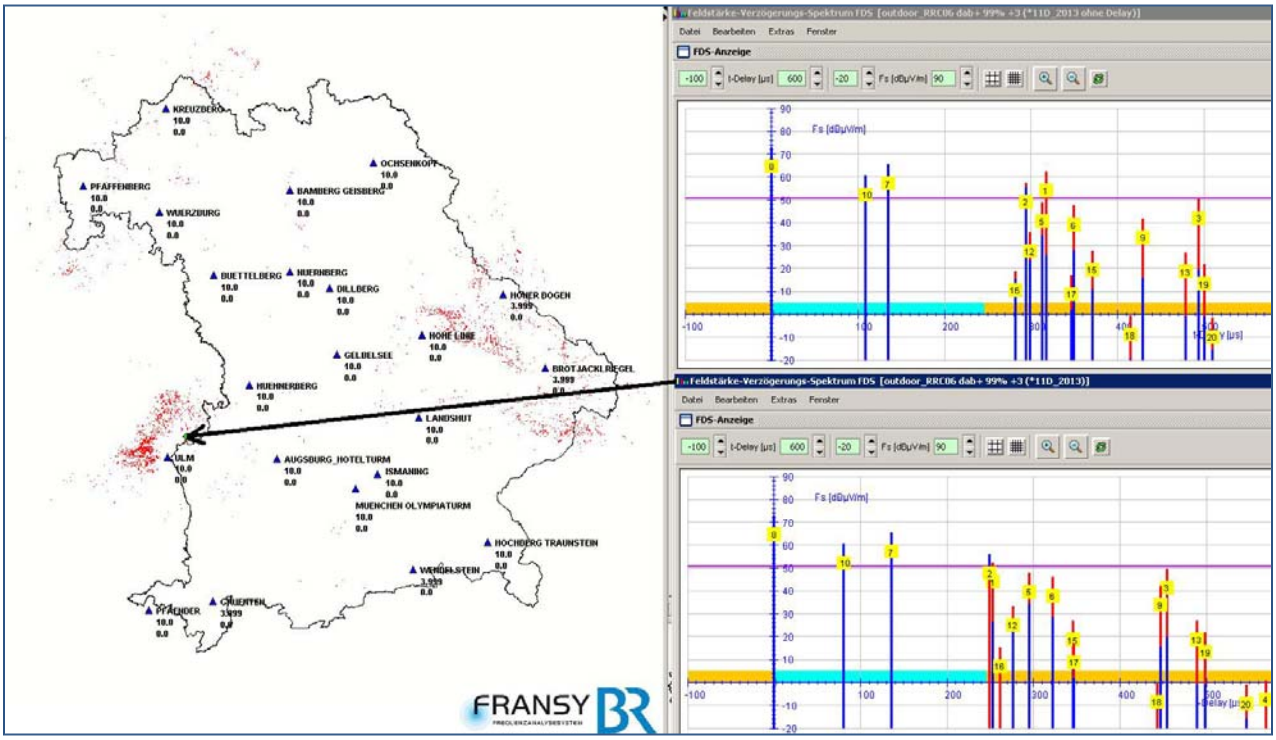


Figure 9: Time delay spectra at a typical receiving location

7.3.3 Optimisation of a DVB-T2 SFN in Malaysia

A national DVB-T2 SFN was planned by Progira **[BNP 087]** in Malaysia as part of an application to become network provider for DTT. The planning was performed for both Western and Eastern Malaysia, but only the results for West Malaysia appear in this example and it should be noted that the network has not yet been implemented. The use of national DVB-T2 SFNs was suggested since they would provide an efficient use of frequencies.

The target was to provide rooftop coverage for 98% of the population, which is equivalent to the current analogue coverage. Additionally there was a secondary requirement to provide indoor coverage in the main cities. Overall the area under consideration has as size of about 700 x 200 km^2.

The main planning parameters were:

- Use of DVB-T2 system variant: 256-QAM, R= 3/5, GI 1/8 or 19/128, 448 µs or 532 µs, PP2 providing about 30 Mbit/s or more
- C/N assumed: 19.6 dB (rooftop)
- Use of existing infrastructure for analogue TV as far as possible which also meant that existing transmitting and receiving antenna would be used whenever possible

In total about 74 transmitters were used in the planning work, assuming ERPs between 1 kW and 60 kW.

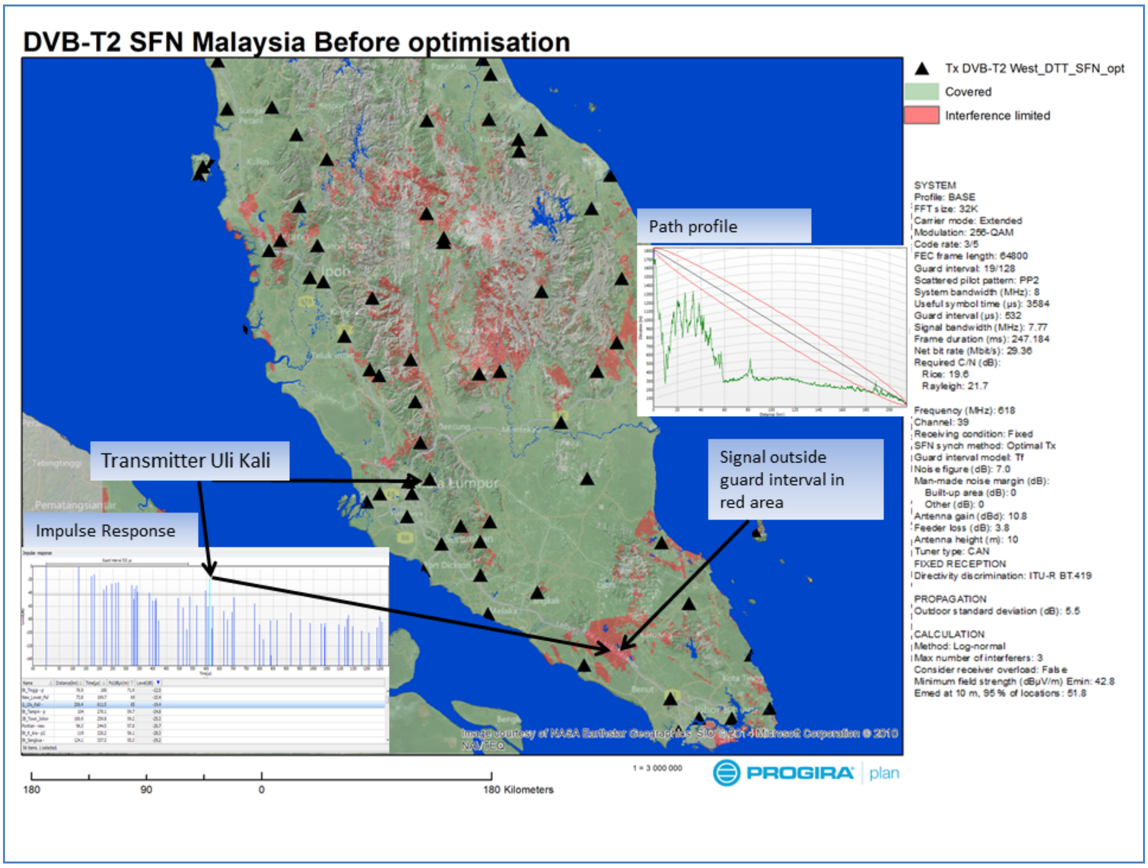


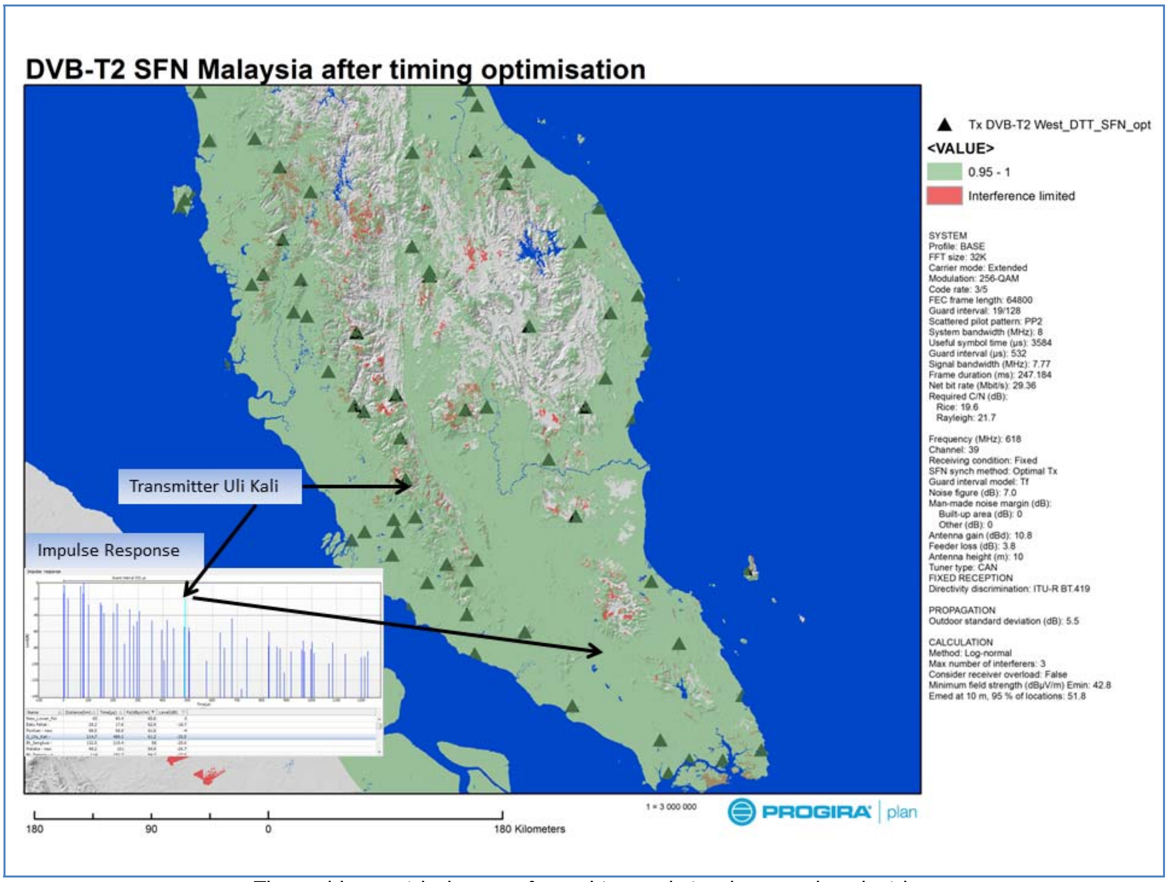
Figure 10: Potential SFN self-interference areas in DVB-T2 SFN

First the coverage was calculated using the nominal transmitter parameters assuming no timing offsets on the individual transmitters in the SFN. The result is given in **Figure 10** whereby coverage to 95% of the population was achieved, slightly below the requirement of 98%. When analyzing the resulting coverage it became clear that some areas would potentially be affected by self-interference, despite the use of the long guard interval. This is shown when analyzing the 1%

time interfering signals where SFN self-interference areas are indicated in red in **Figure 10**. At 50% time, this self-interference is not visible - it is only evident when propagation anomalies are considered, e.g. for 1% of time.

As seen the self-interference is scattered across the whole country but in particular it occurs in the mountains which are, with a few exceptions, not densely populated.

Figure 10 also shows an example of an impulse response at a point where self-interference is predicted. It can be seen that delayed signals beyond the 532 µs guard interval may occur. This may potentially happen from transmitters located in elevated positions. In this example the transmitter Uli Kali has an effective antenna height of about 1700 m in some directions. The path profile from the transmitter to the area where self-interference may occur is also shown in **Figure 10**.



The problems with the out of guard interval signals are reduced with
a combination of timing offsets and adjustments of antenna diagrams.

Figure 11: Resulting DVB-T2 coverage after optimization of SFN self- interference.

In order to reduce the effect of SFN self-interference, optimization was carried out with the following steps:

1) Analysis of the self-interference areas, identifying transmitters that may create out of guard interval interference.

2) Optimizing the static timing of the transmitters to minimize potential self-interference. This was carried out using a feature in the *Progira Plan* planning software where coverage can be optimized based upon the population.

3) Adjustments of antenna diagrams and in particular antenna tilt for a number of transmitters to further reduce potential self-interference.

4) Timing optimization in order to improve the SFN self-interference situation further.

The result of the optimization is shown in **Figure 11**. Limited self-interference may still potentially remain in mountainous areas. However it is less significant compared to the initial case. The total population coverage is predicted to be 98.5%, which is above the requirements. The population that would potentially suffer SFN self-interference is very small.

7.3.4 DVB-T SFN optimization in Italy: A case study

In Italy, the public service multiplex with regional contents (RAI Multiplex 1) is usually deployed by using two VHF frequencies (channels 5 and 9) in an MFN configuration and another UHF frequency for each region in an SFN configuration, taking into account international coordination.

As an example, the region of Puglia, in southern Italy, is considered. It covers a very large area, which mainly consists of flat land and includes some HTHP transmitters: for this reason it represents a relevant case study as for SFN planning.

In Puglia, channel 32 (562 MHz) is used to develop a regional SFN, which includes 27 transmitters distributed throughout the area, as shown in **Figure 12**. Since Multiplex 1 is the public service multiplex, at least 99% of population has to be covered with good quality.

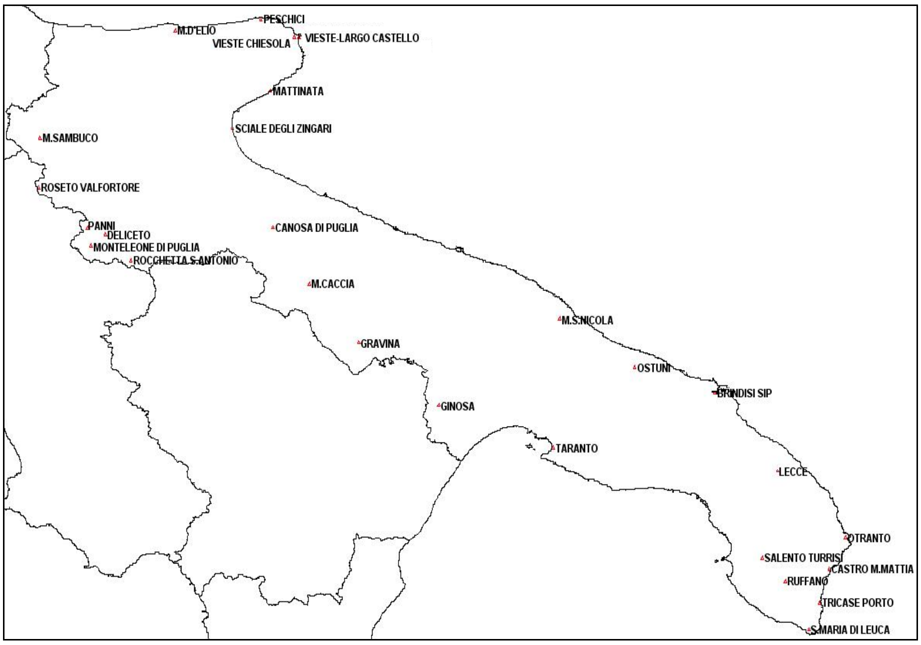


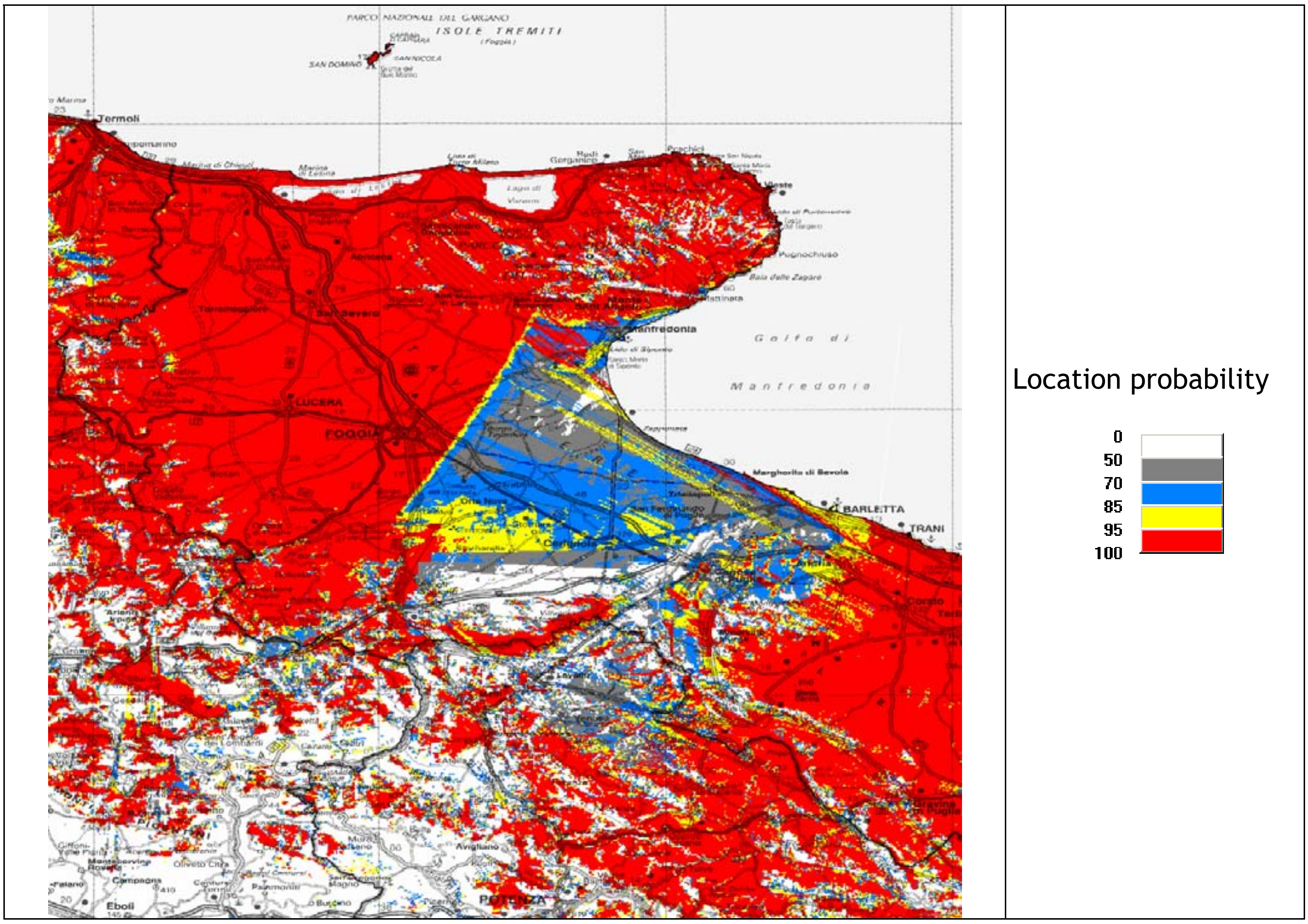
Figure 12: Transmitter sites in Puglia

The choice of the sites depends on:

- coverage requirements (specified in terms of location probability)
- service area of transmitters (verified theoretically and in the field)
- priority use of channels 5 and 9 on other sites
- availability / supply of transmitting antenna in UHF band
- availability of user receiving antenna in UHF band
- international coordination

After site selection, the main technical parameters that are used to optimise the SFN are the following:

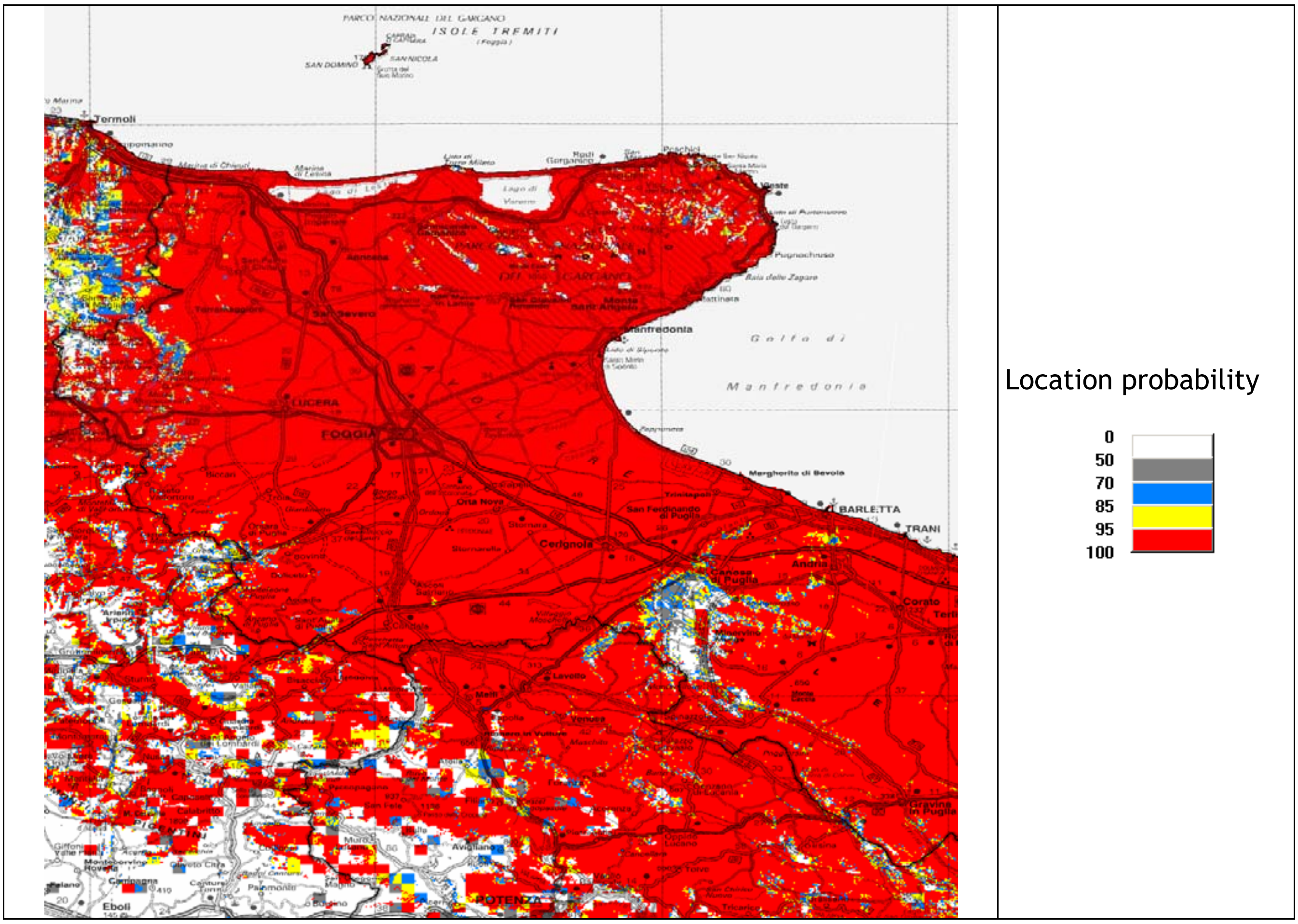
- static delay of each SFN transmitter
- antenna diagram / power of transmitters



Location probability	Inhabitants	Percentage on a regional basis
95%	3,646,682	89.98%
90%	3,742,624	92.35%
70%	3,974,559	98.08%

Figure 13: SFN coverage in Northern Puglia when no static delay / antenna diagram optimization is performed

One of the sites having the highest interferer power in Puglia is M.CACCIA: **Figure 13** shows the SFN coverage area in this region, when no static delay / antenna diagram optimization is performed for the abovementioned transmitter.



Location probability	Inhabitants	Percentage on a regional basis
95%	4,016,147	99.10%
90%	4,031,106	99.47%
70%	4,045,670	99.83%

Figure 14: SFN coverage in Northern Puglia after static delay optimization is performed

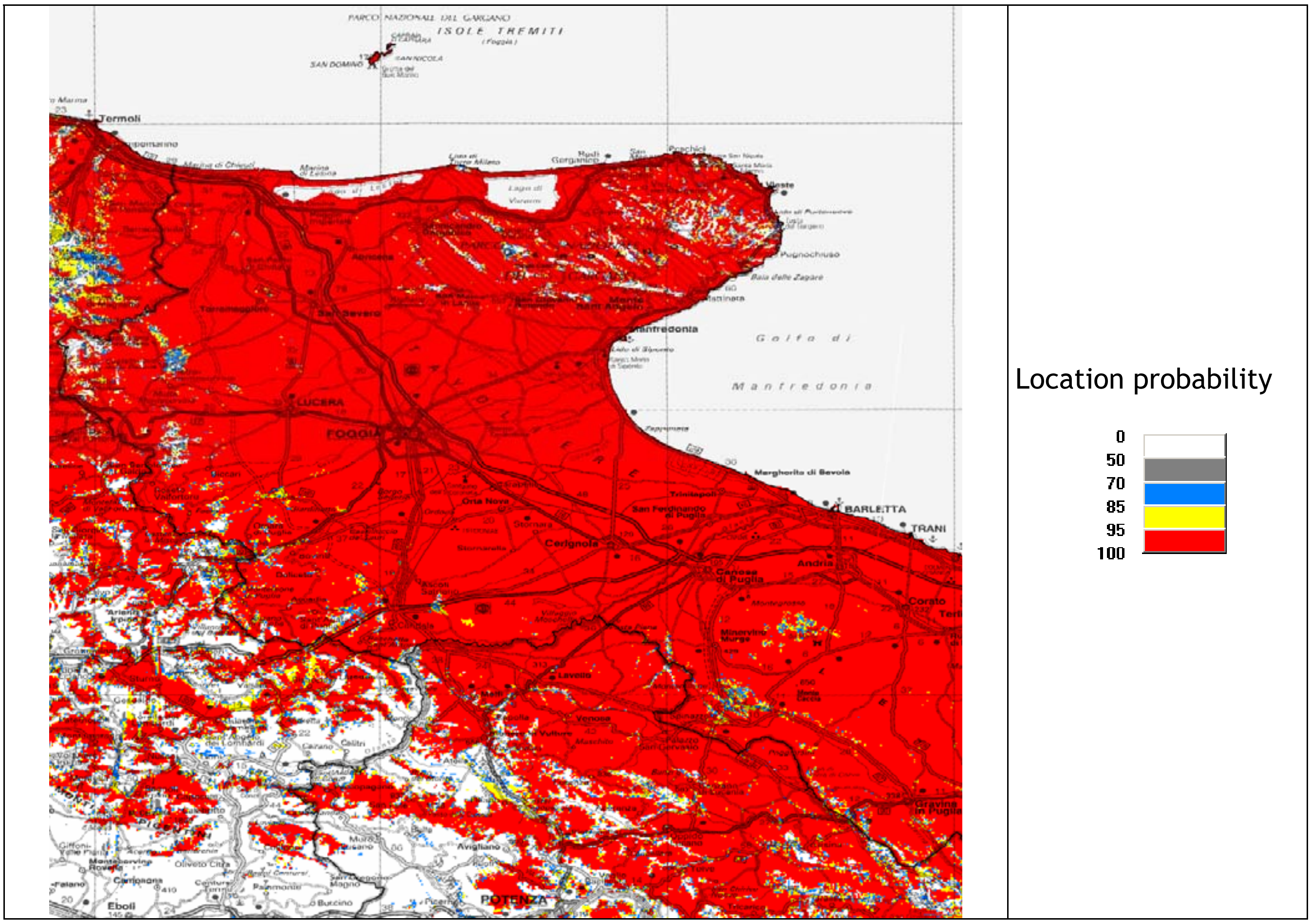
In a large area, between the cities of Foggia and Barletta, the field strength of M.CACCIA is very high, but its signal is not correctly synchronized with the ones of other SFN sites, especially with M.SAMBUCO, which is another high power transmitter (which is further away than 110 km). For this reason, the first action that Rai Way took to improve the coverage was to perform an optimization of static delays, taking into account:

- required bit-rate (modulation, code rate and guard interval)
- population density (e.g. most populous cities at highest priority)
- expected service area of transmitters
- main contribution and potential interferer contributions for each city of the area
- distance between sites
- static delay usable range
- field measurements
- topography
- planning experience in similar contexts.

Therefore the efforts made by Rai Way to optimise the SFN are a mixture of theoretical analysis, field research and the experience of people working.

In order to find the best solution, some tasks of the optimization process could be repeated several times and a few of them, which are suitable to be organized in well-defined procedures, have been implemented in a software module.

Figure 14 shows the SFN coverage area in Puglia after performing static delay optimization. As can be seen, the interference zone has been largely reduced and the coverage target has been achieved, but areas remain where the quality of service is low.



Location probability	Inhabitants	Percentage on a regional basis
95%	4,039,424	99.68%
90%	4,043914	99.79%
70%	4,050,591	99.95%

Figure 15: SFN coverage in Northern Puglia after static delay and antenna diagram optimization are performed

For this reason, Rai Way then performed a reshaping of the antenna diagram of M.CACCIA, taking into account:

- cities where M.CACCIA is historically the main server and, thus, still require that its signal has a field strength suitable to provide service
- cities where the signal of M.CACCIA had a considerable field strength before the switch-off, but other transmitters are the main servers now, thus its contribution is not as necessary
- cities where M.CACCIA was not historically the main server, but after the switch-off its signal has become partially or entirely the main contributor, due to antenna diagram

reshape / frequency change of other transmitters

- cities where the analogue coverage was ensured by M.CACCIA, but quality of service after the switch-off is increased, thanks to new sites added in the network

All these issues have been evaluated both in theory and by means of in field measurements.

Figure 15 shows the service area of the SFN in its final configuration, after also performing antenna diagram optimization. Following these optimisation steps a significant coverage improvement is evident.

7.4 Optimising the guard interval in a national SFN

The optimum guard interval in a national SFN will depend on a number of factors including the size of the country, the length of sea paths and any coverage obligations. The UK is a good example of a difficult country to serve with a national SFN as its width and length exceed the length of the guard interval of any of the available DVB-T2 modes, the country is surrounded by water so consideration of sea paths play a significant part in any planning and it has coverage obligations with respect to the nations that make up the United Kingdom (UK).

An analysis of the coverage obtained across the UK with a National Single Frequency Network (SFN) has been carried out by Arqiva. This was based on DVB-T2 as follows:

- Modulation scheme: 256-QAM
- Mode: 32k
- Code rate: 2/3.

Coverage predictions were run using a sequence of guard intervals to examine the effect of this on population coverage. These were in the range from 300 - 566 µs with an additional value of 900 µs being included as an upper bound [10].

Note, that the values used are not those contained in the DVB-T2 specification; thus, the results given do not necessarily demonstrate practicably achievable scenarios. Rather, the aim has been to consider the trends demonstrated. Of course, in practice, changing the guard interval can have other secondary effects. For example, with the existing DVB-T2 specification, a change in guard interval may also result in the need to change the pilot pattern. Therefore, in practice, the resulting change in data rate may not be the same as an initial calculation would suggest. However, for this study, such considerations have been put aside; any changes in bit rate are considered to be solely due to the change in the guard interval itself [11]. For this reason, when carrying out the analysis, normalized data rate values are used.

The coverage runs were carried out using the 80 Primary Sites [12]. This number was considered to be sufficiently high to assess the impact on coverage while being sufficiently low to carry out numerous runs within a reasonable length of time.

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[10] For DVB-T2, 900 µs represent a guard interval of just over ¼ symbol period; it is not considered worthwhile to explore the effect of using guard intervals which are longer than this.

[11] If the initial Guard interval is a fraction (1/Xold) and the new guard interval is a fraction (1/Xnew) then we assume:

$$\mathrm{DataRate}_{\mathrm{New}} = \frac{(X_{\mathrm{new}})(X_{\mathrm{old}}+1)}{(X_{\mathrm{new}}+1)(X_{\mathrm{old}})} \cdot \mathrm{DataRate}_{\mathrm{Initial}}$$

[12] The UK public sector broadcast (PSB) television network consist of 1154 stations, 80 primary sites that serve about 95% of the population and a further 1074 relays that bring the coverage up to 98.5%.

7.4.1 Results and Analysis

Figure 16 shows the variation in coverage [13] with guard interval. The population for each country is given as a fraction of the total population of that country.

N.B.: The apparent discontinuity at 566 µs is an artefact; it occurs because there are no data points to plot between 566 µs and the final point at 900 µs.

As expected, the population covered increases with increasing guard interval.

The next step in the assessment is to use the results to determine the optimum guard interval. In order to do this we must offset the rising coverage with the associated falling data rate. One approach to use would be to consider the product of the population served with the data rate. However, using a simple product does not allow us to take into account any specific requirements.

For example, full national coverage is expected to beat least 98.5% of the population. Therefore, a high data rate is of less interest if the population coverage is below the required threshold. Similarly, if a sufficient proportion of the population is served, improving the data rate may be considered to have priority over increasing the coverage.

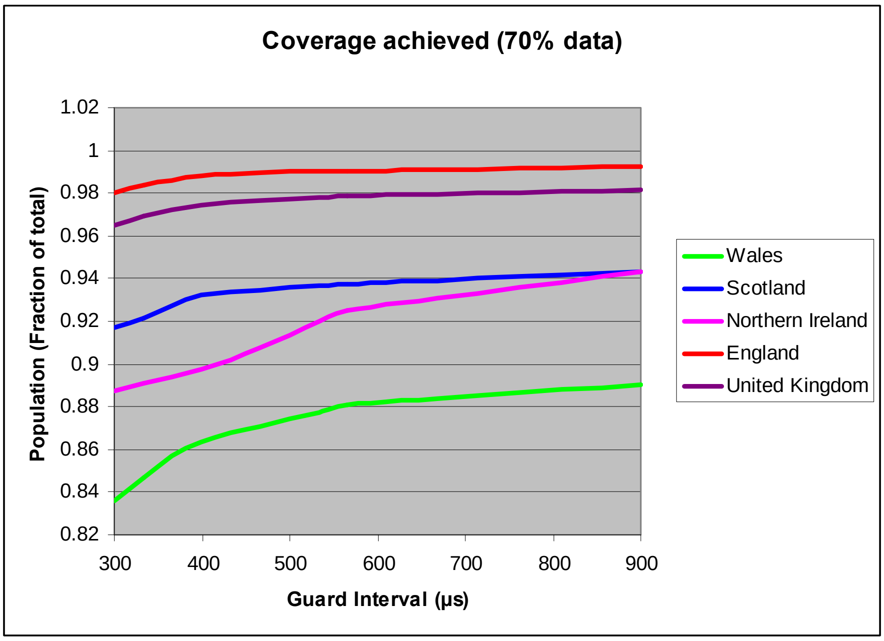

Figure 16: Normalised relative population coverage of the UK and constituent nations, 70% locations served.

To this end, a weighted product of population served and data rate was used.

The weighting has been carried out as follows:

- Define a threshold population coverage. For a full national run, this would correspond to 98.5%. However, in this example, using only the 80 Primary Sites, we have chosen 97.5%; additional relay sites will result in a higher population coverage.

  cf: The 80 Primary Sites using the National Switchover Plan (the Base Configuration) results in an overall UK coverage of 95.5%.
- For population coverage which is below the threshold, use:

[13] UK coverage is based on methodology developed by the Joint Planning Project (JPP). Coverage is for 70% locations with a time availability of 99%.

(Fraction of the population served)^2 x (Normalised Data Rate)

otherwise, use:

(Fraction of the population served) x (Normalised Data Rate)^2

i.e., for low population coverage, more weight is given to the population coverage while for high population coverage, more weight is given to the data rate.

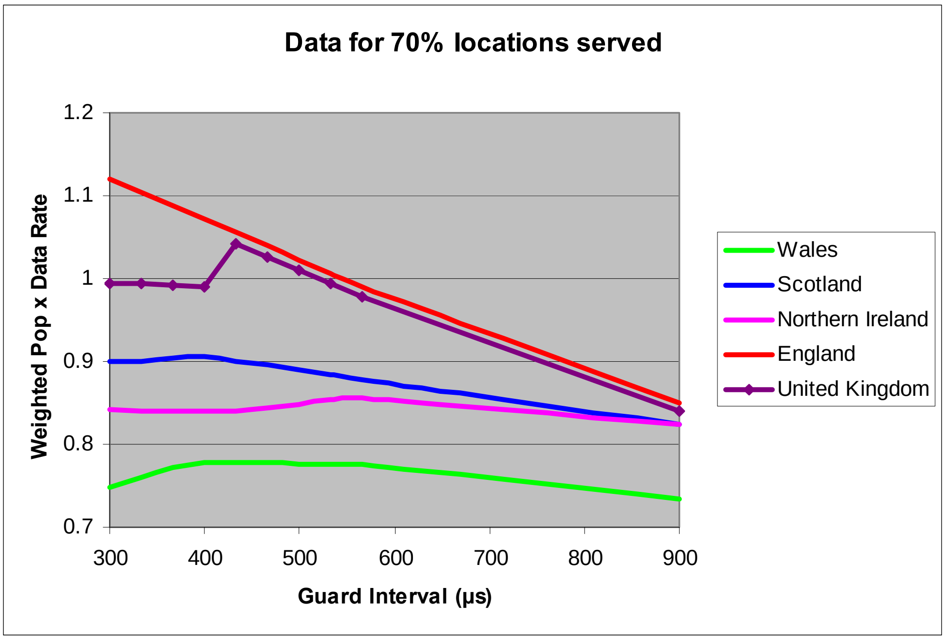

Figure 17: Normalized Coverage weighted for reduction in data capacity with increasing guard interval (70% locations served)

The plot in **Figure 17** summarises the results for 70% locations after accounting for the reduction in data capacity with increasing guard interval; the plot in **Figure 18**, relates to similar the results but for 90% locations.

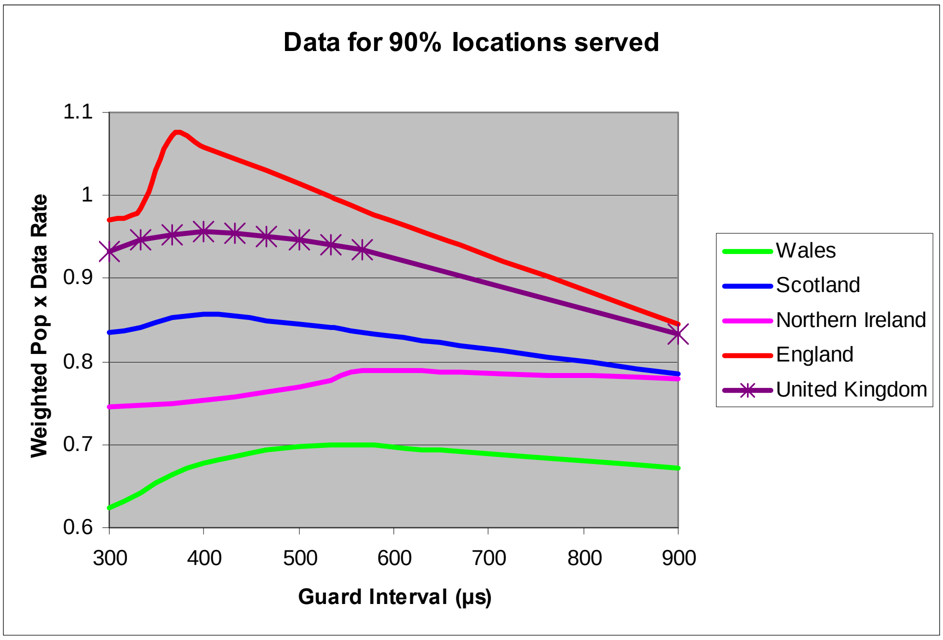

Figure 18: Normalized Coverage weighted for reduction in data capacity with increasing guard interval (90% locations served)

Note that the numerical values on the ordinate scale are, in themselves, not relevant. What is of interest are the relative values.

Using this approach, for the UK as a whole, we see an optimum value for the guard interval of just over 400 µs. If we change the threshold population to 97%, then the peak of the plot corresponds to a guard interval at just under 400 µs.

Repeating this using data for 90% locations, the curve maximum corresponds to a guard interval of around 400 µs for both 97% and 97.5% thresholds.

Thus, for the remainder of this study, SFN coverage analysis has been carried out using a guard interval of 400 µs.

Figure 19: Location of UK Primary sites.

Finally, it is worth spending a little time looking at the curves for the individual nations. As expected, the path of the UK curve is dominated by the England, and to a lesser extent the Scotland curves. This is not surprising since these two countries account for over 90% of the UK's population.

If we were to base the guard interval on the results for Wales and Northern Ireland then the curves would suggest a longer guard interval. This can be explained when we consider the geography.

For Wales and Ireland, the contribution from more distant interferers is arguably more significant owing to the higher percentage of sea path. Conversely, the reverse impact of the main station at

Divis (Northern Ireland, Belfast) on these stations is lower in terms of the overall impact on coverage in England.

Figure 19 shows the locations of the sites. The blue circle has a radius corresponding to a delay of 400 μs.

It can be seen that paths from sites such as Caldbeck to Northern Ireland are predominantly sea paths whereas from the same site (Caldbeck) to Mainland Britain the paths are predominantly over land. Thus the interference from Caldbeck to Northern Ireland will be higher than the interference it causes in areas at a similar distance in England.

7.4.2 Summary

Figure 20 compares the coverage achieved by a national SFN with a guard interval of 400 μs with that achieved from the base configuration (MFN).

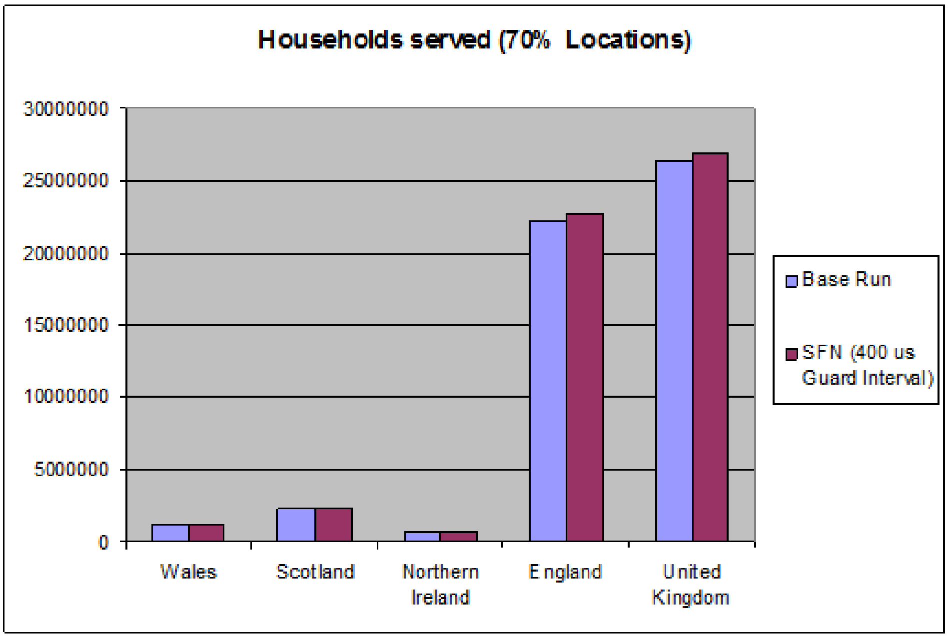

Figure 20: Coverage comparison of a national SFN versus an MFN

This indicates that a national SFN provides an overall UK increase in population, dominated by an increase in coverage in England. Coverage in Wales and Scotland also increased, albeit to a lesser extent while, for Northern Ireland, the population served has fallen slightly.

It should be noted that an MFN network would provide 40 Mbit/s whilst an SFN with an effective guard interval of 400 μs (actual 448 μs) would provide 33 Mbit/s.

The UK has regionality requirements for PSB services that preclude the use of national SFN.

7.5 Distribution networks for SFNs

In order to operate an SFN properly a reliable distribution network is required to provide the multiplex content to the transmitters within it. In many countries this task is performed by means of satellite distribution, but terrestrial distribution is also common, as well as IP distribution. Three examples are described in this section: the distribution network as used in Italy by Rai Way, the DVB-T signal distribution in France and the DVB-T/T2 signal distribution in Sweden.

7.5.1 DVB-T Sat-fed in Italy

In Italy, Rai Way broadcasts 5 multiplexes: the first is the public service multiplex with regional content, whereas the others are multiplexes with national content, as summarized below.

- **Mux1: regional**
  - RAI 1, RAI 2, RAI 3, RAI News, Radio
  - Some other regional programs in specific area
  - > 22 Mbit/s
  - Coverage > 99%
- **Mux2-3-4: national**
  - Thematic channels (RAI Sport, RAI Movie, RAI Scuola, etc.)
  - ≈ 20 Mbit/s
  - Coverage > 90%
- **Mux5: national**
  - RAI HD channels
  - In definition

A logical scheme representing the DVB-T distribution network is highlighted in **Figure 21**.

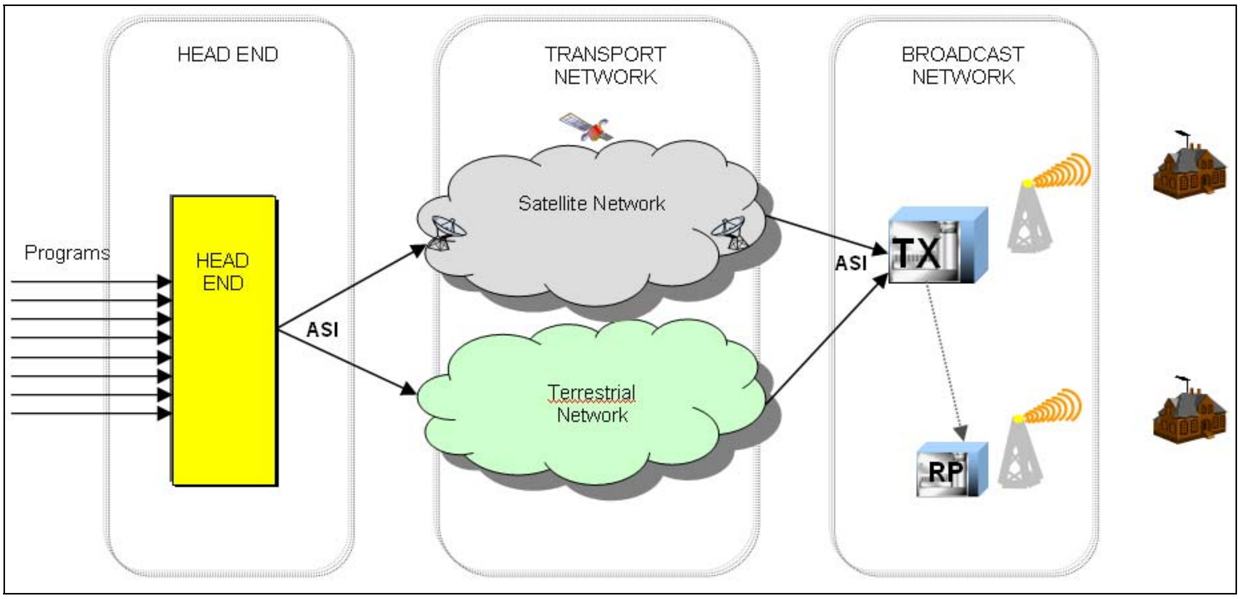

Figure 21: DVB-T distribution network

The distribution transport network uses both terrestrial and satellite systems. The terrestrial transmission network is based on radio links and Fibre leased lines from Rome to regional headquarters. This network uses Next Generation SDH technology (consisting of TS packets mapping on SDH VCs). The satellite transmission network is based on 7 transponders (AB3 5°W / HB8 13°E) using the DVB-S / DVB-S2 standard.

Multiplex 1 requires high coverage and high priority: for this reason, in MFN configuration the main transmission network is the terrestrial one and the satellite network is only used as a backup (with antenna systems typically ≥120 cm), as shown in **Figure 22**. The distribution architecture becomes more complex where SFNs are used. As it is difficult to provide small sites with radio links, satellite distribution (with antenna systems = 90 cm) is required in some cases. For these, regional content is locally inserted into the base national transport stream (received from the satellite). This process, as well as the SFN, requires also a time synchronization signal which is provided via GPS.

For multiplexes with national content the concept is similar: in the main sites, which provide about 80% of population coverage, the main transmission network is the terrestrial one and the satellite network is only used as a backup. In the smallest sites, which cover about 10% population, the only distribution network is satellite (with antenna systems typically ≥120 cm).

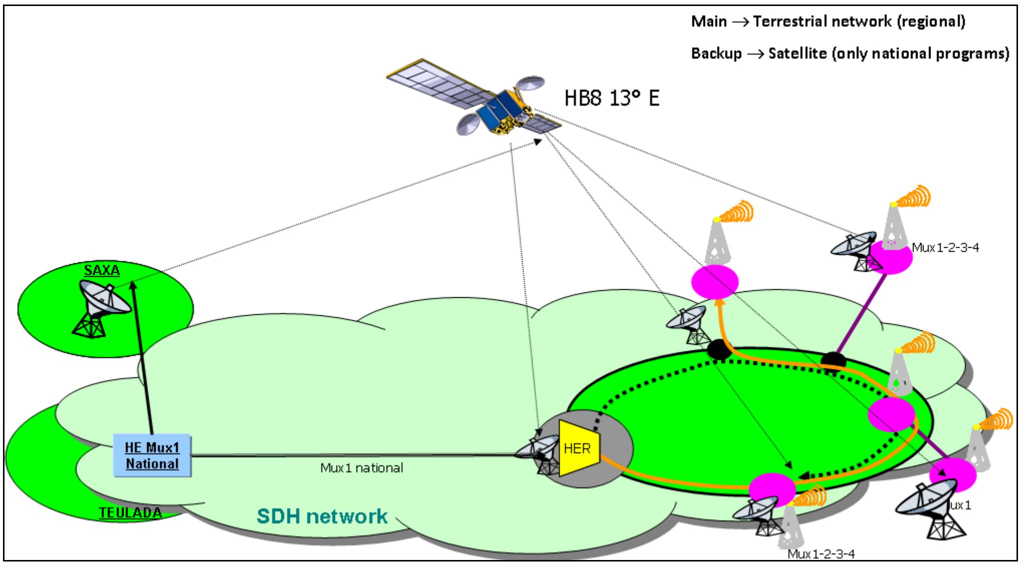

Figure 22: Terrestrial distribution network with satellite network as backup

The Rai Way roadmap is currently evaluating different solutions to create new terrestrial distribution networks, as ASI radio link and IP. In particular, IP is a promising technology with high flexibility; an example is described in **§ 7.5.3**.

7.5.2 DVB-T signal distribution in France

In France, six multiplexes are currently on air, with two additional ones being partially deployed. The first multiplex has regional content, while the remaining ones offer national programs.

The broadcast of all the multiplexes rely on up to 1626 sites for up to 98.5% population coverage, depending on the multiplex, with the following architecture:

- Main sites all rely on satellite or terrestrial transmission links
- Secondary sites either rely on UHF or satellite transmission links (when UHF links are not possible, due for example to poor propagation conditions between the transmitting and receiving sites)

Overall, there are more than 10,000 distribution links:

- More than 3000 links use satellite or terrestrial transmission links
- The remaining use UHF transmission links:
  - 6000 relays are on-channel repeaters (the secondary transmitters re-transmit the same channel as is distributed by the parent transmitter), either in an SFN (same content) or co-channel manner (same content or local insertion of different programs).
  - Approximately 660 relays are MFN repeaters, or relays (the secondary transmitters re-transmit on a different channel to the pilot, or parent transmitter).
  - The remaining relays use an MFN-SFN technique: the piloting signal is received from an MFN repeater, but the content and channel on which it is re-transmitted impose that the transmission forms part of an existing SFN on the designated channel.

7.5.3 Distribution of DVB-T/T2 data to the transmitters using IP in Sweden

Teracom in Sweden operates a DTT network consisting of about 54 main HPHT transmitters and about 450 smaller fill-in transmitters. Currently 7 DTT multiplexes are in operation; 5 DVB-T and 2 DVB-T2.

At the start of the DTT transmissions in 1997 (official launch 1999), using DVB-T, the distribution of the signals to the main transmitters was made using microwave links using ATM/SDH, regardless of whether they operated in an MFN or SFN. The smaller MFN fill-in transmitters were fed with an off-air signal from the main station which they transposed to a different frequency and repeated. Local re-multiplexing was used to insert local and regional content into a national or base feed that was common for all main transmitters - a single layer distribution approach. **Figure 23** broadly shows the architecture of the 'old' DTT distribution network.

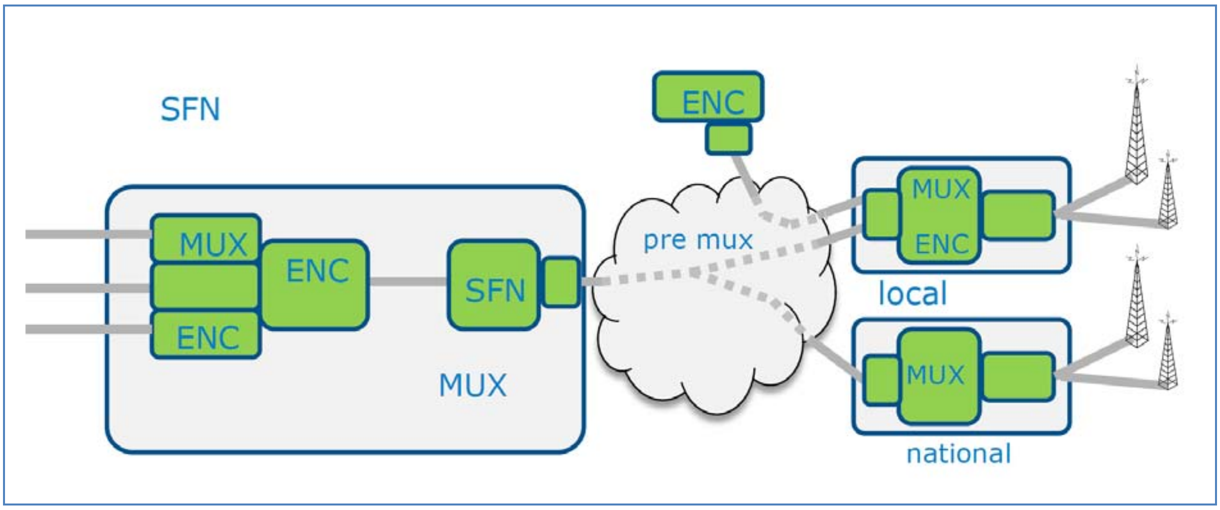

Figure 23: Old MPEG structure of DTT Network. Encoding (ENC) and multiplexing is done at a national level as well as at the local sites for the local /regional content.

More recently however IP/Ethernet over DTM has been used as the primary distribution mechanism from the central head-end (see **Figure 24**) to the main DTT transmitters. The newer DTM based distribution network is based on a two layer principle with a high capacity fibre optical core network and a mix of microwave and fibre for the distribution network from the core network to transmitter sites.

One of the main differences in the new distribution architecture (**Figure 24**) is that all multiplexes are generated centrally at the head-end site. This covers both multiplexes that do not have local content as well as multiplexes with local content. Local content/services are sent back to the central head-end using the DTM network. The multiplex is then distributed along with all the other national and local multiplexes. For example Multiplex 2 has national services which have approximately 30 regional news areas. At the central head-end 30 complete regional versions are created and distributed to the different regions. The local and regional multiplexes are of course only sent to the appropriate regional or local transmitters. This approach is possible since the primary distribution cost per Mbps is lower in the new DTM network compared to earlier. Teracom's new primary distribution DTM based network (core network) has much higher capacity than the old ATM based network which has been replaced. The whole distribution DTM network is owned and operated by Teracom.

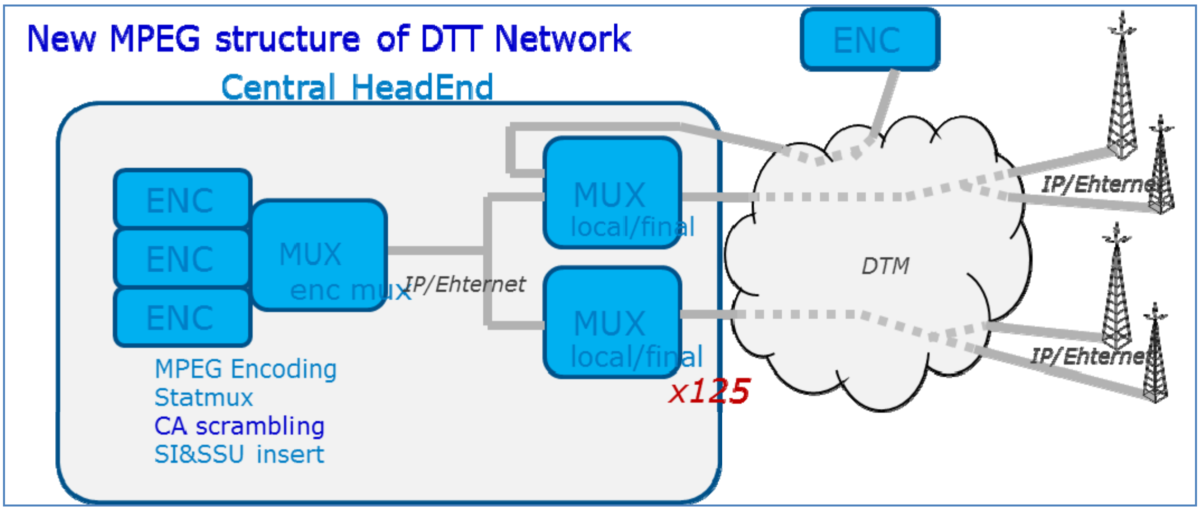

Figure 24: New structure of DTT network using IP distribution

This approach with centralized systems for regional insertion etc. normally means higher cost for primary distribution, but it is well compensated for by the reduced cost for all regional systems. Additionally it makes supervision and operation much easier. With centralizing regional DTT systems (such as MPEG multiplexing, SFN adaptation, T2 gateway etc.) it has been possible to use much more N+1 redundancy strategies for these system which earlier often had to use 1+1 redundancy. But also in a fairly large network some other advantages are: maintenance is easier, spare parts, monitoring etc. This has significantly reduced the cost for the regional systems.

This means that the complexity is reduced at the transmitter site allowing a reduction of the cost for maintenance as this can be done at a central location, rather than at remote transmitter sites. The connection of the transmitters is also simplified since newer transmitters are connected to the same signals, using Ethernet as the interface. (ASI interface is still however used for older legacy transmitters; this is handled via external network adaptor at the transmitter site converting IP/Ethernet signals into ASI). Using IP/Ethernet has simplified switching when N+1 redundancy is used by the transmitters.

7.6 DVB-T2 & DVB-T2-Lite SFN

7.6.1 DVB-T2-Lite

In several countries, DVB-T2 networks for the delivery of SD and HD television content over terrestrial channels have already been deployed, or are planned.

Often these networks are designed for fixed reception, but there is a growing demand for linear TV viewing on portable devices, such as tablets. The increasing number of these devices is placing considerable load on mobile operators' networks which are trying to serve their users with unicast delivery.

Broadcasting would, however, be both technically and economically better to reach large audiences during peak hours or major events. For this reason in 2011 DVB introduced T2-Lite **[EN 302 755]**, which supports portable and mobile reception alongside a DVB-T2 service for fixed reception.

To reduce the cost of network deployment, T2-Lite can be combined together with T2-Base (i.e. DVB-T2) and deployed on the existing networks using Future Extension Frames (FEF) within the DVB-T2 standard, thus avoiding the need to build a new network dedicated exclusively to mobile services. A short description of how this could be achieved may be found in the 4th edition of **[EBU Tech 3348]**.

7.6.2 Experimental tests in the Aosta Valley

The RAI Research Centre, in co-operation with Rai Way and other Italian manufactures conducted a trial where HDTV services for fixed reception and T2-Lite mobile TV services were transmitted on the same channel. In this way, robust reception of very different services was demonstrated.

The trial, based on an SFN with two transmitters in the mountainous Aosta Valley allowed a number of aspects of the system to tested and demonstrated in challenging conditions including: the technical characteristics of the system, mobile coverage performance, the interoperability of different vendors' equipment, particularly for SFNs, and the behaviour of receivers in the field. The trial took place on UHF channel 53 using, in a first step, the Aosta-Gerdaz and Saint Vincent-Salirod transmitters, the results of which are reported here. In a second phase, the network was expanded by including two more transmitters: Tete d'Arpy and Col Courtil, and a new configuration of GI 1/16 (56 µs) for T2-Lite is used. A description of this second phase can be found in **[AI 2014]**.

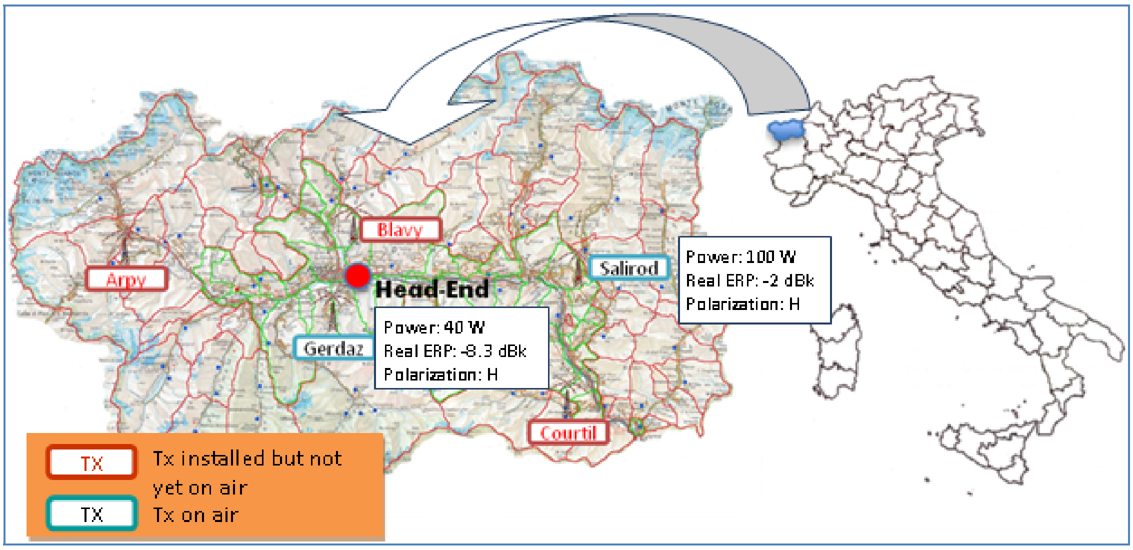

Figure 25: Geographical context - Aosta Valley

The bouquet takes origin in the head-end located in RAI's premises of Aosta and consists of three HD programs for T2-Base and of three services oriented to mobile reception for T2-Lite. The signal was distributed over SDH digital radio links.

The scheme chosen for the testing involved the use of a "mixed" system: the T2 signal was split into two sub frames, one compatible with standard T2-Base, the other T2-Lite, optimized respectively for fixed and mobile reception.

The geographical context together with the location of the transmitters and their characteristics are reported in **Figure 25**.

The modulation parameters adopted during the field trial are the following:

DVB-T2 Base

- Constellation: 256-QAM, rotated
- FEC: 3/4 - available bit rate 28.2 Mbit/s
- FFT: 32k
- Guard Interval: 1/128 (28 µs)
- Pilot pattern: PP7

DVB-T2-Lite

- Constellation: QPSK Rotated
- Tests in three different configurations of FEC:
  - 1/3 - available bit rate 1.6 Mbit/s;
  - 1/2 - available bit rate 2.2 Mbit/s;
  - 2/3 - available bit rate 3.3 Mbit/s
- FFT: 8k
- Guard Interval: 1/32 (28 µs)
- Pilot Pattern: PP4

The two transmitters in phase one (Aosta-Gerdaz and Saint Vincent-Salirod) have partially overlapping coverage; thus, to avoid interferences beyond the guard interval in that zone (28 µs for the selected transmission mode), a static delay of 72 µs was applied to the Aosta-Gerdaz transmitter, as depicted in Figure 26.

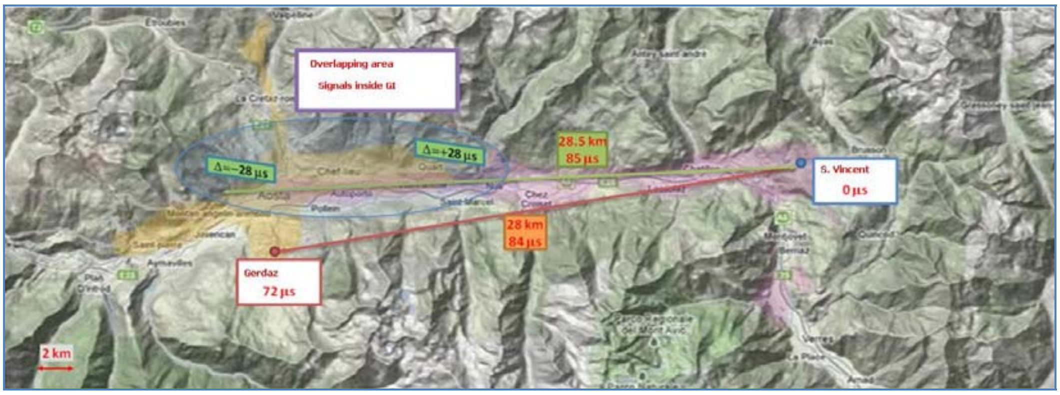

Figure 26: Network set-up of the T2-Lite trial in the Aosta Valley (phase 1)

For each chosen FEC value of DVB-T2-Lite, drive-measurements were performed and more than 400 km were covered along the roads of the Aosta Valley. The results were very promising. DVB-T2-Lite provided excellent mobile reception for cars travelling at speeds of up to 130 km/h. The coverage is very good on all type of roads (motorway, main roads, secondary roads, etc.) in most of the main valley, in the urban areas (Aosta, Saint Vincent and Chatillon) and also a quite good coverage is accomplished in many secondary lateral valleys. The mobile reception availability for the SFN is reported in **Figure 27**.

Figure 27: SFN mobile reception availability (signal received, green; not received, pink) - FEC 1/2

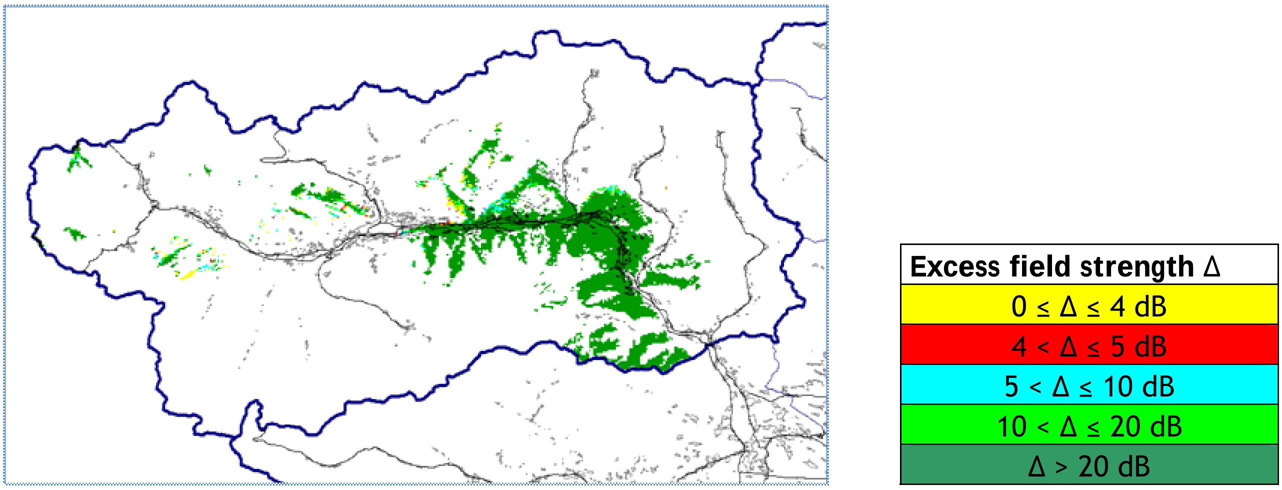

Figure 28: Area where the signal from transmitter Saint Vincent exceeds the signal from transmitter Gerdaz

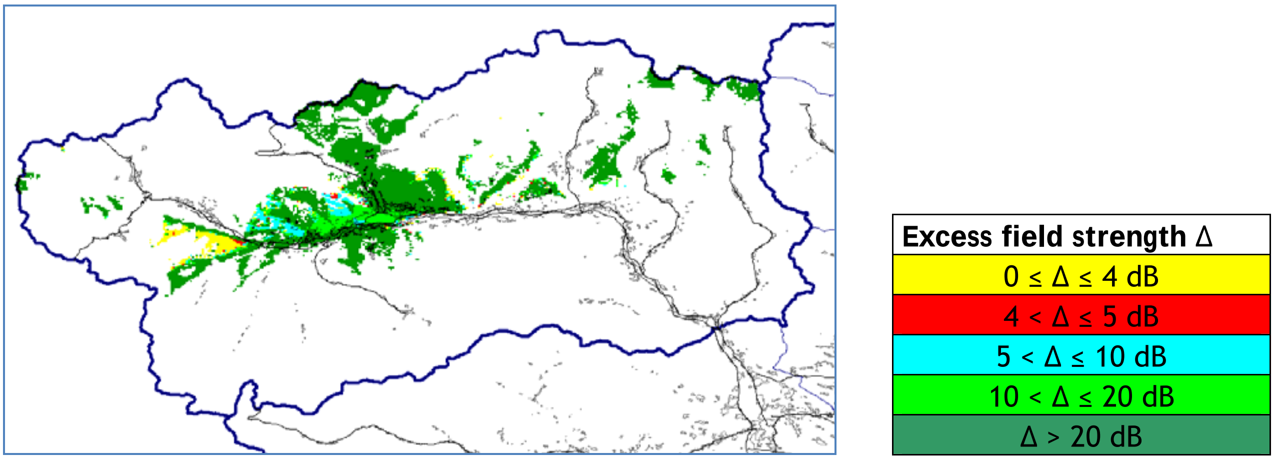

Figure 29: Area where the signal from transmitter Gerdaz exceeds the signal from transmitter Saint Vincent

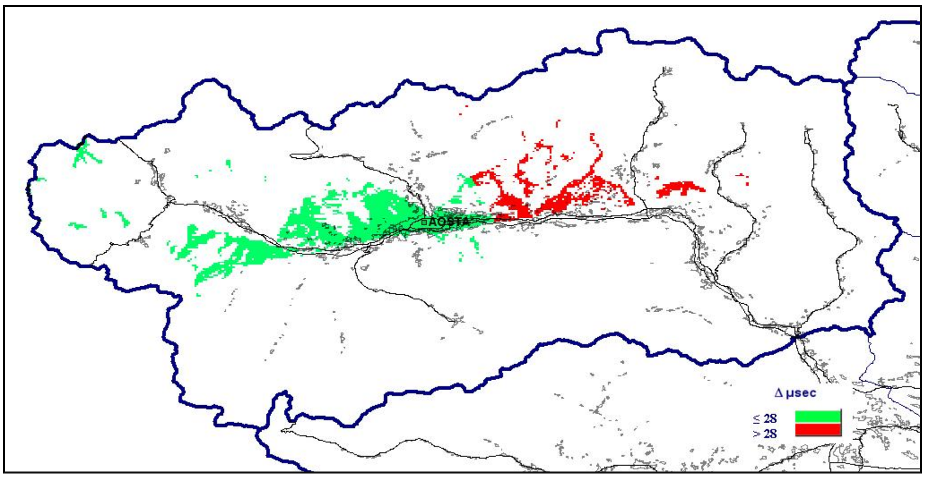

Figure 30: Area where the signals of the two transmitters are within the GI (green) and beyond the GI (red)

Figures 28 and **29** show the predicted relative field strength excess of the signals of the two transmitters. In these areas reception is possible and in some locations, only one transmitter is receivable. **Figure 30** shows the places where both transmitters are receivable and the signals of the two are within the GI and beyond the GI. Matching the areas in the three figures allows identifying the possible critical zones of reception. These zones have been verified during the measurement campaign, see **Figure 27**.

A test with the 8k PP7 profile was achieved but, with this configuration, travelling at a speed of 70/80 km/h in a radial direction with respect to the transmitter, the receiver was not able to properly decode the signal.

Moreover, theoretical studies and laboratory tests show that, with the 8k PP4 profile, reception is possible even up to speeds of 250 km/h or more; therefore this system is suitable also for TV broadcasting for reception on high speed trains.

A set of fixed measurements was also performed in order to evaluate the service area of DVB-T2-Base. The measurements were carried out at 15 m above ground level using a directional yagi antenna for each transmitter. These showed a high reception margin in the entire predicted coverage area. The reception margin was measured by attenuating the incoming signal up to the reception threshold.

Figure 31 sets out the location of the test points together with the measured results.

Tx Gerdaz (45°42'07.18'' - 7°18'33.64'')					
Test point	Position		EMF [dBµv/m]	MER [dB]	Margin [dB]
Saint Christophe roundabout	45°44'21,29''	7°21'14,57''	90,5	32,6	40
Aosta cemetery	45°43'50.57''	7°17'34.10''	91,6	32,5	37
Quart cemetery	45°44'32,98''	7°23'13.35''	83,5	31,2	29
Quart station FF.SS.	45°44'28,39''	7°24'51,53''	55,8	NA	NA
Saint Pierre Hotel Chateau	45°42'32,94''	7°13'37,50''	85,3	31,0	31
Jovencan school parking	45°42'53,15''	7°16'29,67''	89,2	32,9	35
Roisan-Rhins public weight	45°47'28,86''	7°18'23,24''	81,3	31,4	27
Porossan-La Chapelle parking	45°45'17,05''	7°19'35,29''	85,6	31,2	31

Tx Salirod (45°44'37.60'' - 7°40'40,76'')					
Test point	Position		EMF [dBµv/m]	MER [dB]	Margin [dB]
Saint Christophe roundabout	45°44'21,29''	7°21'14,57''	73,1	27,9	18
Brissogne Palafent	45°44'13.7''	7°24'59.6''	77,0	29,7	20
Nus football court	45°44'29,22''	7°28'30.66''	75,0	30,9	20
Chambave cemetery	45°44'36,44''	7°32'56,18''	79,7	32,3	25
Chatillon Perolles van parking	45°44'56,51''	7°37'25,17''	85,0	30,0	30
Montjovet (crossroads Oley Meran)	45°42'24,84''	7°40'05,05''	87,5	NA	32
Champdepraz Piazza Foy	45°41'08,49''	7°39'49,52''	87,0	NA	32

Figure 31: Field strength measurements - Fixed reception, single transmitters

In order to validate the SFN in the service area where the signals of the two transmitters overlap, a lot of measurements were carried out to record information regarding the spectrum, impulse response, constellation, MER, modulation parameters, field strength, etc.

An example of these measurements is shown in **Figure 32**.

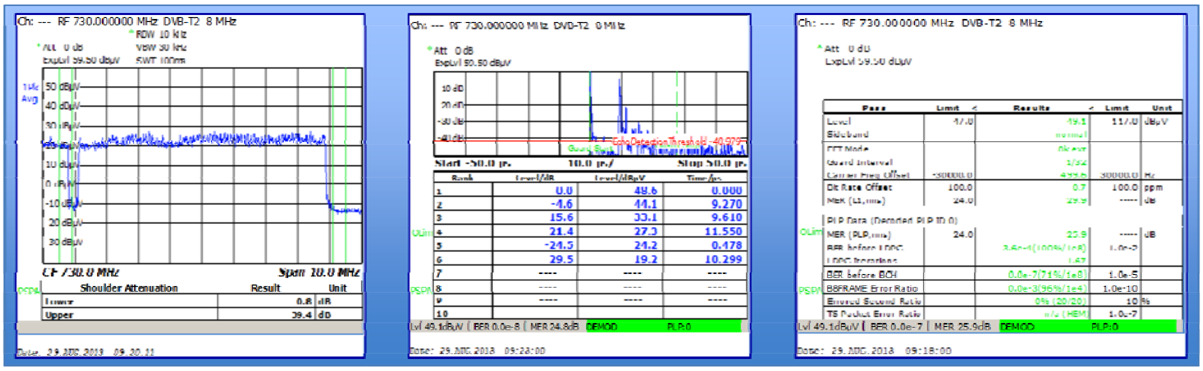

Figure 32: Example of SFN fixed reception measurements

8. Summary

This report on broadcast single frequency networks covers three main topics which relate to DVB-T2, spectrum efficiency, and network design and implementation options of SFNs.

By means of case studies the maximum possible size and the adequate size of SFNs is discussed in the light of the new parameter options which are provided by DVB-T2 on one hand and the service requirements of broadcasters on the other hand. Both aspects contribute to the issue of spectrum consumption by broadcast transmission systems.

The studies show that with DVB-T2, different from the predecessor system DVB-T, large area SFNs are technically feasible, under favourable conditions even for national service areas. This can be achieved by applying large guard intervals, now available with DVB-T2, albeit at the expense of data capacity in the transmission: typically a 15% reduction is to be accepted as compared to regional SFNs.

Regional SFNs are found to offer a good compromise between national SFNs and full MFNs. In these configurations the restricted size of regions allows SFN self-interference to be avoided, while at the same time enabling a high payload, and importantly, efficient delivery of regional content.

Although a national SFN may require a single channel in a particular country, consideration of the wider planning area (immediate neighbours at least) implies that four to five frequency channels would be required to avoid interference from one country into another - a similar number of channels as a regional SFN, which may require four to six. This factor combined with the reduced capacity of a national SFN and given that national SFNs would not allow efficient delivery of regional content, regional SFNs are found an attractive option for broadcasters with regional delivery requirements.

In a second part of the report, the spectrum efficiency of DVB-T2 broadcast networks is investigated in more detail. The raw spectral efficiency of DVB-T2 (data rate of the transmission system per used frequency bandwidth) ranges from 1.6 to 5.0 bit/s/Hz, strongly depending on the envisaged reception mode and the applied network configuration. MFNs for fixed roof-top reception have very high spectral efficiency figures; SFNs have smaller values since data capacity has to be spent to overcome self-interference, and networks for portable indoor reception have the lowest spectral efficiency due to the most difficult transmission channel.

But, spectral efficiency is identified as a rough metric for assessing real spectrum consumption since it does not account for frequency re-use aspects. A more realistic concept, Layer Spectrum Efficiency (LSE), is applied in order to achieve this. This concept reveals that large SFNs are indeed (moderately) more efficient with regard to spectrum consumption than MFNs or small and medium SFNs. However, the more relevant differences with regard to spectrum consumption are introduced by the different reception modes: the more difficult the transmission channel, the lower the efficiency in spectrum usage.

In a further section the spectrum consumption of hypothetical cellular DVB-T2 networks is considered. It is found that, in principal, Low-Tower-Low-Power DVB-T2 networks provide a higher efficiency with respect to spectrum consumption. This advantage is, however, to be paid for with a very high implementation effort. The case study for one country concludes that the main advantage of the cellular approach lies in the flexibility of tailoring the service area, rather than the higher efficiency in spectrum consumption.

In a third part, several aspects of SFN design and optimisation are described.

Two studies emphasise the relevance of taking over sea paths into account. Since tropospheric propagation at small time percentages is particularly relevant for these propagation paths, self-interference effects in SFNs can occur over distances normally uncritical in standard network planning.

Several studies demonstrate the optimization potential of static time delays in SFN network planning. This planning technique allows mitigating self-interference by moving interference zones to unpopulated areas such as the sea, or it may allow them to be moved to areas well served by other transmitters, effectively masking self-interference.

A planning study in the UK investigates the factors which are relevant for the choice of the optimal guard interval in a hypothetical national SFN. These include the size of the country, the length of sea paths and any coverage obligations. In this case, the optimum value for the guard interval turns out to be around 400 μs. A DVB-T2 mode with such guard interval would lose about 20% of multiplex capacity as compared to a DVB-T2 mode which would be applied for an MFN approach.

A further section is dedicated to distribution networks for DVB-T/T2 SFN. Various techniques, distribution via satellite, terrestrial networks or IP, are described by reference to the practice in three countries.

Finally, the successful accommodation of a DVB-T2-Lite service, which provides coverage for mobile receivers, in a DVB-T2 multiplex in a field trial in Italy is described. T2-Lite provides the possibility to offer services to mobile receivers in a DVB-T2 multiplex designed for fixed roof-top reception.

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10. Abbreviations

ATM	Asynchronous Transfer Mode
CR	Code Rate
DTM	Dynamic synchronous Transfer Mode
DTT	Digital Terrestrial Television
DVB-T/T2	Digital Video Broadcasting/Terrestrial
FEC	Forward Error Correction
FFT	Fast Fourier Transformation
GE06	ITU Frequency Plan for DTT Geneva 2006
GI	Guard Interval
GIF	Guard Interval Fraction (= GI)
HD	High Definition
HTHP	High-Tower-High-Power
ISD	Inter-Site Distance
LSE	Layer Spectrum Efficiency
LTLP	Low-Tower-Low-Power
MFN	Multiple Frequency Network
Mbit/s	Megabit per second
PSB	Public Service Broadcaster
RBF	Re-use Blocking Factor
SD	Standard Definition
SFN	Single Frequency Network

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Annex A1: Theoretical Study on Maximum Achievable Data Rates for Large DVB-T2 SFN Areas

(EBU SMR-BNP002r1)

IRT V/FM
Sato Telemi / Roland Brugger
29 July 2013

Optimal DVB-T2 system parameters for the coverage of large single frequency networks

A1.1 Introduction

The objective of this study is to analyse the capabilities of single frequency networks (SFN) in DVB-T2 when there is a mission to cover a large area. This could be a state, a region or an entire country.

Planning a network requires a trade-off between the size of a coverage area and the highest achievable data rate. In other words it is not possible to cover a large SFN with the highest available data rate. This is due to the fact that deleterious delay differences of signals from different transmitters have to be compensated by a so-called guard interval. This mechanism has to be paid for by data capacity. For this reason we try to find an optimisation to fulfil both requirements in the best possible way.

In this optimisation problem different degrees of freedom are available. Some of them are the inter-site distance, transmitter antenna height, effective radiated power, modulation and code rate, and guard interval among others.

In order to have a general understanding of single frequency network behaviour, first a theoretical study is presented in this report. The purpose here is to find the best operational mode which makes the coverage of areas possible. Here these areas are a German state like Bavaria and an entire country like Germany. For both cases fixed roof-top, portable and mobile reception scenarios are analysed.

A1.2 Planning parameters and network structure

The study of large SFN is done on a theoretical hexagon network. The network is located on a flat surface and no topography and morphography data are used during this study. For this reason the ITU-R Rec. P.1546 propagation model **[A1-1]** is the best choice to use.

The structure of such a network is shown in **Figure A1.1**. The distance between transmitters or inter-site distance (ISD) is 60 km. This distance is chosen due to its similarity to the real world networks in Germany. The transmitter antennas have a 300 m effective antenna height and an effective radiated power of 100 kW. This high transmitter power ensures that no coverage deficiencies appear due to a lack of power. In a real network implementation the transmitter powers will be adapted and might be less than 100 kW.

As mentioned earlier the theoretical hexagon networks have to cover areas of the size of Bavaria and Germany in fixed, portable and mobile modes. For this reason the size of the network with three hexagon rings with 360 km diameter for Bavaria ("large size SFN") and six rings with 720 km diameter for Germany ("very large size SFN") is chosen. None of the above mentioned real areas are square-shaped; therefore the hexagon networks are chosen big enough to cover the entire area of Germany and Bavaria. **Figure A1.2** shows the map of Germany with the geographical sizes.

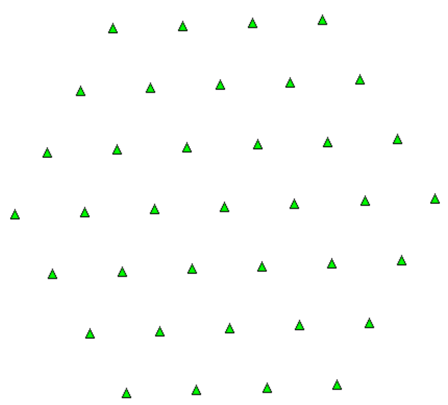

Figure A1.1: Theoretical hexagon network (large size SFN)

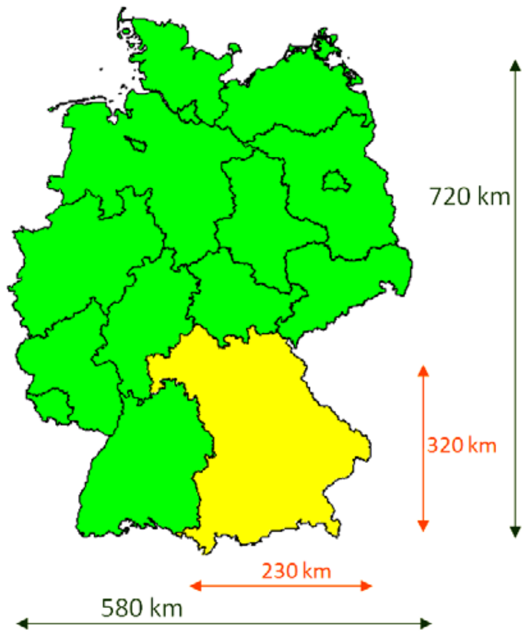

Figure A1.2: Size of Germany & Bavaria

Table A1.1 gives the list of planning parameters that were applied in the simulation. They are either taken from the EBU TECH3348 on DVB-T2 planning **[A1-2]** or from the technical annex of the GE06 Agreement **[A1-3]**. For fixed reception the usual directional antenna as described in ITU-R Rec. BT.419-3 **[A1-4]** is assumed whereas for portable and mobile reception simple non-directional TV receiving antennas are used. These are to be distinguished from built-in handheld antennas which show a worse performance. All calculations were performed in Band IV/V at channel 40. The minimum location probability for mobile reception is assume 98% (for the very large SFN) and 98.5% (for the large SFN), respectively, which differs slightly from the common value of 99%. The reason for this is a pragmatic one: If 99% would have been applied strictly, favourable DVB-T2 variants would have failed in the optimization process only because of small potential gaps in coverage. For fixed and portable reception a minimum location probability of 95% is assumed.

Table A1.1: Planning parameters

	Mobile reception	Portable outdoor reception	Fixed roof-top reception
Receiver noise figure [dB]	7	7	7
Standard deviation of shadow fading [dB]	5.5	5.5	5.5
Rx antenna height [m]	1.5	1.5	10
Coverage probability [%]	98.0 (very large SFN) 98.5 (large SFN)	95.0	95.0
Feeder loss [dB]	0	0	4
Antenna gain [dB]	0	0	11
Rx Antenna diagram	Non-directional	Non-directional	Directional ITU-R BT.419-3-Band IV/V

A1.3 DVB-T2 modes

A large number of DVB-T2 modes, i.e. combinations of DVB-T2 system parameters, were investigated to find optimal variants. The parameters for these and some additional other modes are summarized in **Table A1.2**. The table contains the data rates and the C/N values of these modes in a Rician, static Rayleigh and time-variant Rayleigh channel.

Table A1.2: C/N values and data rates for selected DVB-T2 variants

DVB-T2 mode [FFT size / modulation / code rate / guard interval / pilot pattern]	C/N [dB]			Data rate [Mbit/s]
	Mobile reception	Portable reception	Fixed reception	
16k ext, 64-QAM-1/2, 1/4, PP1	20.1	15.1	13.1	16.8
16k ext, 64-QAM-3/5, 1/4, PP1	21.9	16.9	15.2	20.1
16k ext, 64-QAM-2/3, 1/4, PP1	23.3	18.3	16.5	22.4
16k ext, 64-QAM-3/4, 1/4, PP1	25.4	20.4	18.0	25.2
16k ext, 64-QAM-4/5, 1/4, PP1	27.0	22.0	19.3	26.9
16k ext, 256-QAM-1/2, 1/4, PP1	24.5	19.5	17.5	22.3
16k ext, 256-QAM-2/3, 1/4, PP1	26.7	21.7	19.6	26.9
16k ext, 256-QAM-2/3, 1/4, PP1	28.4	23.4	21.2	30.0
16k ext, 64-QAM-1/2 ,19/128, PP2	20.1	15.07	13.1	18.3
16k ext, 64-QAM-3/5, 19/128, PP2	21.9	16.9	15.2	22.0
16k ext, 16-QAM-3/5, 19/128, PP2	16.9	11.9	10.4	14.7
32k ext, 256-QAM-3/4, 19/256, PP2	30.9	25.9	23.2	39.2
32k ext, 256-QAM-3/4, 1/8, PP2	30.9	25.9	23.2	37.5

The static Rayleigh channel is applied for portable reception, the time-variant Rayleigh channel for mobile reception and the Rician channel for fixed reception. These values are chosen in accordance with EBU Tech 3348 on DVB-T2 planning **[A1-2]**. For mobile reception an additional 5 dB is added on top of the static Rayleigh figures in order to justify the time variance and Doppler degradation of a mobile transmission channel.

The 5 dB increment for mobile reception is to be regarded as tentative. It results from measurements of consumer receivers which are not particularly designed for mobile reception; they rather are used in fixed reception environments. It is expected that in the future dedicated mobile receivers will be available which show a better performance; in particular antenna diversity should be advantageous. The results for mobile reception might therefore be regarded as conservative.

A1.4 Maximum data rate to cover large areas with DVB-T2 theoretical SFNs for mobile, portable and fixed reception

In this section the maximum possible data rate with acceptable robustness which covers the medium and large size SFN in mobile, portable and fixed reception modes is examined. The following approach was chosen. Firstly, all locations within the SFN area have to be covered with the minimum required location probability. Among those DVB-T2 variants which fulfil this requirement the one which provides the highest data rate is chosen. Due to the high vulnerability of 32k FFT mode to Doppler degradation this mode is excluded for portable and mobile receptions. Although this fact is obvious for mobile reception, this condition is also applied to the portable reception mode in order to guarantee a certain amount of mobility in this reception mode as well.

Figure A1.3 presents a snapshot of this process. It shows a coverage plot for mobile reception of the large SFN (360 km x 360 km) for the DVB-T2 variant 16k 64-QAM-2/3-GI 1/4. The colours indicate the coverage probabilities; white: (>98.5%), green: (95% - 98.5%), yellow: (70% - 95%), grey: (<70%). The coverage requirement is fulfilled if the whole SFN area is white. This is not the case here. For this reason the following variant cannot be regarded as appropriate for the coverage of the large SFN for mobile reception.

In practice there is no need to calculate the whole SFN area. The high symmetry of the network topology allows reducing the consideration to a small fraction of the entire area. Indeed, this is helpful since the computing time is quite high for such a large number of transmitters.

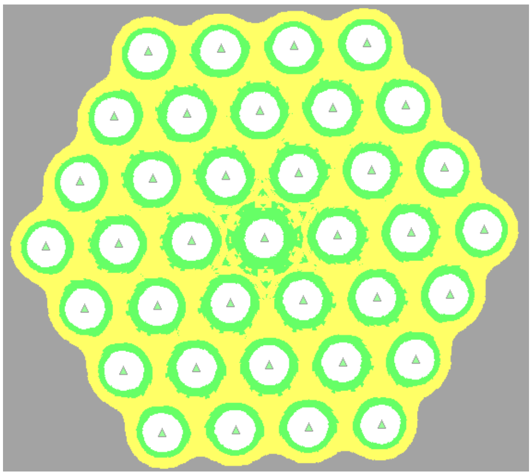

Figure A1.3: Coverage plot of the large hexagon SFN (360 km diameter) for mobile reception with the DVB-T2 variant 16k 64-QAM-3/4, GI=1/4 PP1

Table A1.3 gives an overview of the results. For each category of SFN and reception mode the optimum DVB-T2 variant is given which provides full area coverage, where the optimization criterion is the data rate.

Table A1.3: DVB-T2 modes with maximum data rate while allowing for a full SFN coverage

	Large SFN (360 km x 360 km)	Very large SFN (720 km x 720 km)
Fixed reception	32k-ext, 256-QAM-3/4 PP2 GI 19/256 (266 µs) Data rate: 39.2 Mbit/s	32k-ext, 256-QAM-3/4 PP2 GI 1/8 (448 µs) Data rate: 37.5 Mbit/s
Portable reception	16k-ext, 256-QAM-2/3 PP1 GI 1/4 (448 µs) Data rate: 30.0 Mbit/s	16k-ext, 64-QAM-3/4 PP1 GI 1/4 (448 µs) Data rate: 25.2 Mbit/s
Mobile reception	16k-ext, 64-QAM-3/5 PP1 GI 1/4 (448 µs) Data rate: 20.1 Mbit/s	16k-ext, 64-QAM-1/2 PP1 GI 1/4 (448 µs) Data rate: 16.8 Mbit/s

The maximum data rate for the mobile reception mode is 20.1 Mbit/s for the large SFN and 16.8 Mbit/s for the very large SFN. With this data rate 100% of the areas are covered with the location probability not lower than 98%. For portable reception these figures are 30.0 Mbit/s and 25.2 Mbit/s for the large and the very large SFN, respectively. For fixed reception, 32k FFT modes with a high modulation scheme are found which provide nearly 40 Mbit/s data rate.

In the following we will focus on portable and mobile reception. Three findings are remarkable. Firstly, there is a large difference between the performance of portable and mobile reception modes. It was already mentioned in the previous section that the parameters of the mobile reception case may be conservative. From the other side a static Rayleigh channel might be too optimistic for a robust portable reception. As a result we could conclude that the future portable and mobile DVB-T2 receivers might show a performance somewhere in between the two scenarios described above. However, as long as there are no such receivers available in the market this remains uncertain. At least our study proofs that still more investigations on this item are required.

Secondly, there is still a remarkable difference with the data rates between the large SFN and the very large SFN scenario. This is an interesting finding since it was believed that the size of a large SFN is great enough and the addition of further transmitters would not remarkably increase the deleterious effect of self-interference. The results for the very large SFN show that this is not true. Even at several hundred kilometres distance the self-interference effect is perceivable and addition of transmitters affect the results of self-interference.

Thirdly, according to the results the largest guard interval (448 μs in 16k FFT mode) is the most appropriate choice for the coverage of a large SFN. Instead a smaller guard interval could be used with a robust code rate but then the data rate will be much lower.

The DVB-T2 variants in **Table A1.3** fulfil the requirement of full area coverage. Variants with higher data rate would not provide 100% coverage of the area. Such DVB-T2 modes were also investigated.

For the mobile reception case and the large SFN, **Figure A1.4** gives the percentages of covered locations ordered by their respective location probability for nine DVB-T2 variants. The two variants of **Table A1.3** are also included in this figure. 64-QAM-3/5-GI 1/4 is the best variant which fulfils the 100% coverage requirement. Other 64-QAM-GI 1/4 variants with a less robust code rate fail; however, 64-QAM-2/3-GI 1/4 with a data rate of 22.4 Mbit/s shows at least full area coverage with a location probability higher than 95%. 256-QAM-1/2-GI 1/4 gives a similar, slightly worse, result with nearly full area coverage. Variants with the smaller guard interval of 19/128 (266 μs) show a quite bad performance which emphasizes the crucial impact of the guard interval. In § **A1.5** a more detailed investigation of the guard interval aspect is presented.

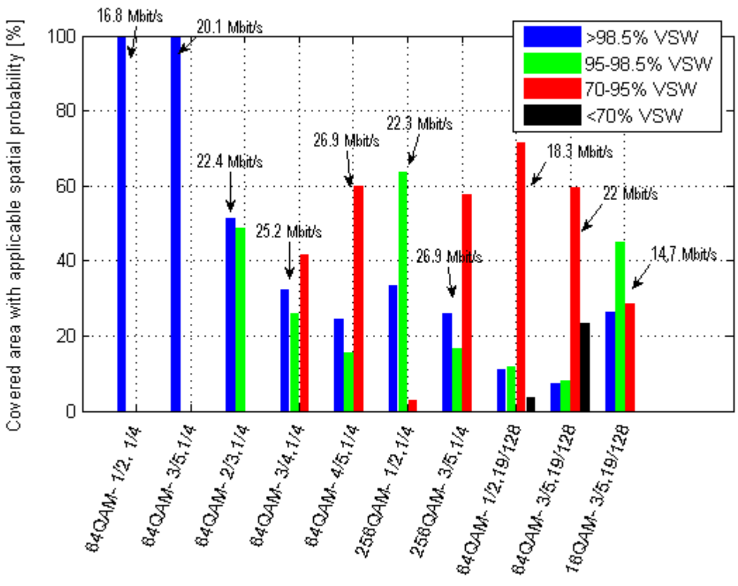

Figure A1.4: Percentage of covered locations in the large SFN (360 km x 360 km) for 9 DVB-T2 variants and mobile reception ordered according to four location probability classes

Figure A1.5 shows the results for the mobile reception and very large SFN. All variants suffer from higher self-interference degradation than in the large SFN case. Now only 64-QAM-1/2-GI 1/4 fulfils the coverage requirements. 64-QAM-3/5-GI=1/4 has at least a nearly full area coverage for 95% location probability, whereas for 64-QAM-2/3-GI=1/4 the percentage of locations with less than 95% location probability is already nearly 20%.

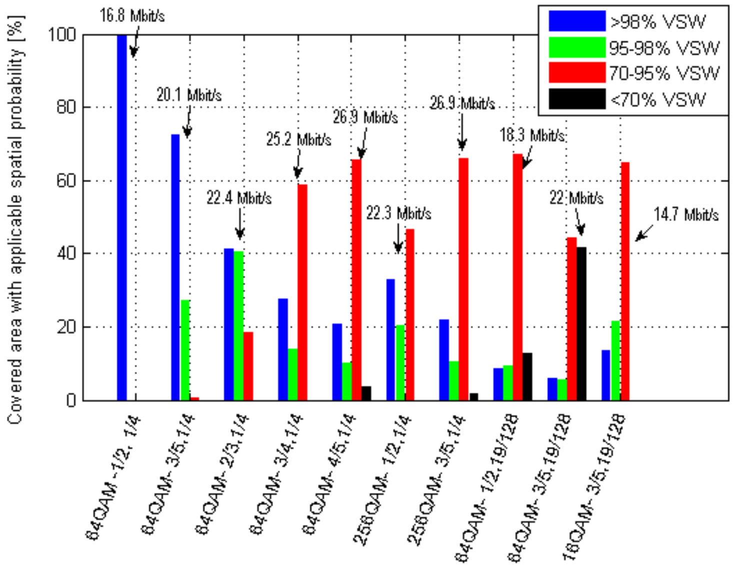

Figure A1.5: Percentage of covered locations in the very large SFN (720 km x 720 km) for 9 DVB-T2 variants and mobile reception ordered according to four location probability classes

As discussed earlier in this section, the situation improves remarkably if the less demanding parameters for portable reception, as compared to mobile reception, are applied. **Figure A1.6** shows the results for the same nine DVB-T2 modes for the large SFN case. Now all GI 1/4 variants fulfil the coverage requirements. The variants with the smaller guard interval of 19/128 still fail to achieve the full area coverage with 95% location probability. Only a change from 64-QAM to the more robust 16-QAM modulation provides the required coverage; however, at the price of lower data rate.

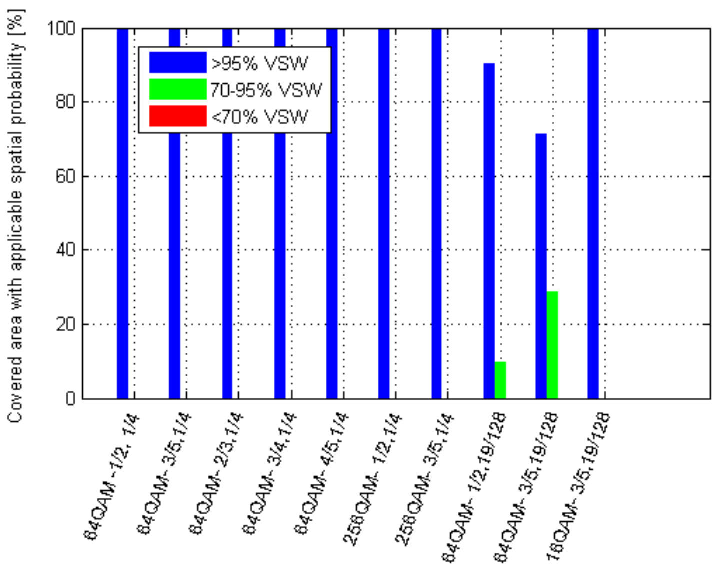

Figure A1.6: Percentage of covered locations in the large SFN (360 km x 360 km) for 9 DVB-T2 variants and portable reception ordered according to three location probability classes

The situation for the very large SFN, depicted in **Figure A1.7**, is very similar to the previous one. Again, the 64-QAM GI 19/128 variants fail; now with a higher percentage of uncovered locations. And again, the more robust 16-QAM variant fulfils the requirement.

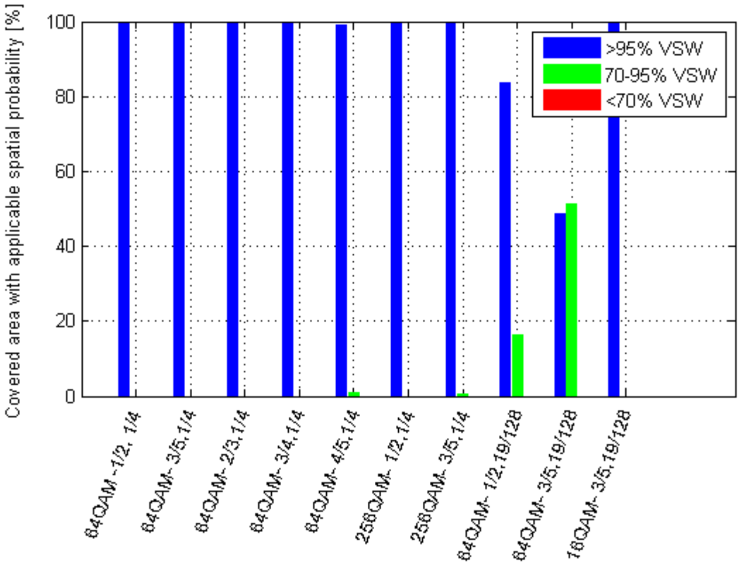

Figure A1.7: Percentage of covered locations in the very large SFN (720 km x 720 km) for 9 DVB-T2 variants and portable reception ordered according to three location probability classes

Furthermore, the influence of the inter-transmitter distance ISD on the SFN performance is shortly investigated. As an example the DVB-T2 mode with 64-QAM modulation, 3/5 code rate and 19/128 guard interval is studied for the mobile reception mode and the large SFN. **Table A1.4** shows how the coverage changes if the inter-site distance decreases from 60 km to 50 km.

Table A1.4: The coverage for a specific DVB-T2 mode with different inter-site distances

DVB-T2 mode 64-QAM-3/5, 19/128	>98.5 % VSW	95 - 98.5% VSW	70 - 95% VSW	<70% VSW
ISD = 60 km	7.4%	8.1%	59%	23%
ISD = 50 km	13.7%	12.9%	71.2%	2.12%

As can be expected, the negative effect of self-interference reduces. In the range of >95% location probability the improvement of 5 to 6 percentage points is observed. Most prominent is the improvement with regard to the 70% level. However, the changes in the higher location probability range are not very large. The results for ISD = 60 km may therefore be regarded as representative, at least for the situation in Germany where the typical main transmitter distance is between 50 km and 60 km, sometimes even beyond that.

A further aspect has to be taken into account. The diameter of the network with ISD = 50 km is smaller which already decreases self-interference for geometrical reasons. An enlargement of the SFN to the former size of 360 km (or 400 km, to remain within the model of hexagon rings) would reduce the above improvement in performance to some extent.

A1.5 Minimum required guard interval for various inter-site distances and C/N values

In this section the relation of guard interval, transmitter site density and robustness (C/N value) is investigated in more detail. The minimum required guard interval to cover an area with different C/N values is examined.

The area is a hexagon with a diameter of 360 km. The effective antenna height is 300 m and 50 kW is the effective radiated power. Full area coverage is required with a location probability of 98.5% for a non-directional receiving antenna at 1.5 m height. Different from the previous section the number of hexagon rings now varies for each inter-site distance in order to cover the same area within the hexagon with 360 km diameter. In only two exceptional cases of inter-site distances of

40 km and 50 km the diameter of network is 400 km.

The guard intervals are not necessarily chosen from the standard DVB-T2 modes but they are the minimum thresholds which makes the coverage within the hexagon possible. This means the guard interval guarantees 100% coverage with the location probability higher than 98.5%. If the guard interval decreases below this threshold then coverage gaps start to appear.

At a given location, self-interference components appear as soon as the relative delay between SFN signals exceeds the guard interval length. In addition there is a small phase after guard interval, characterized by the so-called cliff-edge-coefficient (CEQ), which takes a fraction of received symbols as useful and a fraction as inter-symbol interference. Now the coverage of a location is fulfilled if the sum of field strengths of the useful part is greater than the sum of the field strengths (plus protection ratio) which causes self-interference. These are the paths which arrive after the guard interval plus CEQ time. The more transmitters fall outside the guard interval, the higher value will result from the summation of the field strengths causing self-interference.

As shown in **Figure A1.8** the guard interval increases as the inter-site distance and the C/N value increase. The figure may be used as guidance when choosing a DVB-T2 mode for a particular coverage scenario. To give an example: A DVB-T2 mode with a C/N of 20 dB (green curve, see **Table A1.2**), operated in an SFN with a typical inter-site distance of 50 km requires a guard interval of at least 425 μs. For a 16k FFT there is only one such guard interval value available which is GI 1/4 (448 μs). Or, as a second example, for a DVB-T2 mode with a C/N of 18 dB and a guard interval of GI 19/128 (266 μs for 16k FFT) a typical transmitter-site distance of about 32 km is required to achieve full area coverage in a large SFN.

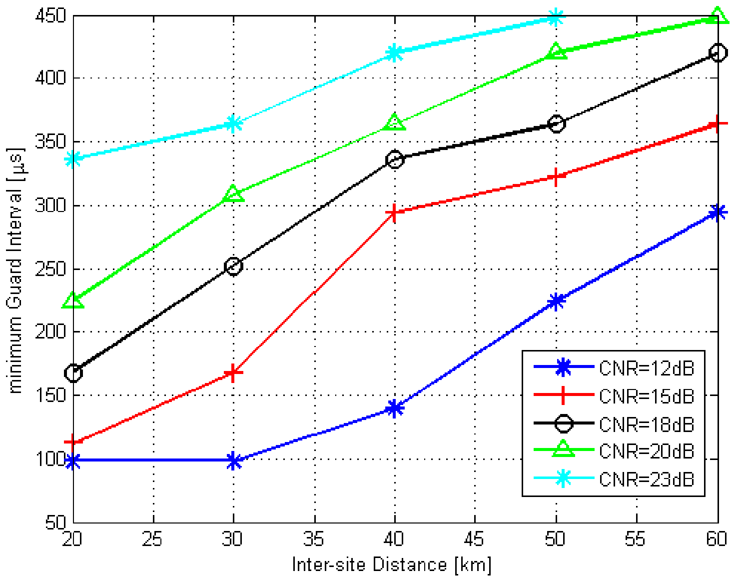

Figure A1.8: Relationship between inter-site distance, robustness (C/N) and minimum guard interval

A1.6 Summary and Conclusions

Theoretical hexagon networks are used in this study to examine the restriction and capabilities of DVB-T2 large SFN. Two cases, a large SFN with a size of 360 km x 360 km and a very large SFN with a size of 720 km x 720 km, are analysed and DVB-T2 modes with the maximum achievable data rate for mobile, portable and fixed reception scenarios are identified.

Additionally the loss of coverage area vs. increasing data rate is discussed. Although the large SFN is already quite extensive, still the additional rings to extent the SFN size affect the performance of the network and impair the reception.

Next the trade-off between higher data rate and less reception quality is examined. With increasing data rate the percentage of covered area decreases. For instance, in the large SFN, 100% coverage with 20.1 Mbit/s for mobile reception could be achieved. Increasing the data rate to 22.4 Mbit/s is possible, but then only 52% of locations are covered with the required location probability (>98.5%) whereas the rest of 48% is (only) covered with 95 - 98.5% probability.

The less demanding parameters for portable reception, as compared to mobile reception, allow for remarkably higher data rates; for instance, for the large SFN up to 30 Mbit/s is possible. This is a large difference which is mainly due to the probably conservative assumptions made for the mobile reception case. As a consequence, there is a need for a more detailed determination of these parameters in order to better model mobile receivers.

Furthermore, it turns out that even for the large SFN, and also for the very large SFN, a guard interval of 448 μs (GI 1/4 for the 16k FFT mode) is required. Smaller GIs cannot fulfil the coverage requirements. Only in the case of portable reception the change to a more robust modulation (from 64-QAM to 16-QAM) allows using a smaller guard interval.

Finally, based on a hexagonal network with the size as of 360 km x 360 km, the relationship between robustness and minimum required guard interval for networks with various inter-site distances is analysed. The results may be used as guidance in the network planning process when choosing a DVB-T2 mode for particular coverage scenarios.

A1.6 References

[A1-1]: ITU-R Rec. P.1546: Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz

[A1-2]: EBU Tech 3348: Frequency and Network Planning Aspects of DVB-T2

[A1-3]: GE06 Agreement: Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)

[A1-4]: ITU-R Rec. BT.419-3: Directivity and polarization discrimination of antennas in the reception of television broadcasting

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Annex A2: Case study on large DVB-T2 SFNs in Denmark

SMR-EDP199

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2012-06-06

Considerations when extending SFNs using DVB-T and DV-T2

A2.1 Introduction

The following document describes a few aspects of SFN planning, in particular when extending the size of an SFN. It also discusses the possibilities to reduce the frequency usage when extending the SFN size. As an example the DTT network in Denmark is used. Currently this DTT network consists of a number of MFNs and regional SFNs using the DVB-T standard. In the examples given all the sites are assumed to be part of a "national" SFN using the DVB-T/T2 standard.

The different SFN considerations are dealt with in separate sections.

It has to be mentioned that this represents a purely theoretical study which does not take into account requirements for local or regional services. Likewise requirements from neighbouring countries are not taken into account.

This study shows that there is generally not any improvement in terms of spectrum efficiency when utilizing large national SFN implemented using DVB-T2. However, there are other benefits of the SFNs in general. One such advantage is in mobile or portable coverage, where contributions from several transmitters at each receiving location will improve and expand coverage.

SFNs also make it relatively easy to add fill-in stations on the same frequency to improve coverage, without any need for re-planning or frequency change.

A2.2 Loss of capacity in an SFN

When introducing a DVB-T/T2 SFN there is a need to use a mode with a longer guard interval compared to the MFN case. In order to create large area SFNs using the DVB-T system the longest guard interval duration of 1/4 (224 μs for 8k mode) is often needed. For the most commonly used DVB-T mode, 64-QAM, R= 2/3, this means that the bitrate is reduced from about 24.1 Mbit/s to 19.9 Mbit/s, going from guard interval fraction 1/32 (28 μs) to 1/4 (224 μs), using the 8k mode. In this case there is a loss of capacity of 20% between the SFN and the MFN case. The result will be that if 5 multiplexes are required using MFNs there is a need for a 6th DVB-T multiplex to compensate for the loss of capacity due to the introduction of the SFNs.

From a spectrum efficiency point of view the use of SFNs should then reduce the overall spectrum requirements by 20% to compensate for this loss of capacity due to the longer guard interval, in order to be able to provide the same total bit rate as in the MFN case.

A2.3 Size of SFN

SFNs require careful planning and if they are made too large in size the transmitters in the SFN will start to interfere with each other, this is called SFN self-interference. It should be pointed out that a guard interval of 224 µs would allow for SFNs with a diameter of up to about perhaps 100 - 150 km, depending on network topology and the terrain. Creation of really large SFNs with diameters of 150 - 400 km may not be possible using the DVB-T system, due to SFN self-interference.

If however DVB-T2 is used, additional guard interval options are available. It will be possible to make SFNs covering larger areas with smaller loss of capacity due to the use of the 32k or 16k modes. For example the DVB-T2 mode 32k 256-QAM R= 3/5 with guard interval fraction 1/8 with a guard interval of 448 µs, or a guard interval fraction of 19/128 with a guard interval of 532 µs.

Using one of these DVB-T2 SFN options will reduce the loss of capacity from 20% (DVB-T) to about 15% (DVB-T2- for GI fraction 19/128) or about 12% (DVB-T2- for GI fraction 1/8). The drawback of using the 32k mode is the lack of mobile reception.

A2.4 Limitation in local/regional programming

One of the drawbacks of using large (national) SFNs is that it is not possible to introduce regional or local programmes. The programmes need to be identical for all of the transmitters in the SFN. If not the transmitters will interfere with each other. An important strength of terrestrial transmission is the possibility to provide local or regional programmes, at least part of the time, for example during advertisement. In many countries one of the main areas of growth for terrestrial TV is considered to be in regional or local transmission, where, for example, satellite delivery has difficulty to compete.

A2.5 Large (national) SFN, example of Denmark

In order to highlight some of the considerations related to SFN planning. A few planning examples are given below.

As an example the DR digital TV network in Denmark will be used. The network consists of 47 transmitters; 18 main transmitters and 29 smaller transmitters. Currently the network consists of mainly regional SFNs with a typical diameter of up to 150 km, and in a few cases with a diameter up to 165 km.

Figure A2.1 shows the predicted coverage using rooftop antennas when the DTT network is turned into a national SFN (except for the island of Bornholm) using DVB-T with the mode 64-QAM R=2/3 and GI= 1/4 (224 µs), which results in a bit rate of 19.9 Mbit/s [14]. It is clear that this SFN will not work. Coverage will be very limited. Only 37% of the population is served, while for the existing DVB-T network using a combination of MFN and regional SFNs, the population coverage is 99.7%. The network is too large to work well as an SFN using the DVB-T standard. Areas indicated in red in **Figure A2.2** will have limitations due to SFN self-interference.

If, however, we use the DVB-T2 standard (**Figure A2.3**) with the mode 256-QAM, Code rate 3/5, GI= 1/8 (448 µs), the predicted coverage becomes much better. The estimated population coverage is about 97.0% This DVB-T2 mode has a C/N value very close to the DVB-T mode used in **Figure A2.1** and gives a bit rate of 29.9 Mbit/s. In **Figure A2.4** we see the potential areas where self-interference may occur. It is clear that there are still some areas where problems may appear, even when using this very long guard interval. Subsequently, about 2.5% of population may be affected by self-interference.

[14] This mode is also used in the present network.

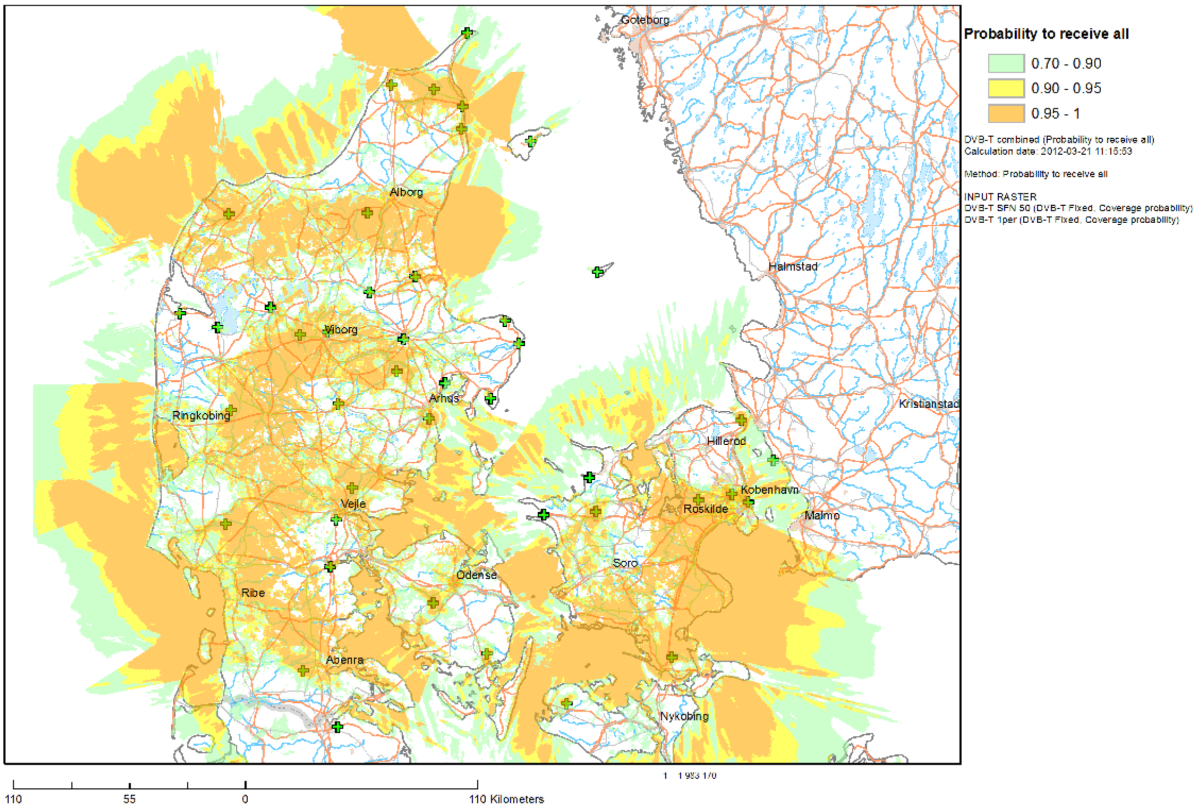

Figure A2.1: DVB-T National SFN 64-QAM R = 2/3 TG 1/4 (224 µs)

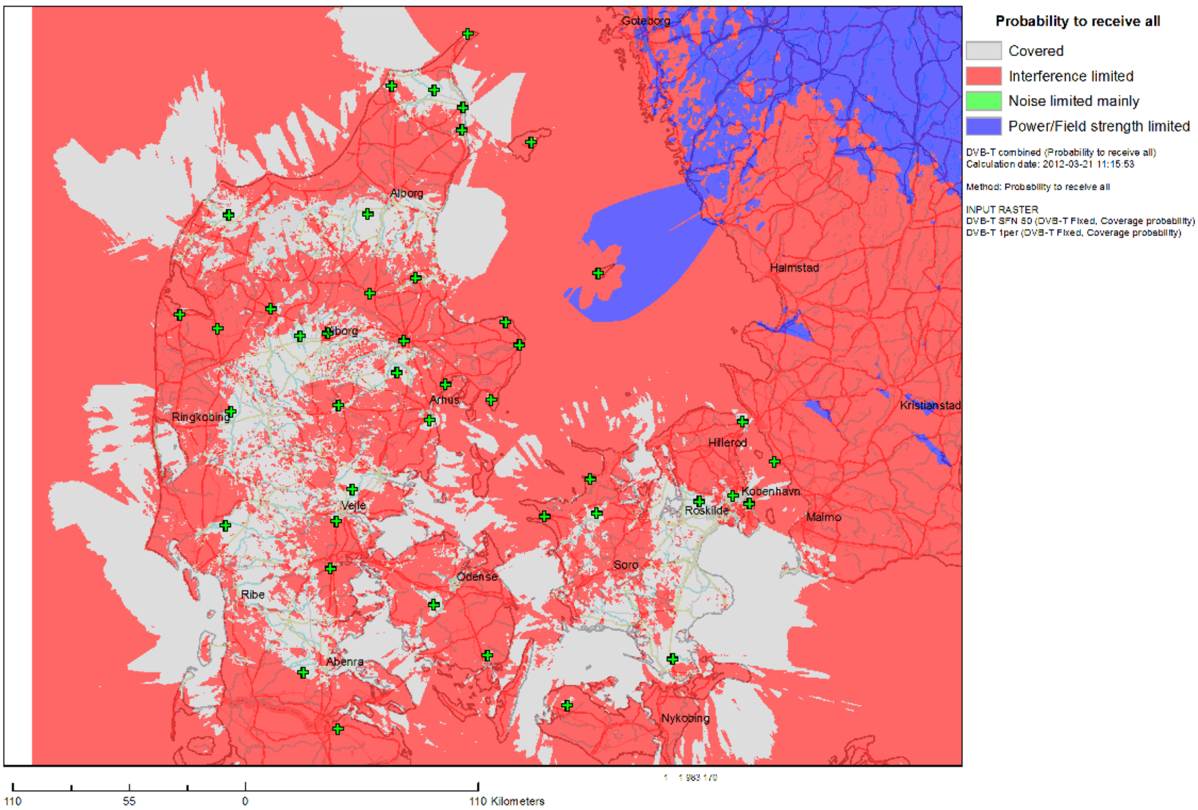

Figure A2.2: DVB-T National SFN 64-QAM R = 2/3 TG 1/4 (224 µs) Self Interference

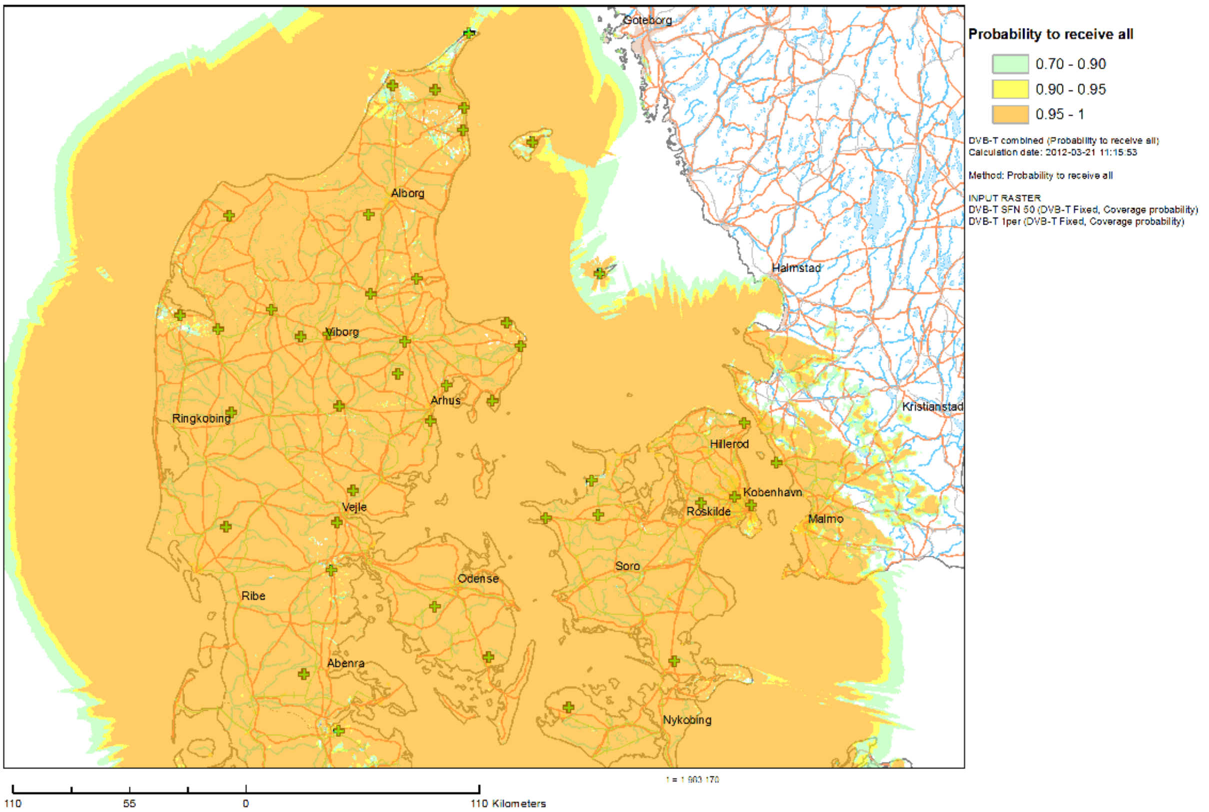

Figure A2.3: DVB-T2 National SFN 256-QAM R = 3/5 TG 1/8 (448 µs) Fixed Reception

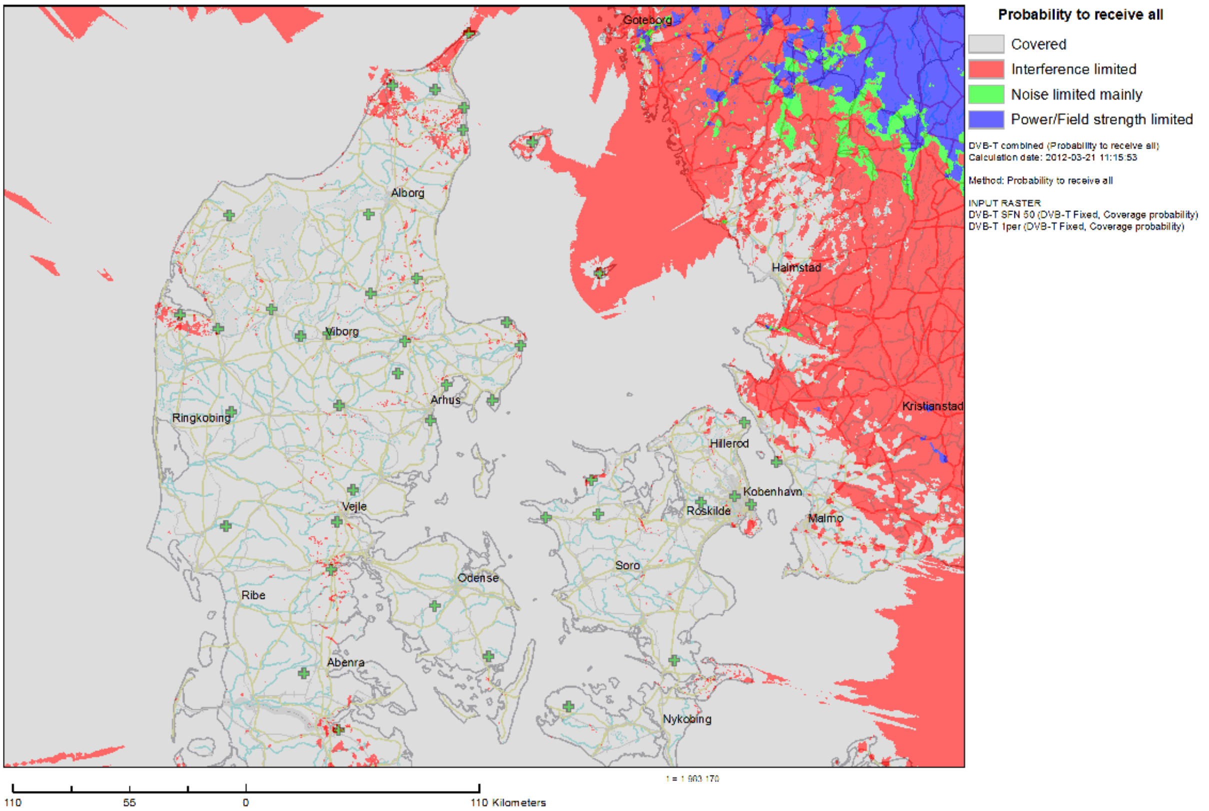

Figure A2.4: DVB-T2 National SFN 256-QAM R = 3/5 TG 1/8 (448 µs) Self Interference

If we now try to cure this self-interference problem by extending the guard interval to 19/128 (532 µs) we can see that the problem is only slightly smaller (**Figure A2.5**). Potential self-interference areas are shown in **Figure A2.6**. The population coverage is now 97.1%. Using this mode the bit rate will be about 29.4 Mbit/s.

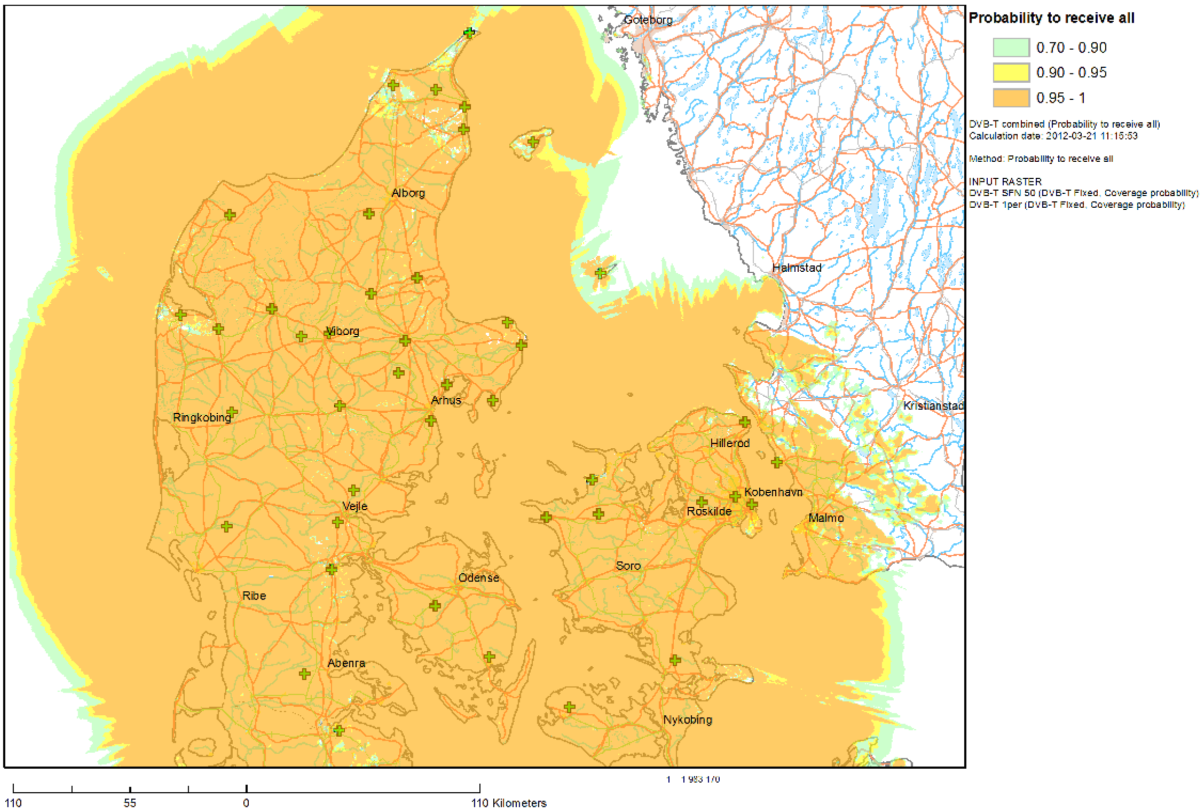

Figure A2.5: DVB-T2 National SFN 256-QAM R = 3/5 TG 19/128 (532 µs)

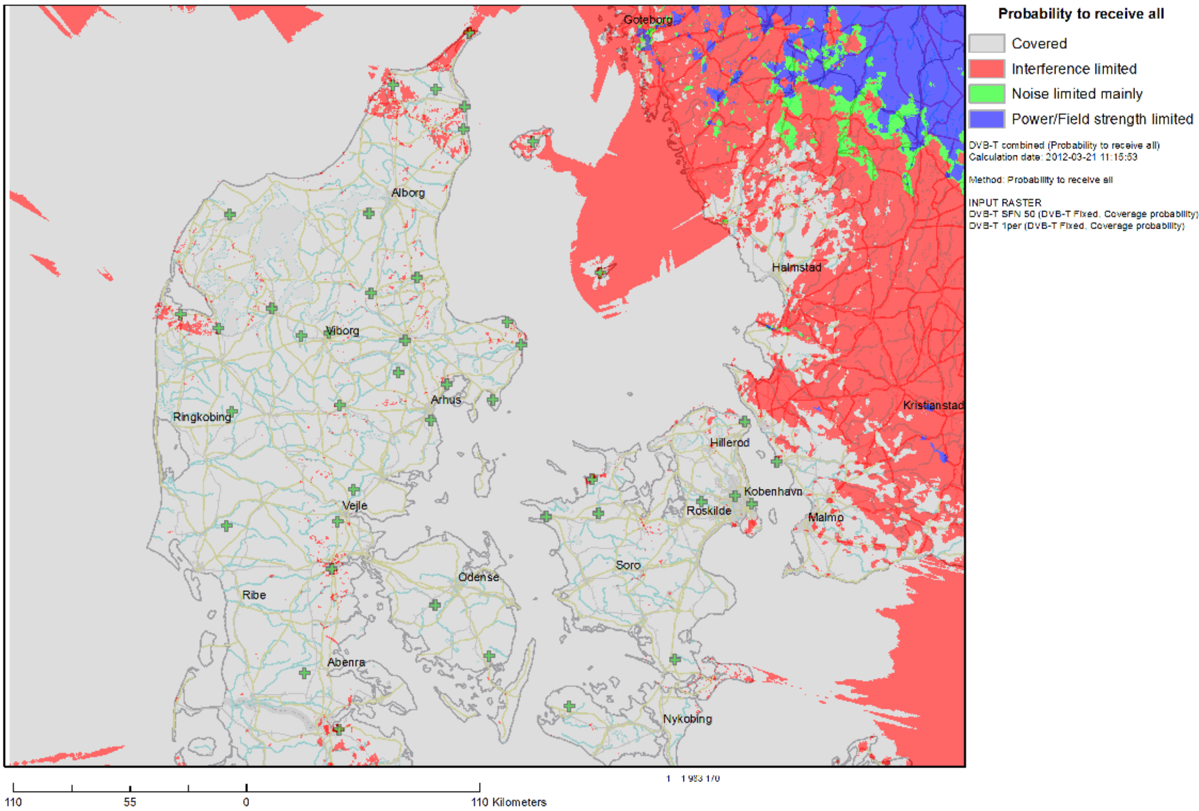

Figure A2.6: DVB-T2 National SFN 256-QAM R = 3/5 TG 19/128 (532 µs) Self Interference

So from these simulations the conclusion drawn is that even when using DVB-T2 it may be difficult to make a very large national SFN. In the case of Denmark the situation is special since there are sea paths between the different Danish islands that will lead to good long-distance propagation (in particular) for lower percentages of time, which may create SFN self-interference from time to time. Even if extra gap-fillers might be able to fill some of the areas without coverage it is also clear that a large number of pixels suffering from self-interference are spread across the country and cannot easily be covered by extra gap fillers.

In smaller regional SFNs it is generally possible to optimize coverage by using, for example, delays on certain transmitters and directional transmitting antennas. However, in an SFN network of this size, and with this number of transmitters it is generally difficult to completely eliminate the SFN self-interference without substantial investments in additional infrastructure. The result of, for example, adding a time delay on some transmitters would be that the zones of self-interference are moved to other places instead.

One remaining possibility would be to use a more robust DVB-T2-mode; it would however result in further loss of capacity. **Figure A2.7** shows the result of a simulation using the DVB-T2 mode 64-QAM R=3/5 and GI-fraction 19/128 (532 µs). Population coverage is just below 99%, indicating that there are still some small areas where self-interference may occur (**Figure A2.8**). The system variant has a C/N of about 15 dB and a capacity of 21.8 Mbit/s. In other words this mode will more or less have the same capacity as the DVB-T network which is currently in operation! This means that capacity in each multiplex is unchanged when moving from DVB-T to DVB-T2.

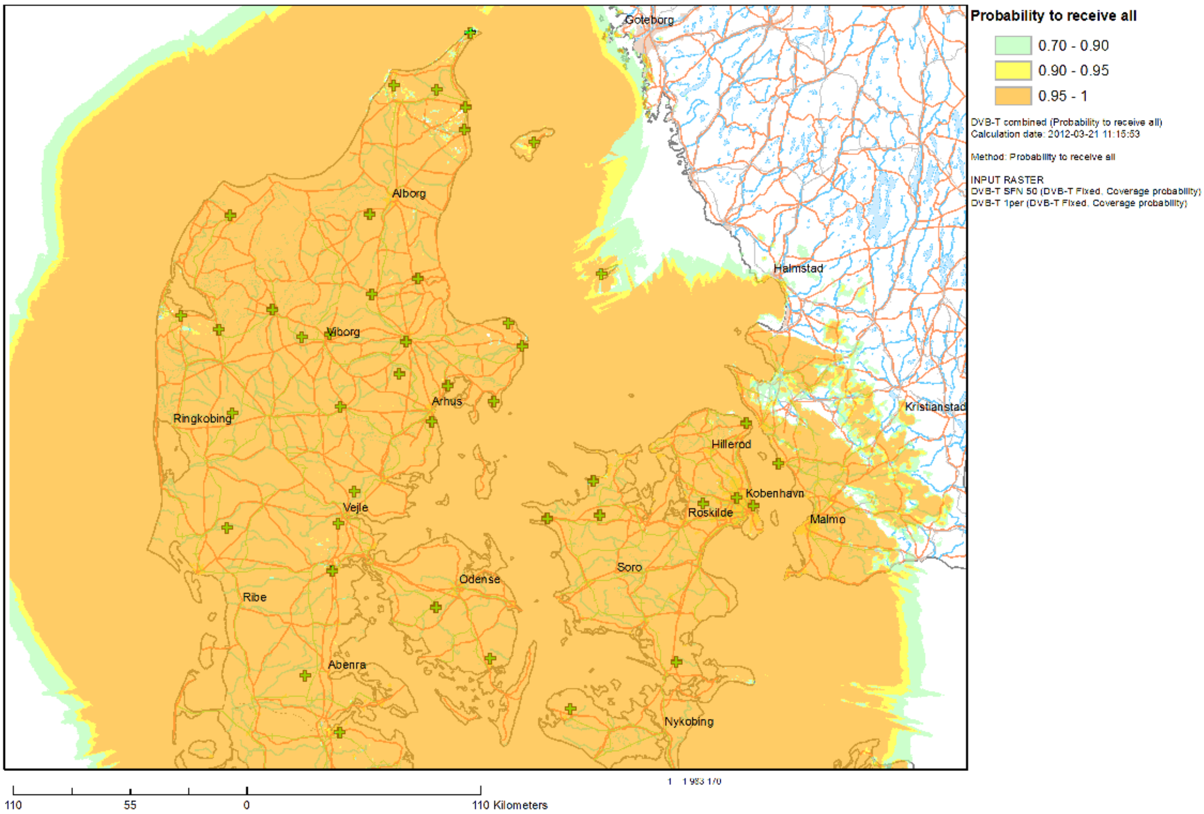

Figure A2.7: DVB-T2 National SFN 64-QAM R = 3/5 TG 19/128 (532 µs)

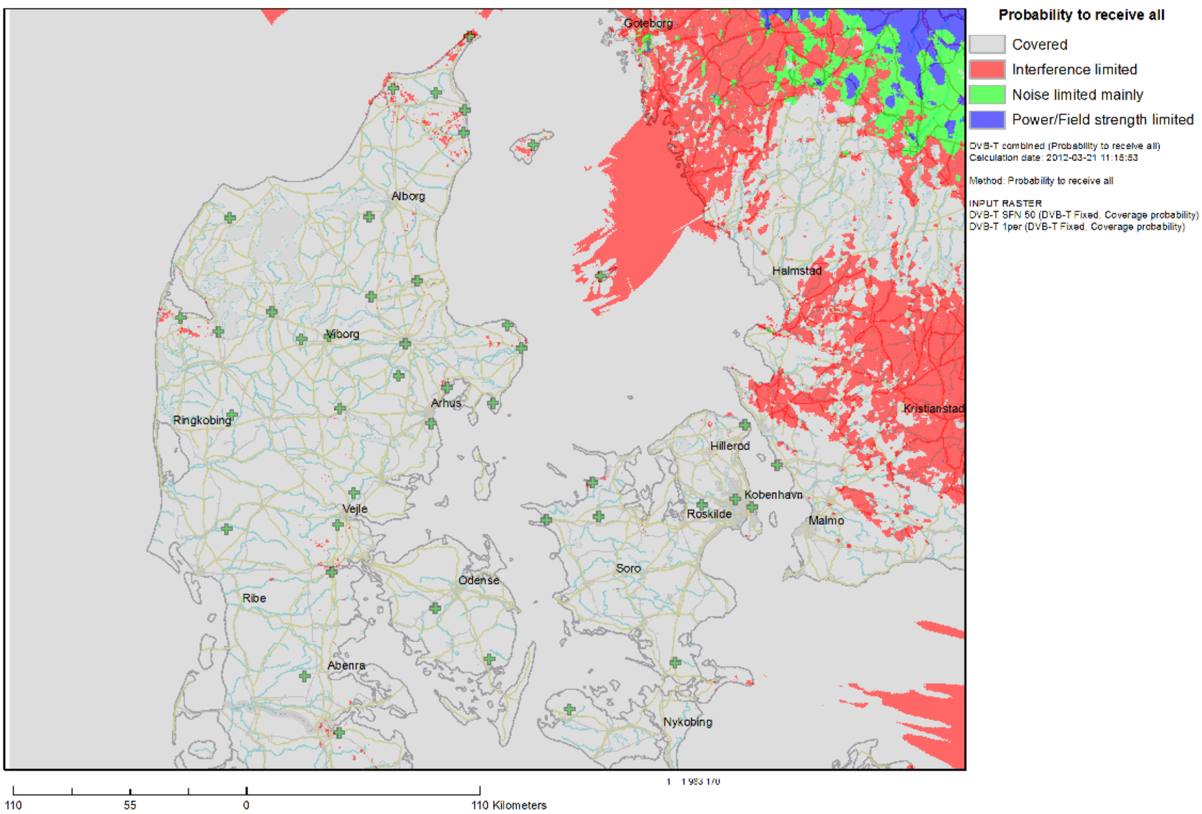

Figure A2.8: DVB-T2 National SFN 64-QAM R = 3/5 TG 19/128 (532 µs) Self Interference

A2.6 How do spectrum requirements change with larger SFNs?

The final question to be answered is if large area SFNs will reduce the number of frequencies needed to complete a coverage layer. There are a few studies made on this subject.

The potential improvements of using an SFN in terms of spectrum efficiency has been studied in EBU TR 023 in terms of the number of frequencies needed to complete one coverage layer. There are a few main factors which determine this, such as:

1. The outgoing interference from SFN network into other adjacent areas (SFNs); This determines the reuse distance of frequencies. It will be possible to reduce the outgoing interference from an SFN if more sites using lower power are used. This would result in a lower reuse distance, which may improve the spectrum efficiency. Extending the infrastructure will of course lead to a large increase of network cost. In such cases it is probably more efficient to use regional SFNs where the coverage area can be tailored to fit the desired geographical coverage area. It will then be easier to find a frequency that can be used on a local or regional basis.

2. The reception mode; A network designed for fixed rooftop antenna reception will need a shorter reuse distance, since the antenna directivity will reduce (discriminate) the interference. For mobile and portable reception, omnidirectional antennas are normally considered which also receive more interference.

3. The robustness of the DVB-T or T2 system variant; As we have seen in the given examples a more robust mode will reduce the impact of interference, but will also of course reduce the capacity in each multiplex.

Table 5 From EBU TR 023

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

The above table gives theoretical numbers on needed channel to complete one coverage layer, in the case of rooftop reception. By equivalent number of channels the capacity of the used DVB-T mode is also taken into consideration.

It can be seen the theoretically there is a need for 3 RF channels in order to complete one coverage layer. These simulations are however based upon hexagon shaped areas. It is clear that countries are normally not hexagon shaped! If we, for example, consider the national SFN in Denmark it will be clear that it will not be possible to use the same frequency in a large part of Norway, Sweden, and Germany, with additional restrictions in part of the Netherlands and Poland as well This would result in that at least 4 - 5 frequencies are needed to create one coverage layer.

If neighbouring countries have different reception mode requirements this will increase the number of frequencies required for each layer.

Comparing this Spectrum efficiency it is not substantially different from the figures we would get when using MFNs, for example, as seen in the UK. This example is based upon rooftop reception.

Annex A3: Case study on DVB-T2 service areas in Sweden

SMR-EDP260

Lovisa Höglund

TERACOM

Large SFN areas for DVB-T2

A3.1 Introduction

This document compares the interference-limited population coverage in Sweden using a national SFN (single frequency) and a number of regional SFNs (a total of four frequencies). In both cases DVB-T2 is used with the same transmission mode.

In the regional SFN case, the maximum distance between any of the larger stations within each SFN area is within the size of the guard interval. However, in some cases there are smaller stations that do not fulfil this.

The study is limited to Sweden, without any considerations of neighbouring countries. This document should not be considered as a proposal but only as an example.

A3.2 Parameters

The DVB-T2 transmission parameters were chosen to maximize the guard interval, while still allowing a reasonably high bit rate (36 Mbit/s). The mode used is 32k, 256-QAM, R=3/4 with guard interval fraction 19/128, allowing a guard interval of 532 µs. This corresponds to a maximum theoretical transmitter distance of 160 km without self-interference.

The assumed infrastructure consists of the existing 54 main stations in Sweden with existing ERP levels and antenna heights. Most stations have an antenna height of approximately 300 m and ERP of 50 kW, although some are smaller and with lower power. In **Figure A3.1** the two types of stations are indicated with different symbols.

A3.3 Network planning

The national SFN coverage was calculated taking into account only self-interference. It was assumed that the reuse distance was large and that the interference was negligible from the next co-channel area.

The 4-frequency network was designed with all larger stations inside the guard interval. Coverage was calculated taking into account self-interference within each area, where applicable, and co-channel interference from the stations of the closest co-channel areas.

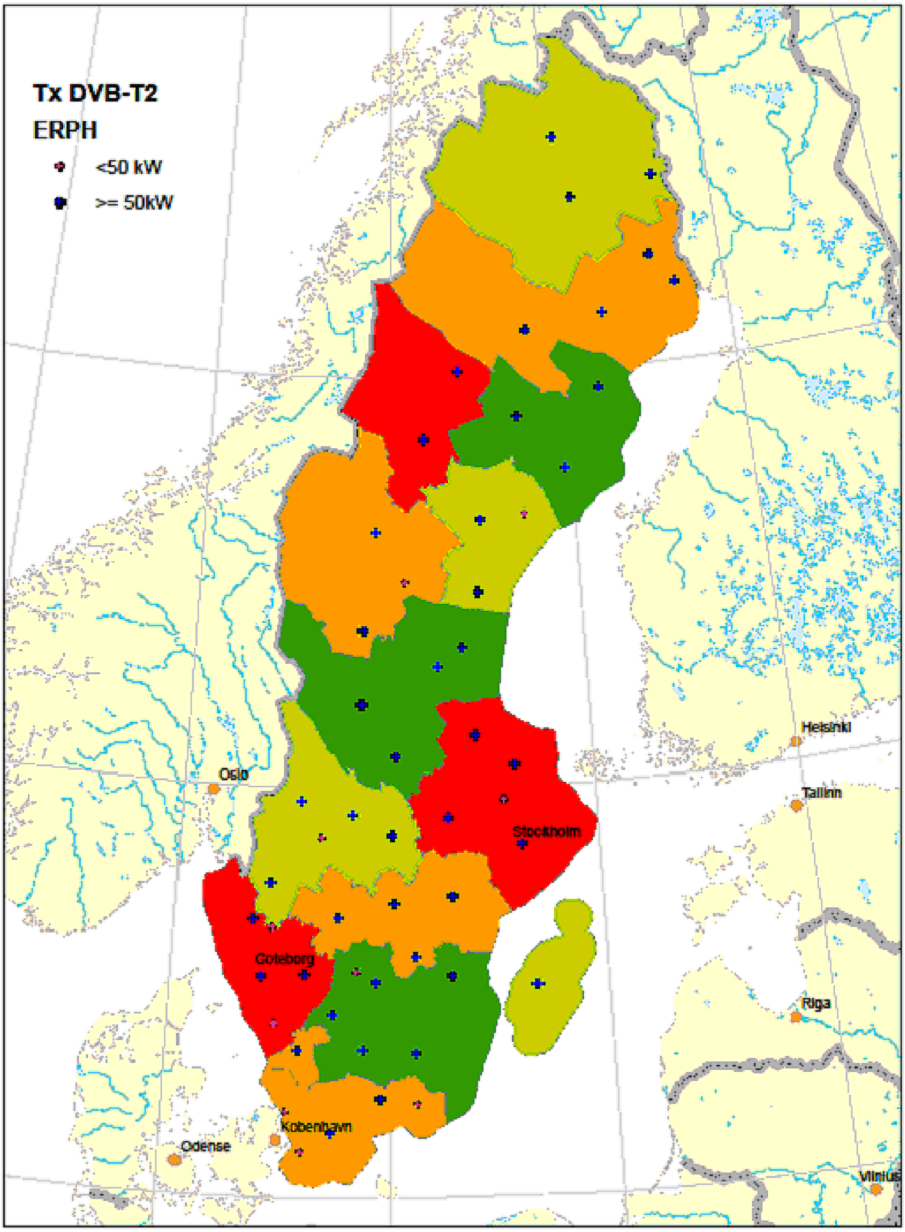

Figure A3.1: 4-Frequency Network in Sweden

A3.4 Population coverage calculation

The interference-limited (i.e. no noise) population coverage was calculated for fixed reception with 95% of locations and with a pixel resolution of 200 x 200 m^2 per pixel. The wanted field strength was calculated for 50% of time and the interference (self-interference and co-channel interference) for 1% of time in all cases.

	National SFN	4-frequency SFN Areas
Population coverage	89.1%	95.4%

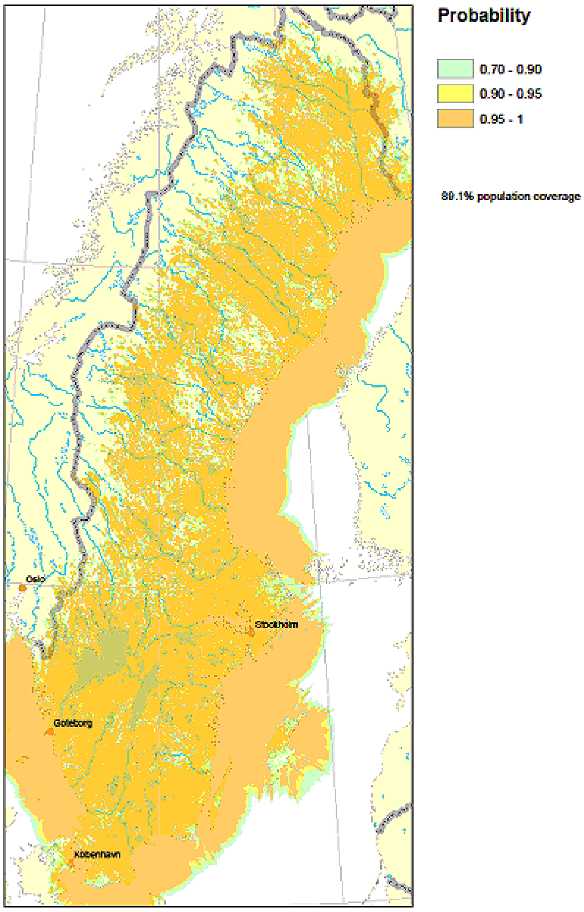

Figure A3.2: National SFN frequency plan, 256-QAM R=3/4 TG=19/128 (532 µs)

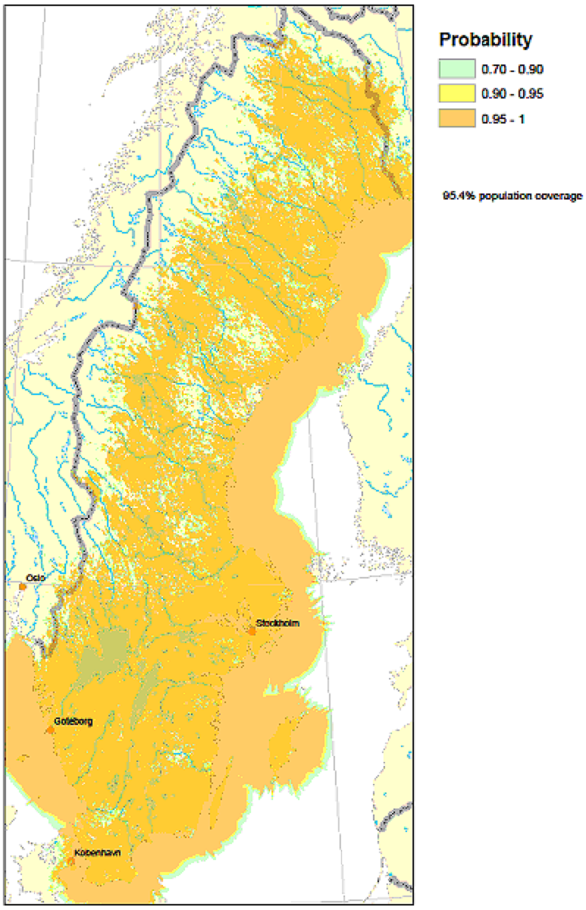

Figure A3.3: 4- frequency plan, 256-QAM R=3/4 TG=19/128 (532 µs)

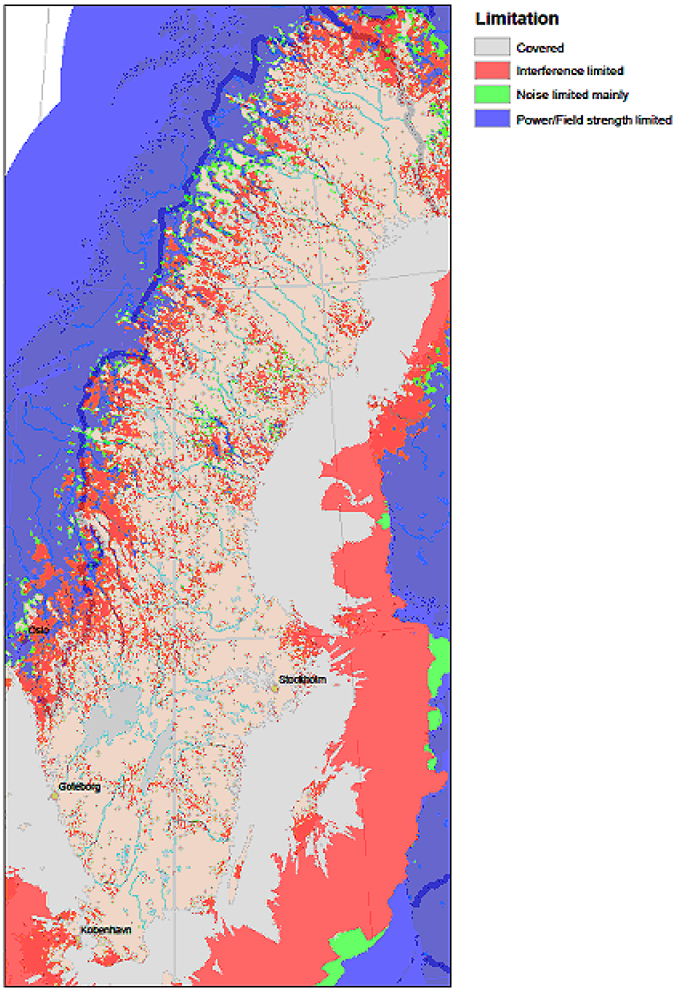

Figure A3.4: Self-interference National SFN

A3.5 Discussion

From the results it is clear that the interference-limited coverage is significantly worse using a national SFN compared to regional SFNs the sizes of which roughly match the size of the guard interval, which is feasible with DVB-T2.

The explanation for this is that the closest self-interfering transmitters of the national SFN appear at a much shorter distance than the closest co-channel interfering transmitters of the regional SFN.

It is a widely held belief that the spectral efficiency increases with the size of the SFN and that large SFNs covering an entire country, like e.g. Sweden, would be more spectral efficient than using smaller SFNs.

It should however be noted that an international frequency plan of large (e.g. national) SFNs will also require a frequency reuse, which may be of the same order as that of the regional SFNs, i.e. at least 4 frequencies (probably some areas will need to use more).

A large SFN with signals outside guard interval is also complex to plan and may require the introduction of additional stations to compensate for coverage loss due to self-interference. In fact a national SFN will, for some countries, suffer from very difficult self-interference which may be difficult to cure and will also have severe limitations in regional programming, if feasible at all without excessive overhead due to simulcasting. The strongest interferers in the national SFN example network appear at distances around 200 km, i.e. just outside the guard interval and arrive from all directions.

A regional SFN with areas in the size of the chosen guard interval can in DVB-T2 be efficiently planned considering frequencies, with no or limited self-interference. Compared to the national

SFN the regional SFN areas offer much better possibilities for regional programming, although still with significant limitations compared to a pure MFN (or hybrid MFN/SFN with small SFN areas such as the current DTT network in Sweden). The largest interferers in the four-frequency example are co-channel interferers at the distance of about 330 km, which can be compared with the 200 km figure for the national SFN.

To get a fair comparison between the two approaches (national and regional SFNs) the networks should in principle be expanded to include a wider area so that interference from reuse areas is accounted for properly in both cases. For the regional SFN case such a wider area should at least include neighbouring countries. It is expected that especially the regional SFN approach would suffer from more harmful interference in this case, but further studies are needed to assess the effects of this. In any case the regional SFN approach, with a 4-frequency reuse, looks promising in that it could potentially require a similar number of "global" frequencies (frequency reuse factor) while at the same time offer better interference-limited coverage and better possibilities for regional programming.

It should also be stressed that the robustness of the used mode also affects the interference-free coverage. One way to increase the interference-limited coverage of the national SFN could be to use e.g. a lower code rate. This would make reception more robust against interference, and therefore somewhat increase coverage, but would of course also reduce the capacity correspondingly. If the regional SFN approach would require slightly more frequencies for an international plan this may be compensated for by a higher capacity per multiplex, for the same interference-limited coverage in the two cases. The advantage of better possibilities for regional programming would still benefit the regional SFN case.

A3.6 Conclusions

Covering Sweden with regional SFNs in a 4-frequency network provides significantly higher interference-limited coverage than a national SFN, although the expected number of frequencies to cover a larger area is likely to be in the same order. More studies are however needed to assess this.

For the same degree of interference-limited coverage the regional SFN approach, which reduces/avoids self-interference within each region, may use a higher capacity mode which may lead to higher total capacity with this approach within a given spectrum.

The regional SFN approach also provides far better - although by no means perfect - possibilities for regional programming.

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Annex A4: Case study on DVB-T2 MFN vs. SFN in the UK

Simon Elliot SMR-EDP261

April 2013 BBC

MFN vs SFN Efficiency

A4.1 Introduction

A persistent question is whether an SFN is more efficient than an MFN. The usual way to respond is to compare the spectral efficiency (Mbit/s/Hz) of one network with the other. However, to do so it is necessary to determine how many frequency channels would be required for the two different network configurations, and this is usually the contentious part. Nevertheless this note attempts to answer the question by considering a range of scenarios - the typical high medium and low cases.

This note also considers the spectral efficiency in terms of programmes per multiplex in order to determine whether practical considerations such as statistical multiplexing would yield an efficiency figure that differs from the standard measure of Mbit/s/Hz.

A4.2 Background

The Building Blocks may be used to determine the number of frequency channels that would be necessary to provide a particular coverage and capacity given various network configurations. Importantly the methodology of the Building Blocks applied equally ideal conditions for each considered case, which makes it possible to directly compare one scenario with another. Broadly, the building blocks concluded the following for DVB-T2 broadcasting networks:

- Six frequency channels would provide 98.5% coverage at 40.2 Mbit/s in an MFN
- Five frequency channels would provide 98.5% coverage at 38 Mbit/s in a regional SFN
- A national SFN providing 98.5% coverage would be capable of delivering up to 33 Mbit/s

It has been assumed that the results of the building blocks for MFNs and regional SFNs could be extended over the entirety of Europe. Although it is not known whether this assumption would, in the end, prove correct, it has been assumed to be true in this note as it appears reasonable in the first instance. Similarly, although National SFNs were included in the Building Blocks the planning area under consideration was not wide enough for a useful outcome to be obtained. For example the building blocks indicate that four frequency channels would be no more beneficial than three. Should the study have been undertaken over a wider area it is expected that more frequency channels would have been found to be necessary, as discussed below.

For an SFN the simplest assumption to make is that four-colour map theory would apply and that it would be possible to cover the entire planning area with four frequency channels. In practice it is likely at least one additional frequency channel would be required in certain 'hot-spot' areas, and therefore over the entire planning area. However, for the purposes of this study four has been assumed sufficient as a starting point though it is noted that SFNs may therefore be assessed favourably in this document.

As mentioned in the summary, two methods of assessing the networks' efficiency have been adopted in this note. They are:

1) Raw payload per frequency channel (Mbit/s/frequency channel)

2) TV programmes per channel (programmes/frequency channel)

Method 1) is the usual way of assessing efficiency and is straightforward. It makes no assumptions about what services could be transmitted in the multiplex - it simply looks at the payload that would be available in equivalent SFN and MFN networks and normalises it with respect to the number of frequency channels that would be required to deliver the payload in each network configuration.

Method 2) looks at efficiency in a more practical way. It considers efficiency in terms of the number of TV programmes that might be deliverable in a multiplex before normalising the result with respect to the required frequency channels. This approach takes into account statistical multiplexing gains as they are often mentioned as an important factor in determining multiplex efficiency. However, as picture quality is subjective, precise bitrate per programme requirements cannot be determined, and guideline values must be used. To overcome the need for a subjective judgement, three picture quality cases: a high, medium and low have been considered in order to gauge how sensitive efficiency may be to particular picture quality choices. EBU TR 015 has been used as the source of the guideline figures for HD and SD MPEG-4 compression.

A4.3 Discussion

A4.3.1 Method 1

The results of Method 1 are set out in **Table A4.1**, which shows a National SFN to be approximately 25% more efficient than an MFN. However, the efficiency would come at the price of regionality, which is an important factor in broadcast networks. Whether the modest efficiency gain would be worthwhile at the high cost of sacrificed regionality is therefore questionable.

To maintain regionality a regional SFN could be adopted. The Regional SFN is shown to be some 10% more efficient than the MFN and some 15% less efficient than a full national SFN. As such it may be a suitable middle ground between the MFN and full SFN.

Table A4.1: DVB-T2 Network Efficiencies

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	6	5	4
Regionality enabled	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Spectral Efficiency (Mbit/s/ channel)	6.7	7.4	8.35
Efficiency relative to an MFN	-	10%	25%

A4.3.2 Method 2

The results from the assessment of method 2 are summarised separately in this section for SD and HD services as the picture quality heavily influences the number of programmes that can be delivered in a multiplex. All the per programme bitrate requirement figures for various picture qualities and stat-mux gains in this note have been obtained from EBU TR 015.

A4.3.2.1 SD

Table A4.2 shows the total number of SD programmes that it would be possible to carry in each network configuration assuming the application of bitrates of Table A2 in EBU TR 015 were applied as well as the stat-muxing gains in Figure A2 of the same document. The results for SD services closely match those of method 1 in **Table A4.1**, above. However, once again it should be noted that the efficiency of a national SFN would come at the expense of regionality, which may not be worthwhile.

It is worth noting that in this instance all network configurations would allow the carriage of a significant number of services. This means that for one network relative to the other there is no stat-mux gain - a saturated 26% saving is evident for each of the networks.

Table A4.2: Relative Efficiencies for SD

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	6	5	4
Regionality possible	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Base bitrate per SD programme	2.65	2.65	2.65
Stat-mux gain (%)	26	26	26
Effective bitrate per programme in stat-mux	1.96	1.96	1.96
Potential programmes per stat-mux	20	18	17
Unused capacity (Mbit/s)	1.0	1.7	0.1
Total programmes per frequency channel	3.3	3.6	4.3
Efficiency relative to an MFN	-	8%	28%

EBU TR 015 provides only a single bitrate requirement per programme for SD services - no indication is provided regarding higher and lower quality SD services. Therefore in order to gauge the sensitivity of spectrum efficiency to picture quality the above assessment has been repeated assuming both 0.5 Mbit/s more per programme and 0.5 Mbit/s less would be required. The results are shown in **Table A4.3**, from which it is clear that the picture quality would have little impact on the efficiency of the network configuration.

Table A4.3: Sensitivity of Spectrum Efficiency to Programme Bit-Rate - Standard Definition.

	MFN	Regional SFN	National SFN
Efficiency relative to an MFN (3.15 Mbit/s/programme)	-	6%	24%
Efficiency relative to an MFN (2.15 Mbit/s/programme)	-	10%	20%

A4.3.2.2 HD

As with SD, the number of programmes that can be transmitted in a multiplex relies on subjective assessment. However fewer HD programmes would fit into a multiplex than SD due to the higher bitrate requirement of HD services. As such the spectrum efficiency of different networks for HD transmission would become more granular and may be more sensitive to particular picture quality choice. Again, to overcome this difficulty three different picture qualities, in the form of the required bitrate per programme, have been considered. This approach will show the sensitivity of efficiency to picture quality.

Table A4.4 summarises the results of **Tables A4.5** to **A4.7** which provide the detailed assessment for the various picture qualities considered. In general, under this analysis, national SFNs remain more efficient than MFNs. However, in the high quality case the benefit is less clear.

Table A4.4: Relative Efficiencies for Various HD Programme Qualities

Programme Quality	Regional SFN	National SFN
HD Programmes per Frequency Channel - High Bitrate per Programme	20%	13%
HD Programmes per Frequency Channel - Medium Bitrate per Programme	20%	20%
HD Programmes per Frequency Channel - Low Bitrate per Programme	0%	25%

Table A4.5: Relative Efficiencies for HD - High Bitrate per Programme

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	6	5	4
Regionality possible	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Base bitrate per SD programme	10.85	10.85	10.85
Stat-mux gain (%)	15	15	12
Effective bitrate per programme in stat-mux	9.22	9.22	9.55
Potential programmes per stat-mux	4	4	3
Unused 'bitrate' (Mbit/s)	3.3	0.1	4.8
Total programmes per frequency channel	0.7	0.8	0.8
Efficiency relative to an MFN	-	20%	13%

Table A4.6: Relative Efficiencies for HD - Medium Bitrate per Programme

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	6	5	4
Regionality possible	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Base bitrate per SD programme	8.35	8.35	8.35
Stat-mux gain (%)	17.5	17.5	15
Effective bitrate per programme in stat-mux	6.89	6.89	7.10
Potential programmes per stat-mux	5	5	4
Unused 'bitrate' (Mbit/s)	5.8	2.6	5.0
Total programmes per frequency channel	0.8	1.0	1.0
Efficiency relative to an MFN	-	20%	20%

Table A4.7: Relative Efficiencies for HD - Low Bitrate per Programme

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	6	5	4
Regionality possible	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Base bitrate per SD programme	7.85	7.85	7.85
Stat-mux gain (%)	19	17.5	17.5
Effective bitrate per programme in stat-mux	6.36	6.48	6.48
Potential programmes per stat-mux	6	5	5
Unused 'bitrate' (Mbit/s)	2.0	4.6	1.0
Total programmes per frequency channel	1.0	1.0	1.3
Efficiency relative to an MFN	-	0%	25%

In some of the scenarios in **Tables A4.5**, **6** and **7**, a significant unused bitrate is evident - for example the MFN in **Table A4.6** has an unused bitrate of 5.8 Mbit/s. This arises because the required bitrate per programme is not an integer divisor of total capacity. In any practical situation it is unlikely that the bitrate would be allowed to lie fallow and the base bitrate per programme would be adjusted slightly to accommodate an additional programme. Such adjustments have been made in **Tables A4.9** and **A4.10** for the low and medium capacity HD cases. In these instances it was possible to reduce the required bit rate per programme by less than 0.3 Mbit/s to obtain an additional programme in some network configurations. This more pragmatic arrangement yields the summary in **Table A4.8** where a national SFN is shown to be up to 25% more efficient than an MFN. It was not possible to undertake a similar adjustment for the high bitrate per programme example as the large bitrate requirements per programme would need too great an adjustment to be considered minor.

Table A4.8: Relative Efficiencies for Various HD Programme Qualities - Pragmatic Approach

Programme Quality	Regional SFN	National SFN
HD Programmes per Frequency Channel - High Bitrate per Programme	20%	13%
HD Programmes per Frequency Channel - Medium Bitrate per Programme	0%	25%
HD Programmes per Frequency Channel - Low Bitrate per Programme	20%	25%

Table A4.9: Relative Efficiencies for HD - Medium Bitrate per Programme

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	6	5	4
Regionality possible	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Base bitrate per SD programme	8.25	8.1	8.05
Stat-mux gain (%)	19	17.5	17.5
Effective bitrate per programme in stat-mux	6.68	6.68	6.64
Potential programmes per stat-mux	6	5	5
Unused 'bitrate' (Mbit/s)	0.1	3.6	0.2
Total programmes per frequency channel	1.0	1.0	1.3
Efficiency relative to an MFN	-	0%	25%

Table A4.10: Relative Efficiencies for HD - Low Bitrate per Programme

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	6	5	4
Regionality possible	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Base bitrate per SD programme	7.85	7.6	7.85
Stat-mux gain (%)	19	19	17.5
Effective bitrate per programme in stat-mux	6.36	6.16	6.48
Potential programmes per stat-mux	6	6	5
Unused 'bitrate' (Mbit/s)	2.0	0.1	1.0
Total programmes per frequency channel	1.0	1.2	1.3
Efficiency relative to an MFN	-	20%	25%

A4.3.2.3 Sensitivity to Frequency Channels Required Per Multiplex

As previously stated, it is unclear whether or not four channels would be sufficient for national SFNs throughout Europe. Bearing that in mind it is informative to consider how sensitive the spectral efficiency may be to the number of required channels. **Table A4.11** shows the Method 1 efficiencies recalculated should an additional channel be required for each network configuration, while **Table A4.12** does the same should only the MFN and Regional SFNs require an additional channel.

Referring to **Table A4.11** it is clear that the relative efficiencies of SFNs would decrease should it be found that each network configuration would require an additional channel. In this case the efficiency of an SFN over and MFN would marginally reduce to approximately 18%. Conversely, **Table A4.12** shows that the relative efficiencies of National SFNs would increase if MFNs and Regional SFNs were found to require an additional channel while four remain adequate for SFNs.

Table A4.11: Method 1 Efficiency Gains Should Each Network Configuration Require an Additional Frequency Channel - Method 1

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	7	6	5
Regionality enabled	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Spectral Efficiency (Mbit/s/channel)	5.7	6.2	6.7
Efficiency relative to an MFN	-	9%	18%

Table A4.12: Method 1 Efficiency Gains Should the MFN and Regional SFN Network Configuration Require an Additional Frequency Channel - Method 1

	MFN	Regional SFN	National SFN
Frequency channels required per multiplex	7	6	4
Regionality enabled	Yes	Yes	No
Capacity of multiplex (Mbit/s)	40.2	37	33.4
Spectral Efficiency (Mbit/s/channel)	5.7	6.2	8.35
Efficiency relative to an MFN	-	9%	46%

A4.4 Summary

Two different methods have been used to assess the relative efficiencies of SFNs. Method 1 is based spectral efficiency measured in Mbit/s/Hz while Method 2 looks at efficiency in terms of programmes that could be delivered per frequency channel. The Builiding Blocks have been used as a base to determine how many frequency channels would be required for a national network comprising of MFN, Regional SFNs and National SFNs.

Method 1 shows SFNs to be some 25% more efficient than a national MFN, and 10% more efficient than a regional SFN.

Method 2 also showed broadly similar results, though as expected there was some slight variation due to the quantising effect that discrete programme numbers have. If, however, a high quality HD programme format is chosen only three or four programmes would be possible per multiplex and the quantising effect becomes more significant which would reduce the efficiency of an SFN in which significant unused capacity would remain.

Method 2 relies on the subjective measure of picture quality which, without study, could be perceived to have the potential to change the efficiency conclusions that are drawn from the method 1 analysis. However, this study looked at various different picture qualities, and although quality influences the outcome to an extent, it is not sufficient enough to change the conclusions, except perhaps for the case of high quality HD pictures mentioned above.

The main factor that influences spectral efficiency is the number of frequency channels required for the different network configurations. As mentioned earlier the Building blocks were used to establish these requirements in the first instance. However, under less ideal circumstances than considered in the Building Blocks, additional channels may be required. To gauge the sensitivity to frequency channel requirements, two additional scenarios were investigated under Method 1. One scenario considered the relative efficiencies should each network configuration require an additional channel. This showed the relative SFN efficiency would reduce to approximately 20% over an MFN. The second showed that if MFNs required an additional channel while SFNs did not, the relative efficiency of an SFN would approach 50% over an MFN.

In all cases it should be noted that the price to pay for the increased efficiency of SFNs would be the loss of regionality. The regional SFN may be a good trade-off between MFNs and full national SFNs as their efficiency generally sits between the MFN and SFN but would allow regionality to be maintained.

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Annex A5: A case study on a national DVB-T SFN and SFN optimization in Italy

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April 2014

The Italian SFN Experience

A5.1 RAI multiplex 2; an example of a very large SFN

RAI multiplex 2 is deployed with a very large 1-SFN. The parameters of the network are: 8k, 64-QAM, guard interval 1/4, code rate 2/3.

Rai Way, the owner of RAI's transmission and broadcasting network, implemented it by using 400 transmitters all over Italy, each broadcasting on the same channel (at the moment the 48 transmitters in Sardinia are broadcasting on a different channel but it is foreseen that they will be re-configured to use the same frequency as the rest of Italy).

The goal of covering more than 90% of the population has been reached and exceeded and a good quality of service is guaranteed almost everywhere.

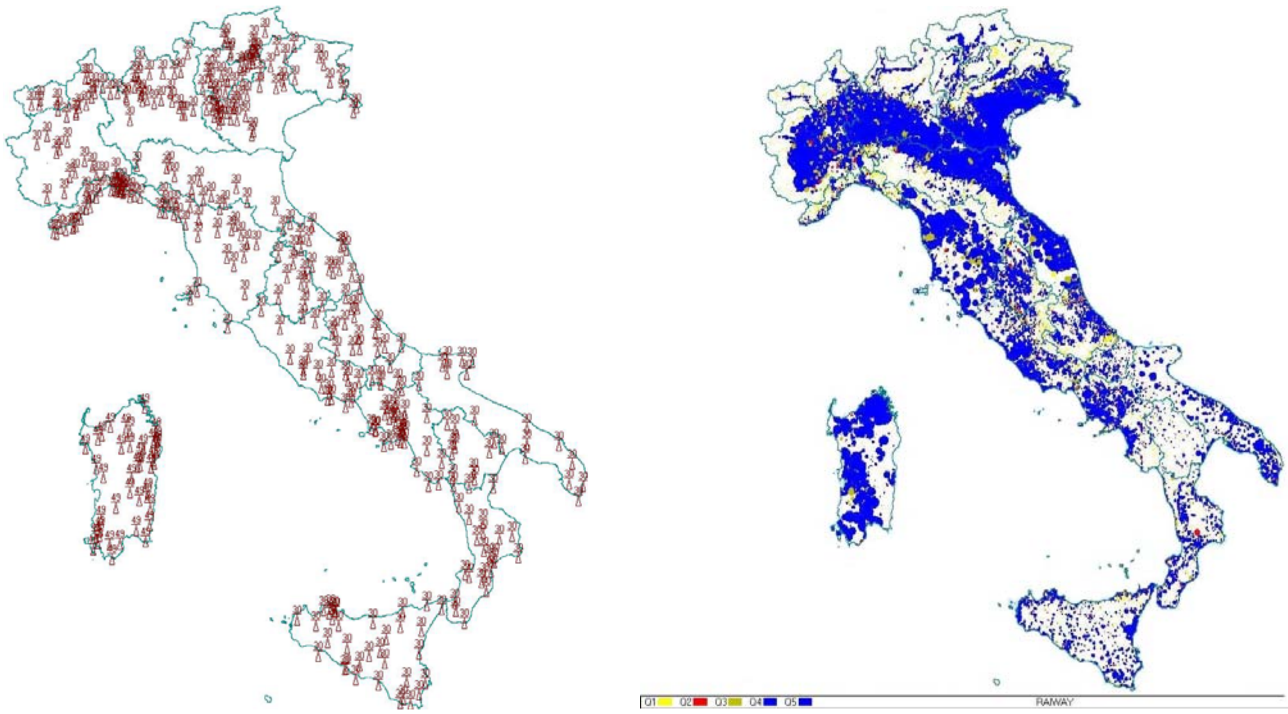


Figure A5.1: RAI multiplex 2: transmitters and map of quality of service

Table A5.1: Transmitter powers

Transmitters' number split into power classes				
	P >1 kW	100 W ≤P ≤1 kW	10 W ≤P ≤99 W	P <10 W
MUX2	22	110	176	92
Transmitters' number split into ERP classes				
	ERP >100 kW	10 kW ≤ERP ≤100 kW	1 kW ≤ ERP <10 kW	ERP < 1 kW
MUX2	4	25	88	283

Considering that ERP of 1 kW (60 dBm) is the LTE BS typical value, it is possible to state that 70% of the transmitting sites in DVB-T 1-SFN can be considered as being of LP type.

The multiplex is comprised of 3 TV programmes and 4 radio programmes.

A5.2 Operating the network

The majority of the work on tuning has been done during the theoretical planning of the network.

The fine tuning of the network required a large amount of time, measures and studies.

Investigating the causes of very short and systematic switching on and off which affected some transmitters, often in the same instant, led to the study of the performance of GPS receivers.

(See Report ITU-R BT.2253 "GPS timing receivers for DVB-T SFN application: 10 MHz phase recovery").

A second class of problem seriously affecting large scale SFNs with FRF = 1 is the considerable number of echoes at the user end. Despite the definition of the network gain, which is applicable only for the field strength, the higher the number of received echoes, the higher is the required C/N.

Rayleigh statistics is assumed for the propagation channel for portable or mobile reception cases and thus the respective C/N value is applied in planning. For fixed reception, basically a Ricean channel is assumed. Also in fixed reception, the channel may become less favourable, especially if artificial echoes, coming from other transmitters of the same SFN, cannot be substantially attenuated by the directional antenna at the receiving point. A smooth transition between the application of the Rice and Rayleigh value to be applied for the C/N, is described by the "effective protection target", EPT.

In this concept, there is a "channel criticality" parameter, K_A defined as the ratio of the power of the main signal compared to the power sum of the artificial echoes. Interpolation between the Rice and the Rayleigh value of C/N depends on this parameter. If the main signal dominates, the Rice statistics is assumed, while if the ratio is balanced, Rayleigh statistics is assumed.

The calculation of the EPT is given by the following formula

$$EPT = C/N\big|_F + \left(C/N\big|_P - C/N\big|_F\right)\left(\frac{0.5}{C/N\big|_P - C/N\big|_F}\right)^{\frac{K_A}{10}}$$

where:

EPT = effective protection target in dB

$C/N|_F$ = C/N for Ricean channel in dB

$C/N|_P$ = C/N for Rayleigh channel in dB

K_A = channel criticality parameter, the ratio of the power of the main signal to the power sum of the active echoes, in dB

If K_A <0 dB, then K_A is set to 0 dB.

A possible implementation margin has been neglected here.

Figure A5.2 shows the values of EPT, depending on the channel criticality parameter for the example with $C/N|_F = 20.4\ \text{dB}$ and $C/N|_F = 26.2\ \text{dB}$.

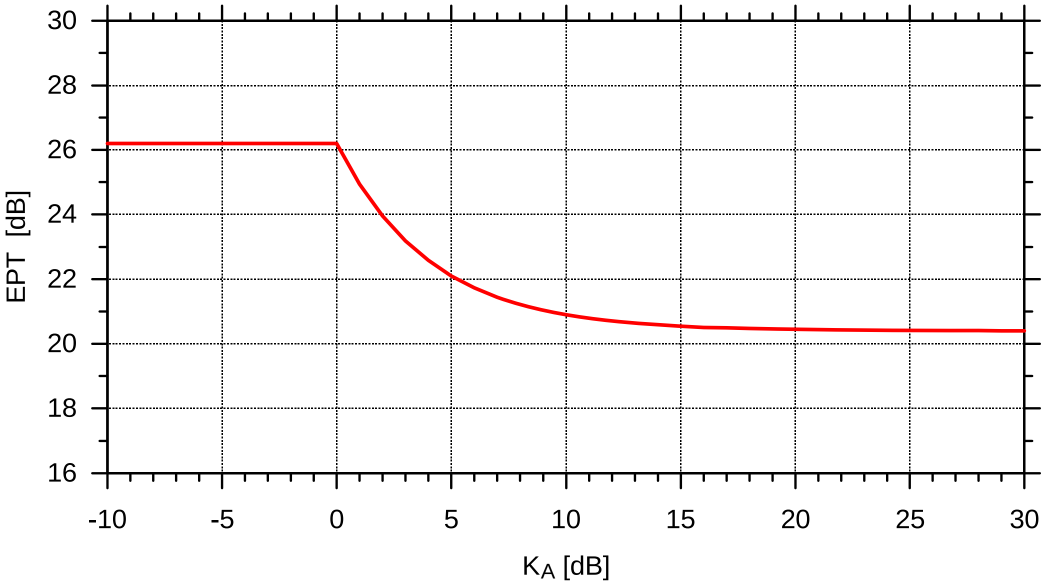


Figure A5.2: EPT as a function of channel criticality parameter, K_A

A5.3 Dealing with Echoes by using Cell ID

As noted earlier, two different kinds of echo, natural and artificial, can be detected.

The first category of echo is originated by reflections or scattering due to nearby obstacles, whilst the second category is originated by other transmitters of the network operating on the same frequency. Propagation effects can further severely complicate reception in areas surrounded by warm sea.

Echoes may fall into the guard interval or outside it; some arrive in advance of the main signal, some after the main signal (see **Figure A5.3**).

The need to accurately deploy and check the behaviour of a large SFN forced Rai Way to use the Cell ID (Cell Identifier) transmission parameter to identify the transmitting site. The use of the Cell ID for the identification of the received transmitter is specified in § 3.1.3.2 of ITU-R Recommendation SM 1875, where it is required that each transmitter belonging to a specific cell should have the same identifier. As described below, Rai Way, after laboratory and field tests, decided to extend the requirement by considering each transmitter as a cell.

The Italian Administration has always strongly supported the use of different Cell IDs in SFN to identify transmitters, and it has invited all Italian broadcasters to use different Cell IDs for each transmitter site (MiSE document "*Richiesta inserimento Cell-Id*" - 14 March 2013 [ ]).

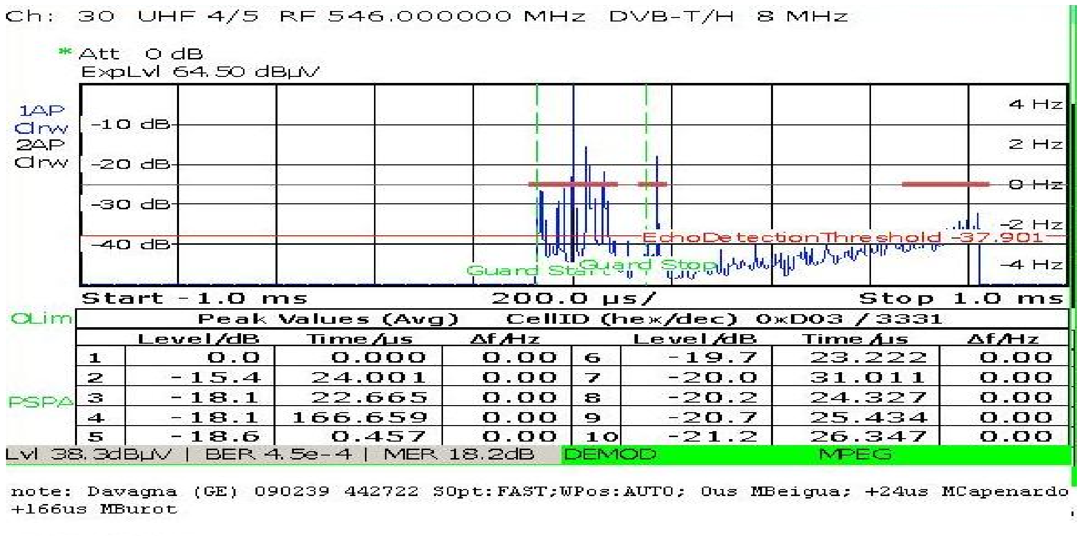


Figure A5.3: Example of echo spread at the receiver end

The adoption of a different Cell ID for each transmitter, in conformity to § 5.2.4 of ETSI TR 101 190 v 1.3.2 (2011-05), simplifies measurements and field monitoring activity without any significant impact on the users' receivers. This option is not widely known, but it is standardized in DVB-T2 with the Future Extension Frames, FEF, that can also be used as Transmitter Signature. They allow measurements to identify which echo in the channel impulse response originates from which transmitter of the SFN.

In a DVB-T SFN, using different Cell IDs, it is possible to identify all the transmitters received at a measuring/monitoring point and to record their Channel Impulse Response (CIR) for further comparative analysis (**Figure A5.4**).

Thanks to this use, Rai Way was able to solve bad reception problems due to propagation and to reflection.

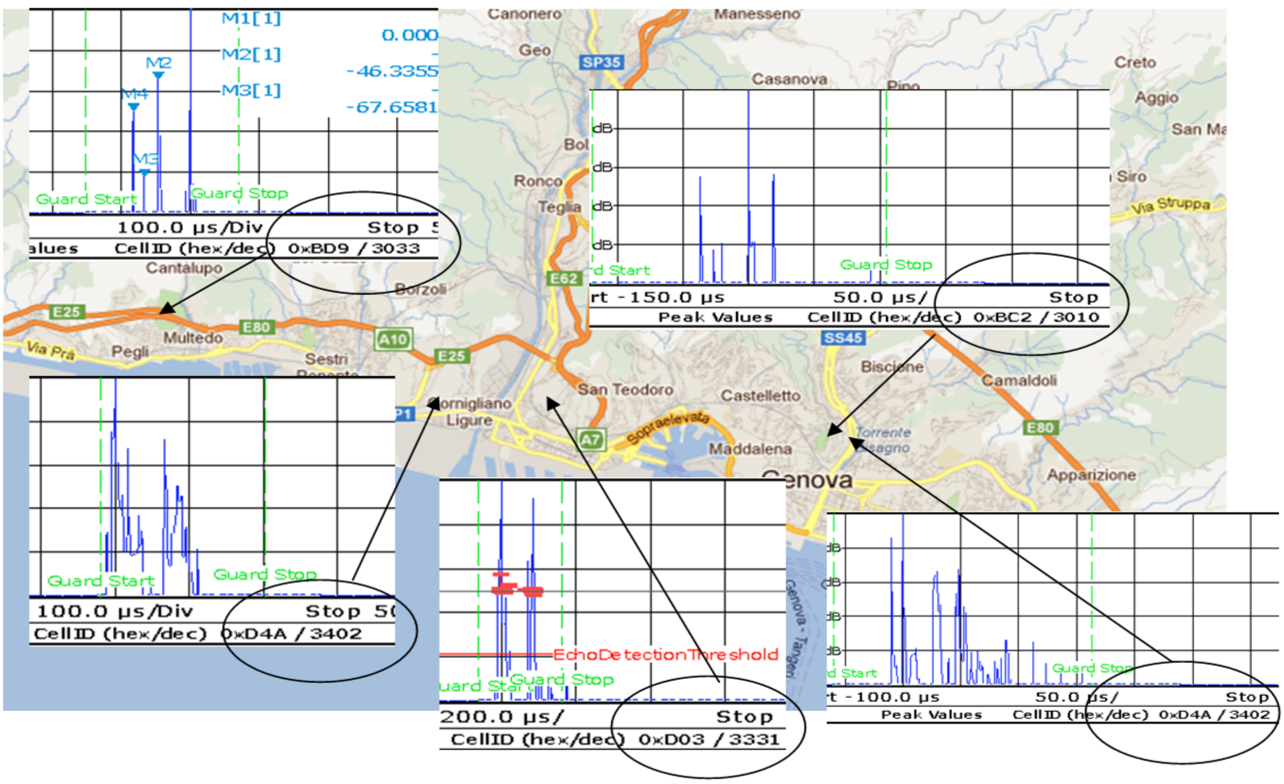


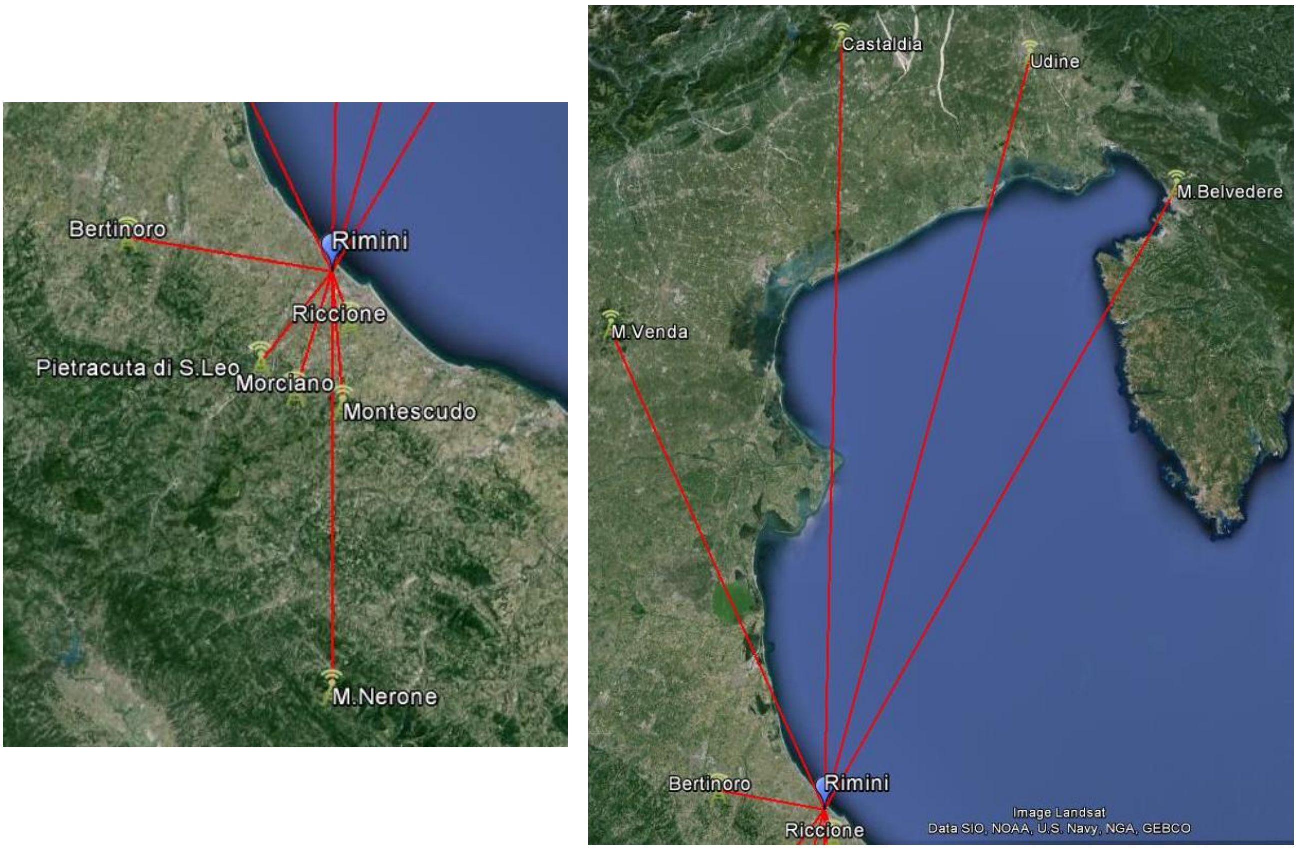
Figure A5.4: Identification of the highest received transmitter through Cell ID

A5.3.1 *Impact of different Cell IDs on end user receivers*

In order to evaluate the impact of the use of different Cell IDs to end users, many surveys on the receivers' behaviour were performed. It is important to emphasize that tests were performed in extremely critical conditions; nevertheless only a few receivers failed to perform adequately. It transpires that no particular problems arise when Cell IDs are different if the length indicator is the same, whereas problems are detected if length indicators are different. This latter situation happens only if the DVB-T transmitters have been configured incorrectly. In a correctly set network this should never happen, because length indicators have to be set identically.

A5.4 SFN and propagation phenomena on the warm sea

After the switch-off of all the area on the Adriatic Sea, Rai Way received many complaints because the service was not guaranteed during a few hours each day. The analysis of the problem was complex because of the many transmitters operating in that region. Continuous monitoring and recording of the RF signal, MER, BER and Cell ID values revealed that the transmitter causing the most annoying interferences on the coast was the one at Udine which is as many as 224 km away.



Transmitter	Distance (km)	Cell ID	Transmitter	Distance (km)	Cell ID
M. Belvedere	203	7192	Pietracuta di S. Leo	16.4	8802
Udine	224	7231	Morciano	18.2	8805
Castaldia	221	7307	Montescudo	19.6	8803
M. Venda	150	6196	Riccione	7.8	8801
Bertinoro	30	8007	M. Nerone	59.8	12303

Figure A5.5: SFN transmitters impacting the Rimini area

The analysis was made with a specially equipped vehicle placed on the coast near Rimini. A continuous monitoring with an "ad hoc" Rai Way software was performed. This software records RF, MER, BER values and channel analysis parameters each minute.

A first study was performed to discover which transmitters were causing reception problems, taking especially into account those transmitters that were not synchronized because they are very far away.

The collected measurements revealed that the Udine transmitter could be received on this part of the coast for many hours a day. A more detailed survey with the antenna pointed in the direction of Udine at 8 m height above ground was then performed.

The recorded values showed that the RF levels fluctuated all the day long and reached 79 dBµV/m, as shown in **Figure A5.6**.

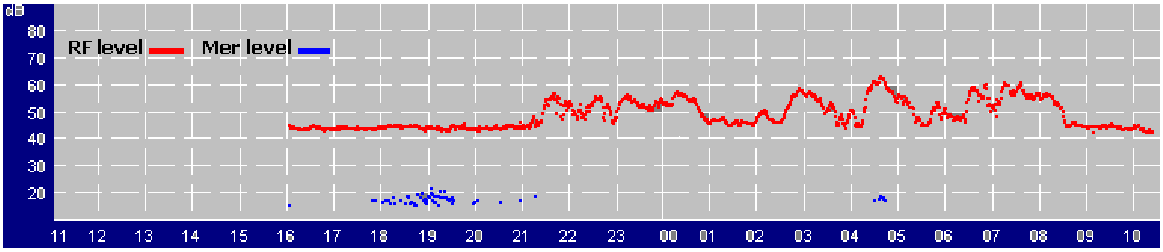


Figure A5.6: Rimini recording, 18 and 19 July

It should be noted that during the recording period, weather conditions were not particularly favourable to propagation phenomena.

Once it was realised that Udine signals were easily receivable with significant levels, a second analysis was carried out to evaluate the impact of this propagation on end users.

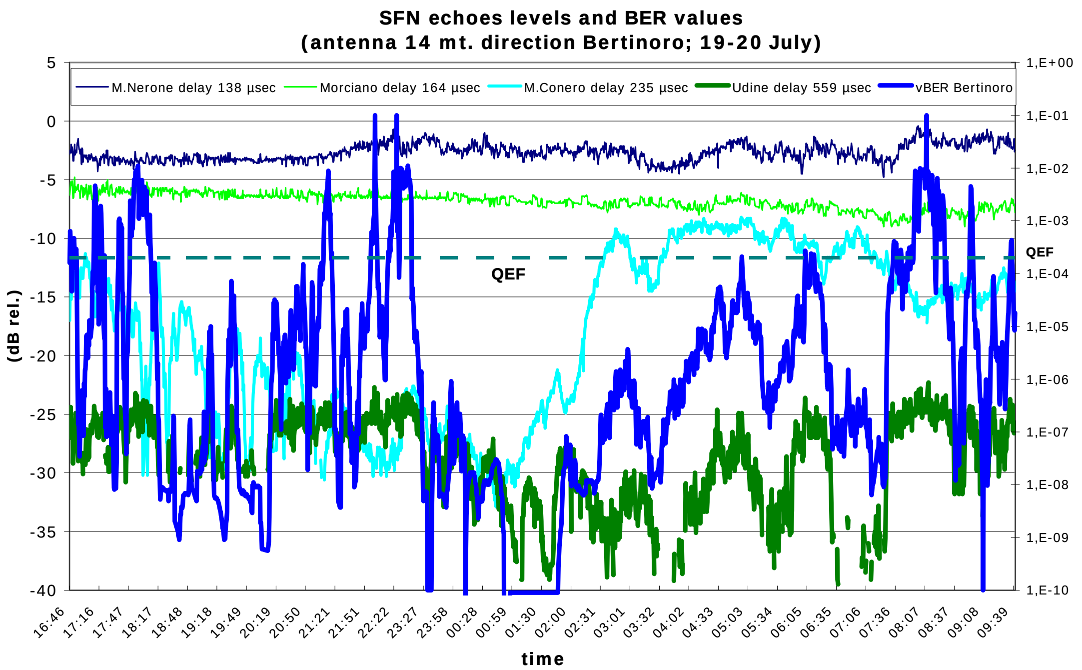


Figure A5.7: SFN Echos measured at Rimini

The measurements were performed setting the antenna at 14 m above ground level and pointing towards Bertinoro, which is the main transmitter for this area, simulating the typical aerial reception system of the residential buildings.

A correlation analysis was done comparing vBER values and the echo levels of all the received signals. The investigation showed that when the echo level of the Udine transmitter increased, vBER decreased and overstepped the QEF threshold. The Udine transmitter is not synchronized and has a 559 µs delay with respect to Bertinoro.

To solve this bad reception problem, Rai Way had no available solution other than to relocate the Udine transmitter.

A5.5 SFN and propagation phenomena on the ground

Similar propagation phenomena were also detected in other parts of Italy and were not originated by warm sea.

A measurement campaign was conducted in Castel San Pietro, not far from Bologna, where many people complained of bad reception during a few hours a day.

This area is the target area of the Monte Venda transmitter, some 100 km away. Almost in the same direction there is also the Col Visentin transmitter which is 200 km away.

Signals coming from Col Visentin cover 200 km and they are subject to propagation phenomena that can significantly vary their intensity even in the course of a single day. The path from Monte Venda extends almost in the same direction but only for half the distance (100 km): this signal can also be affected by propagation phenomena but in a different way and there is no correlation between the two. For this reason, during the day, the relationship between the level of the wanted (Monte Venda) signal and the interferer (Col Visentin) can vary significantly.

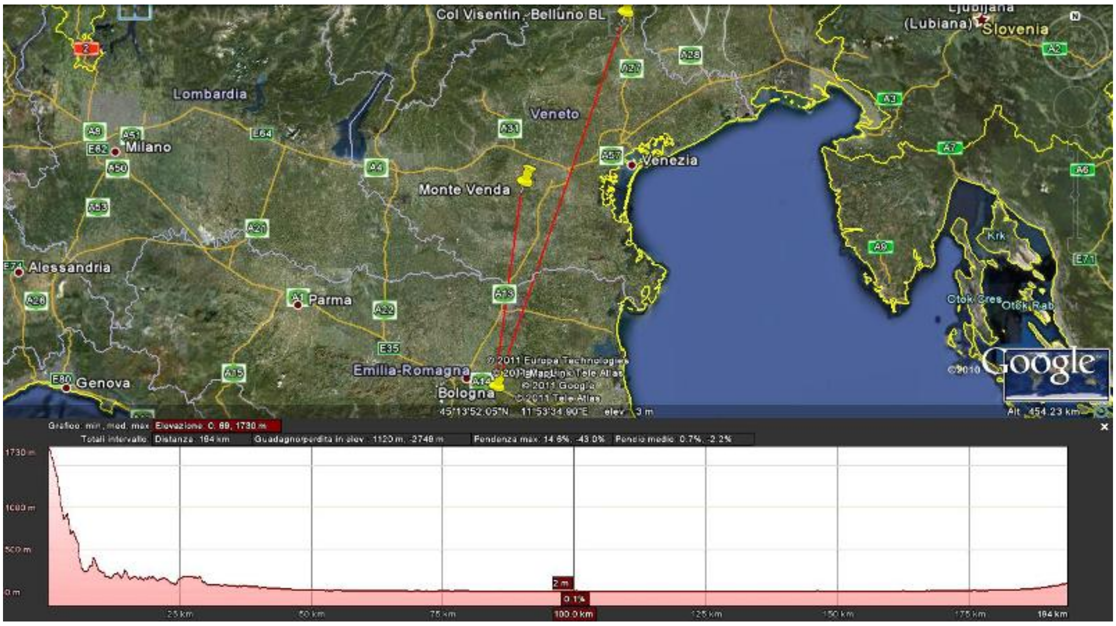


Figure A5.8: Monte Venda and Col Visentin with respect to Castel San Pietro & Castel San Pietro-Col Visentin profile

The analysis gives evidence that, during propagation time, signals coming from Col Visentin transmitter degrade the reception quality. The following figures, related to Monte Venda channel analysis, demonstrate the variability observed in the short period of about one hour.

The Col Visentin echo has a delay of about 285 µs and it appears in **Figure A5.9** also with a spurious image with a delay of -13 µs. Laboratory tests proved that spurious images of echoes appear when an echo falls outside the guard interval and its level is 21 dB or less lower than the main one.

This situation causes a serious degradation of the reception quality, which is confirmed by the bad values of MER (17.4 dB) and BER (1.4E-3).

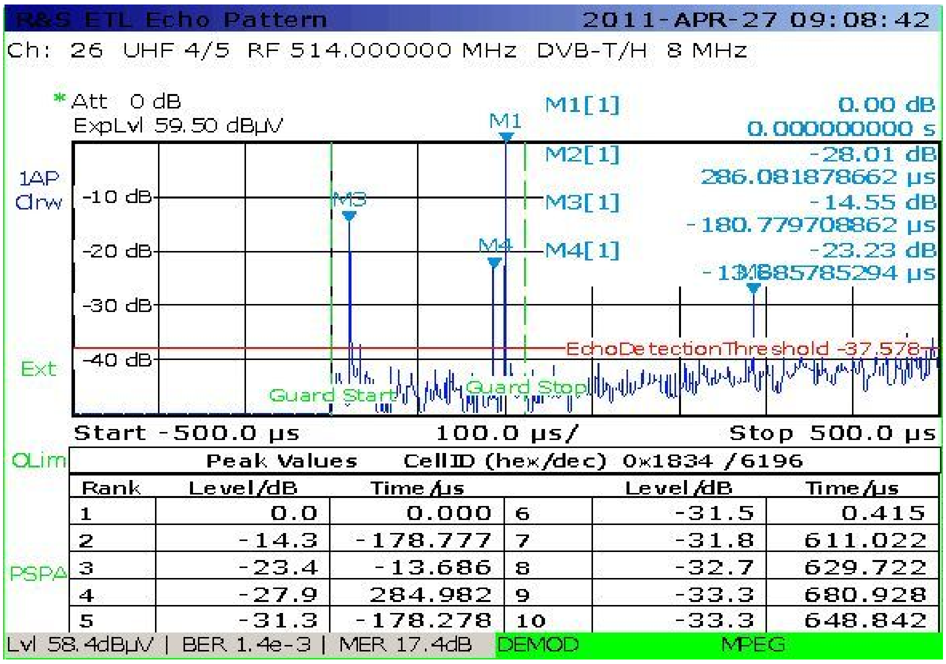


Figure A5.9: Castel San Pietro (BO) - Monte Venda signal analysis, 09:08

Figure A5.10 shows the same analysis repeated after 40 minutes. In the meantime the level of the Col Visentin echo was decreased and better values of MER and BER were recorded.

An additional test was made in order to evaluate if the degradation of signal was also due to other transmitters of the SFN.

The Col Visentin transmitter was switched off for a short period and an additional improvement of the Monte Venda signal was observed. This served to confirm that the local SFN was well optimized and only the signal of Col Visentin damaged the quality of service (**Figure A5.11**).

To solve this problem the radiation power of Col Visentin transmitter in this direction was reduced and the antenna tilted.

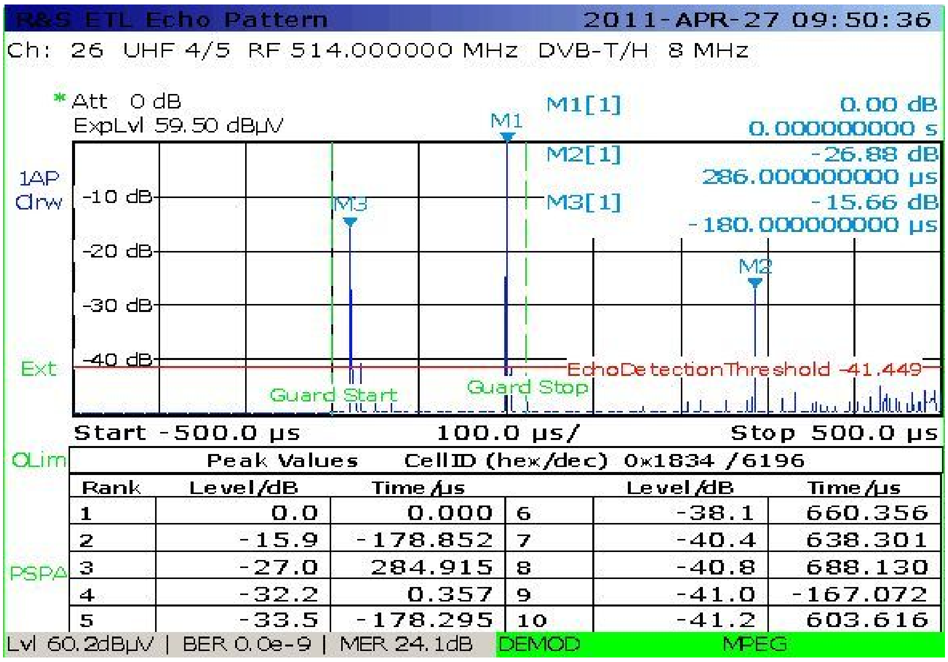
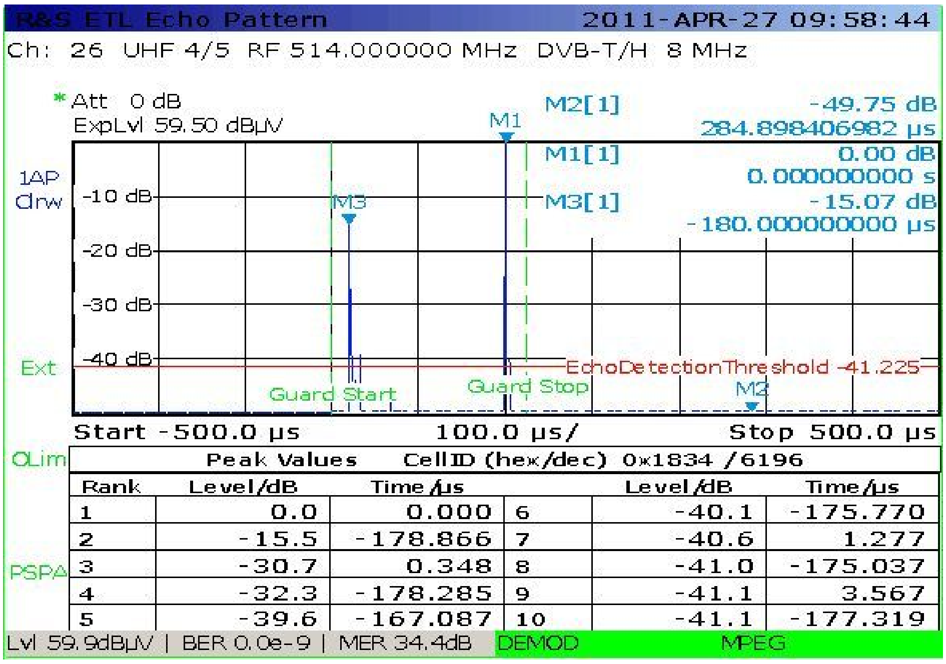


Figure A5.10: Castel San Pietro (BO) - Monte Venda signal analysis, 09:50



Rank	Level/dB	Time/µs		Level/dB	Time/µs
1	0.0	0.000	6	-40.1	-175.770
2	-15.5	-178.866	7	-40.6	1.277
3	-30.7	0.348	8	-41.0	-175.037
4	-32.3	-178.285	9	-41.1	3.567
5	-39.6	-167.087	10	-41.1	-177.319

Figure A5.11: Castel San Pietro (BO) - Monte Venda signal analysis with Col Visentin switched off

A5.6 SFN and reflection/scattering phenomena

Another interesting study was performed to optimize the SFN on Como Lake.

This lake is narrow and surrounded by mountains and reflection phenomena are very common.

The broadcasting service is provided by transmitters placed up in the mountains and directed toward the opposite side of the lake.

In particular, a measurement campaign was set up in the northern part of the lake, near Stazzona.

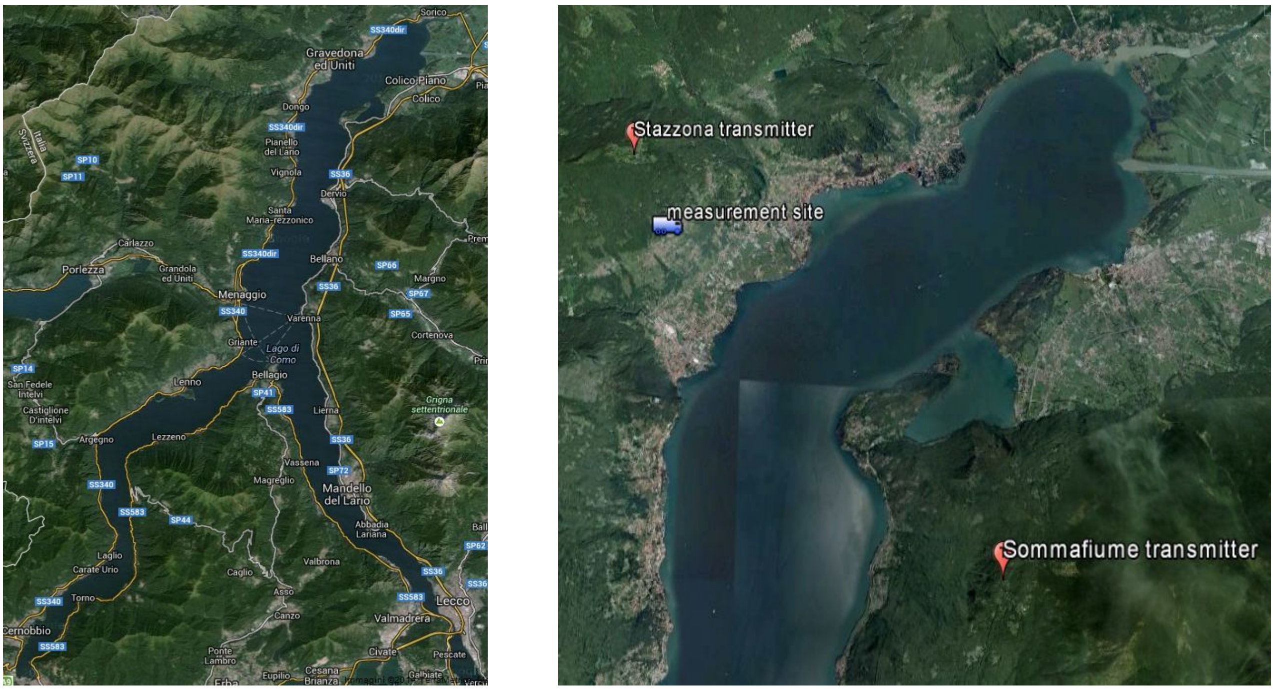


Figure A5.12: Como Lake overview - Detail of the northern part of the lake

This Stazzona side of the lake is the Sommafiume transmitter target area and all the antennas of the buildings are pointed towards Sommafiume. In spite of the clear line of sight between transmitting and receiving antennas and the short distance between them (around 6 or 7 km), the reception quality proved to be very poor in a wide area and was impossible at some points. This was mainly due to the many artificial and natural echoes. Many of them were related to Stazzona transmitter; its signal was reflected back by the opposite side of the mountain directly or through the lake (see **Figure A5.13**) Stazzona echoes are around 12 µs delay and with a level ≈ -26 dB).

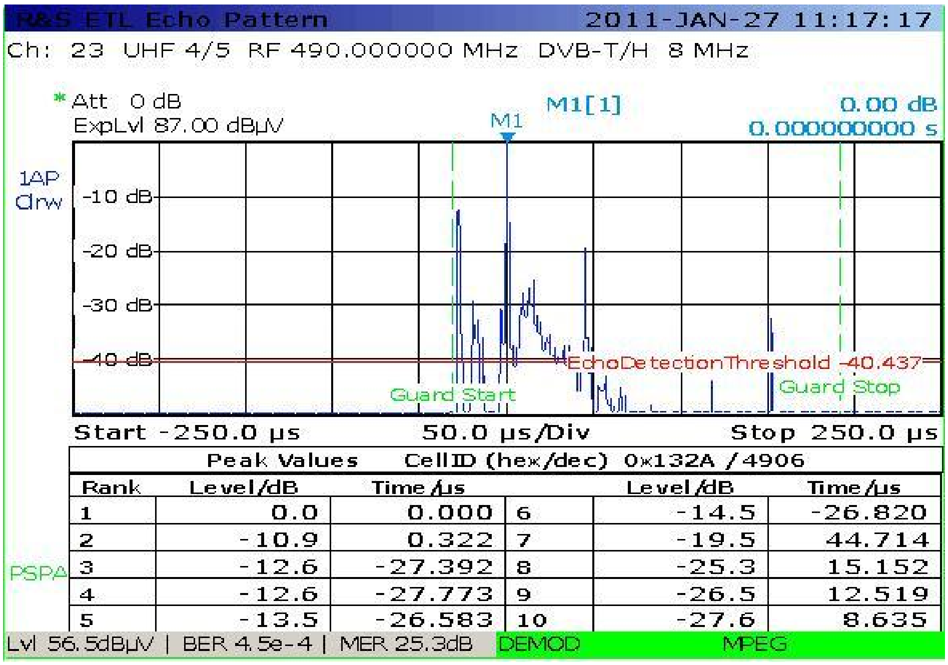


Figure A5.13: Stazzona Channel analysis

The improvement of quality of service was obtained by optimizing the power of the two transmitters and the relative delays.

A5.7 SFN, echoes and analysis of correlation

An improvement of the statistical analysis of the propagation method based on field strength recording can be achieved through the analysis of the correlation between the received signal quality and the received echo levels.

Rai Way started a project together with university researchers to investigate possible SFN self-interference areas, to determine the duration of the self-interference inside these areas and to identify which of the propagation paths are responsible for the observed service degradation.

After long duration recording at test sites it became possible to calculate the percentage of time for which the service is lost or degraded and to understand the dynamics of the propagation over each path observed as being responsible for the self-interference. The data collected can be used for tuning the network and for feeding a propagation database.

Annex A6: Re-use distances of DVB-T2 networks

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20 September 2013

A Study on Reuse Distance in DVB-T2 Networks

A6.1 Introduction

In order to make optimum use of the frequency spectrum, which is a finite natural resource, it is inevitable to reuse the same frequency band over different geographical areas. Each of these areas covered with a single frequency network (SFN) is called a service area. To make the repetition of frequency channels possible, a minimum distance between the co-channel service areas is vital otherwise there would be a disturbance in the operation of the co-channel systems.

This report represents the general behaviour of a reference hexagonal network in presence of another co-channel reference network. In addition the minimum required distance between operating co-channel service areas is studied. It is also shown how the change of various system parameters of SFNs affects the reuse distance.

A6.2 Methodology

The theoretical network used in this paper corresponds to the RN1 hexagon network of RRC-06 document **[A6-1]**. This network with seven transmitters is shown in **Figure A6.1**.

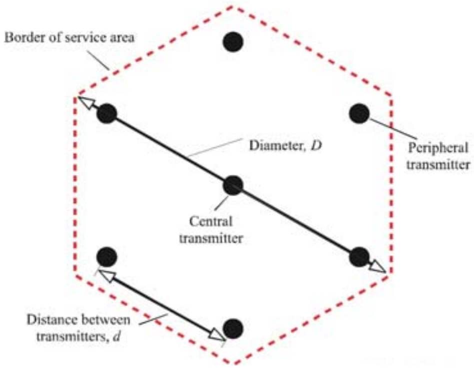

Figure A6.1: Reference network used for reuse distance studies

The area within the red dashed line is the service area. Within the service area, coverage with a specific location probability is guaranteed. In our case the probability is 95% for portable and fixed reception and 99% for mobile reception. As shown in **Figure A6.1**, the service area does not only include the area that connects the transmitters together but it extends a bit further. In fact, an extra 15% of the inter-site distance (d) is added to the diameter (D) from each side.

As shown in **Figure A6.2**, the goal is to find out a minimum required distance between two SFNs which operate on the same frequency band and do not cause interference to each other. In other words if the two networks come closer than this minimum distance then the total coverage of the grey area with the 95% location probability will start to fail.

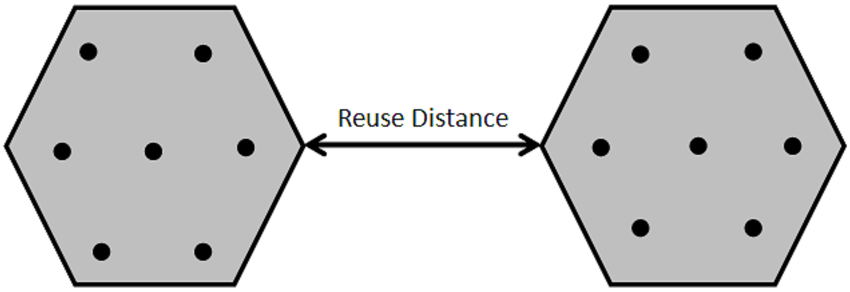

Figure A6.2: Schematic of a co-channel reuse distance on a reference network

The system parameters are chosen in a way that 100% coverage with considered location probability is guaranteed when no interference effect is considered. In other words the lack of transmitted power or very high required minimum field strength should not be the reason for the lack of coverage.

Apart from the effective radiated power there is an additional 3 dB power added to the initial transmitted power. This power margin is provided to allow the initial network to be more co-channel interference tolerable.

The CNR value is one of the important parameters in estimating the reuse distance and the variation of it influence the minimum filed strength. The only parameters in a modus that vary CNR value remarkably are code rate and modulation scheme. For this reason all chosen modes during this study have the same window size, guard interval, pilot pattern and the only difference of them are code rate and modulation.

After choosing appropriate system parameters the two networks are slipped nearer and nearer up to a distance where first uncovered pixels appear in the service area. This is the distance which is defined as the reuse distance.

A6.3 Results

A6.3.1 Dependency of the reuse distance to CNR value, effective radiated power (ERP) and the effective antenna height (H_{eff})

In this section the dependency of the reuse distance on effective radiated power, transmitter effective antenna height and CNR value is discussed.

The modulation scheme applied during different studies is 64-QAM and the code rate varies between 1/2 and 3/4. In fact, the modes with 1/2 and 3/5 code rate correspond to the maximum achievable data rate in the very large and large SFN mobile reception **[A6-2]** consequently the chosen modes result into the data rate value between 16.8 Mbit/s and 25.2 Mbit/s. Then the CNR values are between 15.1 dB and 20.4 dB as shown in **Figure A6.3**.

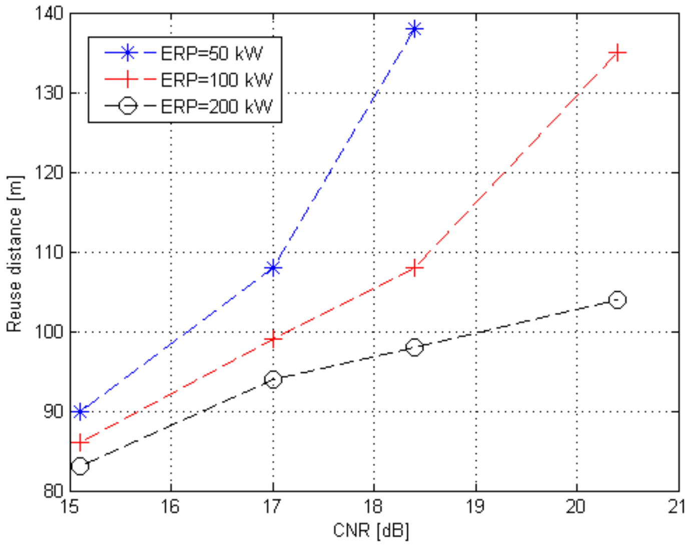

Figure A6.3: Reuse distance of the reference networks with H_{eff}=300 m, ISD=60 km, different CNR values and various effective radiated powers (ERP) in the portable outdoor reception mode

In both **Figures A6.3** and **A6.4** the reuse distance increases with the CNR value. With increasing CNR the chosen mode becomes more sensitive and less robust to the self- or co-channel interferences. In this network and all modes used during this report the co-channel interference is in any case higher than the self-interference effect. In order to compensate the co-channel interference, the distance between two networks should be increased. This is the reason of a larger re-use distance on higher CNR modes.

In **Figure A6.3** an increase of the radiated power in both networks within an operation mode results in the increase of useful and disturbing field strengths at the same time. However with various radiated powers the networks have different resistibility to the interference and this fact is also proved in **Figure A6.4**.

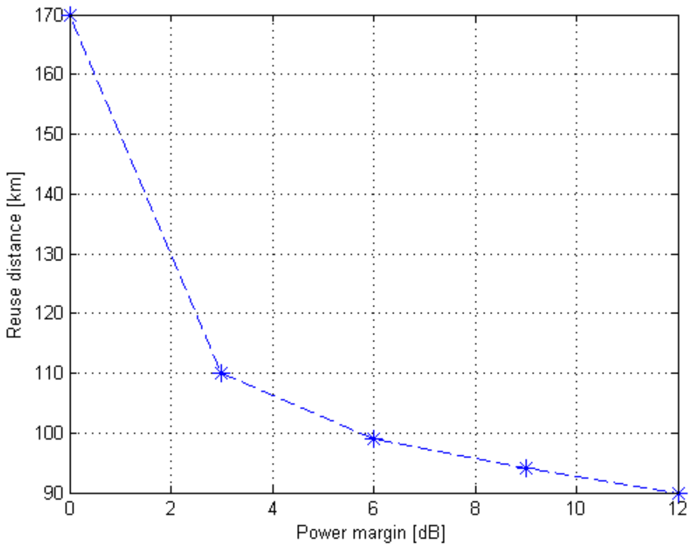

Figure A6.4: Reuse distance of two co-channel networks with H_{eff}=300 m, CNR=17 dB, ISD=60 km with the initial 44 dBW and increase of 3 dB power margin in each step

The initial radiated power in **Figure A6.4** is 25 kW or 44 dBW. In every step a power margin of 3 dB is added to the initial power value. In this way the required reuse distance for the radiated power of 25, 50, 100, 200 and 400 kW is calculated.

Figure A6.5 shows the relation between the reuse distance and the effective antenna height. According to the propagation and path loss curves in the ITU-R Rec. P.1546 model **[A6-3]** the differentiation of two field strength varies with the distance from the transmitter. In fact the differentiation of field strength between the curves of different antenna heights is much higher on the lower distances than on higher distances from the transmitter. Therefore the useful field strength increases with the antenna height whereas the disturbing field strength remains nearly constant and this causes lower possible reuse distance for higher antennas.

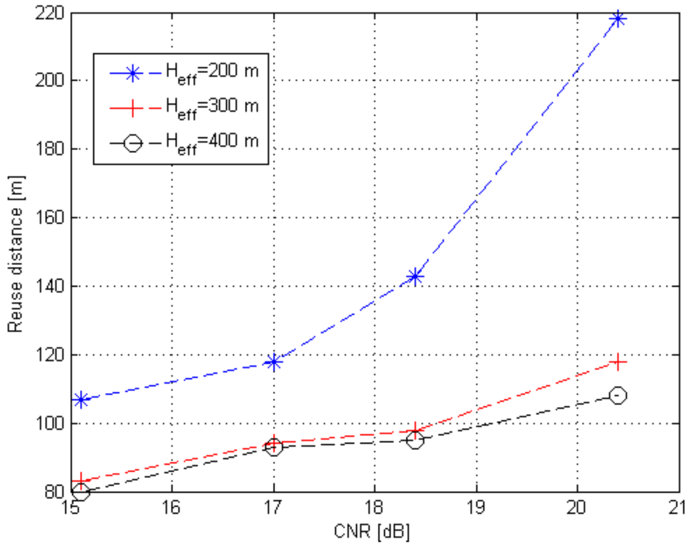

Figure A6.5: Reuse distance of the reference network with ERP=200 kW, different CNR values and various effective antenna heights (H_{eff})

The reason for the large difference between the required reuse distance of the blue curve and the other two curves is because of the inequality of the incremental change of curves for different antenna heights on lower distances. The difference between two propagation curves increases with the increasing antenna height on lower distances. The difference between the interfering fields remains nearly constant. This causes a huge difference of useful field strength between 200 m and 300 m which causes great difference in reuse distances.

A6.3.2 Reuse distance in different reception modes

In this part the reuse distance is compared between different reception scenarios. The chosen mode for this comparison is the one that results in the maximum data rate by the mobile reception in large SFNs **[A6-2]**. However it is worth to mention that in the previous paper the coverage is observed for the closed network whereas here the network is open and has 15% of its inter-site distance as a margin from each side.

In **Table A6.1** the location probability is 95% for all three cases. Basically for the mobile scenario 99% location probability is usually considered in the planning processes but even without considering any kind of interferences this coverage is not reached in this specific modus. The location probability for the mobile mode is fulfilled only if we decrease the CNR and in the result the data rate decrease.

Table A6.1

64-QAM- 3/5 , pp1, 1/4 , 16k , data rate = 20.1 Mbit/s (95% location probability)		
Fixed rooftop reception	Portable outdoor reception	Mobile outdoor reception
Reuse distance = 60 km	Reuse distance = 100 km	Reuse distance = 165 km

[A6-3] showed that a more accurate measurement and information about the CNR value of the mobile reception of DVB-T2 is required and the approximated 5 dB higher CNR value could be unrealistic and influence the results enormously. During the preparation of this study there is unfortunately still no information about the more concrete findings and measurements. For this reason here the 5 dB higher CNR in mobile case is assumed until more results of this value are available. The greater required reuse distance in mobile mode is the result of 5 dB CNR value difference in comparison with portable.

A6.3.3 Dependency of reuse-distance to inter-site distance (ISD)

The reuse-distance is calculated for different inter-site distance to see how it changes if the distance between both useful and disturbing network decrease or increase at the same time.

The results for both fixed and portable reception modes are examined. It is important to mention that the reception antennas used in the two scenarios are different. The fixed reception antenna is directional with the antenna diagram available in ITU-R BT.419-3-Band-4-5 **[A6-4]**. The portable reception antenna is assumed to be non-directional and without any antenna gain. For this reason it is not possible to directly compare the reuse distances of these two different reception modes. The result is rather for comparison of reuse distance with the same reception type with different ISDs together only.

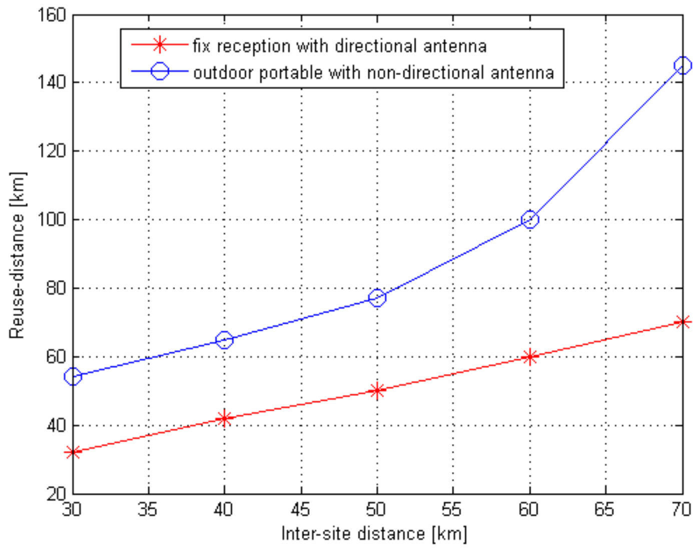

Figure A6.6: Reuse distance versus inter-site distance for fixed and outdoor portable reception mode with 16-QAM-3/5, GI=1/4-pp1, ERP=100 kW, GI=60 km and H_{eff}=300 m

In fact the value of guard interval does not have any influence on the reuse-distance. However the greatest possible guard interval is used to insure no presence of self-interference and to make sure that the restriction of minimum possible distance between two networks is only influenced by the co-channel network. As **Figure A6.6** shows, in both reception scenarios the reuse distance reduces with decreasing inter-site distance.

A6.3.4 Reuse distance of the reference network with different number of the transmitters:

The previous results are all observed with the hexagon consisting of 7 transmitters. It is interesting to see whether the addition of extra transmitters would influence the result of reuse distance or if it remains unchanged.

In this section the coverage restriction is in any case caused by external networks and is not due to self-interference. The reuse distance is calculated for three different numbers of transmitters; for 7, 19 and 37.

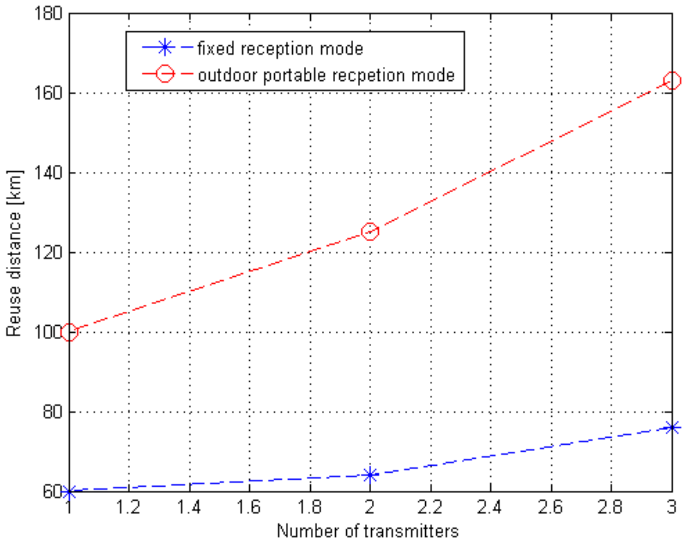

Figure A6.7: Effect of the number of transmitters on reuse distance for fixed and portable reception modes (64-QAM-3/5, pp1, 1/4, 16k), H_{eff}=300 m, ERP=100 kW

According to **Figure A6.7** the addition of transmitters does not influence the reuse distance remarkably in fixed reception scenario whereas in portable reception the reuse distance increases with the number of transmitters. According to these results the required reuse distance for the theoretical network of the national wide SFN mentioned in **[A6-2]**, with 127 transmitter antennas would be very high.

A6.4 Conclusion

The required reuse distance for two co-channel networks is studied in this article. The dependency of the reuse distance to the different system parameters such as antenna height, radiated power and number of transmitters is observed. According to the results it is concluded that in frequency and network planning there would be a trade-off between the frequency efficiency and the operation costs. With increasing the radiated power two co-channel networks could operate with short reuse distance without interference which is a very frequency-efficient solution. However the higher radiated power increases the operation costs noticeably. The same applies to the transmitter antenna heights and the inter-site distance of transmitters.

A6.5 References

[A6-1] GE06 Agreement: Final Acts of the Regional Radio communication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06)

[A6-2] S. Telemi, R. Brugger, 'Optimal DVB-T2 system parameters for the coverage of large single frequency networks', EBU, SMR-BNP, July 2013

[A6-3] ITU-R Rec. P.1546: Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz

[A6-4] ITU-R Rec. BT.419-3: Directivity and polarization discrimination of antennas in the reception of television broadcasting