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Digital terrestrial broadcasting: Design and implementation of single frequency networks (SFN)

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Digital terrestrial broadcasting: Design and implementation of single frequency networks (SFN)

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Abstract

Digital broadcasting techniques, that have been massively introduced during the last 15 years, allow the use of single frequency networks (SFN), in which the same frequency is assigned to all transmitters in a given service area in order to broadcast the same programme.

Although the implementation of SFN permits a use of the spectrum in a more efficient way, SFNs are not the panacea for the resolution of the increasing spectrum demand. In the document benefits and drawbacks of SFNs are analysed.

Many practical examples are described with the aim to share experiences and to give guidance in design and implementation to those have the intention to start the deployment of this kind of network.

The Report is organized in parts in order to be consulted more practically.

The document opens with a general part, which examine the concepts and the features of SFNs, common to every type of standard in use in the ITU Regions.

The remaining parts are related to the different digital transmission standards.

The present edition presents three different category of network: the DVB and DAB family, ISDB and DTMB.

In each part, the key elements of the system are mentioned, with references to the standards or others ITU Reports, but more relevance is given to designs, implementations and case studies.

In particular, in the part related to DVB-T, T2 and DAB, propagation and scattering phenomena, optimization, timing, distribution and studies on large SFN and T2-Lite are well treated.

In the ISDB and DTMB sections, the deployment of a network is carefully described.

Acronyms

ASI	Asynchronous serial interface
ATM	Asynchronous transfer mode
BBFrame	Base band frame
BER	Bit error rate
CEPT	Conférence Européenne des Administrations des Postes et Télécommunications
CEQ	Cliff edge coefficient
C/N	Carrier to noise ratio
CNR	Carrier to noise ratio
COFDM	Coded orthogonal frequency division multiplexing
DSL	Dynamic label segment
DTTB	Digital terrestrial television broadcasting
DTM	Dual transfer mode
DTT	Digital terrestrial television
EBU	European broadcasting union
EMC	Electromagnetic compatibility
e.r.p.	Effective radiated power
ETSI	European Telecommunications Standards Institute
GE06	ITU-R Conference and Agreement Geneva 2006
FEC	Forward error correction
FEF	Future extension frame
FFT	Fast fourier transformation
FIC	Fast information channel

FM	Frequency modulation
FRF	Frequency reuse factor
GI	Guard interval
GIF	Guard interval fraction
GPS	Global positioning system
HD	High definition
HDTV	High definition TV
HPHT	High power high tower
ISD	Inter-site distance
ISI	Inter symbol interference
LSE	Layer spectrum efficiency
MER	Modulation error rate
MFN	Multi frequency network
MIP	Megaframe initialization packets
MPEG	Moving picture experts group
OFDM	Orthogonal frequency division multiplexing
PN	Pseudo random noise
PSB	Public service broadcasting
QAM	Quadrature amplitude modulation
QEF	Quasi error free
QPSK	Quadrature phase shift keying
RBF	Re-use blocking factor
RF	Radio frequency
RSL	Receiving signal level
SD	Standard definition
SDH	Synchronous digital hierarchy
SDTV	Standard definition TV
SFN	Single frequency network
SIP	Session initiation protocol
TDS-OFDM	Time domain synchronous orthogonal frequency division multiplexing
TII	Transmitter identification information
TS	Transport stream
UEP	Unequal error protection
vBER	Bit error rate after Viterbi decoder
VC	Video codec

VHF	Very high frequency
VSW	Coverage probability
UHF	Ultra high frequency

Part 1

Overview of Single Frequency Networks

1 Definition and characteristics of single frequency networks

Broadcast networks provide coverage over certain geographical areas (the “coverage area”). A service area is generally a subset of the coverage area, being limited to the area within which an administration can seek protection for a service. 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.

1.1 Definition of single frequency networks

Digital broadcast systems introduced the potential to use single frequency networks (SFN). An SFN is a network of transmitters, all operating on the same frequency channel and all carrying the same data. In a SFN 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.

1.2 Benefits of single frequency networks

A major advantage of using SFN is the possibility to increase the frequency efficiency. In traditional networks all the nearby stations uses different frequencies. With SFN technology it is possible to form the cluster of nearby stations using the same frequency. The maximum coverage extent for a SFN cluster depends on the parameters of the radio emission system.

In many circumstances the use of an SFN may enable a service area to be covered by a single frequency, rather than multiple frequencies.

SFN technology permits higher layer spectrum efficiency compared to traditional MFN technology. The basis for this is that network implementation with SFN cluster requires a smaller number of frequencies for a network layer compared to MFN. The number of frequencies necessary for a network layer can be significantly reduced when the SFN is used, having the asymptotic value equal to 1. The cost of the SFN functionality is that the transmission system have somewhat lower data capacity for a single RF channel. But overall, SFN techniques provide a very valuable tool to significantly increase the efficiency in frequency use.

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.

As a result of the local ground cover variations will the signal level to vary. Typically an SFN would introduce multiple transmissions from multiple sites, meaning that many locations would often be served by more than one transmitter. The signal contribution from multiple transmitters results in signal diversity, which often improves the reception of the SFN case, especially for mobile reception without the need of any kind of handover, unlike the MFN case. 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 total signal field strength. For example, if one source is shadowed, others may be more easily receivable, and the field strength variation could thereby be reduced. Compared with an MFN, this effect reduces the overall location variation, resulting in lower field strength being required to meet a particular reception requirement

Furthermore, receivers can 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 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.

These two factors are often referred to as “network gain”. The actual quantity of such “gain” varies with many factors, such as the propagation environment, the number of signals received and their relative levels. In fixed reception environments, the directivity of the receiving antenna is likely to reduce the relative levels of some signals, and the propagation channel is more Ricean. So the resultant network gain is likely to be lower for fixed reception than for portable or mobile reception.

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 allotment 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.

1.3 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.

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 deliberately 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 complexity is 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 Report ITU-R BT.2253 "GPS timing receivers for DVB-T SFN application: 10 MHz phase recovery", that, despite the title, refers to a problem that could affect any kind of SFN.

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 may be more efficient to limit the size of SFNs to the particular area in which the content is required.

1.4 Type of SFN

SFNs can be used in a variety of coverage situations. Most typically, they are used to cover a whole country or part of one, but can be used for smaller local areas (even at the level of just one city).

A further distinction of SFNs is given by categorising them as either open or closed:

In an **open network,** no measures are taken to minimize the level of radiation towards areas outside the coverage area. In the limiting case an open network can consist of only a single transmitter.

In a **closed network,** the level of radiation towards areas outside the coverage area is deliberately reduced without reduction of the coverage within the intended area. This can be done by using directional antennas on transmitting stations near the periphery of the coverage area.

1.5 Consideration of network structures for SFN

Open and closed configurations

In a real network, covering a large area there may be considerable distances between the transmitters. If such a network is designed as a closed network it will cause less interference at a given distance outside its coverage area than if it had been designed as an open network. The reason for this is that the level of interference is mainly determined by the radiated power from the transmitters closest to the boundary of the coverage area in the direction considered.

However, in a closed network covering a small area the radiated power from transmitters on the side of the coverage area opposite to the direction under consideration contributes relatively more to the outgoing interference level than in a closed network covering a large area. Thus the use of directional transmitting antennas on transmitters near the boundary of the coverage area consequently brings less advantage, in term of less outgoing interference, than in the case of networks covering larger areas.

It follows that for relatively large coverage areas, the separation distance between co-channel areas will generally be less for closed networks than for open ones. For smaller coverage areas the separation distance for closed networks approaches that for open networks.

Transmitting sites

Digital terrestrial broadcasting deployment can re-use existing sites, or use new sites or alternative network architectures. In turn, this will affect the choice of the selected digital terrestrial broadcasting variant and the frequency requirements.

The number of transmitter sites deployed and the separation distances between them will vary a lot from network to network, and from country to country, and will depend on the system variant, the reception mode (fixed, portable or mobile), the country size and boundary situations.

In an SFN using appropriate digital terrestrial broadcasting standards, the separation distance between transmitters influences the choice of the guard interval, which in turn limits the size of the network. The separation distance and the antenna height will also influence the effective radiated power (e.r.p.) required to provide the desired coverage.

The use of "dense networks", a network of closely situated, low to medium power stations, can offer some advantages over networks based on high power transmitters separated by large distances.

Particularly in the case of regional SFNs, but also for national SFNs, it is possible to consider various forms of dense networks having significantly lower e.r.p. than that required by a single transmitter serving the same area. For digital terrestrial broadcasting, the concept of "distributed emission" can provide the required field strength over the entire service area by a number of low power, synchronized SFN transmitters, located on a more-or-less regular lattice, or to use on-channel repeaters receiving their signal off-air from the main transmitter, to improve the coverage of the main transmitter. In the latter case, the repeaters are synchronized in time by default, and no parallel distribution infrastructure is needed to bring the signal to them.

Furthermore, local high density SFNs could be used to supplement large SFN in areas where the coverage would otherwise be inadequate, due (for example) to the topography. Finally, they offer a reduction of the impact of co-channel interference beyond the border of the service area, by introducing a sharper field strength roll-off. This can be further improved by suitable choice of the transmitting antenna directivity.

For example, it is possible to envisage transmitter topologies in which the central part of the service area is covered by a large SFN (with high power transmitters separated by large distances), but near the edge a dense transmitter network is installed (with low e.r.p., and with low-height and directive antennas). This allows the e.r.p. to be "tailored" according to the service area contour, reducing the interference to adjacent areas and keeping the high service availability inside the wanted area.

Transmitting antenna types and radiation patterns

Transmitting antennas will have either omni-directional or directional pattern. For stations located close to the edge of an SFN coverage area, directional antennas could be used to reduce interference outside the service area, thus reducing the separation distance for the frequencies in question, and to protect the coverage areas of other existing services. This is especially true for high and medium power stations.

Beam-tilt is an efficient tool to target the radiated power of high power stations to the outer part of the coverage area and, at the same time, to reduce the interference potential at large distances and to other radio services.

Factors influencing the transmitter separation distance

There are several factors that influence the transmitter separation distance, for example radiated power, antenna height, reception mode, system variant and propagation path. It must be noted that these may be different for different networks. In SFNs, the separation between adjacent transmitters is limited by the length of the guard interval.

Factors influencing the co-channel separation distance

The separation distance between two co-channel service areas is the minimum distance needed in order to avoid undue interference to either of the two service areas.

The separation distance has a significant influence on the number of frequency blocks or channels needed to establish coverage of a larger area containing several countries or regions, each having its own programmes transmitted in one frequency block or channel.

Coverage areas served by transmitters located along the periphery and using directive antennas pointing inwards (that is, in a closed network) will result in shorter separation distances compared to equivalent coverage achieved by the use of non-directional antennas (that is, in an open network). In the case of propagation paths with a significant amount of sea, separation distances will be larger than for the case of land-only paths.

1.6 Classification of transmitting stations

Just as SFNs can be used to cover areas of different sizes, so the transmitting stations that make up an SFN can vary in e.r.p. or antenna height. Although a "classical" SFN is normally thought of a relatively homogenous network with all transmitters having the same heights and e.r.p.s, in practice, many SFNs are built using a mixture of high, medium and low power transmitters.

For example section 1.6.17 of the Report from the First Session of the 2004/06 ITU Regional Radio Conference gave three classifications of transmitting station, with e.r.p.s ranging from over 10 kW to under 50 W.

1.7 Spectrum utilization

Flexibility in use of spectrum

SFN configuration allows a very large flexibility in the use of spectrum. For example, a network can be initially designed to provide coverage to fixed roof-level antennas, but can be developed later, without the need for additional frequencies, to provide mobile or portable services by the addition of supplementary transmitter stations.

This can be a way of spreading the cost of introducing a new digital network over a period of time. For example, if the initial investment required to provide a network which delivers indoor coverage to the whole target area is too high, an administration or network operator could chose to implement a network with a variety of reception modes, such as coverage to fixed roof-level antennas across a wide service area, with portable reception in some towns inside the service area. The fixed coverage network can then be developed to provide further indoor coverage over a period of time.

Another flexibility that SFNs bring is the freedom for a broadcasting operator to implement new stations to improve coverage within an existing network, without having to use additional spectrum.

2 Coverage criteria

2.1 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 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.

A distinction is also 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.

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.

2.2 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 uniformly 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 area coverage.

Population, while perhaps intuitively being measured in numbers of people, is often measured in households as a proxy for the number of people they contain.

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 × 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 households, 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 overall total coverage is determined by summing together all households, or areas where pixels are served to at least the cut-off threshold for a defined service area.

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, but it cannot be said which part of the pixel is covered, or which is not covered. 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. While useful as an aggregate measure of coverage, because it "averages out" reception variations across many pixels, this method is not suitable to quantify coverage within any particular pixel.

2.3 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[1] 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 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 P1-1a

Example of full area coverage using 7 channels

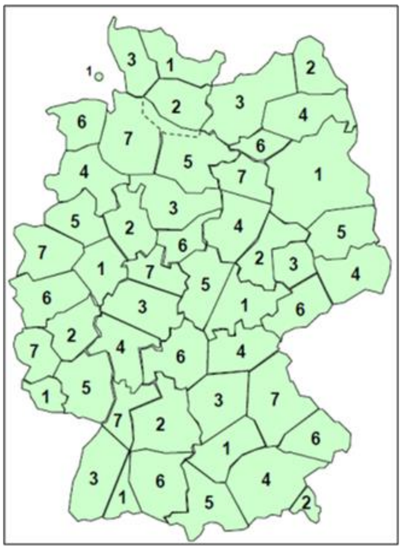
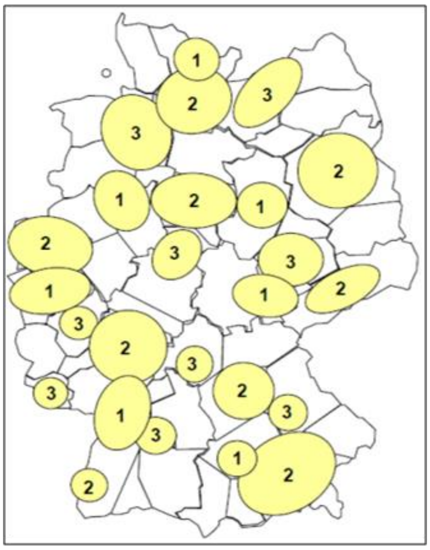


FIGURE P1-1b

Example of metropolitan area coverage using 3 channels



Examples are given in Figs P1-1a and P1-1b where fictional coverage scenarios for Germany are sketched. Figure P1-1a represents full area coverage and Fig. P1-1b 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. In this example, 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.

A closely related case is the requirement 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

[1] The minimum required distance between different allotments using the same frequency is called "frequency re-use distance".

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.

3 Layer definition

In broadcast planning, a “layer” is considered as the set of frequency channels, together with their associated service areas, which can be used to provide one full national or partial nationwide coverage for a multiplex.

4 Broadcasters’ requirements

4.1 Service area requirements

Broadcasters have different needs that effect 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 demographic 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 different countries. 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 always suit the local circumstances.

4.2 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 or household 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.

4.3 Operational/Network requirements

The nature of broadcasting, particularly for “high-tower, high-power” (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 in services which may in turn cause a significant reduction of enjoyment for viewers or listeners 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, network operators and planners when designing, implementing and operating networks have 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.

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 synchronisation can be managed. Failure of the timing in any part of the network or a drift in the frequency of a transmitter within an SFN can result in significant interference, the source of which can be difficult, and time consuming, to track down.

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 such 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 may affect much larger areas than would be affected in an MFN during the same propagation event. As such in SFNs, if care is not taken when planning, network coverage problems may occur. This is particularly true for networks within which propagation paths over sea or other extensive areas of water are involved (as these paths are subject to greater time variation in propagation).

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.

5 Implementation of the transmitter network

The implementation of any particular SFN is unlikely to be identical to any other. Factors such as terrain, population distribution and coverage requirements will vary and have a significant impact on network design and implementation. The section is intended to provide some guidelines and practical advice on the design and development of a network, but it cannot be entirely comprehensive. Planners should use their own knowledge and judgement on which parts are appropriate to their needs. In particular, the section on Coordination and Conformity (sections 5.1 and 5.2) are likely to be applicable only in some parts of the world.

5.1 Coordination

A plan for a new SFN will either be based on an existing allotment in a Plan (for example, the GE06 Plan), or represent a new requirement which will require coordination. The coordination process itself is outside the scope of this Report. Once coordination is successfully completed the transmitter network can be implemented. At this point some additional transmitter characteristics specific to SFN will need to be considered. These are the self-interference caused within the network and transmitter synchronisation.

5.2 Conformity with the Plan Entry

If the SFN is represented in a Plan by an allotment, then the assignments used to implement the allotment must be in conformity with the Plan Entry. Details on how to check conformity will normally be given in the Plan's accompanying document (for example, the GE06 Plan is accompanied by the GE06 Agreement, which contains these details). Most usually, calculations of outgoing field strengths are made to a series of Test Points outside the allotment area. Any proposed assignments will need to generate less than an agreed level of interference at each of those Test Points to be in conformity with the Plan Entry.

Should the required transmitter network not be in conformity with the Plan Entry, further coordination with neighbouring administrations will be necessary, according to procedures in the appropriate Regional Agreement or in the Radio Regulations.

5.3 Self interference

In an SFN it is possible for signals to arrive from distant transmitters outside the guard interval. Signals outside the guard interval can cause self-interference in the network. Although it may only occur for short percentages of time it does need to be considered. Self-interference can be reduced by either advancing or delaying the launch of the service from some transmitters in relation to a fixed reference.

Signals exceeding guard interval may arrive from distant SFN sites by the abnormal propagation. Possible solutions for such cases could include assigning the other channels than the SFN, or building complementary transmitting sites.

5.4 Transmitter synchronisation

In order for an SFN to operate correctly all of the transmitters in the network need to be synchronised with one another. This requirement is true in both the frequency and time domains.

5.5 Frequency synchronisation

The frequency accuracy of the digital transmitter will normally be very stable. However in order to minimise any drift all transmitters should be locked to a reference source, for instance with GPS.

5.6 Timing synchronisation

In order to reduce intra network interference it is possible to adjust the time at which a specific signal frame is launched from each transmitter of the network, the relative transmitter timing. Optimising this delay allows the signals from both near and distant transmitters to arrive at the receiver within the guard interval, thus being constructive rather than destructive. The relative transmitter timing can be adjusted to be either in advance of or after the reference point.

However, in all cases the time of signal transmission at each transmitter of the network needs to be referenced to a time reference. Distribution of the service content also needs to be considered so that the same data frame is transmitted during the same time period, either with or without any required delay. Over a large, e.g. national, network the arrival of the content information to transmitters may vary significantly. One option is to feed the content signal directly to the network sites using satellite distribution.

In a small SFN, i.e. one that is not larger in diameter than the signal can travel in the guard interval, it should not be necessary to consider this element of network planning.

When initially designing the network configuration the planner needs to predict both the wanted coverage and the interference potential of each transmitter. These predictions should be carried out at 50% time for the wanted service and 1% time for the interferer. With the relative timing delay set to zero the coverage of the whole network can be derived. At which point the overall interference caused by each transmitter into the SFN can then be calculated.

In general it will be the highest power assignments which will cause the most interference and it is reasonable to focus on them initially. However, adjusting the timing of sites with lower e.r.p.s. can lead to significant coverage gains around the periphery of their service areas.

Transmitter that can interfere with should ideally be identified during the planning of the network. Once the destructive transmitters have been identified the network timings can be adjusted and the interference recalculated. It should be noted that the transmitter causing the greatest interference may not be the one to adjust since a change may simply cause a problem in a different part of the network. It may be a better strategy to retard the smaller site(s) so that their signals are received within the guard interval of the distant high power site.

Consideration should also be given to how receiver synchronization is implemented in the prediction models.

5.7 Effect of synchronisation loss

If a transmitter is allowed to drift out of synchronisation with the rest of the network it will become a source of interference to the coverage of the rest of the network. This will be noticeable as an area of lost coverage toward the periphery of the un-synchronised transmitter’s coverage area, a “mush” zone. As the transmitter drifts further out of synchronisation with the rest of the network the mush zone will become progressively larger. It should be noted that reception close to the drifting transmitter, where received field strengths are high, are unlikely to be affected.

Part 2

SFN application and implementation of DVB-T, DVB-T2 and DAB system

1 Multipath capability of DVB-T, DVB-T2 and T-DAB

1.1 General

In OFDM the information is carried via a large number of individual carriers in a frequency multiplex. Each carrier transports only a relatively small amount of information and high data capacities are achieved by using a large number of carriers within a frequency multiplex. The individual carriers are modulated by means of phase shift and amplitude modulation techniques. Each carrier has a fixed phase and amplitude for a certain time duration during which a small portion of the information is carried. This unit of data is called a symbol; the time it lasts is called the symbol duration. After that time period the modulation is changed and the next symbol carries the next portion of information.

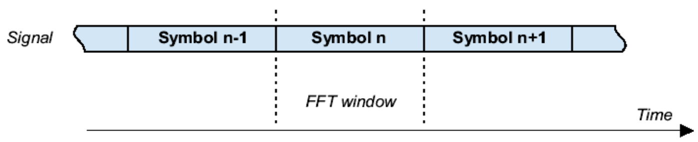
A DVB-T, DVB-T2 or T-DAB receiver has to cope with the adverse conditions of the broadcast transmission channel. In general, signals arriving at a receiver by different paths show different time delays which result in inter-symbol interference (ISI), a degradation in reception. An OFDM system with a multipath capability allows for the constructive combination of such signals. This is achieved by inserting a guard interval, a cyclic prolongation of the useful symbol duration of the signal. The FFT-window, i.e. the time period for the OFDM demodulation, is then positioned in such a way that a minimum of inter-symbol interference occurs.

1.2 Inter-symbol interference

In order to demodulate the signal – and looking at only one carrier – the receiver has to evaluate the symbol during the symbol duration. Three consecutive symbols in time, denoted by n-1, n and n+1, and the setting of the FFT-window such that symbol n is evaluated by the receiver, are shown in Fig. P2-1. No guard interval is used in this example, and the FFT-window has the same duration as the symbol.

FIGURE P2-1

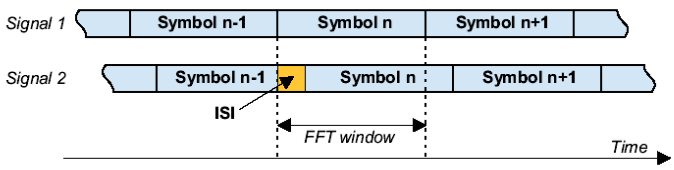
OFDM symbol duration and FFT-window (no guard interval)



In an environment where several useful signals—either from multipath echoes or from other transmitters in an SFN—are available to the receiver, things become more complex. Usually, the signals arrive at different times at the receiver which, in the absence of a guard interval, makes correct synchronisation to all of the signals impossible. Such a situation with two signals as an example is depicted in Fig. P2-2. Synchronisation to symbol n of signal 1 leads to an overlap of the FFT-window with the preceding symbol n–1 of the delayed signal 2. Since this symbol n–1 carries different information from symbol n, the overlap acts as interference to the evaluation of symbol n. The degradation of the reception caused by this mechanism is called inter-symbol interference (ISI).

FIGURE P2-2

Inter-symbol interference with a delayed signal (no guard interval)

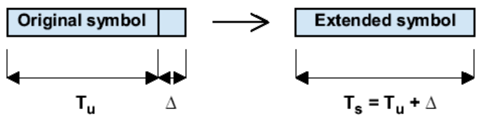


1.3 Guard interval

In order to overcome the inter-symbol interference problem in DVB-T, DVB-T2 and T-DAB, part of the symbol is copied from the beginning of the symbol to the end, increasing its duration by a certain amount of time called the guard interval. This cyclic prolongation of the original symbol is shown in Fig. P2-3. The guard interval is denoted by Δ.

FIGURE P2-3

Increase of the symbol duration by the guard interval

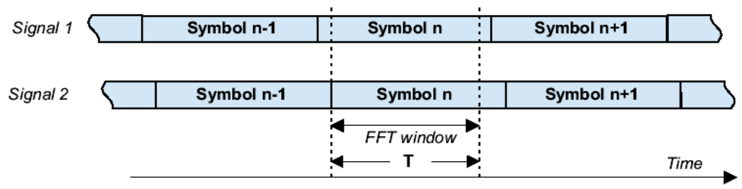


The new increased symbol duration is denoted by T_S and the original symbol duration is often called useful symbol duration T_u. The duration of the FFT-window during which the symbol is evaluated is kept at the original value T_u. The orthogonal relationship is kept with the original symbol duration T_u, not the extended T_S.

The improvement that is achieved by the insertion of the guard interval can be seen from Fig. P2-4 with two signals as an example. The guard interval now allows for the FFT-window to be positioned so that there is no overlap with a preceding or subsequent symbol, thus avoiding ISI.

FIGURE P2-4

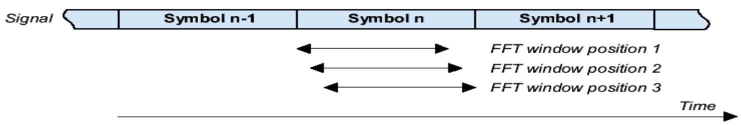
Guard interval utilisation



The fact that the duration of the FFT-window is now smaller than the symbol duration allows for a variety of different possible FFT-window positions for the evaluation of a symbol. This is indicated in Fig. P2-5 for the simple case of synchronisation to a single signal. Three possible FFT-window positions are indicated as examples. Here, all positions are equivalent with regard to evaluation of the symbol because all the FFT-window positions shown include samples from only one symbol.

FIGURE P2-5

Three possible FFT-window positions



The insertion of the guard interval reduces the data capacity because not all of the symbol duration T_s is used for "useful" data.

In a multipath or SFN environment, where many potentially useful signals are available to the receiver, the choice of the FFT-window position becomes more complex. A number of different strategies that can be applied are discussed in the next chapter.

All signals with time delays that cannot be absorbed by the guard interval in the way described above introduce a degradation of reception, similar to that shown in Fig. P2-2. Any part of each of these received signals that falls outside the guard interval has an interfering characteristic, which will be dealt with in more detail in paragraph 1.4.

OFDM, due to its multicarrier nature, exhibits relatively long symbols. This long symbol period already provides a certain degree of protection against inter-symbol interference caused by multipath propagation. However, as described above, this protection is greatly enhanced by use of the guard interval. The guard intervals for the 2k and 8k DVB-T systems are given in Table P2-1 below.

TABLE P2-1

Guard interval durations (from ETSI EN 300 744 v1.6.1).

Mode	**8k mode**				**2k mode**			
	Guard Interval							
	1/4	1/8	1/16	1/32	1/4	1/8	1/16	1/32
8 MHz channel	224 µs	112 µs	56 µs	28 µs	56 µs	28 µs	14 µs	7 µs
7 MHz channel	256 µs	128 µs	64 µs	32 µs	64 µs	32 µs	16 µs	8 µs
6 MHz channel	*298.667 µs*	*149.333 µs*	*74.667 µs*	*37.333 µs*	*74.667 µs*	*37.333 µs*	*18.667 µs*	*9.333 µs*

NOTE – values in italics are approximate values.

As the proportion of the symbol used to make the guard interval is increased, the transmission capacity decreases. However, if a system with a greater number of carriers were used, the symbol period would increase and therefore the same proportion of guard interval would give a greater protection in terms of absolute time. However, increasing the number of carriers has also some drawbacks:

– higher complexity (FFT performed on a higher number of samples and more memory)

– higher sensitivity to tuner phase noise.

The following table gives the absolute guard interval duration Δ, expressed in multiples of the elementary period T[2] for each combination of FFT size and guard interval fraction for DVB-T2 system.

TABLE P2-2

Duration of the guard interval in terms of the elementary period T (from Table 67 ETSI EN 302 755 v1.3.1)

FFT size	Guard interval fraction (Δ/T_u)						
	1/128	1/32	1/16	19/256	1/8	19/128	1/4
32K	256T	1 024T	2 048T	2 432T	4 096T	4 864T	NA
16K	128T	512T	1 024T	1 216T	2 048T	2 432T	4 096T
8K	64T	256T	512T	608T	1 024T	1 216T	2 048T
4K	NA	128T	256T	NA	512T	NA	1 024T
2K	NA	64T	128T	NA	256T	NA	512T
1K	NA	NA	64T	NA	128T	NA	256T
NOTE – There are further restrictions on the combinations of FFT size and guard interval allowed for T2-Lite							

The guard interval for T-DAB Mode I (the most suitable for terrestrial SFN in VHF band) is ¼ of the symbol period (246 μs) (see Table 38 of ETSI EN 300 401 v1.4.1).

1.4 Contributing and interfering signal components with inter-symbol interference

For network planning, the power of all the echoes received within a window of duration Δ (guard interval width) is considered as useful, and contributes positively to the total available signal power. Outside the guard interval, a part of the echo power is associated with the same OFDM symbol as the primary signal, and which therefore contributes positively to the total useful signal power.

Another part of the echo power is associated with the previous or subsequent OFDM symbol and produces ISI, which has a similar effect to uncorrelated Gaussian noise interference. Therefore, as the echo delay is progressively increased beyond the guard interval, the useful contribution decreases and the ISI increases with a quadratic law. The echo power becomes fully interfering (i.e. it contains no useful power) when the delay is larger than or equal to one OFDM symbol.

DVB-T

Moreover, with DVB-T there is a further degradation mechanism effective: the channel estimation process in the receiver, for constellation equalisation and coherent detection, is based on a frequency domain interpolation filter, which allows recovering of the channel response from the scattered pilot carriers. The pass-band T_p of this filter is designed to be larger than the guard interval ($\Delta=T_u/4$) (3), but, because of theoretical limitations, cannot exceed $T_u/3$ (practical figures are up to $T_p= (7/24)T_u$ for a sophisticated receiver). The following cases can take place:

– the echo is within the guard interval Δ: its power adds to the "useful" signals;

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[2] The elementary period T is specified for each bandwidth in table 65 of ETSI EN 302 755 v1.3.1.

[3] For smaller guard intervals (e.g. $\Delta=T_u/8,..., T_u/32$), it can be assumed that the interpolator filter bandwidth remains the same as for $T_u/4$.

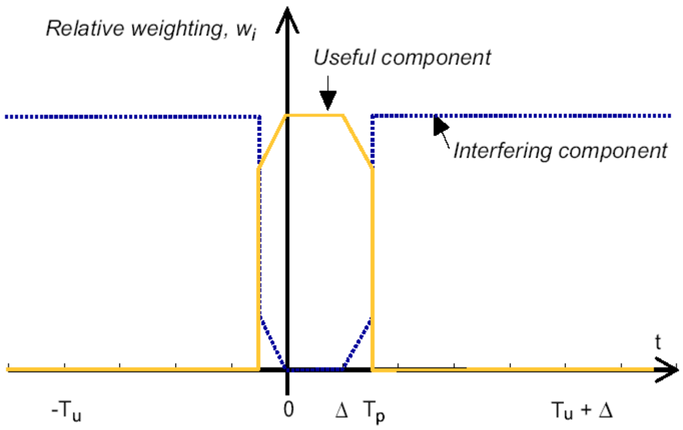
– the echo is outside Δ, but within T_p: it is correctly equalised, but is split into a useful component (relevant to the actual OFDM symbol) and an interfering component (relevant to the previous OFDM symbol), as described in the formula below;

– the echo is outside T_p: it is to be considered as pure interference, with the same effect as an equal-power Gaussian noise.

The situation for DVB-T is depicted in Fig. P2-6.

FIGURE P2- 6

DVB-T model - Splitting of the signal power into contributing and interfering components.



Mathematically, the rule for splitting the signal power into a useful component and an interfering component is expressed as follows:

$$w_i = \begin{cases} 0 & if \quad t \le \Delta - T_p \\ \left(\dfrac{T_u + t}{T_u}\right)^2 & if \quad \Delta - T_p < t \le 0 \\ 1 & if \quad 0 \le t \le \Delta \\ \left(\dfrac{(T_u + \Delta) - t}{T_u}\right)^2 & if \quad \Delta < t \le T_p \\ 0 & if \quad T_p < t \end{cases}$$

$$C = \sum_i w_i C_i$$

$$I = \sum_i (1 - w_i) C_i$$

where:

C_i : is the power contribution from the i-th signal at the receiver input

C : is the total power of the effective useful signal

I : is the total effective interfering power

w_i : is the weighting coefficient for the i-th component

T_u : is the useful symbol length

Δ : is the guard interval length

t : is the signal arrival time

T_p : is the interval during which signals usefully contribute.

It should be remembered that *I*, the total effective interfering power, is weighted by the appropriate DVB-T-to-DVB-T protection ratio when being regarded as a source of interference in a coverage calculation.

As already mentioned, a value of $T_u/3$ is regarded as a theoretical limit for T_p, and would require an interpolation filter with an infinite number of taps. The formula $T_p = 7T_u/24$ is often quoted and this gives a sensible practical limit given real filter design. At the present time, many DVB-T receivers do not even reach this performance.

DVB-T2

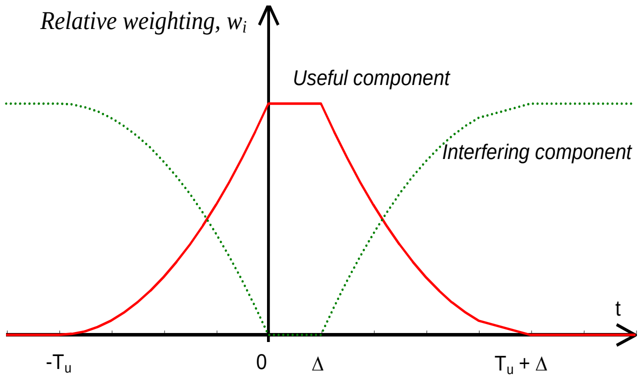
See Report ITU-R BT.2254.

T-DAB

T-DAB uses differential demodulation. Therefore, the restrictions arising from the interpolation filter for the channel estimation do not exist for T-DAB and the degradation function looks slightly different. It is depicted in Fig. P2-7.

FIGURE P2-7

T-DAB model - Splitting of the signal power into useful and interfering components



For T-DAB, the rule for splitting the signal power into a useful component and an interfering component is expressed as follows:

$$w_i = \begin{cases} 0 & if \quad t \le -T_u \\ \left(\dfrac{T_u + t}{T_u}\right)^2 & if \quad -T_u < t \le 0 \\ 1 & if \quad 0 < t \le \Delta \\ \left(\dfrac{(T_u + \Delta) - t}{T_u}\right)^2 & if \quad \Delta < t \le T_u + \Delta \\ 0 & if \quad t > T_u + \Delta \end{cases}$$

$$C = \sum_i w_i C_i$$

$$I = \sum_i (1 - w_i) C_i$$

where:

- C_i : is the power contribution from the *i*-th signal at the receiver input
- C : is the total power of the effective useful signal
- I : is the total effective interfering power
- w_i : is the weighting coefficient for the *i*-th component
- T_u : is the useful symbol length
- Δ : is the guard interval length
- t : is the signal arrival time.

It must be borne in mind that *I*, the total effective interfering power, is weighted by the established T-DAB-to-T-DAB protection ratio when being regarded as a source of interference in a coverage calculation.

2 FFT-window synchronisation

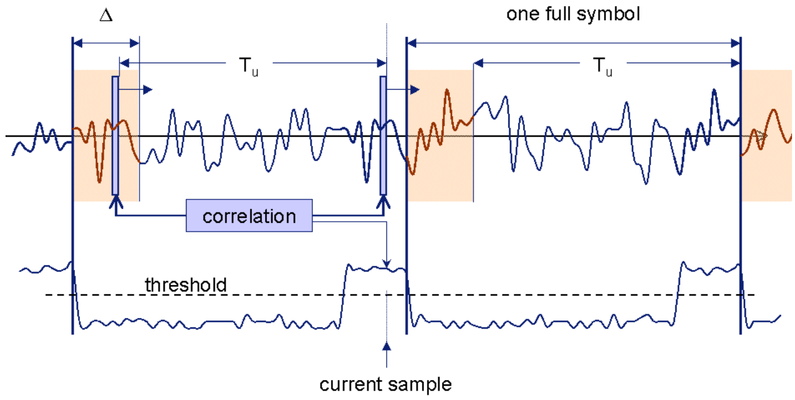
2.1 General

The synchronisation of an OFDM receiver is performed in two stages: the initial synchronisation in which the receiver is aligned with the symbol rate, and the secondary synchronisation in which the receiver positions the FFT-window to demodulate the signal.

The initial synchronisation is normally done by correlating samples taken T_u apart in time. When the waveform repeats, as shown in Fig. P2-8, the correlator output exceeds a threshold value. From this the receiver can detect the start of a new symbol period.

FIGURE P2-8

Initial Receiver Synchronisation (image courtesy of Philips Ltd)



In a real multipath environment, the receiver encounters a multitude of echoes that make the second-stage synchronisation process, i.e. finding the “best” position for the FFT-window, a complex task. As a consequence, various strategies can be applied in order to optimize the receiver performance.

For coverage calculations a model is needed to describe the synchronisation performance of real receivers. A natural way to describe the reception situation in planning simulation tools would be to model real receiver behaviour. Unfortunately, the receiver FFT-window positioning is not prescribed in detail in the DVB-T, DVB-T2 or T-DAB system specifications. This means that all manufacturers have their own solutions and, moreover, regard these various solutions as confidential, making a single description of receiver FFT-window positioning difficult.

A detailed consideration of the difference between direct signals and echoes is relevant at this stage. In an MFN, where each transmitter acts independently on its own frequency, the receiver may get one direct signal and a number of scattered echoes. The direct signal is not necessarily the strongest signal nor is there necessarily a direct signal at all, particularly in the case of portable or mobile reception. On the other hand, there are also cases where there is only the direct signal present. In a SFN, all transmitters in the network use the same channel. In this case, the receiver gets a number of direct signals and a number of scattered echoes.

The difference between direct signals and echoes becomes important in the computer simulation of a coverage calculation.

Most coverage prediction methods use two dimensional (2-D) prediction models taking into account only the direct path. Therefore in an MFN, the modelling of the FFT-window positioning is simple and unique since there is only one direct path present. In an SFN, receiver synchronisation modelling is no longer unique since there are usually several direct path signals present.

In some three-dimensional (3-D) prediction models a multipath propagation environment for each transmitter is considered. Therefore, the FFT-window positioning for an MFN becomes as complex as that for an SFN when 3-D prediction models are used.

A further difference arises from the fact that real receivers have to account for the time variation of the transmission channel, whereas software modelling of the receiver FFT-window positioning usually assumes a static reception situation. This, to some extent, is justified by the different time scales of successive synchronisation instants and the time variation of shadow fading in a transmission channel. But it means that a real receiver will not show exactly the same synchronisation behaviour as that described in the simple model cases below.

2.2 Synchronisation strategies

This chapter describes five different strategies for second-stage synchronisation (i.e. positioning of the FFT-window) that are commonly used in receiver modelling. Four of them are relatively simple, straightforward strategies, while the fifth is an idealised, optimal strategy.

FFT-window synchronisation is of particular importance for mobile and portable reception, when the receiver will need to be able to synchronise in a rapidly changing environment and in the presence of pre- and post-echoes.

The strategy employed by a receiver determines which peak in the time-domain impulse response of the received signal is used by the receiver uses for synchronisation, and where the receiver sets the FFT-window relative to this peak.

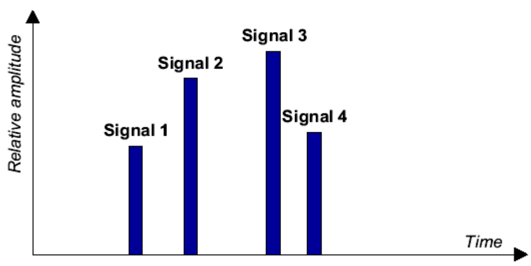
In a single signal environment, the synchronisation configuration is simple and clear. The principle was already explained in the previous chapter and can be seen from, e.g., Figure P2-5. When two or more signals are involved various approaches are possible.

2.3 Strongest signal

A natural approach for the FFT-window positioning is to synchronise to the strongest signal. In order to demonstrate the principle, a configuration with four signals is chosen as an example. Figure P2-9 shows the channel response function for the configuration, where the peaks represent a characteristic time instant of the signals, such as the start of symbol *n*.

FIGURE P2-9

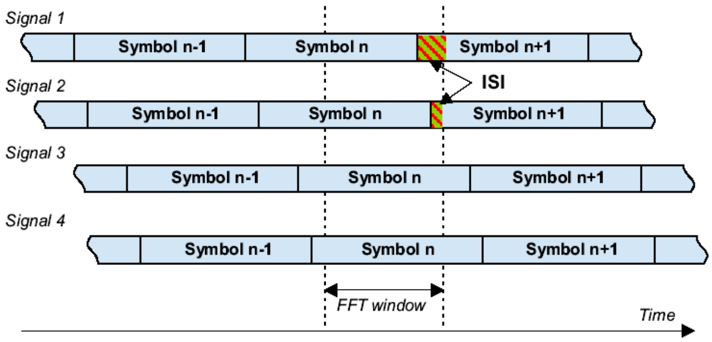
Synchronisation to the strongest signal (signal 3); time-domain impulse response



Signal 3 is the strongest signal. Accordingly, the FFT-window is synchronised to signal 3. Since relevant contributions of further signals may be found preceding signal 3 or following signal 3, it seems reasonable to locate the centre of the FFT-window at the centre of symbol *n* of signal 3. This is depicted in Fig. P2-10. In the example, signals 3 and 4 contribute fully to the evaluation of symbol *n*, whereas the FFT-window exhibits an overlap with symbol *n+1* of signals 1 and 2, which results in a certain amount of ISI.

FIGURE P2-10

Synchronisation to the strongest signal (signal 3) FFT-window position



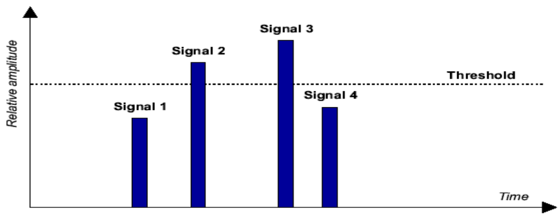
A more sophisticated synchronisation strategy based on the strongest signal approach would not be fixed to the centre of the symbol duration but would check for better positions within the symbol duration of the strongest signal. E.g., in the chosen example it would be advantageous to move the FFT-window a little bit backwards in time to avoid the small amount of ISI arising from the overlap with symbol *n+1* of signal 2. Also the inter-symbol interference from signal 1 would be reduced.

2.4 First signal above a threshold level

This strategy takes the first signal of the time impulse response as a reference for the FFT-window. Normally, a minimum threshold level is necessary for a signal in order to be accepted as a trigger. Again the 4-signal configuration of the previous chapter is taken as an example. The impulse response is given in Fig. P2-11 with the threshold value indicated by a horizontal dashed line.

FIGURE P2-11

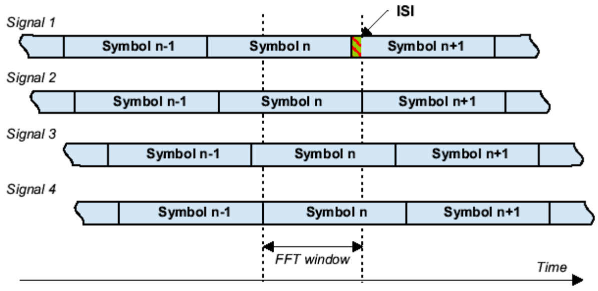
Synchronisation to the first signal above a threshold (signal 2); impulse response



The first signal above the threshold is signal 2. It serves here as the trigger for the FFT-window. If the threshold is chosen reasonably it can be expected that there is no significant signal preceding signal 2, therefore it is logical to align the end of the FFT-window with the end of the symbol *n* of signal 2. This is indicated in Fig. P2-12.

FIGURE P2-12

Synchronisation to the first signal above a threshold (signal 2); FFT-window position



With this synchronisation strategy, in this example, signals 2, 3 and 4 contribute fully constructively, whereas signal 1 adds a certain amount of ISI.

The choice of the threshold value is a specific issue of this synchronisation strategy. It may be taken as the power corresponding to the minimum field strength or, more pragmatically, as a value, say 6 to 10 dB, below the strongest signal.

2.5 Centre of gravity

In this case the receiver looks at the impulse response, calculates the 'centre of gravity' of the impulse response spectrum and centres the FFT-window on that point in time:

$$t_c = \frac{\sum_i p_i t_i}{\sum_i p_i}$$

where:

t_c : centre of gravity

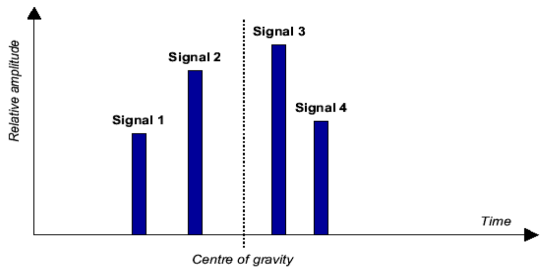
p_i : power of the *i*-th signal of the impulse response

t_i : time of the *i*-th signal of the impulse response.

The impulse response of the chosen example with the corresponding centre of gravity indicated by a dashed line is given in Fig. P2-13.

FIGURE P2-13

Synchronisation to the centre of gravity (between signal 2 and 3); impulse response

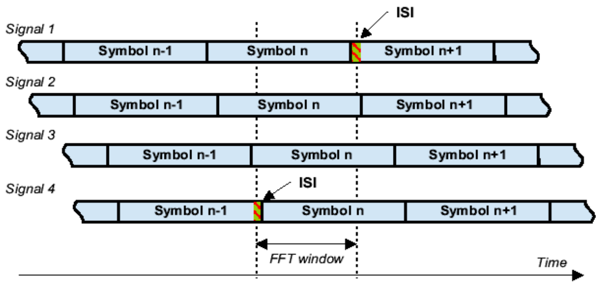


In this example, signals 2 and 3 fully contribute constructively. Signals 1 and 4 show a small amount of inter-symbol interference arising from an overlap of the FFT-window with symbol *n+1* of signal 1 and with symbol *n-1* of signal 4. This is depicted in Fig. P2-14.

The centre of gravity approach responds well to pre-echoes and delayed signals of similar amplitude, since it does not fix the FFT-window to a particular signal but takes into account the average behaviour of the impulse response of the transmission channel. On the other hand, it can lead to ISI in cases where other strategies may not: for example, most two-echo cases, separated by virtually the whole guard interval, would cause this strategy difficulties unless the two echoes were of equal power.

FIGURE P2-14

Synchronisation to the centre of gravity (between signal 2 and 3); FFT-window position



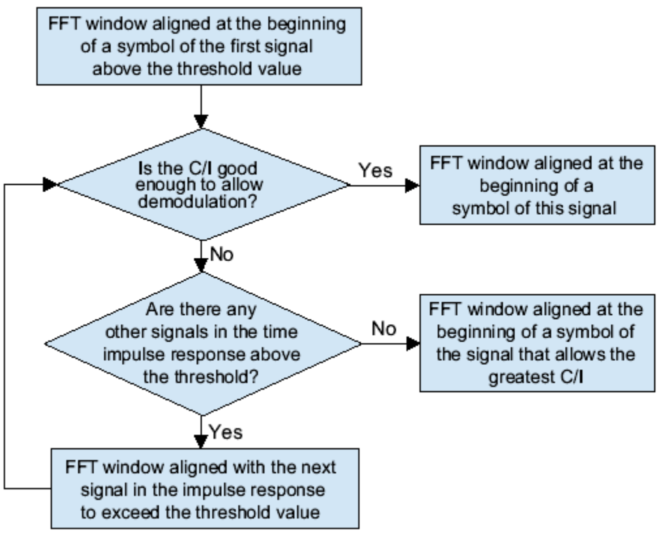
2.6 Quasi-optimal

This strategy builds on that described in the chapter “first signal above a threshold” in an attempt to approach the "Maximum *C/I*" described below.

The first signal of the impulse response above a minimum threshold level is taken as a reference for the FFT-window. The process is described in the flowchart below, Fig. P2-15.

FIGURE P2-15

Flowchart describing the Quasi-Optimal Strategy



s2.7 Maximum *C/I*

Whereas the previously discussed strategies all give means of quickly finding a good FFT-window position, an optimal choice would be a position where the effective *C/I* is maximised. This position, however, is not easily found and would in general take too much time to be calculated. Therefore, normally one of the above simpler strategies, or a combination of them, is applied. Such simpler approaches can be justified by the fact that the optimum *C/I* will often show a relatively flat maximum, i.e. errors introduced by sub-optimal synchronisation are small. But there are also difficult configurations possible, e.g. in a two-echo case, if the difference in delay is close to the guard interval, there is only one position that will result in no ISI, so the optimum here would be very sharp.

Note that the method in the previous chapter (the "Quasi-Optimal" strategy) does not attempt to find a position for the FFT-window that gives the best *C/I*. It merely seeks to find a position for the window at which the *C/I* is good enough to allow demodulation and decoding with an acceptable error rate.

Receiver manufacturers indicate that the evaluation of *C/I* is by no means trivial for a DVB-T receiver, and for a DVB-T mode with a large guard interval of $T_u/4$ there seem to exist theoretical limits for the evaluation of *C/I* which would prevent the application of a "maximum *C/I*" synchronisation strategy in this case.

With regard to receiver modelling in computer simulations, e.g. for coverage calculations, the detection of the maximum *C/I* position of the FFT-window is not a principle problem. A simple but time consuming approach would be to scan the time period of interest with an appropriate step size, calculate the *C/I* for each sampling point and to use the time position with the maximum *C/I* as the reference.

A more sophisticated strategy to find the maximum *C/I* position is based on the observation that the maximum *C/I* is always found at a position where the FFT-window is aligned with the start or the end of one of the incoming signals for the symbol under consideration. A check of all these possible positions, which amounts to 2N evaluations of *C/I* for *N* signals, then gives the maximum *C/I* position. Practical experience shows that the computational effort is about twice that of the basic strategies described in the previous chapters.

3 Site selection and management

Once the planner has a definition of the service requirements the next stage is to consider what resources are available and what sort of transmission network will be required to deliver it. Chapter 1 of Part 1 gives guidance regarding some of the different types of network structures which could be implemented.

The first requirement of any terrestrial broadcast network is the sites at which it is to be implemented. Are the existing broadcast sites sufficient to facilitate the service or are others likely to be required? In some cases more sites will be needed for a digital service than for an analogue one due to the requirement to deliver services to a higher percentage of locations and the use of more difficult reception modes. When considering sites the following criteria should be considered:

– What sites are presently available?
– Existing broadcast sites used at high powers for analogue services may not be appropriate for implementing some types of SFN coverage, due to their distance from population centres and the large distances over which they can cause out-going interference.
– Are rooftop sites within towns and cities more appropriate for delivering the required coverage? Although there may be concerns over high field strengths in populated areas.
– There may be economic advantages using particular sites, for example those already used for broadcasting.
– Is aperture available at the site? If not it may be possible to combine some services, for instance VHF FM and DAB services may be able to share aerial aperture.

– Is there an existing antenna at the site and if so can this be shared? This may not be the case if allotments using the site have different constraints, service areas or implementation rights.
– Consideration might also be required when trying to serve population centres at the edge of an allotment, for example in coastal areas.
– It is becoming more difficult to achieve approval for the use of new sites due to the perceived EMC hazards.

Where multiple services are present in the same area some further considerations may need to be taken into account:

– Whilst adjacent channel digital services can operate in the same area, care should be taken to avoid interference between them. Interference may occur to other services around a transmitter site from which only one of the services is transmitted. In most cases this problem can be resolved by site sharing, even if the services have very different radiated powers and aerial patterns.
– Different types of network, both in terms of size of coverage (local, national etc.) and reception mode may require significantly different transmitter network configurations. This difference may in turn lead to adjacent channel interference problems.
– If a number of different multiplexes are expected to have similar coverage areas, but have very different frequencies allocated to them, use of the same transmission parameters for each will not necessarily deliver this. To facilitate similar coverage differing radiated powers, and possibly, aerial systems may be required.
– It is likely that the interference environment of different frequencies will vary.

4 Coverage and interference management

4.1 General

In an ideal situation the planner can design a network which delivers the required coverage whilst keeping outgoing interference within the levels allowed for the coordinated allotment. However, in reality achieving an acceptable final result will often require a number of compromises, these may not all be of a technical nature.

Whilst the allotment will have been planned to have an acceptable level of in-coming interference it would be advisable to calculate what the actual level is. This will give the minimum usable field strength for the wanted service over the coverage area. This calculation may be difficult to quantify exactly especially where interference comes from unimplemented allotments.

The coverage and interference planning process normally involves a number of steps which may form an iterative loop. The main steps being the calculation of wanted coverage and out-going interference.

4.2 Wanted coverage prediction

In order to start the process a calculation of the wanted coverage should be made. Initially this should only be the coverage provided from the primary sites selected for the service, on the basis that they are likely to be the main sources of out-going interference. Account should be taken of the following factors during the prediction process:

– transmitter powers
– aerial directionality, both in azimuth and the vertical plane
– aerial height

– polarisation
– network gain
– the level of background interference
– the reception mode
– initial signal launch delay

When a good level of coverage is achieved from these sites proceed to the stage described in the paragraph below.

4.3 Out-going interference management

4.3.1 General

Having achieved a good level of coverage from the primary sites the next step is to make your own calculation of the level of out-going interference. There is little point spending a significant period of time producing a final network design at this stage. This is because if the out-going interference is unacceptably high the proposed network will need to be modified significantly. There are different methods of calculating the out-going interference from T-DAB and DVB-T/DVB-T2 allotments; these are considered in the two following sub-sections below.

If the out-going interference exceeds the required limit some steps will need to be taken to resolve the problem. Whilst the options are similar to those available for analogue systems they are detailed below.

– Reduce the radiated power at the worst sites.
– Increase directional restrictions – either in azimuth or VRP.
– Change one or more of the primary sites.
– Can other sites with more terrain shielding be used?
– Can international co-ordination be carried out to increase the allowable levels of out-going interference?

Most of these options will have an impact on the wanted coverage. As a result some amount of re-planning will be required before re-calculating the outgoing interference.

Once the levels of out-going interference and the coverage are acceptable the final network plan should be completed. Since it is expected that the rest of transmitters will be of a lower power or cause less out-going interference they should not cause any significant co-ordination problems. However, it would be advisable to re-calculate the level of the overall network before proceeding further.

4.3.2 Calculation of out-going T-DAB interference

For T-DAB out-going interference is calculated to a set of test points generated specifically for the purpose.

In the T-DAB case it may be possible to relax interference levels at some test points, for instance where they lie either in the sea or within your own country boundary.

4.3.3 Calculation of out-going DVB-T/DVB-T2 interference

In the DVB-T/DVB-T2 case there is no agreed method of calculating out-going interference yet. The allowable levels of out-going interference caused by an allotment are agreed through bilateral and multilateral agreements between the administrations concerned. This means that there may be different methods of calculating the levels of interference and different field strength limits imposed.

5 Post implementation of the network

5.1 Network coverage and improvement

Once the network is in operation some consideration of the following might be appropriate:

– The coverage delivered by the network could be measured in order to confirm that any planned target has been achieved.

– Measurements to confirm that network self-interference is managed correctly.

– Shortfalls in predicted coverage may be filled by the addition of additional gap filling transmitters.

– Gap filling transmitters can also be built to compensate for environmental changes, such as the construction of new buildings.

5.2 Network problems

As mentioned in previous chapters, the transmitters of an SFN need to be synchronised in order to prevent self-interference. If a fault occurs it is possible for a transmitter to lose this synchronisation. The effect is that the transmitter will slowly move out of phase with the ones which surround it and become a source of destructive interference. This will result in a narrow ring of lost coverage developing around, but kilometres away from, the faulty transmitter, although users near to it are unlikely to notice a problem. In the T-DAB case some mobile listeners may only notice a small zone of lost coverage as they pass through it. A fault like this may take a significant time before it manifests itself, and before being identified could have an impact over a significant area.

Changes to coverage may occur due to seasonal variations, such as snow causing reflection points. Problems of this type are extremely difficult to resolve.

The implementation of a new transmitter for service operating on an adjacent channel may cause a problem to an existing service. In such cases users may lose a service for no apparent reason and receivers may still display information for services which are no longer available. This problem can be resolved through the use of a transmitter co-sited with the interferer or avoided through agreements between operators to use common sites.

DVB-T SFN

6 Impact of DVB-T parameters on SFN performance

6.1 Constellation

The DVB-T specification allows for three different phase/amplitude constellations, QPSK (4-QAM), 16-QAM and 64-QAM, in order to meet the different requirements in terms of spectral efficiency and the reliability of the broadcast service.

The choice of constellation determines the number of bits that are carried at a time on each sub-carrier; either 2 bits (QPSK), 4 bits (16-QAM) or 6 bits (64-QAM) may be carried. Moreover, the modulation has an important impact on the performance in a SFN as the choice of constellation also determines noise tolerance, with QPSK being around 4 to 5 times more tolerant than 64-QAM.

QPSK provides a low data capacity but it does provide a very rugged service. Networks using QPSK may be of particular value in urban areas for services to pedestrians and vehicles.

16-QAM provides a moderate capacity and, therefore, this variant may be of interest for providing reasonably rugged services to medium or densely populated areas.

64-QAM variant has a high data capacity but does not provide rugged services and is particularly sensitive to self-interference effects in large area SFN.

6.2 Code rate

Different code rates can be used to trade bit rate versus ruggedness, e.g. the signal strength required and interference protection required.

The code rate of 1/2 has the highest redundancy and in doing so the highest transmission safety albeit at the cost of data throughput. This mode should only be applied to channels that have a high degree of interference. The variants using code rates higher than 3/4 offer additional capacity but may be not worthwhile as the system becomes less rugged. For code rates 5/6 and 7/8 the implementation margins may also be higher than expected making those variants even less attractive. The code rate of 7/8 has the lowest redundancy but the highest throughput. As such, it should only be used for channels with low levels of interference.
In the case of mobile reception under SFN environment, since the speed of the mobile receiving terminal relative to different transmitters is often different, this will result in strong Doppler effects, which have to be dealt with by channel estimation and error correction system. A lower rate of convolutional coding like 1/2 is thus recommended for mobile implementation.

6.3 2k/8k FFT

The DVB-T standard defines two FFT modes (2k and 8k) each using different numbers of sub-carriers (2048 and 8192) to constitute the OFDM signal. This means different symbol times T_u = 896 µs and T_u = 224 µs.

The 8k FFT systems provide a higher degree of protection against inter-symbol interference caused by multipath propagation. The use of a higher number of carriers within the same bandwidth increases the symbol period (in order to preserve orthogonality) and therefore the same proportion of guard interval gives a greater protection. In the 2k FFT systems, signal delays that exceed the guard interval are very much more conspicuous due to the considerably shorter usable symbol time of 224 µs. Thus, the 2k FFT systems are not meant for large area SFN.

However, the 8k FFT mode presents a higher complexity and a higher sensitivity to tuner phase noise and may be less suitable for mobile reception. The DVB-T 2k FFT systems can withstand moving echoes up to several hundreds Hz. Therefore, this mode is superior for mobile applications.

The working frequency of each SFN transmitter should be accurately managed and monitored. For COFDM SFN operation, the stability and the accuracy of the transmitter’s working frequency shall ensure that each sub-carrier has the same absolute frequency position in the RF channel.

6.4 Guard interval

In an SFN each transmitter is required to radiate the same OFDM symbol at the same time. This comes from the fact that echoes (natural or artificially generated by co-channel transmitters) shall be confined in the guard interval period. The OFDM receiver has to setup a time-window during which it samples the on-air OFDM signal. The objective is to synchronize this time-window with the useful period of the OFDM symbol. Accordingly, it will ignore the signal during the guard interval period where the receiver signal is made of a mixture of two or more OFDM symbols. If the transmitters deliver the same OFDM symbol at the same instant, or with a sufficiently small time delay, the differential propagation path delay to the OFDM receiver will remain inside the guard interval period. Accordingly, the sum of the received signals will be constructive because they constitute the same OFDM symbol (no inter-symbol interference).

The DVB-T specification offers a selection of system guard intervals, i.e., 1/32, 1/16, 1/8 or 1/4 times the duration of the useful symbol duration. For 8k(2k) mode, 8 MHz channel, this represents a permitted guard interval duration of 28(7) µs, 56(14) µs, 112(28) µs and 224(56) µs, respectively.

The selection of the appropriate guard interval parameter for digital terrestrial television affords resilience against delayed, interference–causing signals in television reception. Moreover, the guard interval value chosen to operate an SFN has a major implication on the topology of the SFN network: as the guard interval duration governs the maximum echoes delay admissible by the system, it governs accordingly the maximum possible distance between co-channel transmitters (producing active echoes). Some modes allow setting up large SFN networks having a great distance between high and medium power transmitters sites. Some others allow smaller service areas with a greater density of low power transmitters.

The recommendation given in the Implementation Guidelines ETSI TR 101-190 v1.3.2 for DVB-T is that guard interval selection should be based on the distance between the transmitters. The spacing between adjacent transmitters in an SFN should not be significantly greater than the propagation time permitted in the guard interval:

In a 2k-FFT – 8 MHz channel system the guard interval values are: 7 µs, 14 µs, 28 µs, 56 µs. These values translated into distance give respectively: 2.1 km, 4.2 km, 8.4 km, and 16.8 km.

In an 8k-FFT – 8 MHz channel system the guard interval values are: 28 µs, 56 µs, 112 µs, 224 µs. These values translated into distance give: 8.4 km, 16.8 km, 33.6 km, and 67.2 km (Table 5 ETSI EN 300 744 v1.6.1).

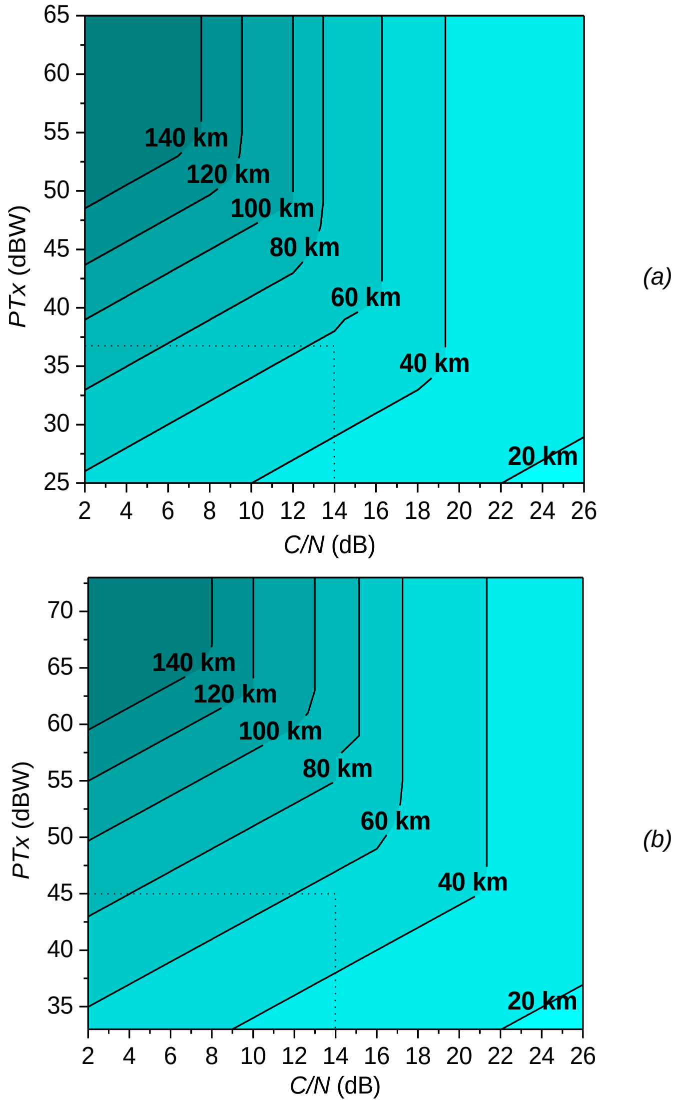
For an 8k-FFT – 8 MHz channel system and guard interval of 1/4 it means that the permissible signal delay times are outside the signal delay between adjacent transmitters, when these transmitters are situated less than 67.2 km apart.

Values for 6 and 7 MHz channel systems can be found in tables E.2 and E.4 of ETSI EN 300 744 v1.6.1.

Studies on the maximum distance between transmitters in theoretical SFN for DVB-T and T-DAB systems have shown that together with the guard interval the maximum inter-transmitter distance is influenced by the system variant required and the effective radiated power of the transmitters in the network.

FIGURE P2-16

Dependence of the maximum distance between transmitters in a DVB-T SFN on the e.r.p. and minimum required *C/N* for coverage target of 100%: (a) portable outdoor reception with 95% of location probability in Band III; (b) portable outdoor reception with 95% of location probability in Band IV.

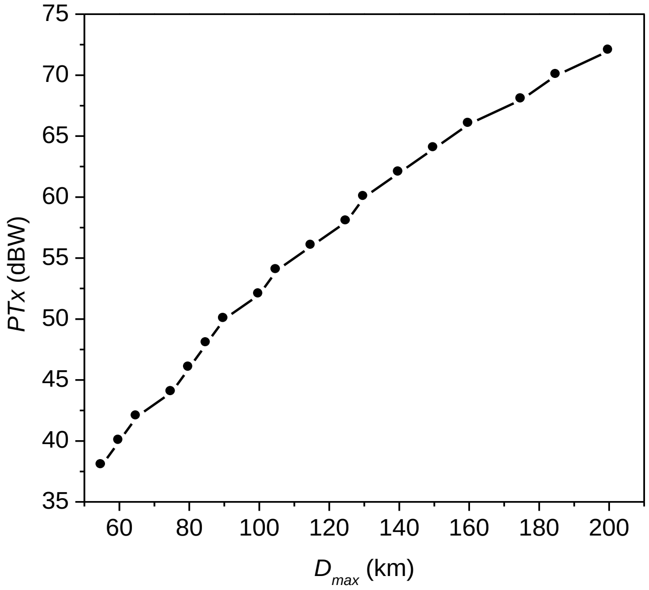


For a given DVB-T system variant there exists an optimal SFN size with a proper radiated power of transmitters. The influence of *C/N* required by DVB-T system and the e.r.p. of the transmitters (P_{Tx}) on the maximum distance between transmitters D_{max} in the SFN to reach 100% of the coverage is presented in Fig. P2-16 for different frequency bands. With an increase of *C/N* and at fixed power levels, D_{max} should be decreased in order to maintain self-interference free SFN coverage. Increase of D_{max} could be obtained by augmenting the power radiated by transmitters in the SFN. However, this could be done up to a certain e.r.p. value only. After this limit the self-interference effects result in a degradation of the SFN coverage. This is reflected by vertical lines in Fig. P2-16.

Because of the long guard interval (246 µs) and the relatively low required *C/N* (15 dB) in the case of T-DAB the size of the SFN is only limited by the e.r.p. of the transmitters but not by self-interference. This is demonstrated in Fig. P2-17. The maximum distance increases as the power radiated by the SFN transmitters augments. It should be also mentioned that T-DAB is characterised by less rapid performance degradation versus the echo delay as DVB-T.

FIGURE P2-17

Dependence of the distance between transmitters in a T-DAB SFN on the e.r.p. for a coverage target of 100% at portable indoor reception with 95% of location probability in Band III.



Transmitter spacing can be increased beyond that defined by the guard interval by varying the radiated power, transmission polarisation and the relative transmitter timing. Effective planning of the required radiated power and transmission polarisation at the secondary site(s) will optimise SFN performance and provide effective management to eliminate most potential interference problems.

There is no limit on transmitter spacing providing the secondary site has a directional antenna transmitting away from the main site utilising an appropriate delay. However, where two transmit sites are radiating towards each other careful planning is required.

6.5 Data rate versus guard interval

Because the guard interval reduces the amount of time available for data transmission, its setting has an effect on the DVB-T net deliverable bit rate. Lengthening the guard interval decreases the bit rate. The guard interval 1/32, 1/16, 1/8, 1/4 produce respectively a loss of 3.1%, 6.2%, 12.5% and 25% in the transmitted bit rate. Table P2-3 indicates the net bit rate in Mbit/s for various modulations, combinations of guard interval settings and error protection code rates. The data are given for the bandwidth of 8 MHz and 7 MHz (in brackets) (for 6 MHz channel, see Table E.3 of ETSI EN 300 744 v1.6.1).

TABLE P2-3

DVB-T net bit rate in Mbit/s; 8 MHz bandwidth (in brackets for 7 MHz bandwidth)

Modulation	Code rate	Guard interval			
		1/4	1/8	1/16	1/32
QPSK	1/2	4.98 (4.35)	5.53 (4.84)	5.85 (5.12)	6.03 (5.28)
	2/3	6.64 (5.81)	7.37 (6.45)	7.81 (6.83)	8.04 (7.04)
	3/4	7.46 (6.53)	8.29 (7.26)	8.78 (7.68)	9.05 (7.92)
	5/6	8.29 (7.26)	9.22 (8.06)	9.76 (8.54)	10.05 (8.80)
	7/8	8.71 (7.62)	9.68 (8.47)	10.25 (8.97)	10.56 (8.80)
16-QAM	1/2	9.95 (8.71)	11.06 (9.68)	11.71 (10.25)	12.06 (10.56)
	2/3	13.27 (11.61)	14.75 (12.90)	15.61 (13.66)	16.09 (14.08)
	3/4	14.93 (13.06)	16.59 (14.52)	17.56 (15.37)	18.10 (15.83)
	5/6	16.59 (14.52)	18.43 (16.13)	19.52 (17.08)	20.11 (17.59)
	7/8	17.42 (15.24)	19.35 (16.93)	20.49 (17.93)	21.11 (18.47)
64-QAM	1/2	14.93 (13.06)	16.59 (14.52)	17.56 (15.37)	18.10 (15.83)
	2/3	19.91 (17.42)	22.12 (19.35)	23.42 (20.49)	24.13 (21.11)
	3/4	22.39 (19.60)	24.88 (21.77)	26.35 (23.05)	27.14 (23.75)
	5/6	24.88 (21.77)	27.65 (24.19)	29.35 (25.61)	30.16 (26.39)
	7/8	26.13 (22.86)	29.03 (25.40)	30.74 (26.90)	31.67 (27.71)

To maximise the net bit rate, the guard interval is often chosen as small as possible, reducing accordingly the maximum echoes delay but also the maximum distance between transmitters, thus practically disallowing in many cases to operate 2k-SFN.

FIGURE P2-18

Relation between *C/N*, Profile, net bit rate and guard interval

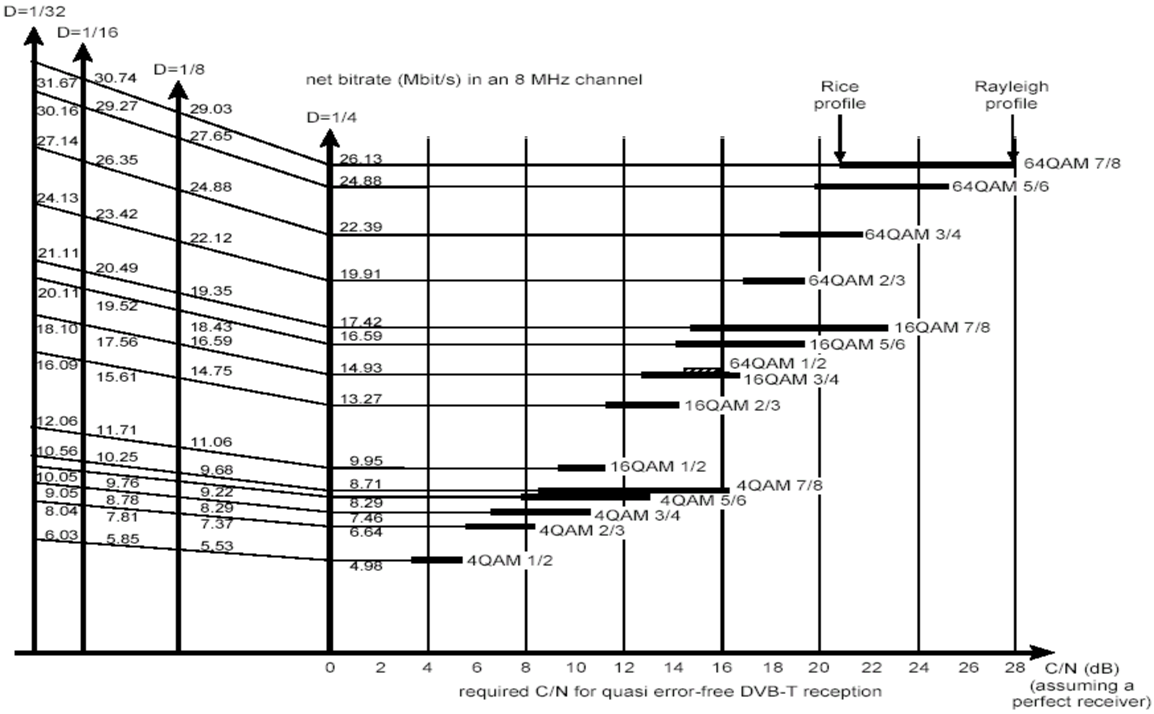


Figure P2-18 gives an overview of the relation between *C/N*, profile, net bit rate and guard interval for the various DVB-T configurations.

7 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.

7.1 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.

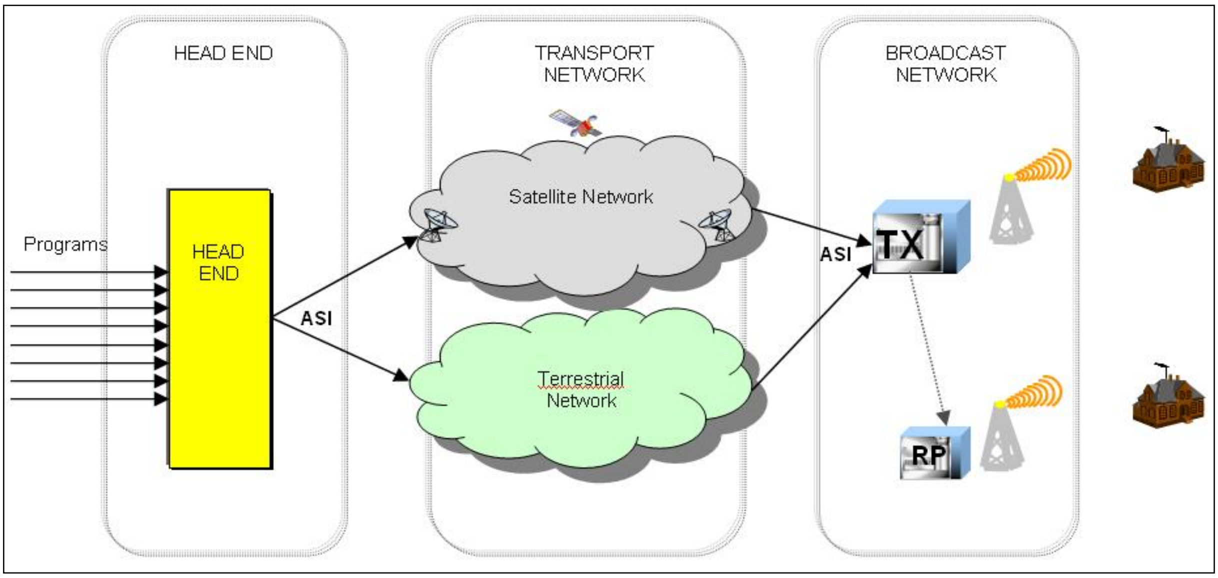
– **Mux1: regional**
  - RAI 1, RAI 2, RAI 3, RAI News, Radio
  - Some other regional programs in specific area
  - > 22 Mbit/s
  - Coverage > 99%
– **Mux2-3-4: national**
  - Thematic channels (RAI Sport, RAI Movie, RAI Scuola, etc.)
  - ≈ 20 Mbit/s
  - Coverage > 90%

– **Mux5: national**
  - RAI HD channels
  - In definition

A logical scheme representing the DVB-T distribution network is highlighted in Fig. P2-19**.**

FIGURE P2-19

DVB-T distribution network



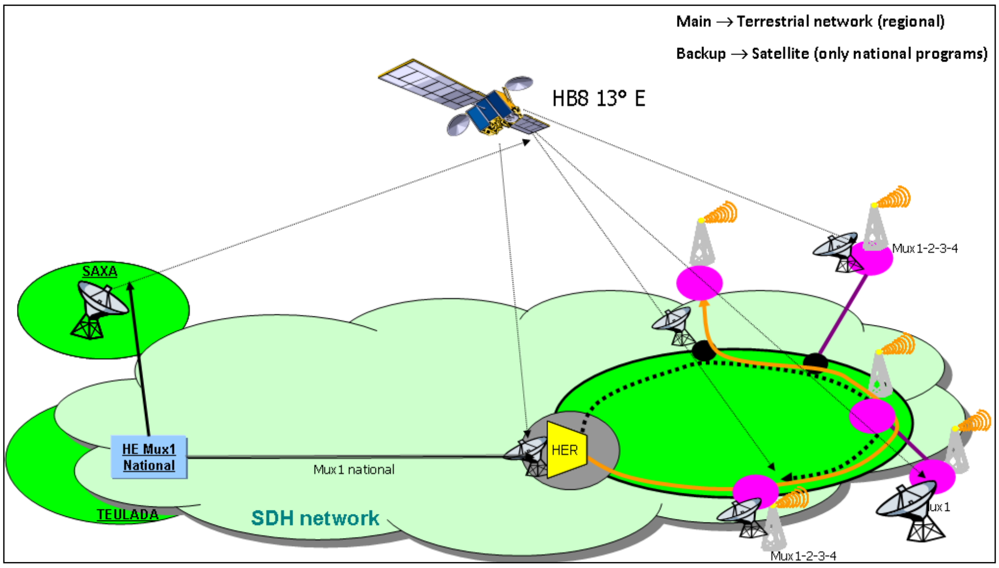
The distribution transport network uses both terrestrial and satellite systems. The terrestrial transmission network is based on radio links and Fibre leased lines from Rome to regional headquarters. This network uses Next Generation SDH technology (consisting of TS packets mapping on SDH VCs). The satellite 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 Fig. P2-20. 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 P2-20

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 paragraph 7.3.

7.2 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 3 000 links use satellite or terrestrial transmission links

– The remaining use UHF transmission links:

  • 6 000 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.

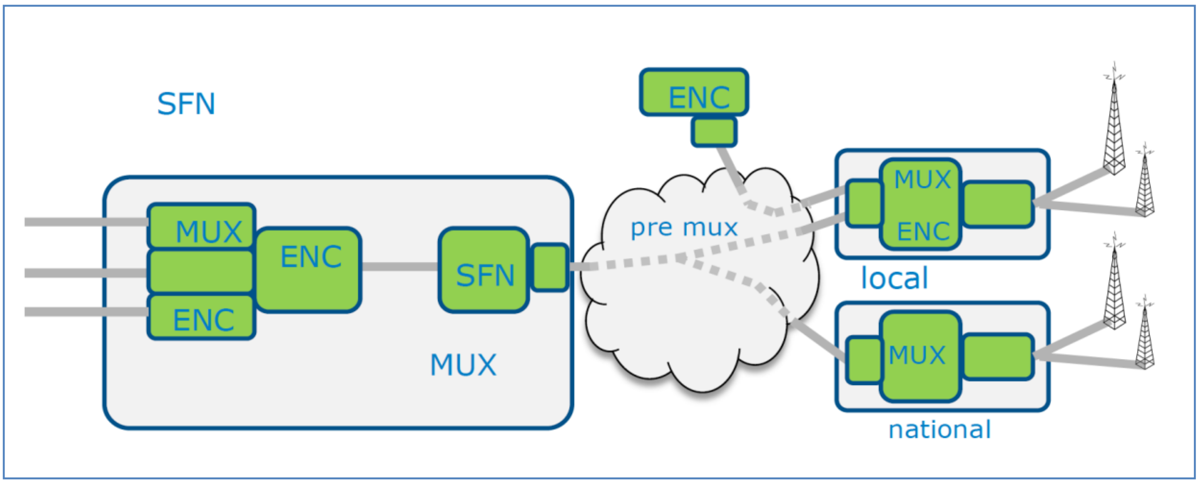
7.3 Distribution of DVB-T/T2 data to the transmitters using IP in Sweden

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 P2-21 broadly shows the architecture of the 'old' DTT distribution network.

FIGURE P2- 21

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

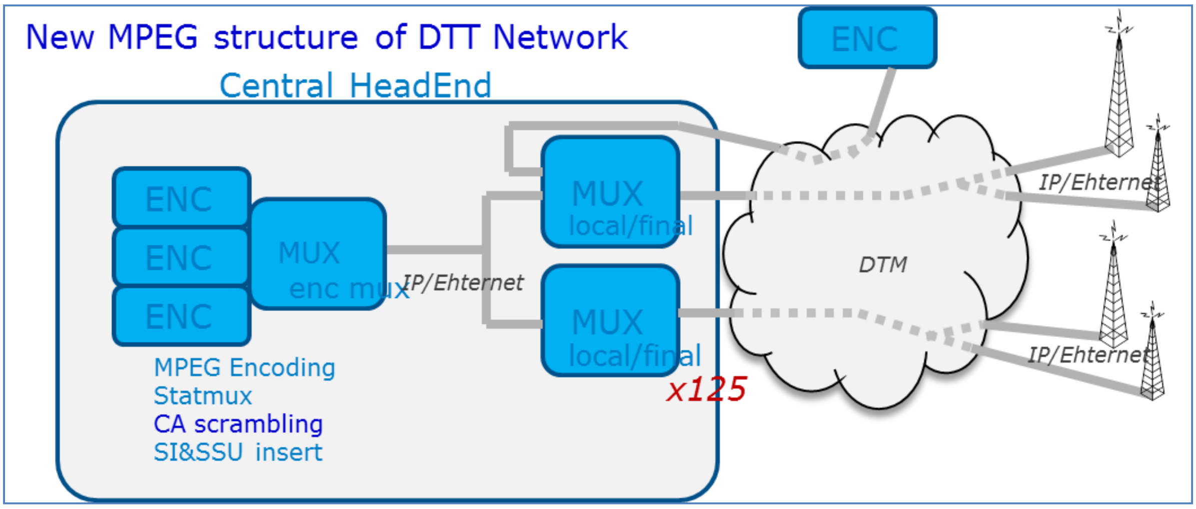


More recently however IP/Ethernet over DTM has been used as the primary distribution mechanism from the central head-end (see Fig. P2-22) to the main DTT transmitters. The newer DTM based distribution network is based on a two layer principle with a high capacity fibre optical core network and a mix 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 (Fig. P2-22) 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 P2-22

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.

8 DVB-T case studies

8.1 National DVB-T SFN deployment in Italy

In Italy switch-off began in 2008 in Sardinia which had been chosen as the trial region for the implementation of a very large SFN.

After the success obtained in this area, the Italian Authority ruled that Italian broadcaster should implement national SFN and authorized the implementation of 21 national DVB-T multiplexes and 4 DVB-H multiplexes, in addition to regional multiplexes (AGCOM resolution 181/09/CONS).

Twenty SFN were set up utilizing one or at most 2 frequencies each one. One SFN (RAI multiplex 1) is the public service multiplex with regional contents, was deployed utilizing 2 VHF frequencies and 12 frequencies in the UHF band. The remaining part of the spectrum reserved to broadcast (VHF and UHF band) was utilized for regional multiplexes.

During recent years the scenario changed: the 800 MHz band was assigned to mobile services and the WRC-12 resolution to allocate the frequency band 694-790 MHz to mobile services on co-primary basis, induced the Italian Administration to review the spectrum attribution.

Resolution 451/13/CONS, as updated by resolution 631/13/CONS, of the Italian Administration established to revise the number of national multiplexes (22 DVB-T multiplexes and none for DVB-sH) and to reduce to 9 the numbers of the UHF channels utilized by Rai multiplex 1, to clear channels from 57 to 60 within the year 2016 and to avoid granting any new licence in the upper part of the 700 MHz band. The licences for DVB-T are granted for at least 20 years. As before, all the national multiplexes, except RAI multiplex 1 (Fig. P2-23), have to be deployed with 1 or at most 2 frequencies.

FIGURE P2-23

Regional SFN of RAI multiplex 1

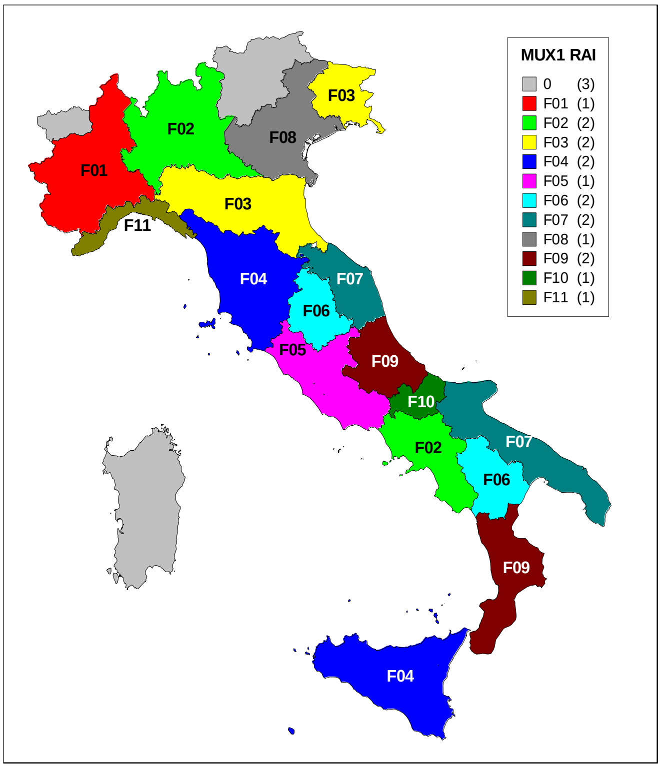


TABLE P2-4

Italian national planned networks

Details	Main channel	Additional channel	Note: the second channel covers usually a small area
2 × SFN	VHF	VHF	
2 × SFN	VHF	UHF	auction
1 × SFN	UHF		
1 × SFN	UHF		
1 × SFN	UHF		
2 × SFN	UHF	UHF	auction
1 × SFN	UHF		
2 × SFN	UHF	UHF	
2 × SFN	UHF	UHF	

Details	Main channel	Additional channel	Note: the second channel covers usually a small area
1 × SFN	UHF		
2 × SFN	UHF	UHF	
1 × SFN	UHF		
1 × SFN	UHF		
1 × SFN	UHF		
1 × SFN	UHF		
2 × SFN	UHF	UHF	The second channel only in Sicily
2 × SFN	UHF	UHF	The second channel only in Sicily
1 × SFN	UHF		
2 × SFN	UHF	UHF	The second channel only in Sicily
2 × SFN	VHF	VHF	auction
1 × SFN and local	VHF	VHF	

Based on these Italians ruling, very large scale SFNs with a frequency reuse factor = 1 are now operating in Italy.

8.1.1 Example of a very large SFN: RAI multiplex 2

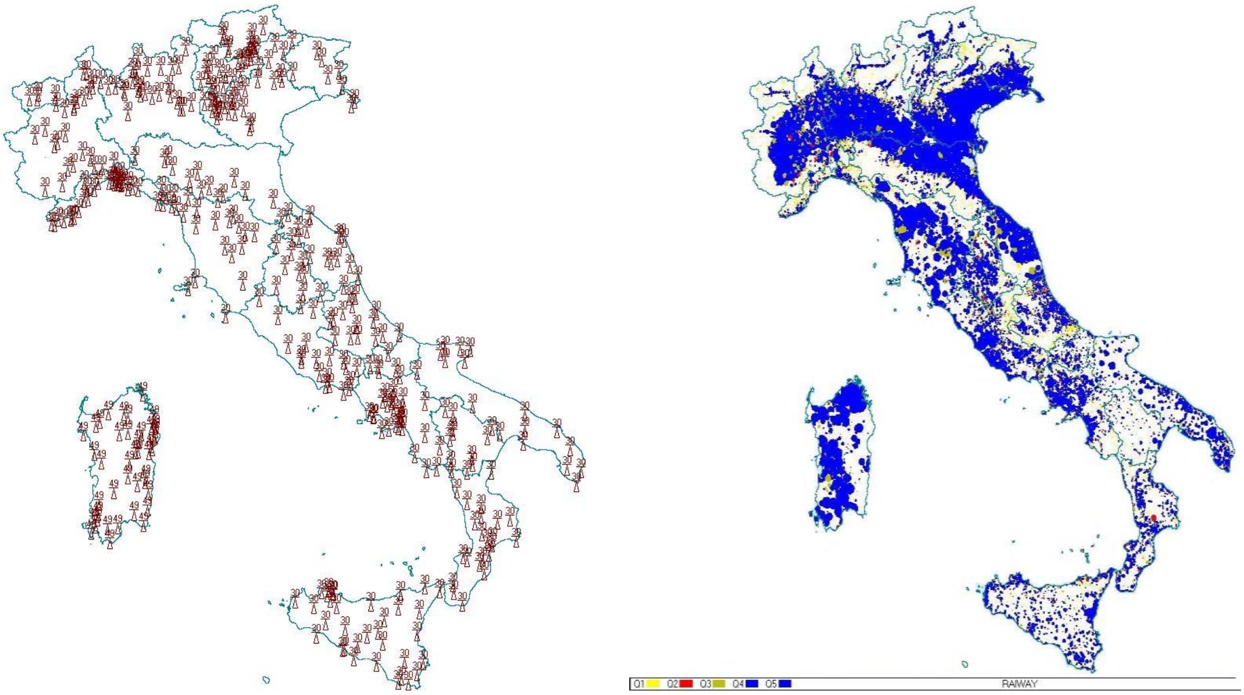
Unlike Rai multiplex 1, RAI multiplex 2 is deployed with a very large SFN.

Rai Way, the owner of RAI's transmission and broadcasting network, implemented it by using 366 transmitters all over Italy (Sardinia excluded), each one broadcasting on channel 30.

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

FIGURE P2-24

RAI multiplex 2: transmitters and map of quality of service



The parameters of the network are: 8K, 64QAM, guard interval ¼, code rate ⅔.

The multiplex is composed by 3TV programs and 4 radio programs.

8.1.2 Operating the network

The 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 many 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").

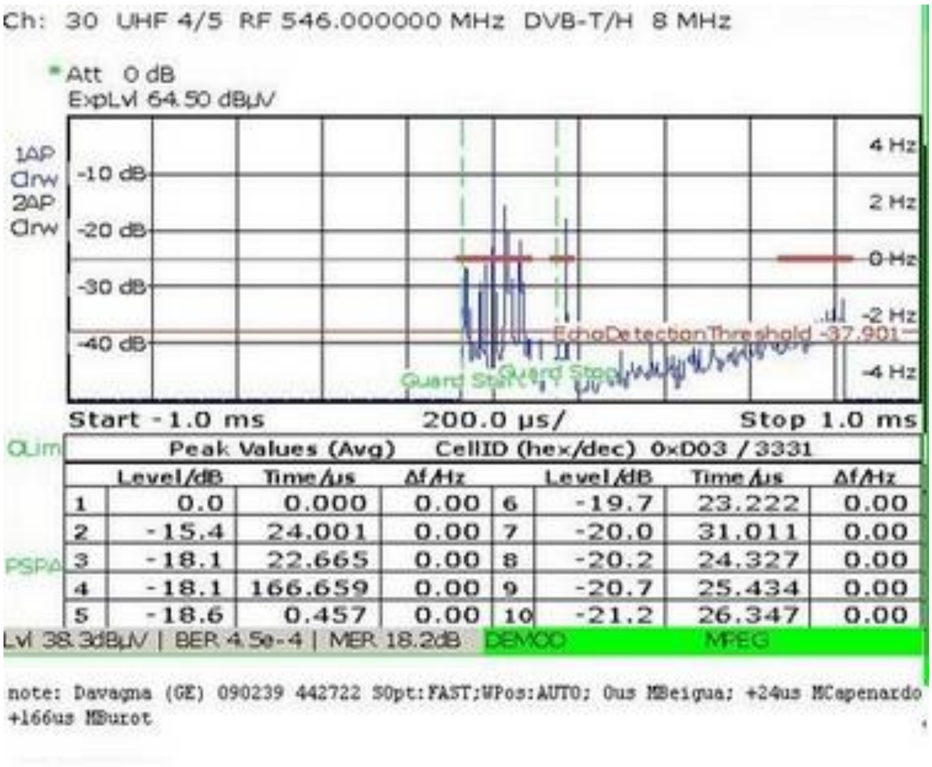
A second class of problems seriously affecting large scale SFN with FRF = 1, is the considerable number of echoes at the user end. Two different kinds of echoes, natural and artificial, can be detected.

The first category of echoes is originated by reflections or scattering due to nearby obstacles, the second one 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 of them arrive in advance of the main signal, some others after it (Fig. P2-25).

FIGURE P2-25

Example of echo spread at the receiver end



The need to accurately deploy and check the behaviour of a large SFN forced Rai Way to use transmission parameter Cell ID, Cell Identifier, to identify the transmitting site.

Rai Way is continuously using this method when performing in-field surveys and the Italian Administration has always strongly supported the use of different Cell IDs in SFN to identify transmitters.

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

A method of DVB-T transmitter identification has been developed. This method permits to identify all received signals from transmitters of a DVB-T SFN, at a receiving point. The full description of the method is contained in the Report ITU-R SM.2304 – *Application of Technical Identification and Analysis of Specific Digital Signals.*

In order to evaluate the impact of the use of different Cell Ids to end users, many surveys on receivers' behaviour were performed. Results are shown in the embedded document "Identification of transmitters in a SFN".

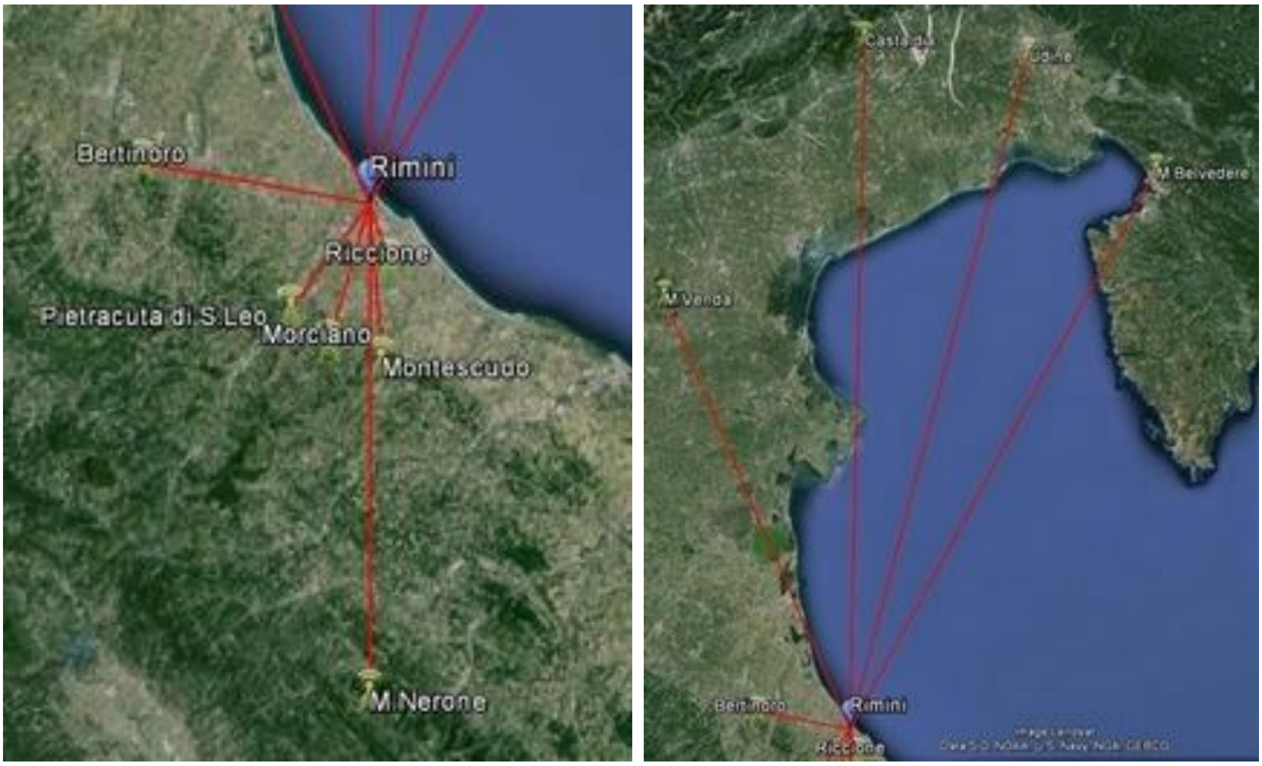
IdentificationTxSFN.
docx

8.1.3 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 many transmitters are operating in that region. Continuous monitoring and recording of the RF signal, MER, BER and Cell Id values permitted to discover that the transmitter that was causing the most annoying interferences on the coast was the one of Udine which is as many as 224 km away.

FIGURE P2-26

SFN transmitters insisting on Rimini area



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

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

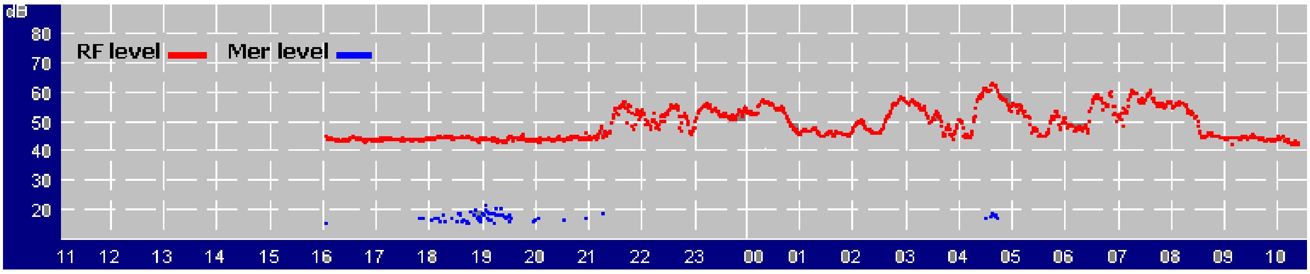
A first study was executed in order to discover which transmitters was causing reception problems, keeping into account especially those transmitters which were not synchronized because very far away.

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

The recorded values showed that the RF levels fluctuated all the day long and reached 79 dBµV/m, too (see the figure below).

FIGURE P2-27

Rimini registration 18 and 19 July



Note that, during registration time, weather conditions were not particularly favourable to propagation phenomena.

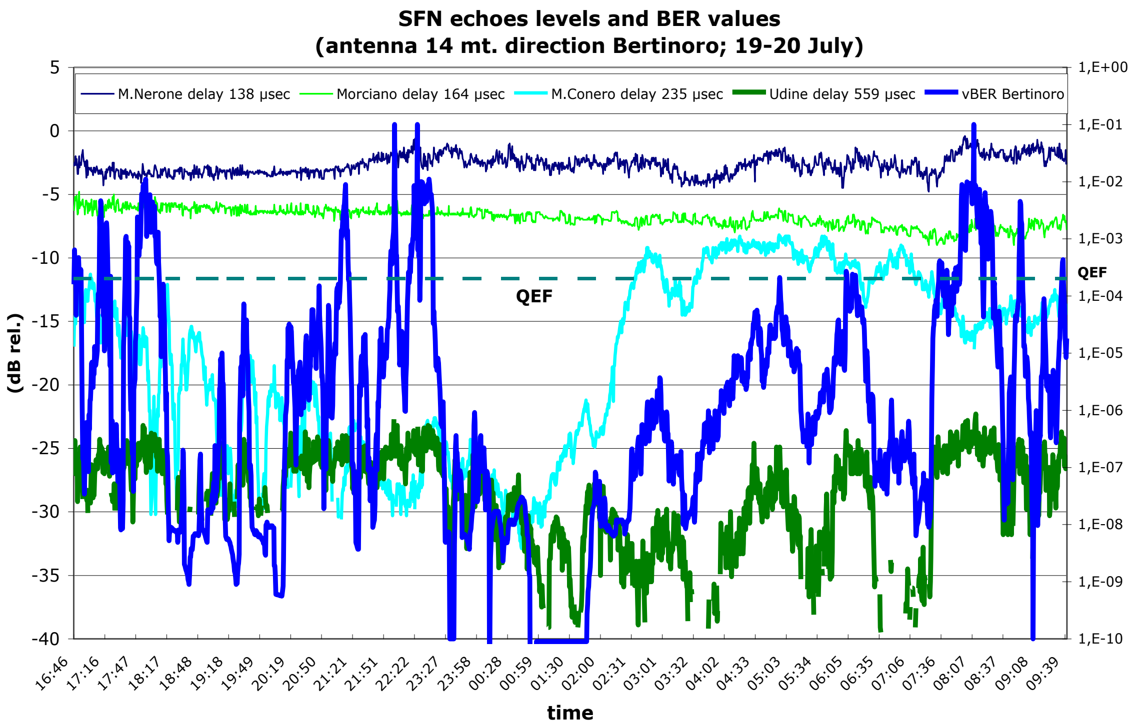
Once detected that Udine signals easily arrived with significant levels, a second analysis was carried out in order to evaluate the impact of this propagation on end users.

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

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

In order to solve bad reception problems, Rai Way had no other solution than to relocate the transmitter of Udine.

FIGURE P2-28



8.1.4 SFN and propagation phenomena on the ground

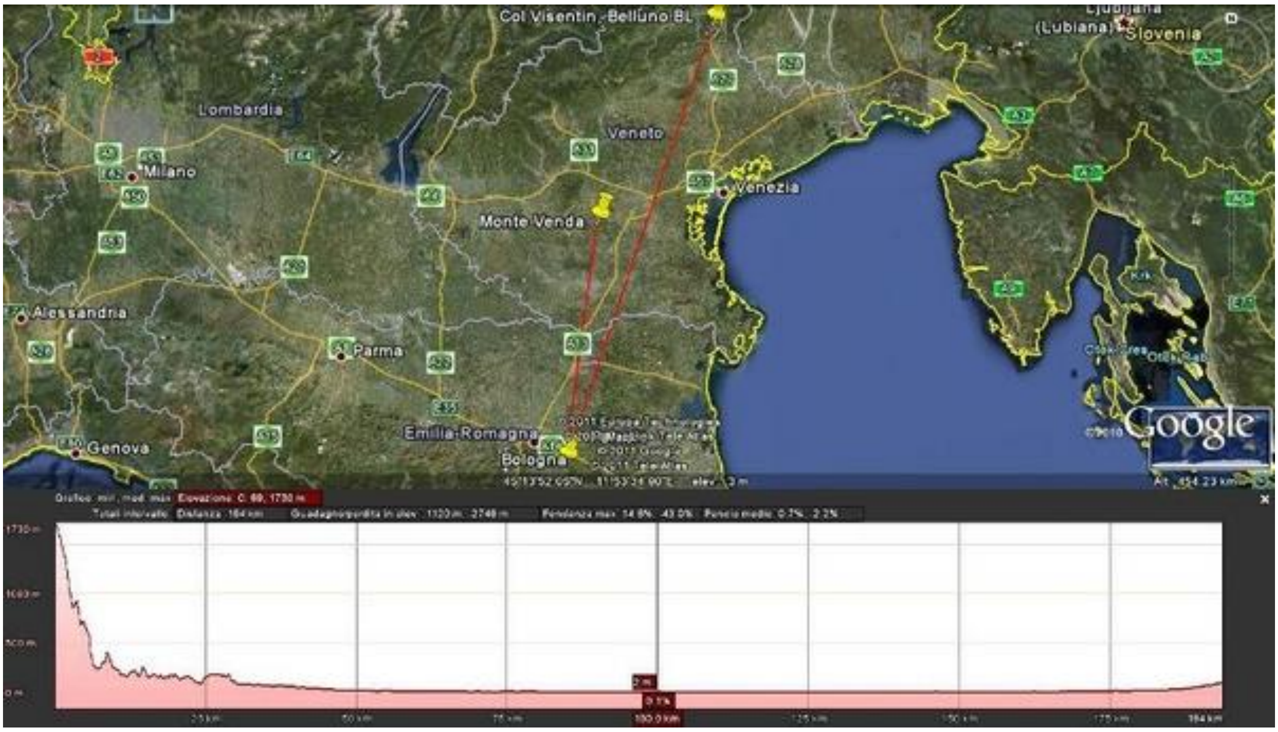
Similar propagation phenomena were detected also in other part of Italy and not originated by warm sea.

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

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

FIGURE P2-29

Monte Venda and Col Visentin position respect to Castel San Pietro – Castel San Pietro-Col Visentin profile



Signals coming from Col Visentin cover 200 km and therefore 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 signal and the interferer one can vary significantly.

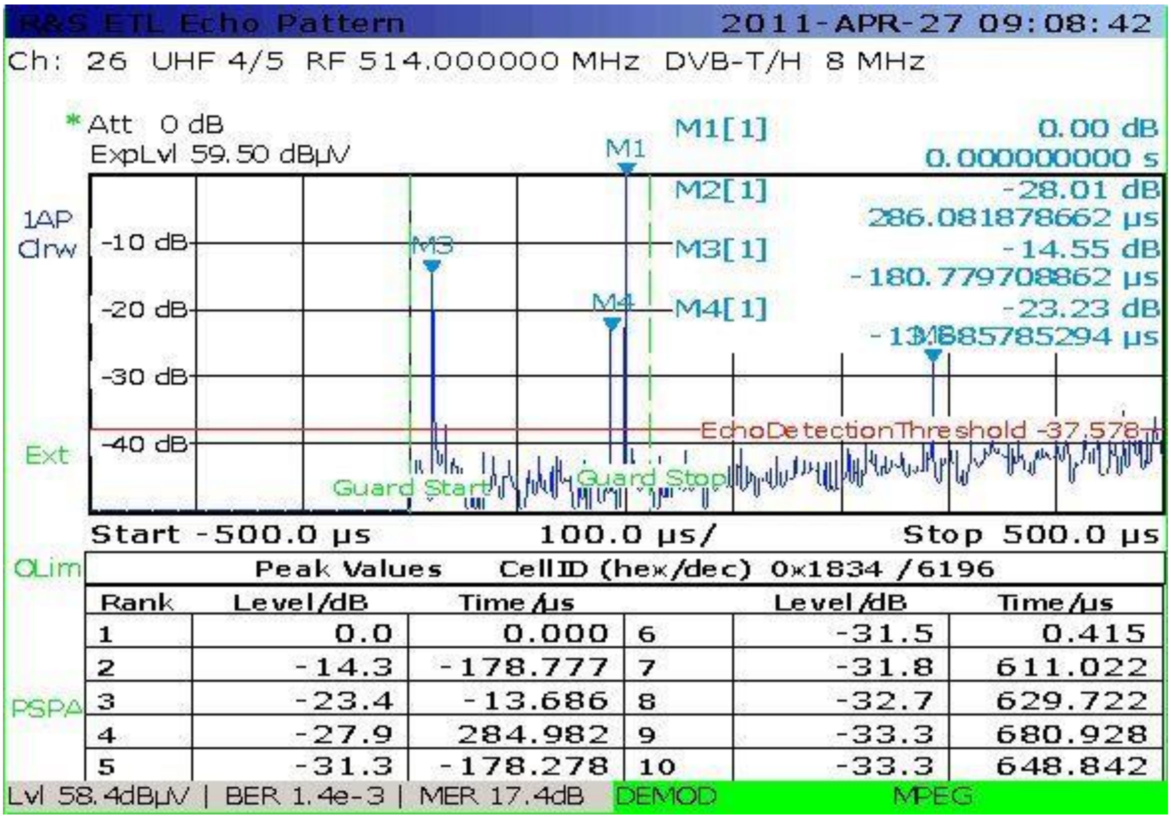
The analysis gives evidence that, during propagation time, signals coming from Col Visentin transmitter degrades the reception quality. The following figures, related to Monte Venda channel analysis, demonstrate the variability observed in the short period of about one hour.

Col Visentin echo has a delay of about 285 µs and appears in the Fig. P2-30 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 P2-30

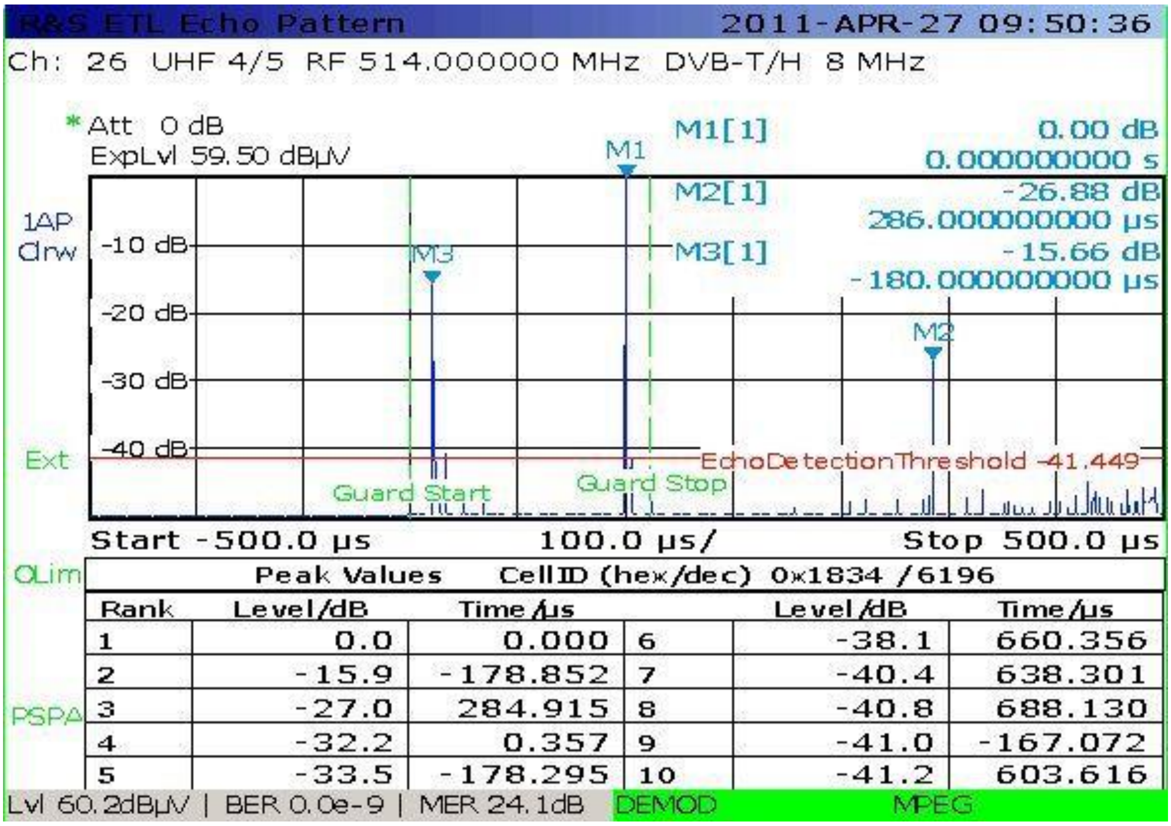
Castel San Pietro (BO) - Monte Venda signal analysis - h 9.08



The Fig. P2-31 shows the same analysis repeated after 40 minutes. In the meantime the level of Col Visentin echo was decreased and better values of MER and BER were registered.

FIGURE P2-31

Castel San Pietro (BO) - Monte Venda signal analysis - h 9.50



Rank	Level/dB	Time/µs		Level/dB	Time/µs
1	0.0	0.000	6	-38.1	660.356
2	-15.9	-178.852	7	-40.4	638.301
3	-27.0	284.915	8	-40.8	688.130
4	-32.2	0.357	9	-41.0	-167.072
5	-33.5	-178.295	10	-41.2	603.616

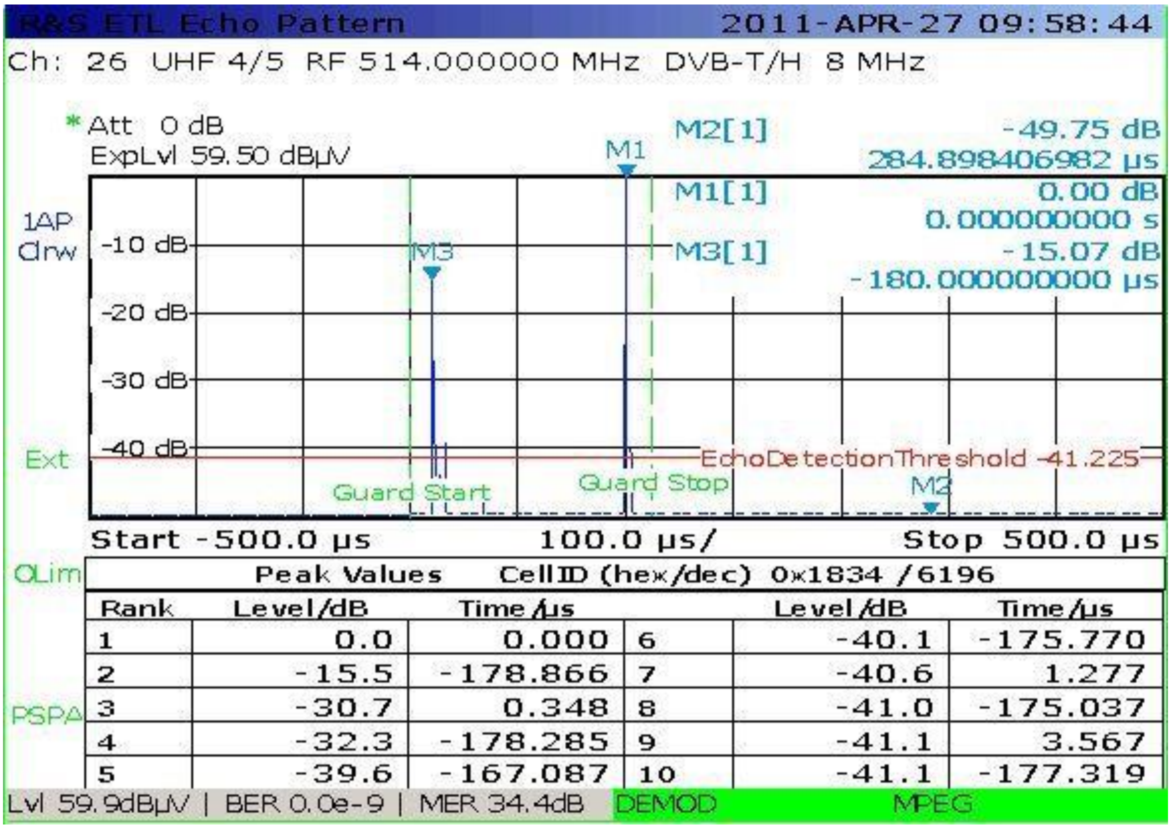
An additional test was made in order to evaluate if the degradation of signal was also due to other transmitters of SFN.

Col Visentin transmitter was switched off for a short period and an additional improvement of Monte Venda signal was observed: this confirmed that the local SFN was good optimized and only the signal of Col Visentin damaged the quality of service (Fig. P2-32).

In order to solve this kind of problems, the radiation power of Col Visentin transmitter in this direction was reduced and the antenna tilted.

FIGURE P2-32

Castel San Pietro (BO) – Monte Venda signal analysis with Col Visentin switched off



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

8.1.5 SFN and reflection/scattering phenomena

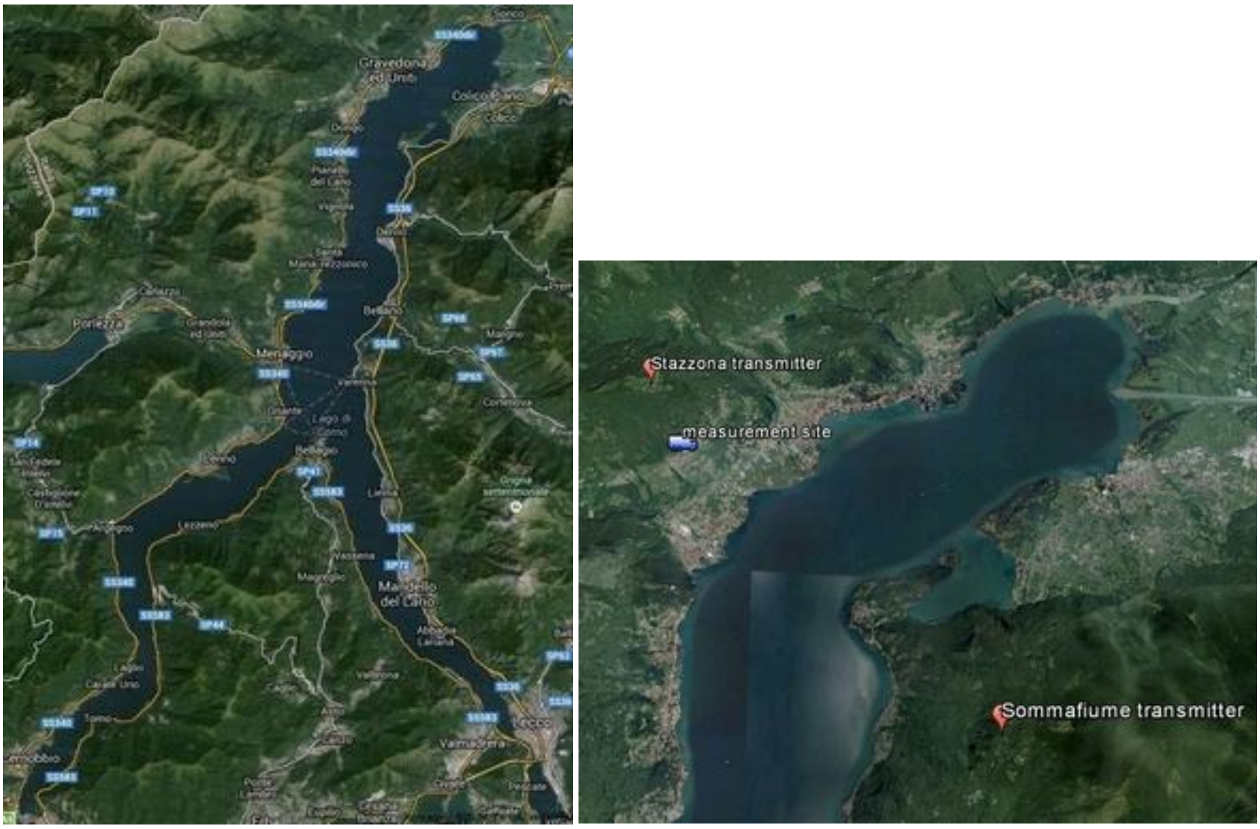
Another interesting study was achieved in order to optimize the SFN on Como Lake.

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

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

FIGURE P2-33

Como Lake overview – Detail of the northern part of the lake



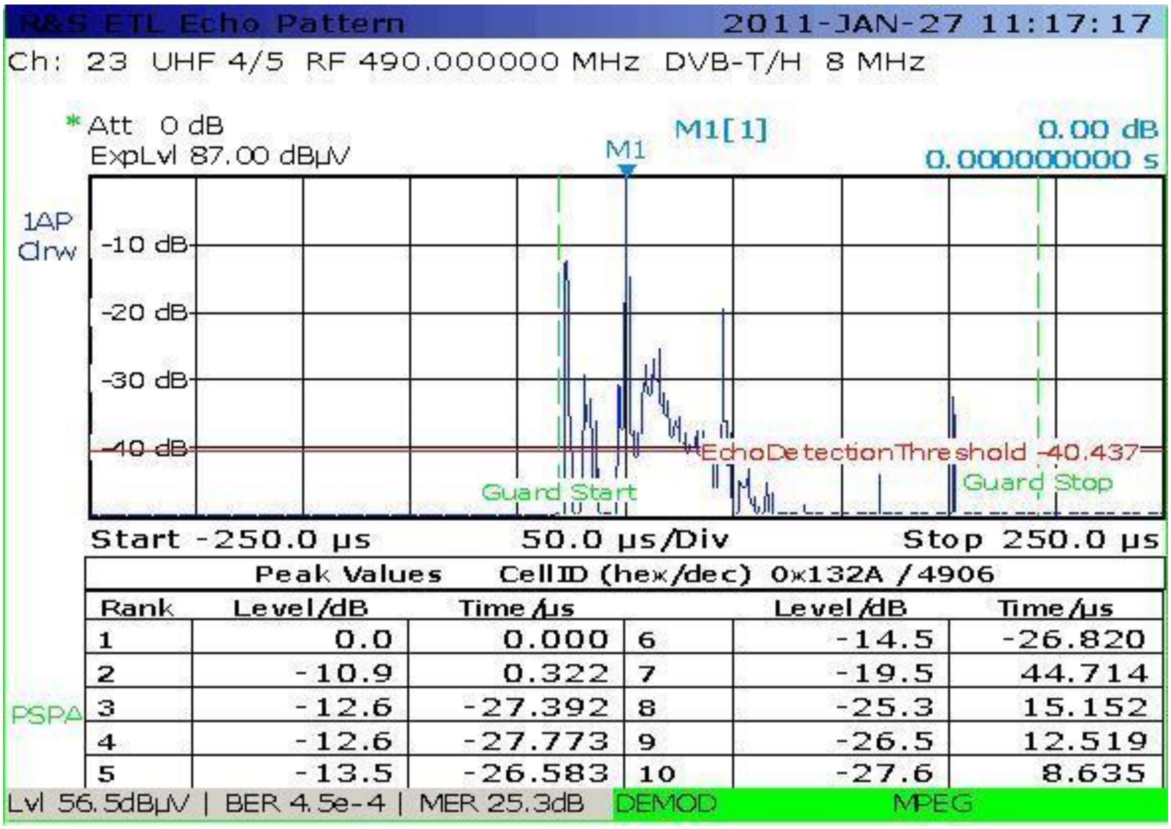
In particular, a measurement campaign was set up in the northern part of the lake, near Stazzona.

This side of the lake is Sommafiume transmitter target area and all the antenna of the buildings are pointed in that direction. 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 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 Fig. P2-34– Stazzona echoes around 12 µs delay and level ≈ –26 dB).

FIGURE P2-34

Stazzona Channel analysis



Rank	Level/dB	Time/µs		Level/dB	Time/µs
1	0.0	0.000	6	-14.5	-26.820
2	-10.9	0.322	7	-19.5	44.714
3	-12.6	-27.392	8	-25.3	15.152
4	-12.6	-27.773	9	-26.5	12.519
5	-13.5	-26.583	10	-27.6	8.635

The improvement of quality of service was obtained optimizing the power of the two transmitters and the relative delays. A more detailed dissertation on this topic is presented in the Report ITU-R BT.2252 "Objective quality coverage assessment of digital terrestrial television broadcasting signals of Systems A and B".

8.1.6 Optimization of SFN – DFREE[4] experience

Besides the choice of the Guard Interval, Modulation and Code rate, there are also other technical parameters that can be used to optimise a SFN:

– static delay of each SFN transmitter;

– power of transmitters;

– antenna diagrams;

– site selection.

Parameters are listed in order of decreasing simplicity: in other words, changing a static delay is easier than changing the power of a transmitter.

For example, excluding those sites that could be critical for the SFN and replacing them with different ones always requires great efforts and large investments.

8.1.7 Parameters details

To implement large DVB-T 1-SFNs, the value 1/4 of the Guard Interval is strongly preferred. This is the maximum possible value and, with 8k carriers mode, it leads to a GI duration of 224 µs. This

4 DFREE is an Italian national commercial broadcaster.

choice gives a penalty[5] in terms of useful bit rate, but the gain on the reuse of frequencies always compensate this loss, because each frequency is used 2, 3 times or even more.

The simpler action to obtain the proper SFN tuning is to modify the static delay of each transmitter of the SFN. The starting point is the static delay equal to “0” for every transmitting site. This static delay has usually[6] a value that could be set in between ±1 ms (with steps of 1 µs) with respect to the “0” reference. In line of principle, having a “main” transmitter that is assumed with static delay “0”, all the other “minor” transmitters could have a static value that is increased in order to receive inside the GI all the contributes from different transmitters. On the contrary, near the “main” transmitter, the possible negative effect of the other transmitters (that could be outside the GI and, therefore, creating interferences) is reduced.

Decreasing the power of the transmitter of 7 dB[7] with respect to the analogue operating value is the typical starting point to implement a DVB-T network that reuse the same site. Especially if the network is a SFN, it might be useful in some sites to modify this value (increasing or decreasing it), in order to optimize their coverage and reduce ISI.

Transmitting Antenna diagrams could be changed to improve the SFN coverage. As an example, in MFN operation, in a first direction could be useful to limit the coverage in order not to interfere another co-channel transmitter, while in a second different direction the coverage could be wider. In a SFN, it could be preferable to extend the coverage in the first direction (because the co-channel site is now part of the SFN itself) and, on the contrary, in the second direction is better to limit the coverage, to avoid “long distance contributes” that are outside the guard interval.

In a SFN the contemporary presence of many high altitude sites that cover wide overlapping areas might create trouble to the complete coverage. In a limited number of cases, it might be the case to dismiss one of these “high altitude” sites, replacing them with one or more different sites.

8.1.8 Final technical considerations on SFN design

In a SFN it is not desirable to have strong in-homogeneities characteristics with regard to transmitter because self-interferences would then become dominant. In line of principle, for the optimisation of a large SFN it is preferable to identify a minimum number of “high-altitude-high-power” transmitting sites (ideally, one for each region) that could offer large coverage and simply require the proper static delay tuning.

All the other transmitters (typically with smaller coverage) have to adopt initially a proper static delay tuning: if this is not enough, also the power or the aerials of these minor sites could be changed.

Finally, it can be considered that a DVB-T2 network could offer a larger guard interval with respect to the DVB-T, with a minimum penalty on the useful capacity.

In fact, adopting DVB-T2 32k mode, it’s enough 1/16 of the useful symbol to obtain the same maximum guard interval of DVB-T (224 µs, with 8k, GI ¼) and with 1/8 of the useful symbol it is possible to increase the GI up to 448 µs. With such a large guard interval, it’s easier to obtain a large

---

5 In a MFN network GI 1/32 is possible, therefore the “penalty” for the useful bit-rate is the difference between 1/4 – 1/32 of the total capacity.

6 A minimum step of 0.1 µs is foreseen by the DVB-T SFN specification and implemented by all transmitter manufactures. This limit value derives from the 10 MHz frequency reference. For tuning purposes, a step of 1 µs is usually adopted.

7 7 dB of power reduction with respect to the former analogue peak sync value is the “famous" Chester rule (Chester 1997 – CEPT Multilateral Coordination Agreement relating to Technical Criteria, Coordination Principles and Procedures for the introduction of Digital Terrestrial Television).

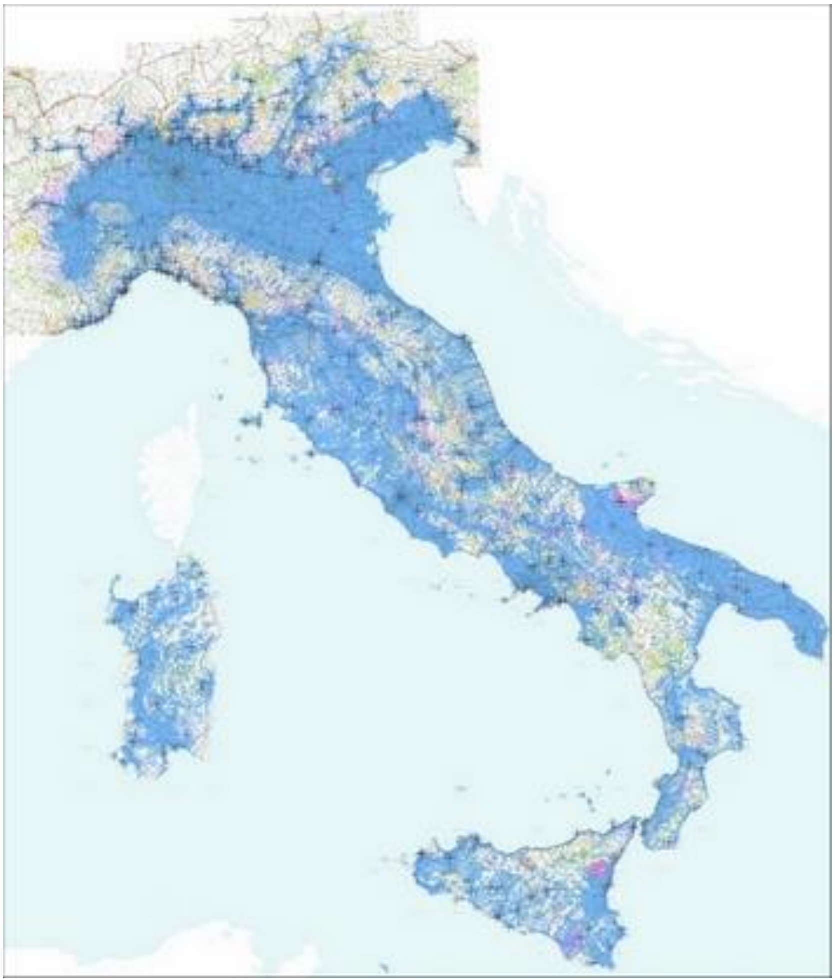
SFN without residual ISI problems, even taking into account all the possible negative propagation effects in the worse months.

8.1.9 Examples of 1-SFN

To preserve the useful coverage of the former MFN analogue or digital network, some additional requirements and constraints on the 1-SFN were adopted (e.g. the alienation of few SFN critical sites replacing them with other additional ones, to change some transmitter aerials, re-tuning power and static delay).

FIGURE P2-35

DFREE at the end of the Analogue Switch Off (1-SFN) - More than 400 sites – Useful coverage > 90% population



The Fig. P2-36 and Fig. P2-37 show details of the 1-SFN in two cases: a well optimized network and at the beginning of the tuning process where all the static delays of the network are set to the value “0”.

Adopting different configuration for the 1-SFN, the indicative values for the ISI should be:

– power –7 dB, no other tuning: ISI = 10%;

– power –7 dB and static delay tuning: ISI = 3.5%;

– power and static delay tuning: ISI = 1.5%;

– sites, antenna diagrams, power and static delay tuning[8]: ISI < 1% (see Fig. P2-36)

ISI is expressed in terms of population coverage.

FIGURE P2-36

Detail of the 1-SFN coverage (“site”, “power”, “diagrams” and “static delay” tuning)

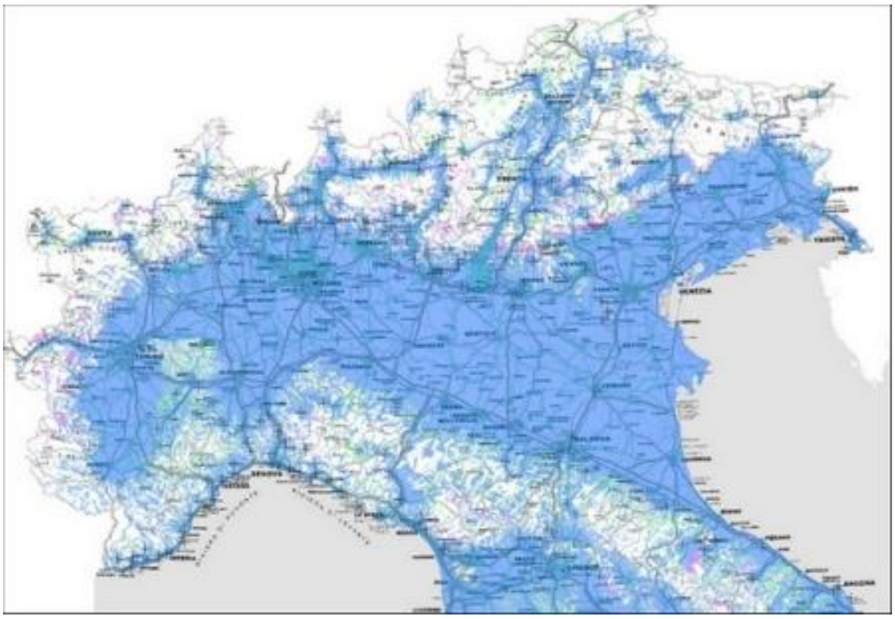
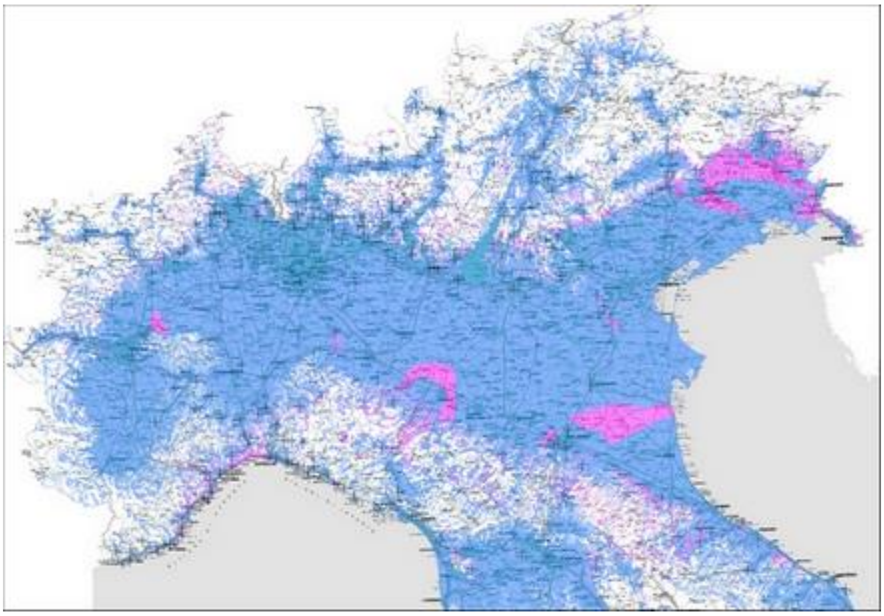


FIGURE P2-37

Detail of the 1-SFN coverage without “static delay” tuning (pink areas would be interfered)



[8] Minimum median field-strength = 58 dBµV/m, *C/I* = 27 dB, interference % time 1%.

DVB-T2 SFN

9 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.

In order to see how these factors would affect SFNs in practice, several studies have been undertaken and few are here summarized (for the detailed description see the Annexes of the EBU document Technical Report TR 029 https://tech.ebu.ch/).

10 Spectral efficiency and spectrum consumption of DVB-T2 networks

10.1 Spectral efficiency and spectrum consumption

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).

10.2 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 P2-5 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 Report ITU-R BT.2254 “Frequency and network planning aspects of DVB-T2” 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 P2-5

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

10.3 Layer spectrum efficiency of DVB-T2

In paragraph 10.2 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 the EBU Technical Review 2014[9] 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 the EBU Technical Review 2014 are summarized here.

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

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

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 paragraph 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. For an SFN approach for regional service areas, which requires medium size SFNs, an RBF of 5 is used as calculated in the EBU Technical Review 2014. 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 the EBU Technical Review 2014.

Table P2-6 collects these data for the DVB-T2 based scenarios of paragraph 10.2 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 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.

9 Brugger, R., Schertz, A., “TV Distribution via Cellular Networks I: Spectrum Consumption”, EBU Tech Rev Q2/2014, Geneva, 2014.

TABLE P2-6

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

10.4 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[10] (see document EBU Technical Report TR 029 – Annex A6 – https://tech.ebu.ch/), 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

[10] IRT is the Research and Development Institute of ARD, ZDF, DRadio, ORF and SRG/SSR.

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 P2-7 gives an example for a particular DVB-T2 mode.

TABLE P2-7

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 rooftop reception due to the directional character of the receiving antenna in the fixed reception case.

11 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 Report ITU-R BT.2254 “Frequency and network planning aspects of DVB-T2”.

12 DVB-T2 and DVB-T2 Lite case studies

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

In a study by IRT, theoretical hexagonal networks have been used in conjunction with the Recommendation ITU-R 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 × 360 km and a very large SFN (720 km × 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 e.r.p. 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).

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 × 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.

12.1.1 Introduction

The objective of this study is to analyse the capabilities of single frequency networks 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.

12.1.2 Planning parameters and network structure

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

The structure of such a network is shown in Fig. P2-38. 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 P2-39 shows the map of Germany with the geographical sizes.

FIGURE P2-38

Theoretical hexagon network (large size SFN)

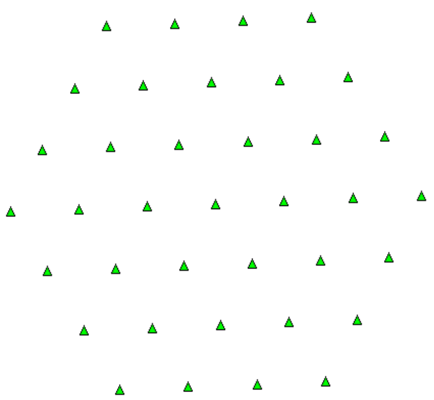


FIGURE P2-39

Size of Germany & Bavaria

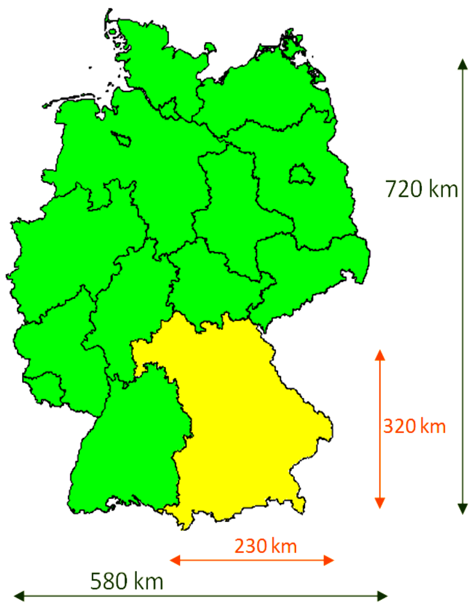


Table P2-8 gives the list of planning parameters that were applied in the simulation. They are either taken from the Report ITU-R BT.2254 on DVB-T2 planning or from the technical annex of the GE06 Agreement. For fixed reception the usual directional antenna as described in Recommendation ITU-R BT.419-3 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 P2-8

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 (dBd)	0	0	11
Rx Antenna diagram	Non-directional	Non-directional	Directional ITU-R BT.419-3-Band IV/V

12.1.3 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 P2-9. 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 P2-9

***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 Report ITU-R BT.2254 on DVB-T2 planning. 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.

12.1.4 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 P2-40 presents a snapshot of this process. It shows a coverage plot for mobile reception of the large SFN (360 km × 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 P2-40

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

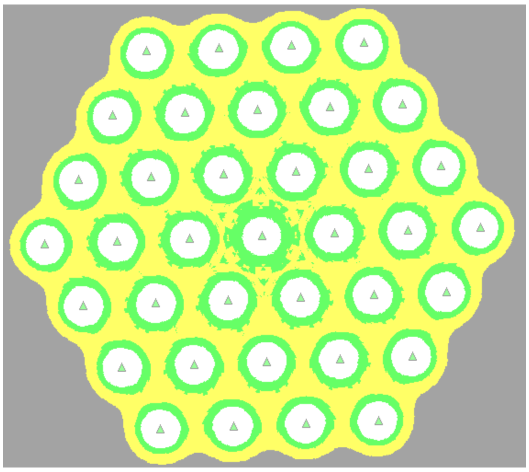


Table P2-10 gives an overview of the results. For each category of SFN and reception mode the optimum DVB-T2 variant is given which provides full area coverage, where the optimization criterion is the data rate.

TABLE P2-10

DVB-T2 modes with maximum data rate while allowing for a full SFN coverage

	Large SFN (360 km × 360 km)	**Very large SFN (720 km × 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 P2-10 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, Fig. P2-41 gives the percentages of covered locations ordered by their respective location probability for nine DVB-T2 variants. The two variants of Table P2-10 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 § 4.1.5 a more detailed investigation of the guard interval aspect is presented.

FIGURE P2-41[11]

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

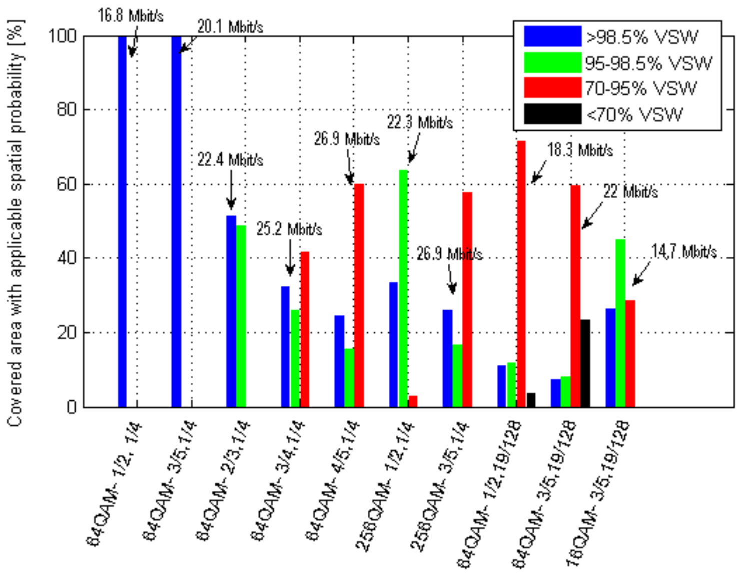
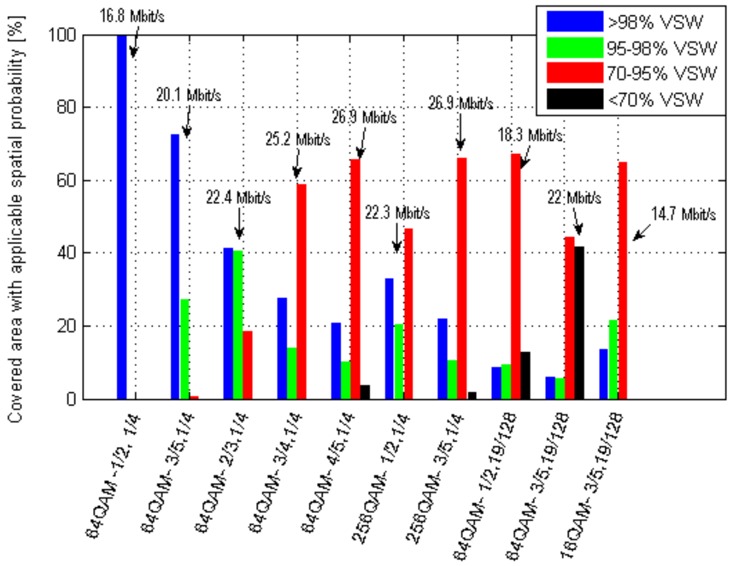


Figure P2-42 shows the results for the mobile reception and very large SFN. All variants suffer from higher self-interference degradation than in the large SFN case. Now only 64-QAM-1/2-GI 1/4 fulfils the coverage requirements. 64-QAM-3/5-GI=1/4 has at least a nearly full area coverage for 95% location probability, whereas for 64-QAM-2/3-GI=1/4 the percentage of locations with less than 95% location probability is already nearly 20%.

[11] VSW is the German abbreviation for reception location probability.

FIGURE P2-42

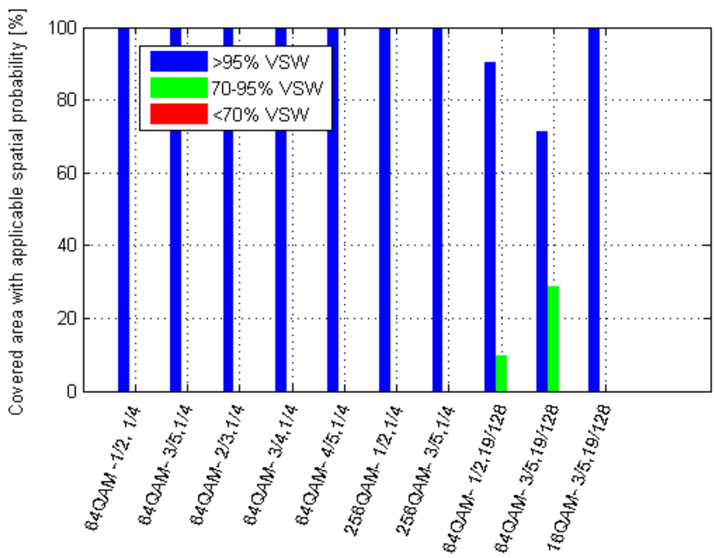
Percentage of covered locations in the very large SFN (720 km × 720 km) for 9 DVB-T2 variants and mobile reception ordered according to four location probability classes



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 P2-43 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 P2-43

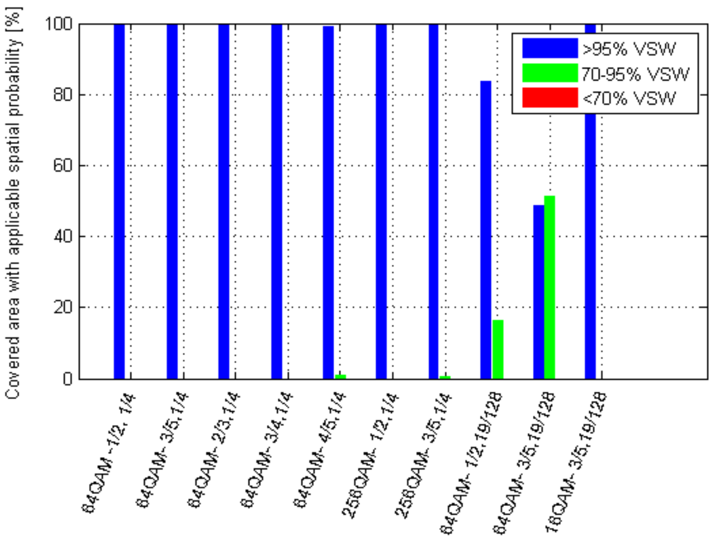
Percentage of covered locations in the large SFN (360 km × 360 km) for 9 DVB-T2 variants and portable reception ordered according to three location probability classes



The situation for the very large SFN, depicted in Fig. P2-44, 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 P2-44

Percentage of covered locations in the very large SFN (720 km × 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 P2-11 shows how the coverage changes if the inter-site distance decreases from 60 km to 50 km.

TABLE P2-11

The coverage for a specific DVB-T2 mode with different inter-site distances

DVB-T2 mode 64-QAM-3/5, 19/128	>98.5% reception location probability	95 - 98.5% reception location probability	70 - 95% reception location probability	<70% reception location probability
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.

12.1.5 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.

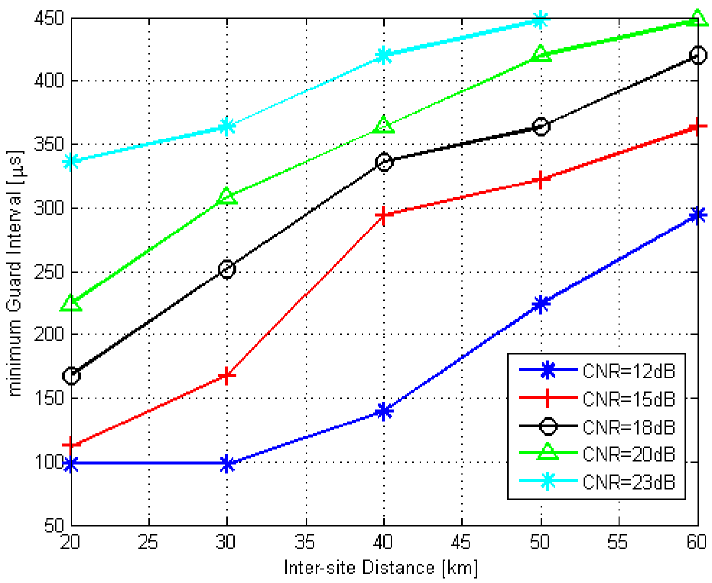
The guard intervals are not necessarily chosen from the standard DVB-T2 modes but they are the minimum thresholds which makes the coverage within the hexagon possible. This means the guard interval guarantees 100% coverage with the location probability higher than 98.5%. If the guard interval decreases 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 Fig. P2-45 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 P2-9), 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 P2-45

Relationship between inter-site distance, robustness (*C/N*) and minimum guard interval



12.1.6 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 × 360 km and a very large SFN with a size of 720 km × 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 × 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.

12.2 DVB-T2 and DVB-T2 Lite: Experimental tests in Italy (Aosta Valley)

After experimenting in the laboratory the first prototypes of DVB-T2 Lite, the RAI Research Center in co-operation with RAI WAY and with the technical support of some Italian manufactures launched an experimental trial where HDTV services for fixed reception and T2 Lite mobile TV services are being transmitted on the same channel to demonstrate an optimal exploitation of the UHF spectrum and guaranteeing adequate transmission robustness for very different services.

The trial, based on a SFN with four transmitters in a mountainous area, allowed to validate the technical characteristics of the system, to evaluate the coverage in mobility, to check interoperability related to the implementation of a SFN using equipment from different vendors and, last but not least, to test the behaviour of receivers in the field. The experiment took place in the Aosta Valley on the UHF channel 53 using the transmitting centers of Tete de Arpy, Aosta-Gerdaz, Saint Vincent-Salirod and Col de Courtil. In a second phase, currently underway (February 2015), the network has been expanded with other transmitters.

TABLE P2-12

Aosta Valley transmitters

Transmitter	P_{out}	e.r.p.$_{max}$	Polarization	Static Delay	Transmitter identifier
Tete de Arpy	50 W	–5.1 dBk	H	20 μs	3
Aosta Gerdaz	50 W	–5.3 dBk	H	45 μs	1
Saint Vincent – Salirod	100 W	–1.3 dBk	H	0 μs	2
Col de Courtil	50 W	–6.9 dBk	H	5 μs	4

FIGURE P2-46

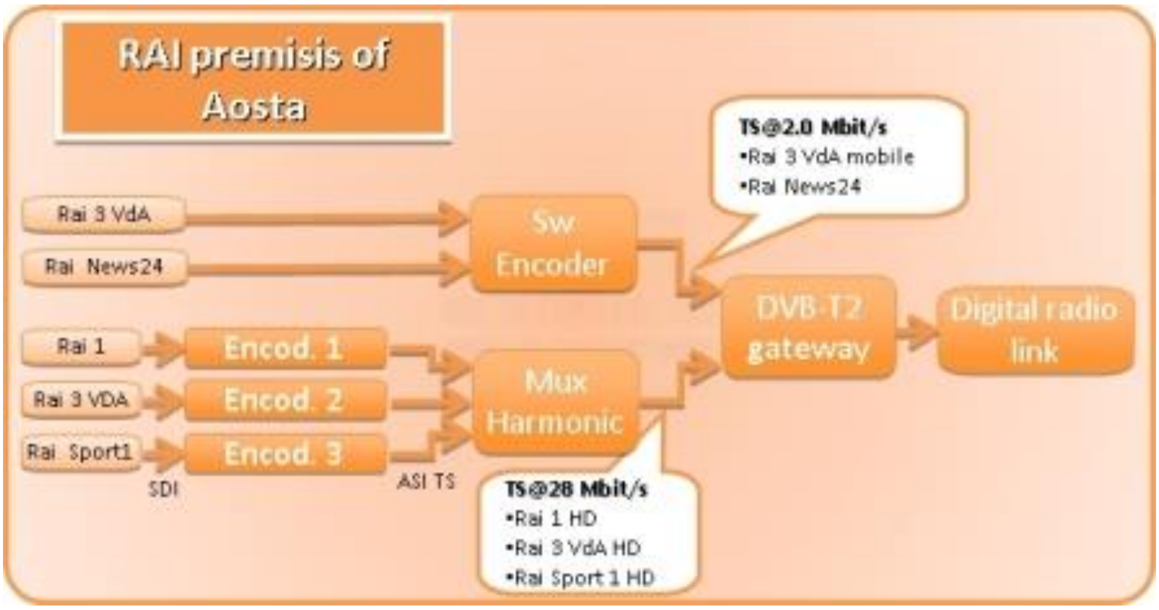
Geographical context – Aosta Valley

The geographical context together with the location of the transmitters and their characteristics are reported in Fig. P2-46.

The bouquet takes origin in the head-end located in the Rai's premises of Aosta and consists of three HD programs for the T2 base and of three services oriented to mobile reception for the T2 Lite. The distribution of the signal toward the transmitters is performed by SDH digital radio link.

FIGURE P2-47

Head End Scheme



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

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

DVB-T2 Base

– Constellation: 256QAM, 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:

  • ⅓ – available bit rate 1.6 Mbit/s;

  • ½ – available bit rate 2.2 Mbit/s;

  • ⅔ – available bit rate 3.3 Mbit/s

– FFT: 8k

– Guard Interval: 1/32 (56 µs)

– Pilot Pattern: PP4.

The transmitters have common coverage overlapping; thus, to avoid interferences beyond the guard interval in that zone (28 µs for the selected transmission mode) static delays have been added on the transmitters, as depicted in the table above.

FIGURE P2-48

Location probability for fixed reception

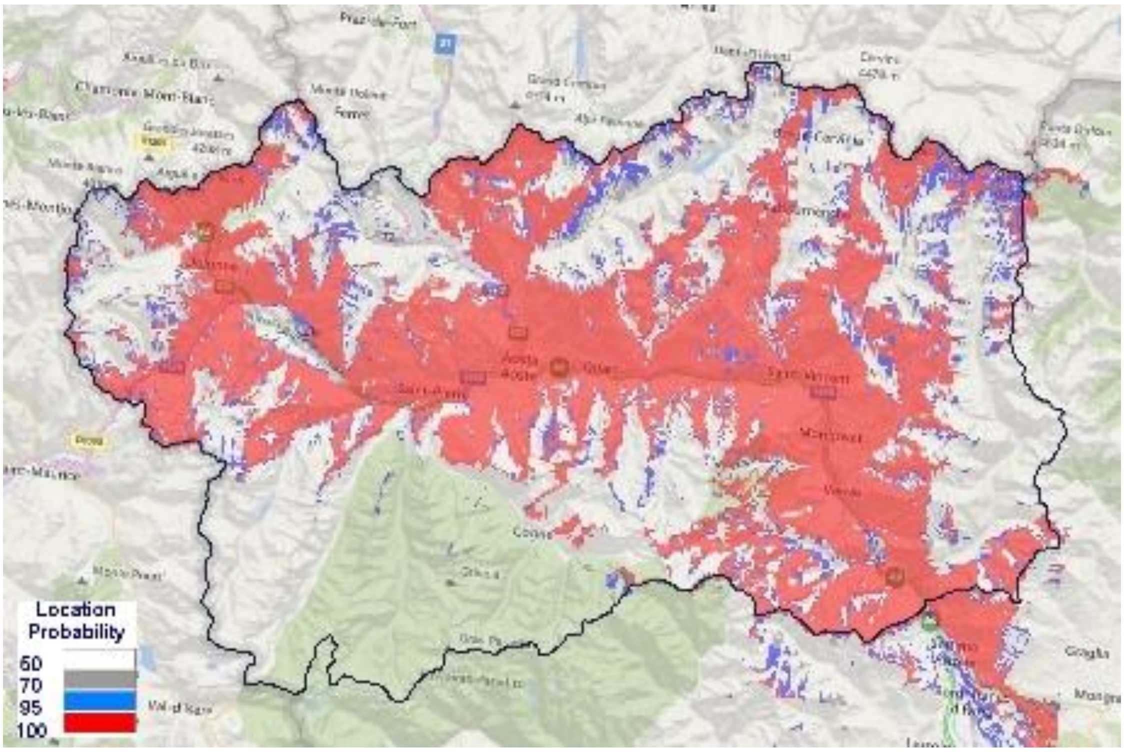


FIGURE P2-49

Location probability for mobile outdoor reception

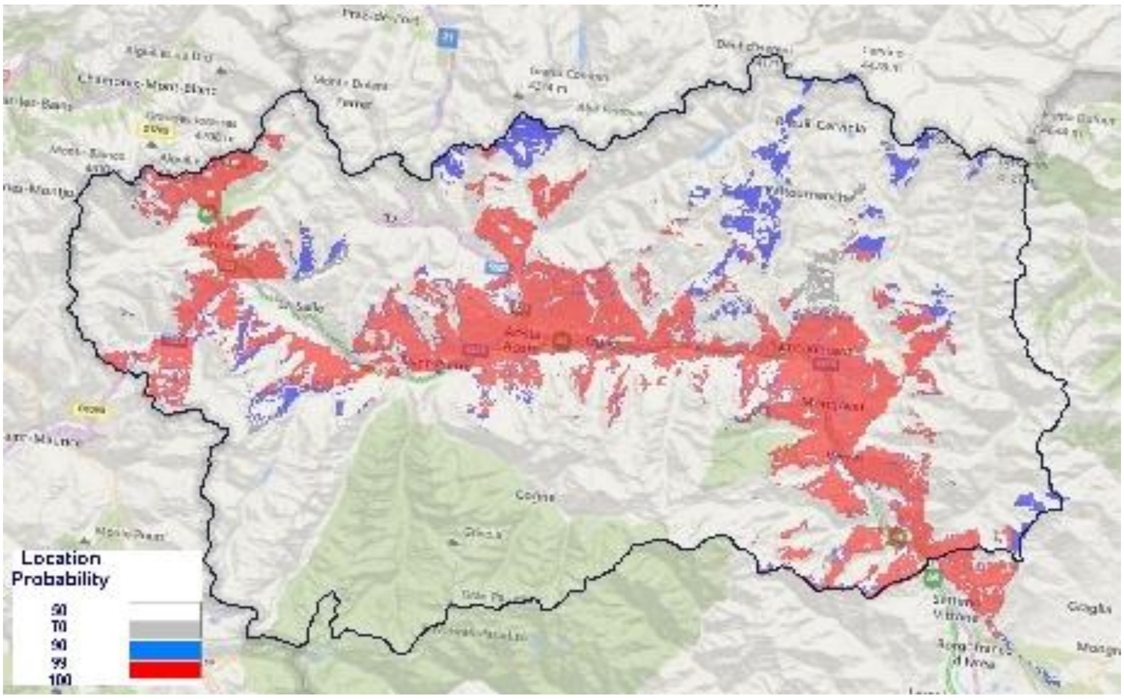


FIGURE P2-50

Area where the signals of the transmitters are within the GI (green) and beyond the GI (red)

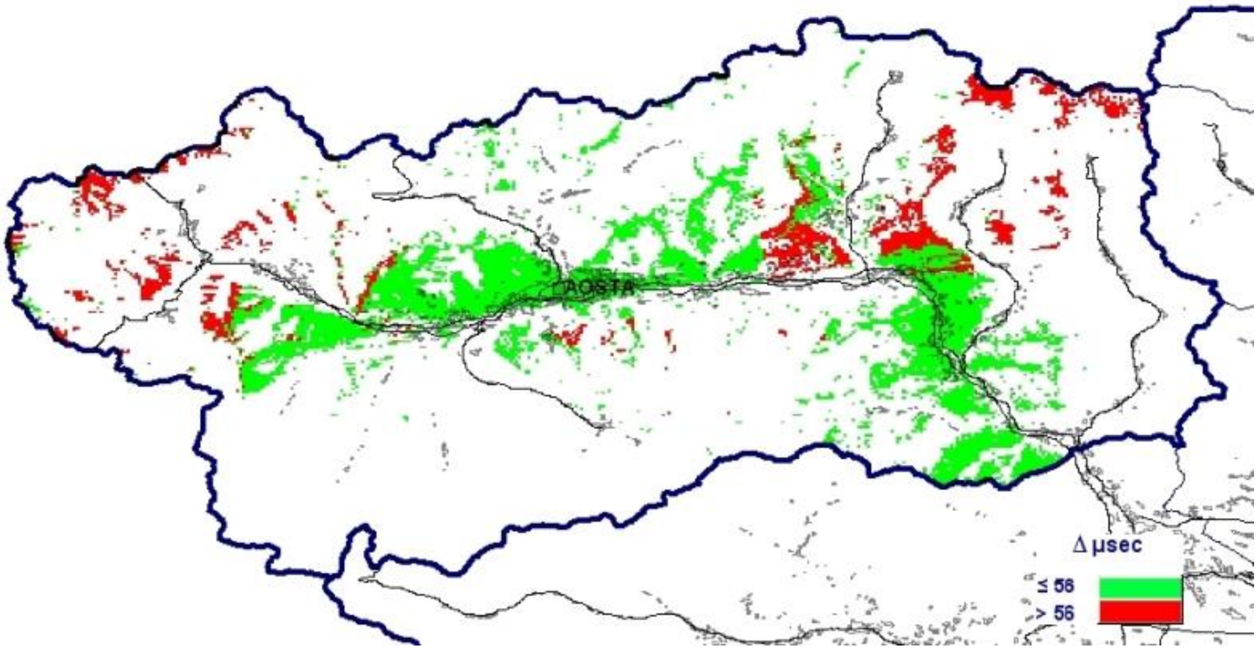


FIGURE P2-51

Difference in field strength between strongest signal and second strongest signal

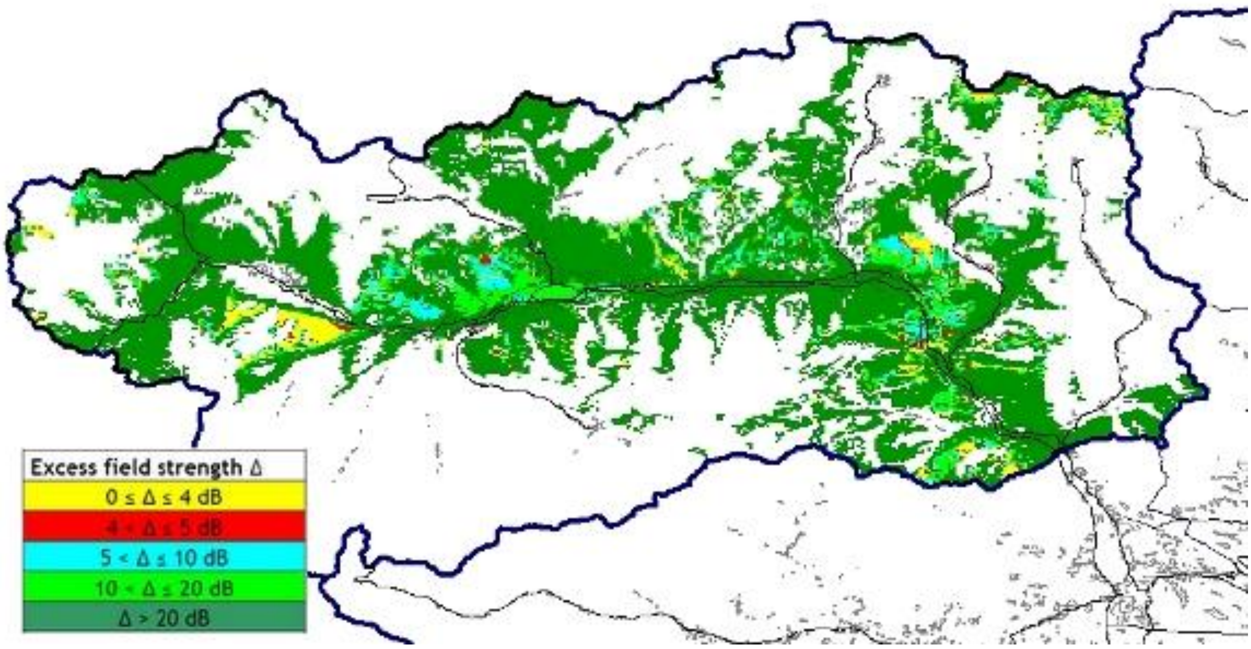
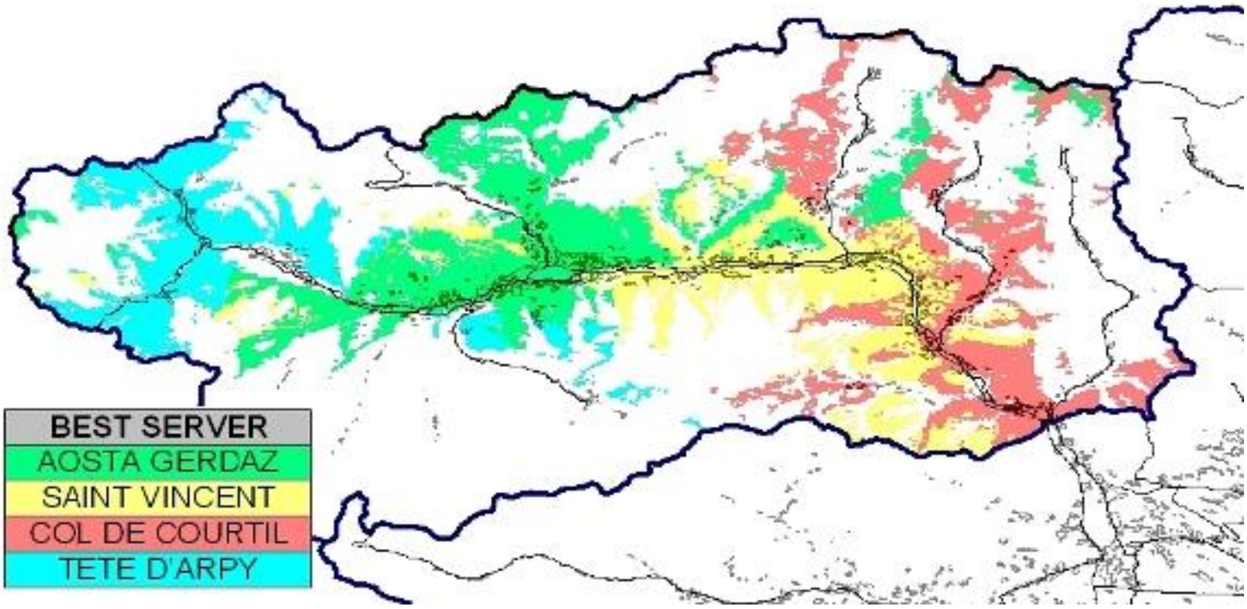


FIGURE P2-52

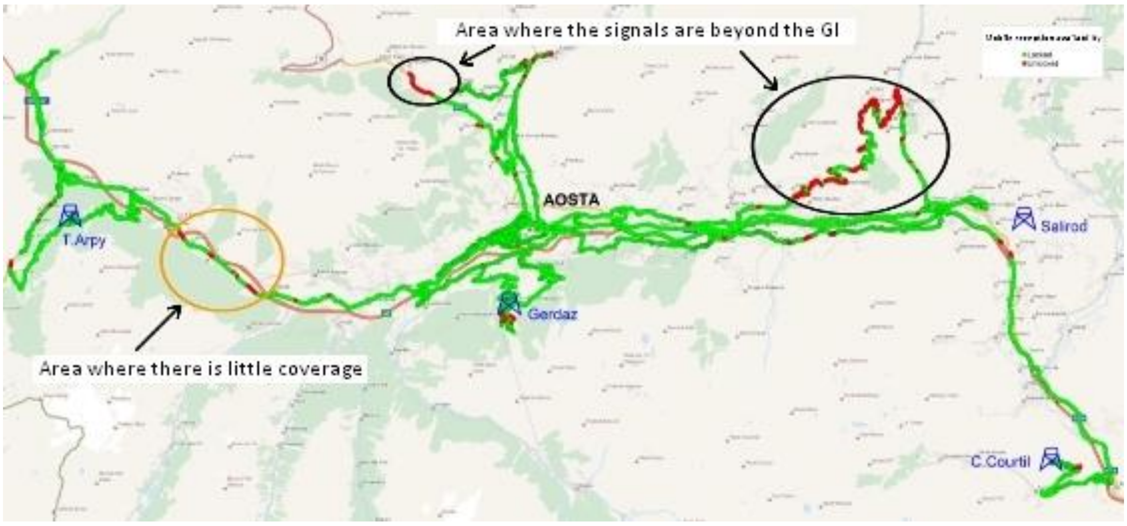
Area of the best server



For each chosen FEC value of DVB-T2 Lite, measurements "on route" were performed and more than 400 km were covered along the roads of the Aosta Valley. The results are very promising. DVB-T2 Lite allows an excellent mobile reception on cars travelling at speeds 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 Single Frequency Network is reported in Fig. P2-53.

FIGURE P2-53

SFN mobile reception availability (signal received, green; not received, red) – FEC 1/2



The measurement campaign pointed out three critical areas: one due to the lack of coverage (see the Fig. P2-53) and the other two due to the fact that the signals of Aosta Gerdaz and Saint Vincent Salirod transmitters arrive in the area outside the Guard Interval.

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

Moreover, theoretical studies and laboratory tests show that, with 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 were also performed in order to evaluate the service area of DVB-T2 Base. The measures were carried out at 15 m a.g.l. using directive yagi antenna for each transmitter and showed a high reception margin in all the predicted coverage area. The reception margin was measured by attenuating the incoming signal up to the reception threshold.

In Fig. P2-54 is reported the location of the test points together with the achieved results.

FIGURE P2-54

Field strength measurements – Example of measures of a single transmitter

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

In order to validate the SFN in the service area where the signals of the transmitters are overlapped, a lot of measurements has been carried out collecting information regarding the spectrum, impulse response, constellation, MER, modulation parameters, field strength, etc.

An example of the measurements is shown in the Figures below.

FIGURE P2-55

Example of SFN fixed reception measurements – Spectrum

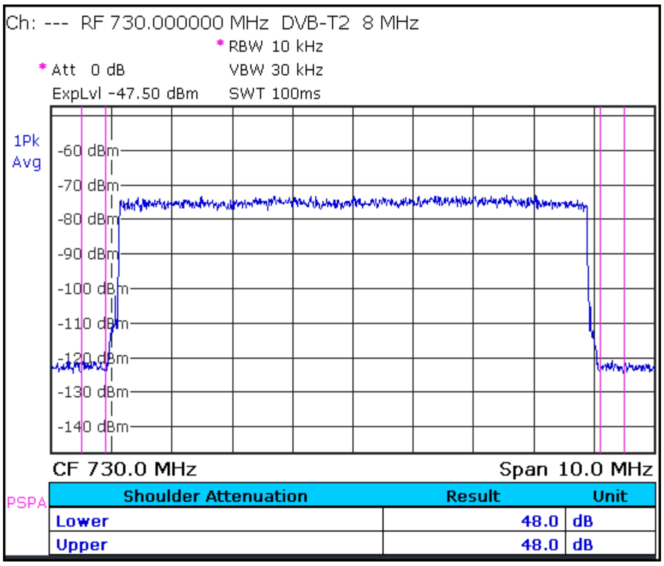


FIGURE P2-56

Example of SFN fixed reception measurements – Channel Impulse Response T2 base and T2 Lite

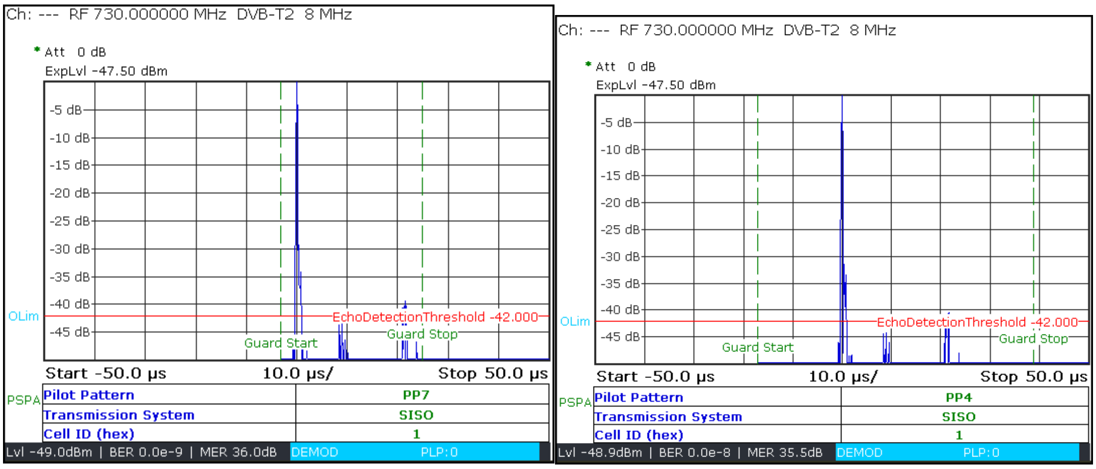


FIGURE P2-57

Example of SFN fixed reception measurements – Overview T2 base and T2 Lite

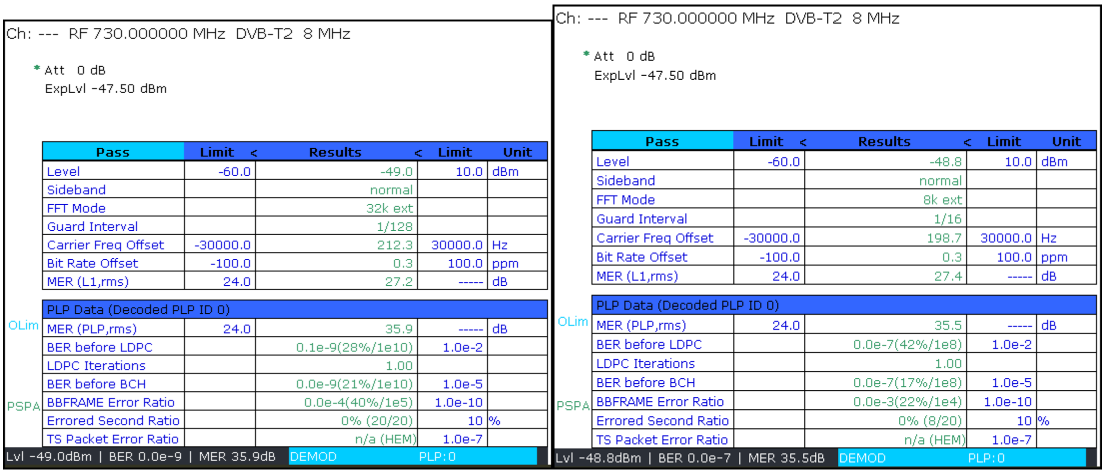
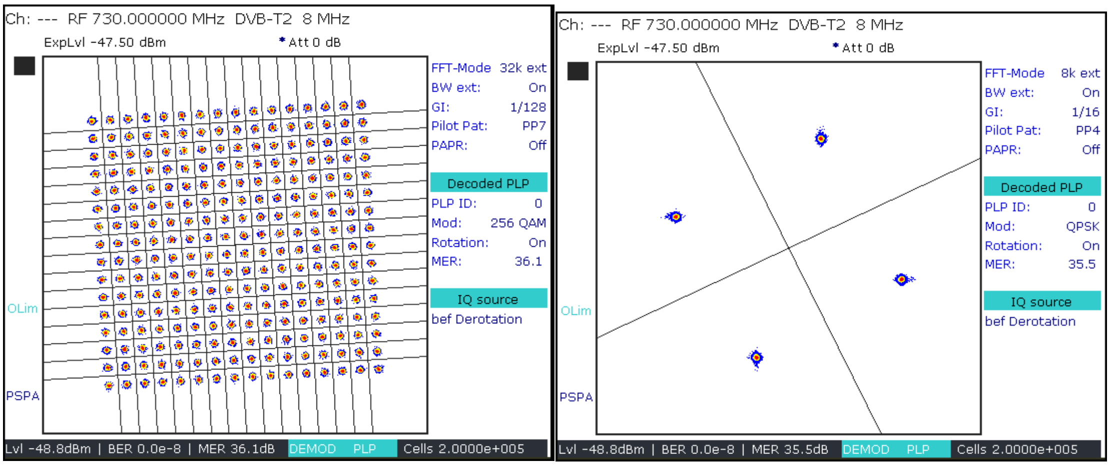


FIGURE P2-58

Example of SFN fixed reception measurements – Constellation T2 base and T2 Lite



The T2 Lite signal is very robust and even in critical conditions it is possible to decode it. In the following Figure, there is an example of this kind of situation.

FIGURE P2-59

Example of critical conditions – T2 Base overview – T2 Lite overview and constellation

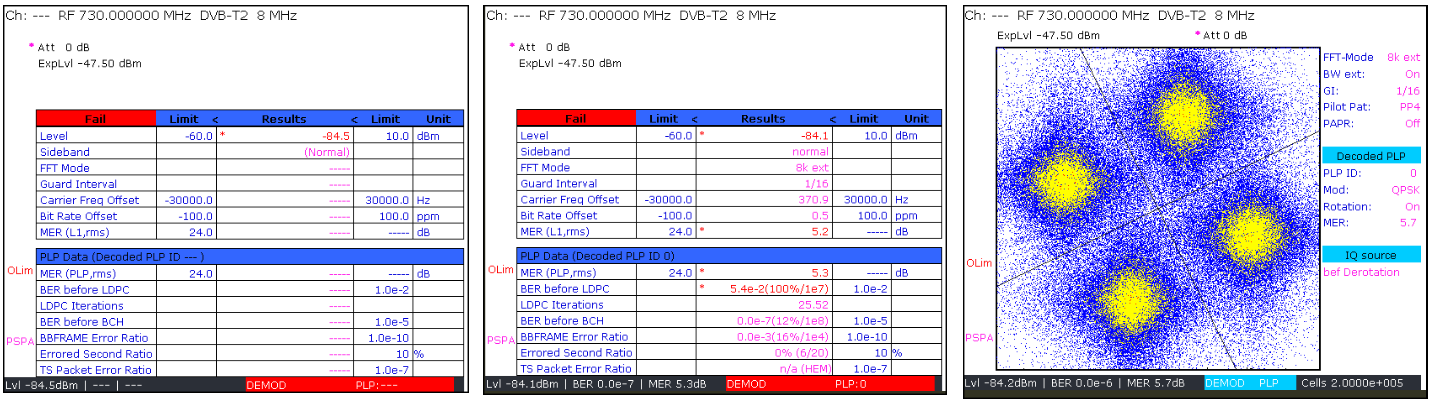


FIGURE P2-60

12.3 Case study on large DVB-T2 SFN in Denmark

A study by Progira and DR 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 P2-13 shows that the current DTT network in Denmark provides near universal coverage (99.7% 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 P2-13

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 study 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.

12.3.1 Introduction

The following study 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.

12.3.2 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.

12.3.3 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.

12.3.4 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.

12.3.5 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 P2-61 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[12]. 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 Fig. P2-62 will have limitations due to SFN self-interference.

If, however, we use the DVB-T2 standard (Fig. P2-63) 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 Fig. P2-61 and gives a bit rate of 29.9 Mbit/s. In Fig. P2-64 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.

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

FIGURE P2-61

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

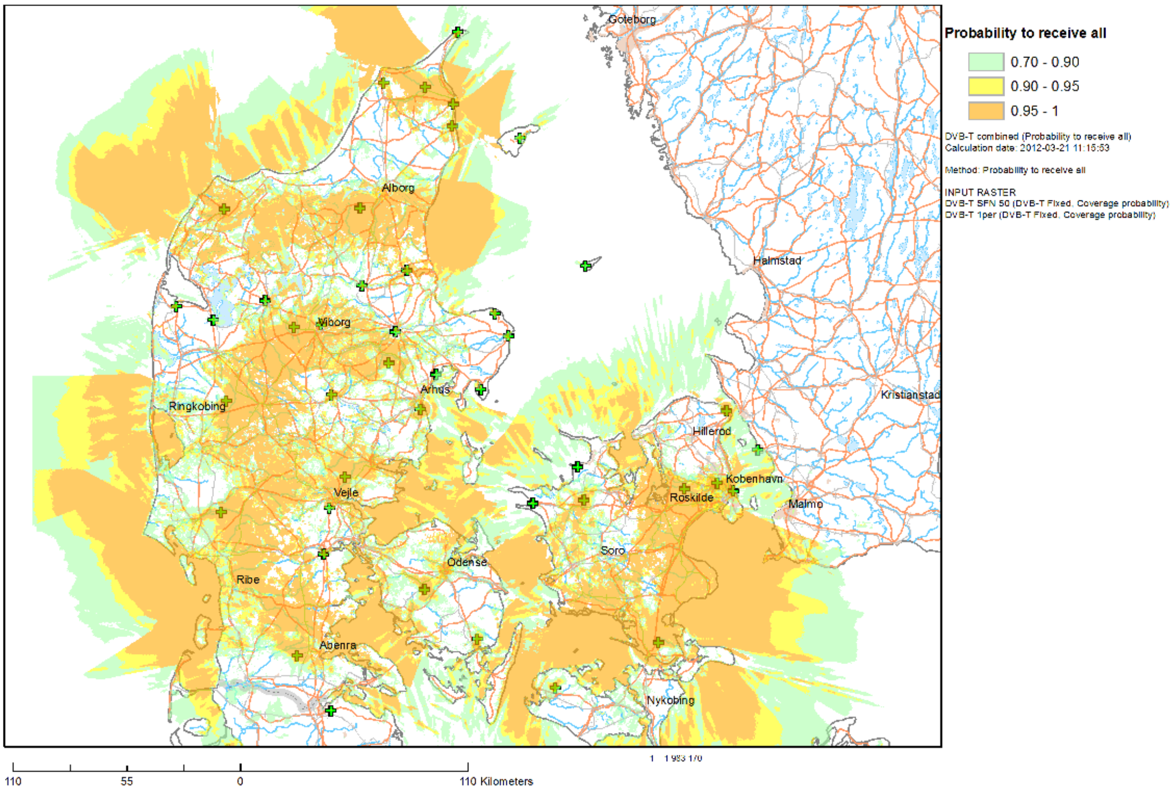


FIGURE P2-62

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

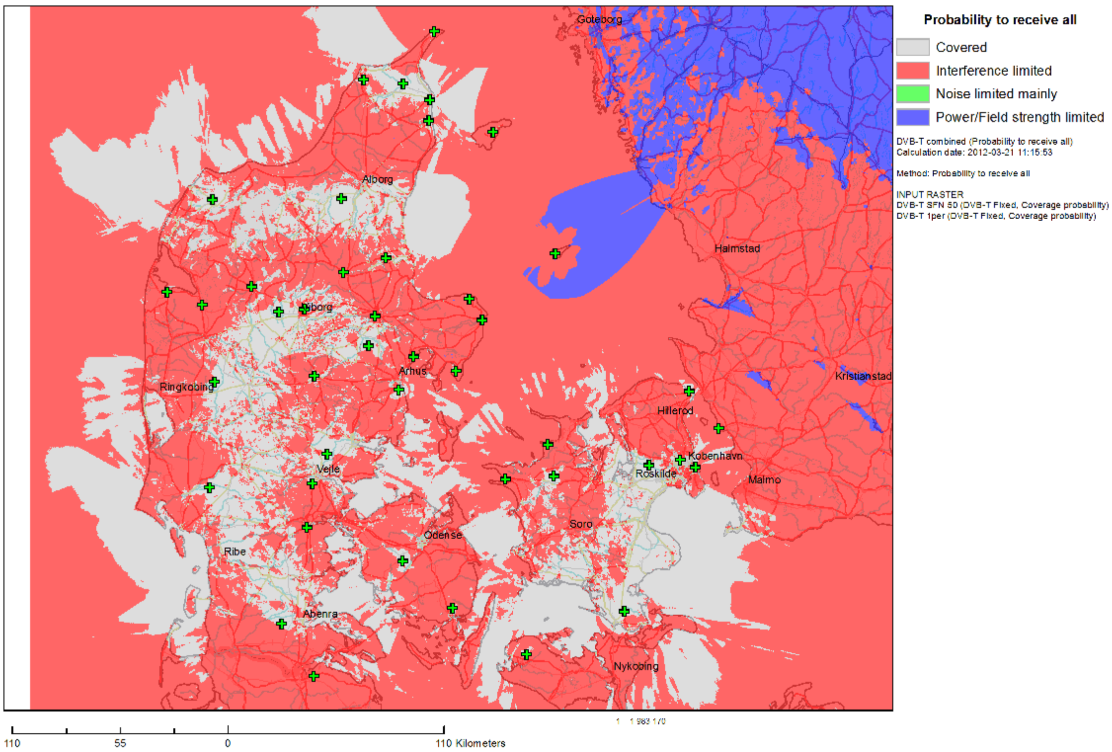


FIGURE P2-63

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

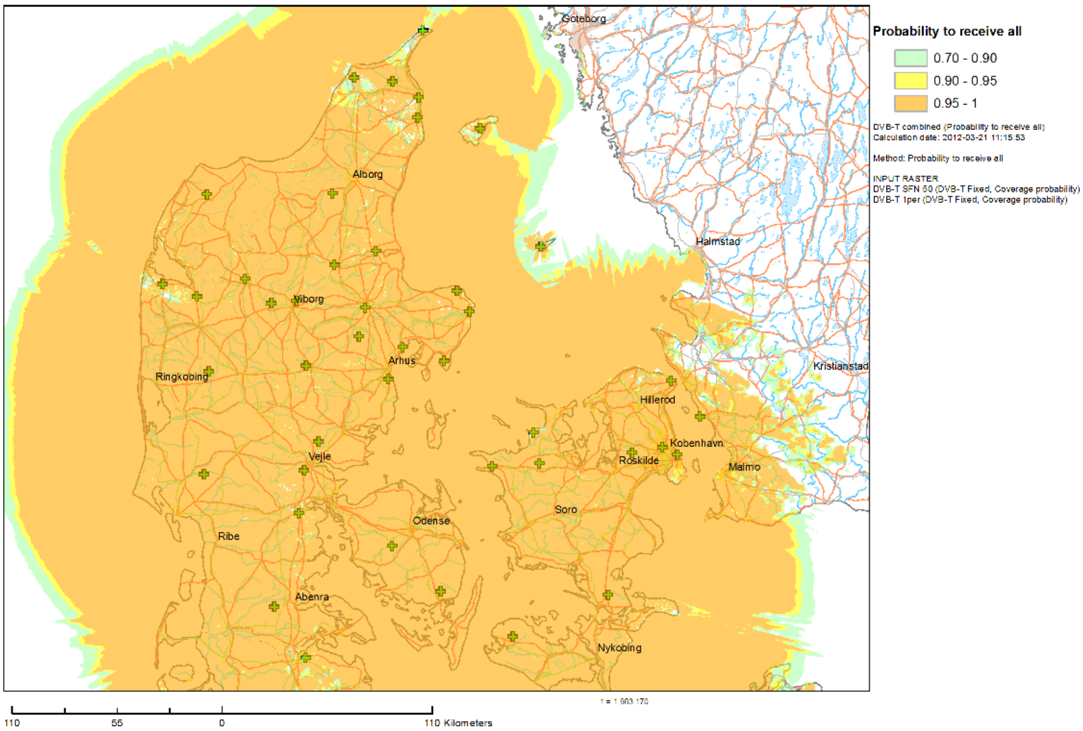
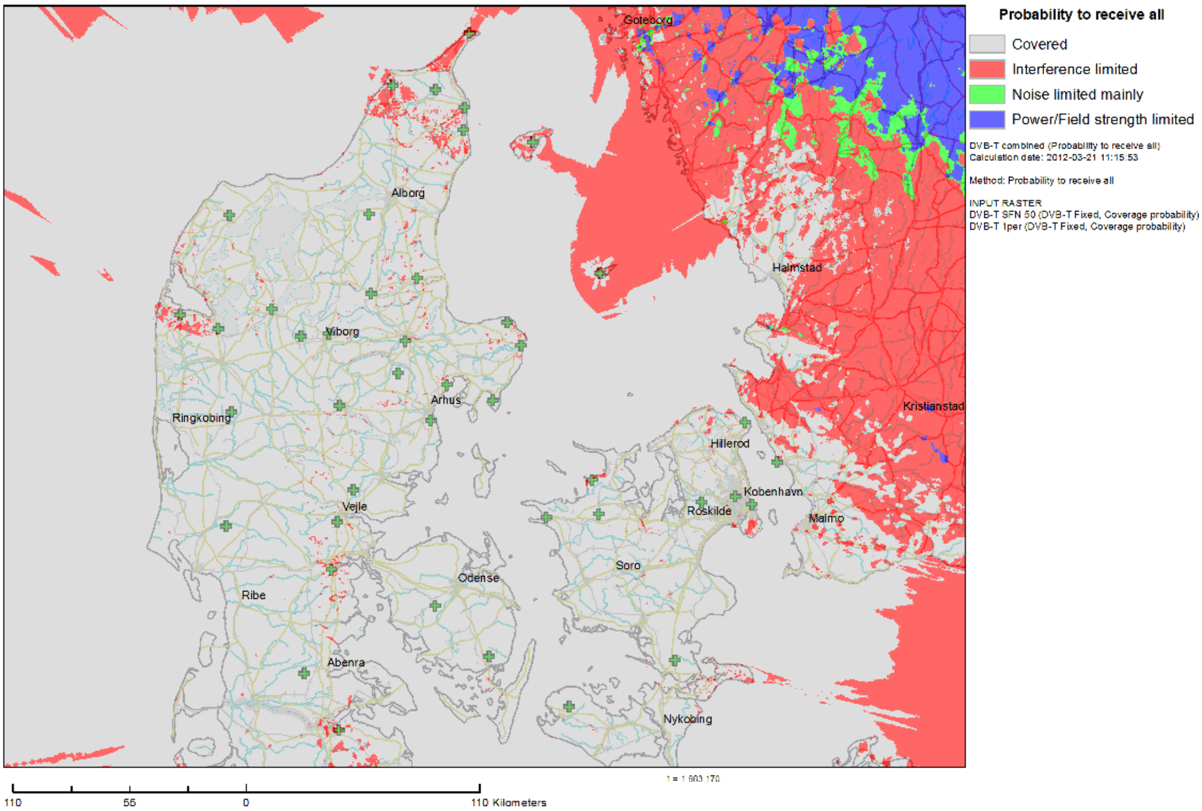


FIGURE P2-64

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 (Fig. P2-65). Potential self-interference areas are shown in Fig. P2-66. The population coverage is now 97.1%. Using this mode the bit rate will be about 29.4 Mbit/s.

FIGURE P2-65

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

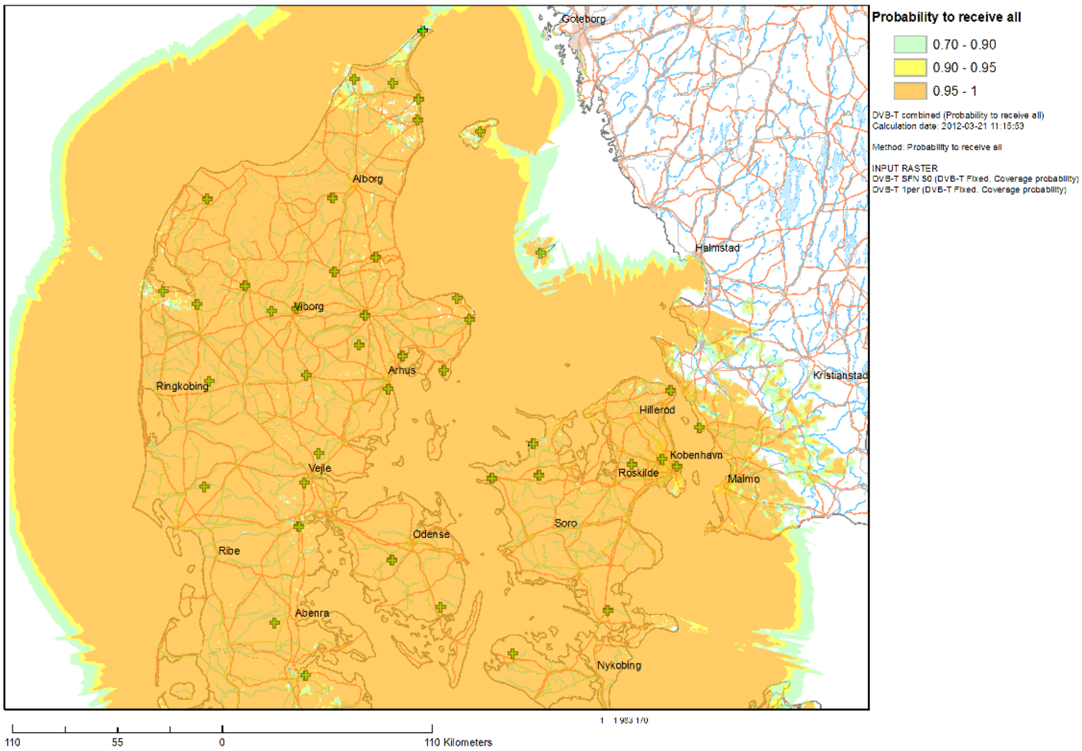
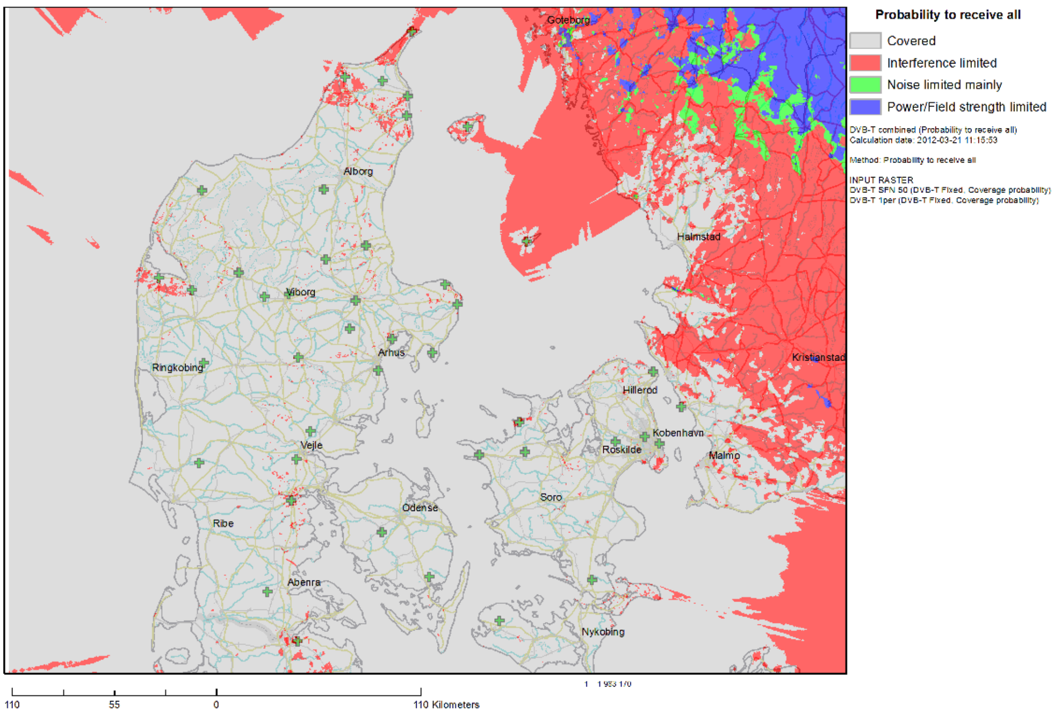


FIGURE P2-66

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 P2-67 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 (Fig. P2-68). 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 P2-67

T2 National SFN 64-QAM R = 3/5 TG 19/128 (532 µs)

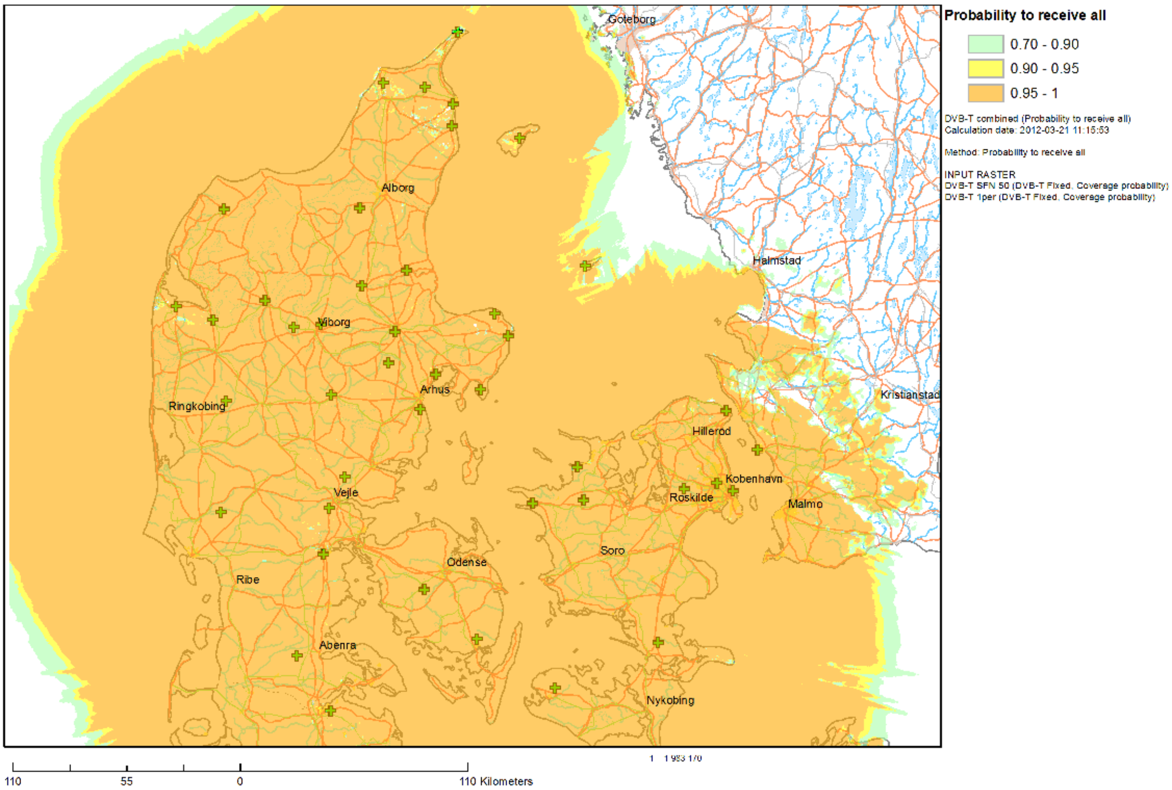
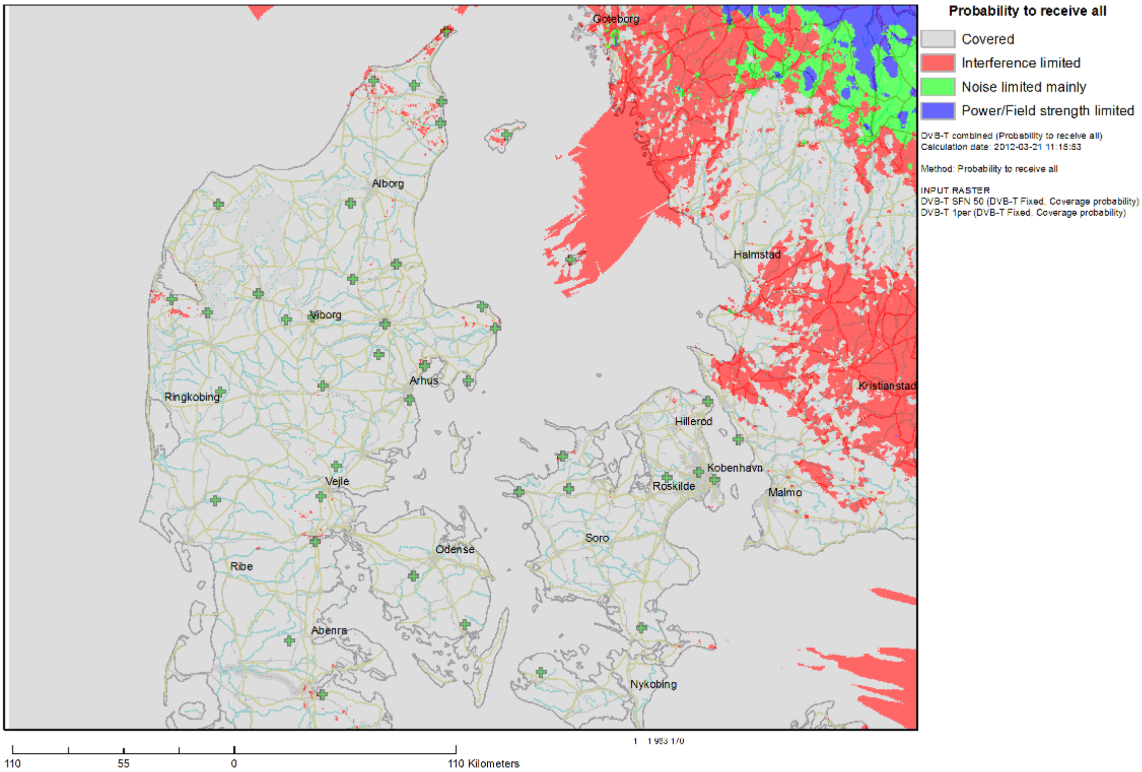


FIGURE P2-68

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



12.3.6 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 Technical Report TR 023 (https://tech.ebu.ch/) 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 P2-14

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.

12.4 Case study on DVB-T2 service areas in Sweden

A study by Teracom 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’[13] 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

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

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.

12.4.1 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.

12.4.2 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 e.r.p. levels and antenna heights. Most stations have an antenna height of approximately 300 m and e.r.p. of 50 kW, although some are smaller and with lower power. In Fig. P2-69 the two types of stations are indicated with different symbols.

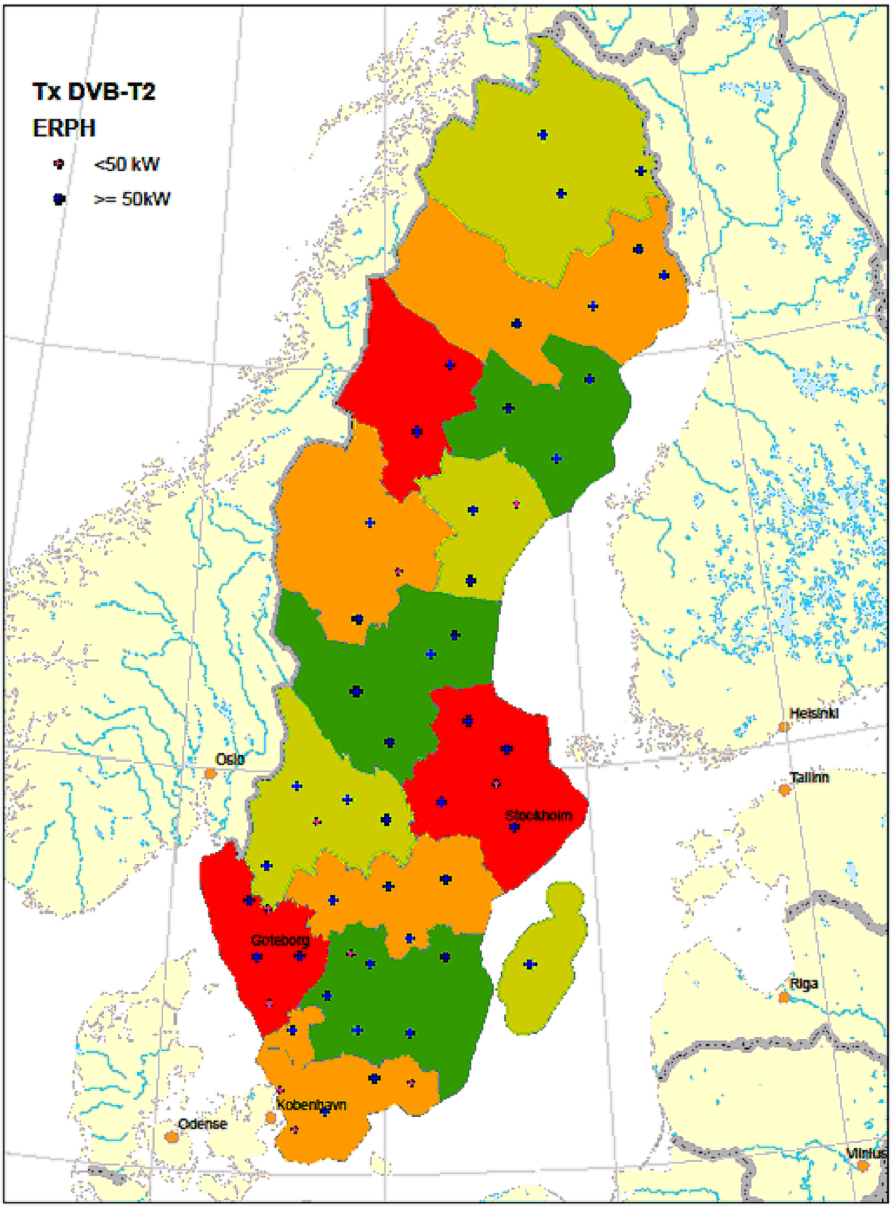
12.4.3 Network planning

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 P2-69

Frequency Network in Sweden



12.4.4 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 × 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 P2-70

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

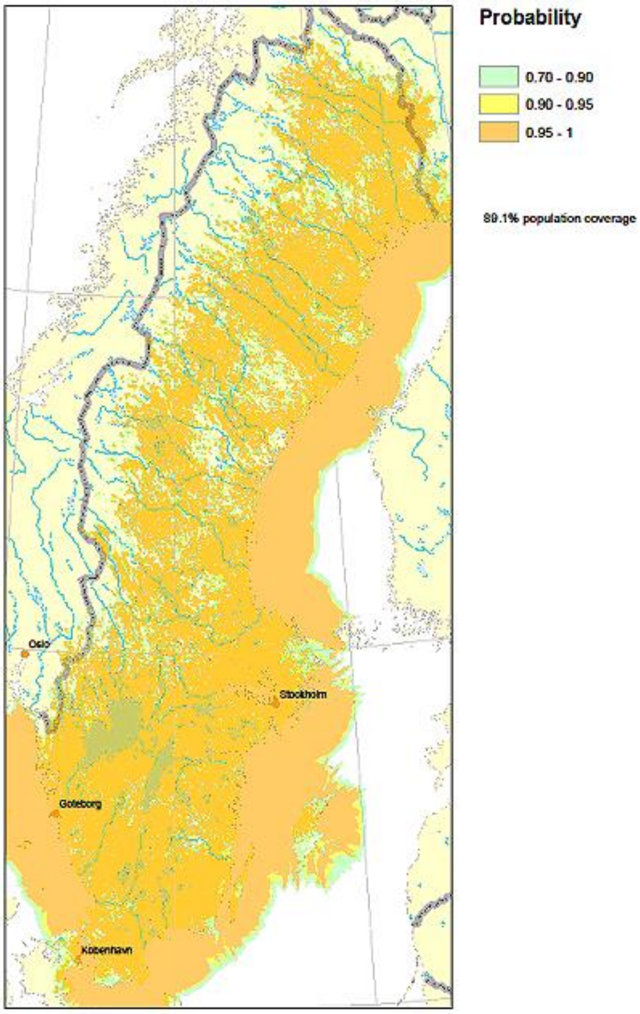


FIGURE P2-71

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

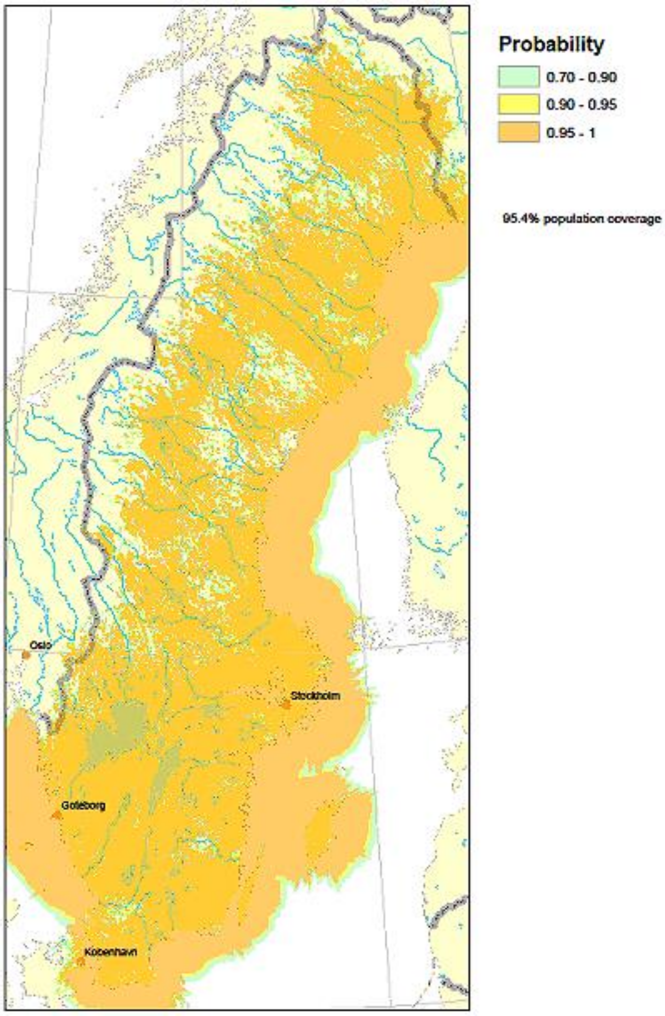
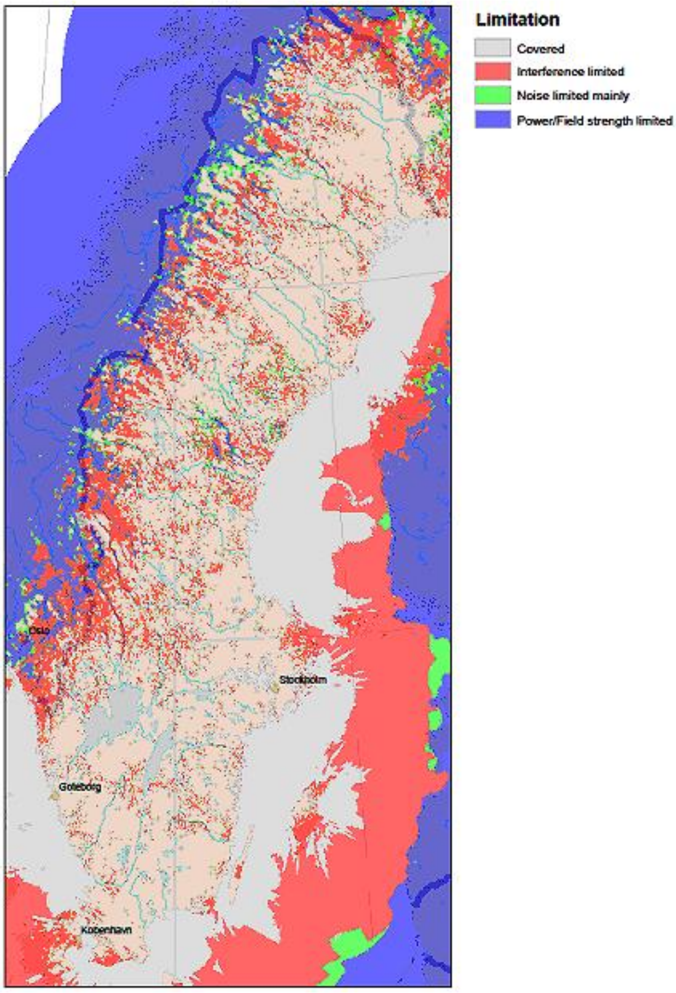


FIGURE P2-72

Self-interference National SFN



12.4.5 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.

12.4.6 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.

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

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[14].

The study included real terrain information, and to the extent known, existing antennas 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.

12.5.1 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 P2-15.

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.

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[14] 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 P2-15

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[15] 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.

12.5.2 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 P2-73 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 P2-74 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.

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

National SFNs, as shown by Fig. P2-75 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 guard interval can improve coverage, but it reduces capacity.

FIGURE P2-73

MFN

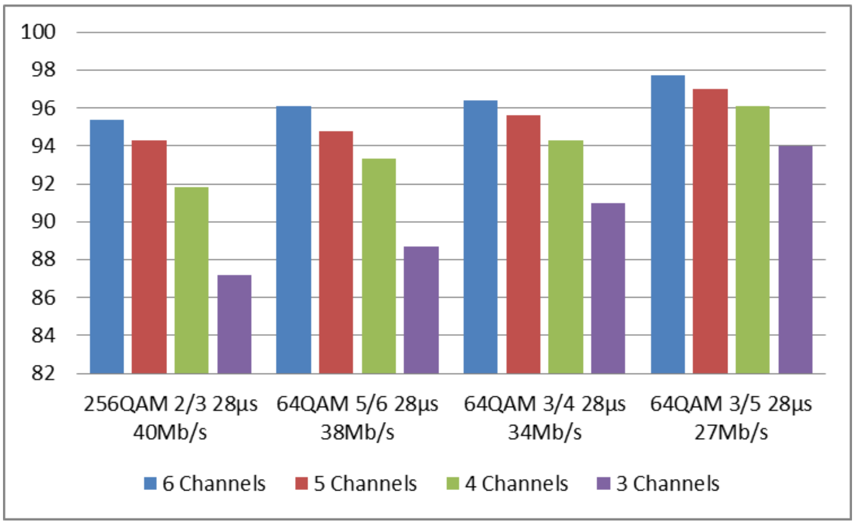


FIGURE P2-74

Regional SFN

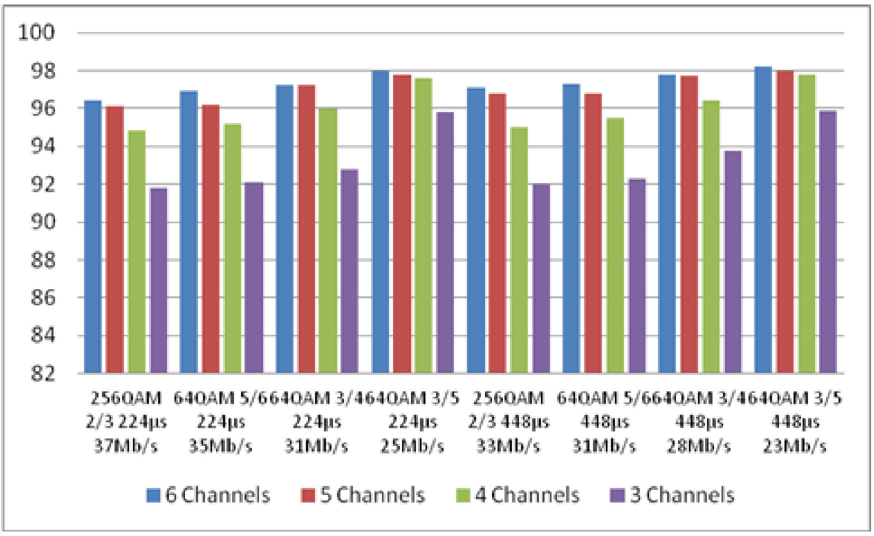
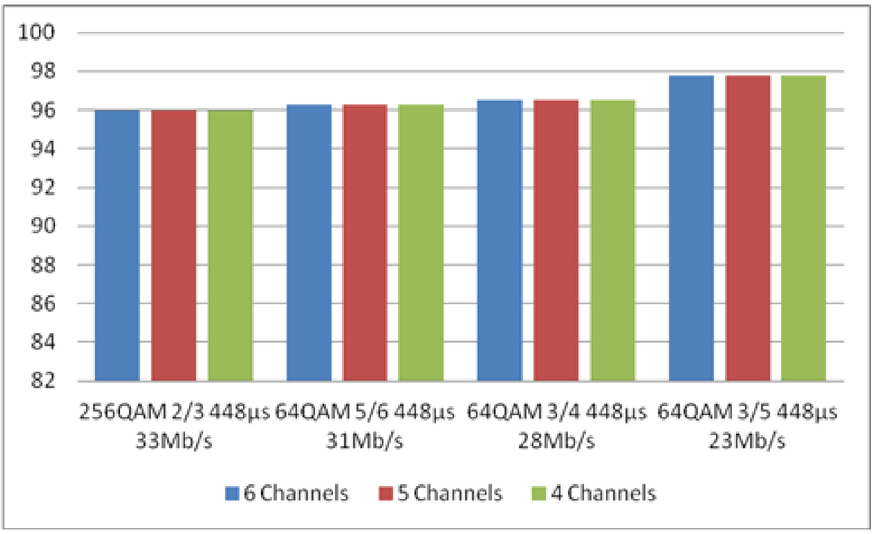


FIGURE P2-75

National SFN



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

A study by BBC incorporates and follows on from the results in § 12.5. 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 bits/s/Hz. Method 2 looked at efficiency in terms of the number of programmes that could be delivered per frequency channel[16] while taking into account the effects of statistical multiplexing and MPEG compression. Both methods were based on the results from § 12.5 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 Mb/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.

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

The main factor that influences spectral efficiency is the number of frequency channels required for the different network configurations. The results in § 12.5 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 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.

12.6.1 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.

12.6.2 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 Technical Report TR 015 (https://tech.ebu.ch/) has been used as the source of the guideline figures for HD and SD MPEG-4 compression.

12.6.3 Discussion

12.6.3.1 Method 1

The results of Method 1 are set out in Table P2-16 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 P2-16

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%

12.6.3.2 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 Technical Report TR 015 (https://tech.ebu.ch/).

SD

Table P2-17 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 Technical Report TR 015 (https://tech.ebu.ch/) 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 P2-16, 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 P2-17

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 Technical Report TR 015 (https://tech.ebu.ch/) 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 P2-18, from which it is clear that the picture quality would have little impact on the efficiency of the network configuration.

TABLE P2-18

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%

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 P2-19 summarises the results of Table P2-20 to Table P2-22 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 P2-19

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 P2-20

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 P2-21

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 P2-22

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 Table P2-20, Table P2-21 and Table P2-22, a significant unused bitrate is evident – for example the MFN in Table P2-21 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 Table P2-24 and Table P2-25 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 P2-23 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 P2-23

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 P2-24

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 P2-25

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%

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 P2-26 shows the Method 1 efficiencies recalculated should an additional channel be required for each network configuration, while Table P2-27 does the same should only the MFN and Regional SFNs require an additional channel.

Referring to Table P2-26 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 P2-27 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 P2-26

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 P2-27

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%

12.6.4 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 Building 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.

12.7 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[17] 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 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

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[17] Arqiva, "CH21 to CH60. Creation of Layers 7 and 8 in Released Spectrum", Study by Arqiva, prepared for Ofcom, 2009.

http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-policy-area/projects/ddr/ch21.pdf

Arqiva, "Creation of Broadcast Layers 7, 8 and 9 in 600 MHz Released Spectrum", Study by Arqiva, prepared for Ofcom, 2011. http://stakeholders.ofcom.org.uk/binaries/spectrum/spectrum-awards/600mhz/600MHz-Band-Study.pdf – 7 March 2011.

be impractically low due to the long guard interval requirements. DVB-T2 would, however offer significant benefits to both coverage and capacity.

Table P2-28 and Table P2-29 summarise the results of the studies[18].

TABLE P2-28

Re-Use 3 Coverage

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

TABLE P2-29

National SFN Coverage

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

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

This paragraph 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 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 below.

12.8.1 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

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[18] 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.

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[19].

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[20]. 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[21]. 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.

12.8.2 Results and Analysis

Figure P2-76 shows the variation in coverage[22] 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.

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[19] 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.

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

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

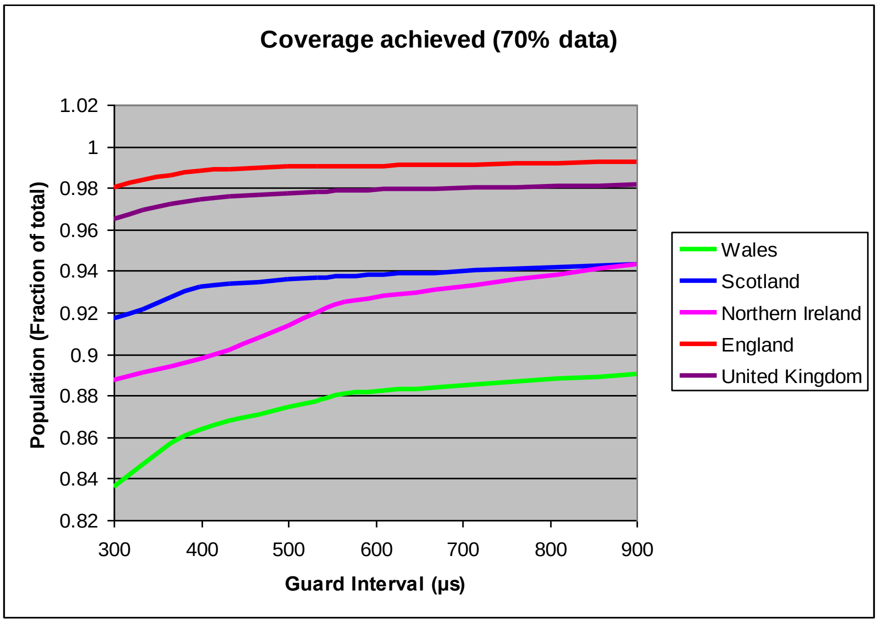
[21] The UK public sector broadcast (PSB) television network consist of 1 154 stations, 80 primary sites that serve about 95% of the population and a further 1074 relays that bring the coverage up to 98.5%.

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

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 P2-76

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.

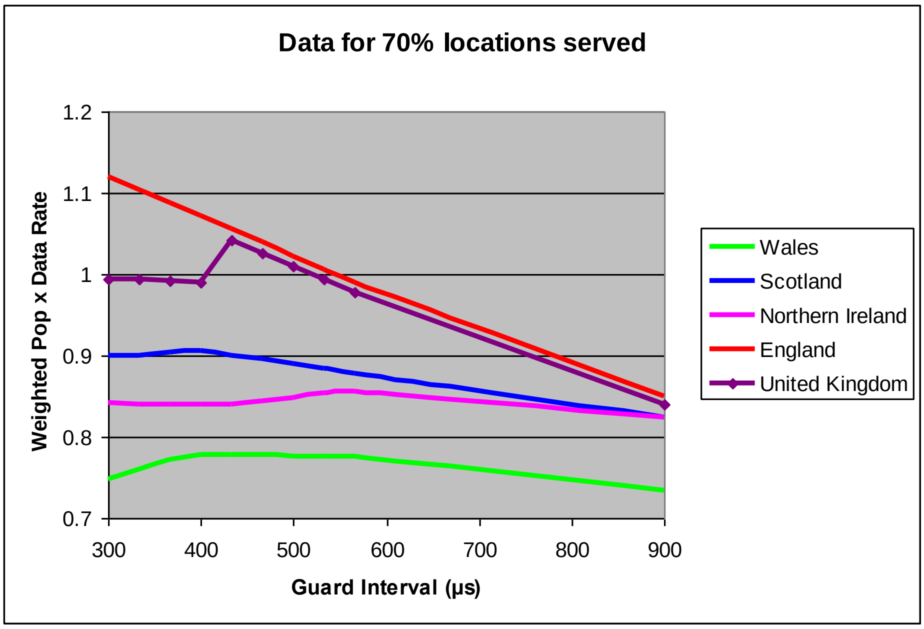
The weighting has been carried out as follows:

– 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:
(Fraction of the population served) 2 × (Normalised Data Rate)
otherwise, use:
(Fraction of the population served) × (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 P2-77

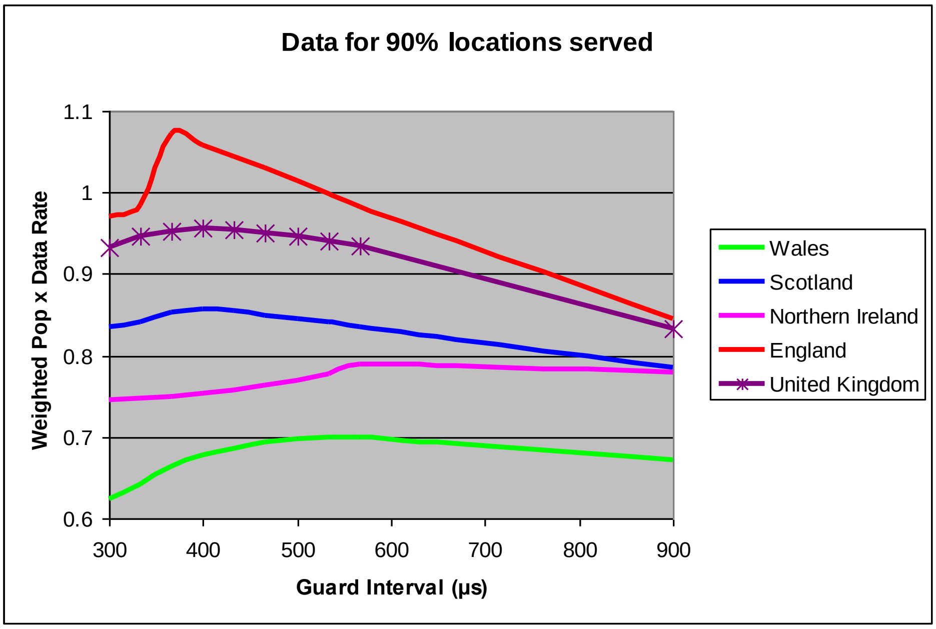
Normalized Coverage weighted for reduction in data capacity with increasing guard interval (70% locations served)



The plot in Fig. P2-77 summarises the results for 70% locations after accounting for the reduction in data capacity with increasing guard interval; the plot in Fig. P2-78, relates to similar the results but for 90% locations.

FIGURE P2-78

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.

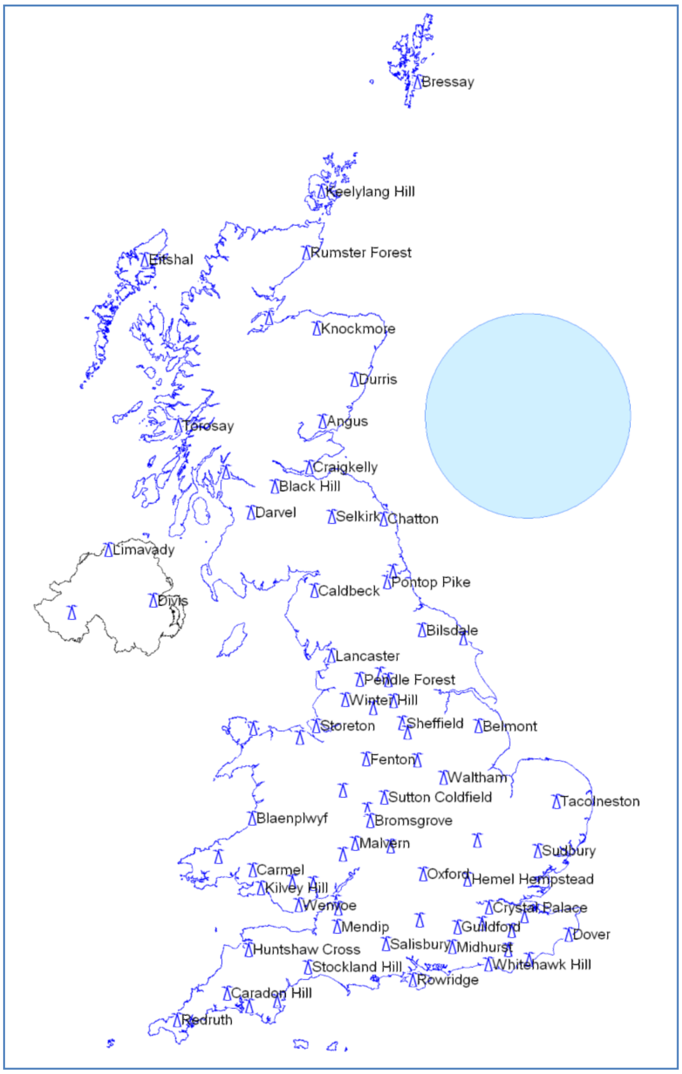
Using this approach, for the UK as a whole, we see an optimum value for the guard interval of just over 400 µs. If we change the threshold population to 97%, then the peak of the plot corresponds to a guard interval at just under 400 µs.

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 P2-79

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 P2-79 shows the locations of the sites. The blue circle has a radius corresponding to a delay of 400 µs.

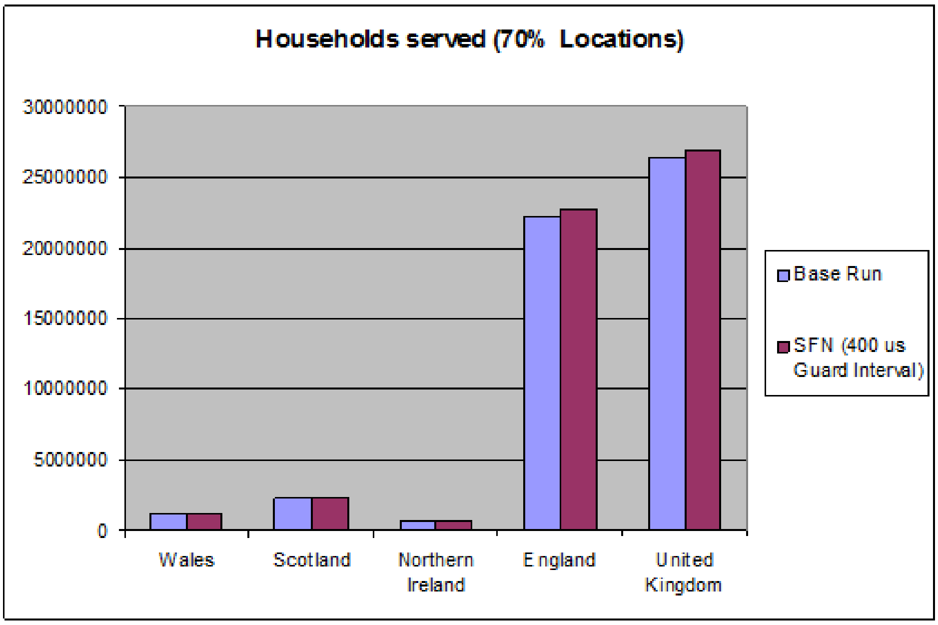
It can be seen that paths from sites such as Caldbeck to Northern Ireland are predominantly sea paths whereas from the same site (Caldbeck) to Mainland Britain the paths are predominantly over land. Thus the interference from Caldbeck to Northern Ireland will be higher than the interference it causes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

12.8.3 Summary

Figure P2-80 compares the coverage achieved by a national SFN with a guard interval of 400 µs with that achieved from the base configuration (MFN).

FIGURE P2-80

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.

12.9 Optimisation of a DVB-T2 SFN in Malaysia

A national DVB-T2 SFN was planned by Progira 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 × 200 km^2.

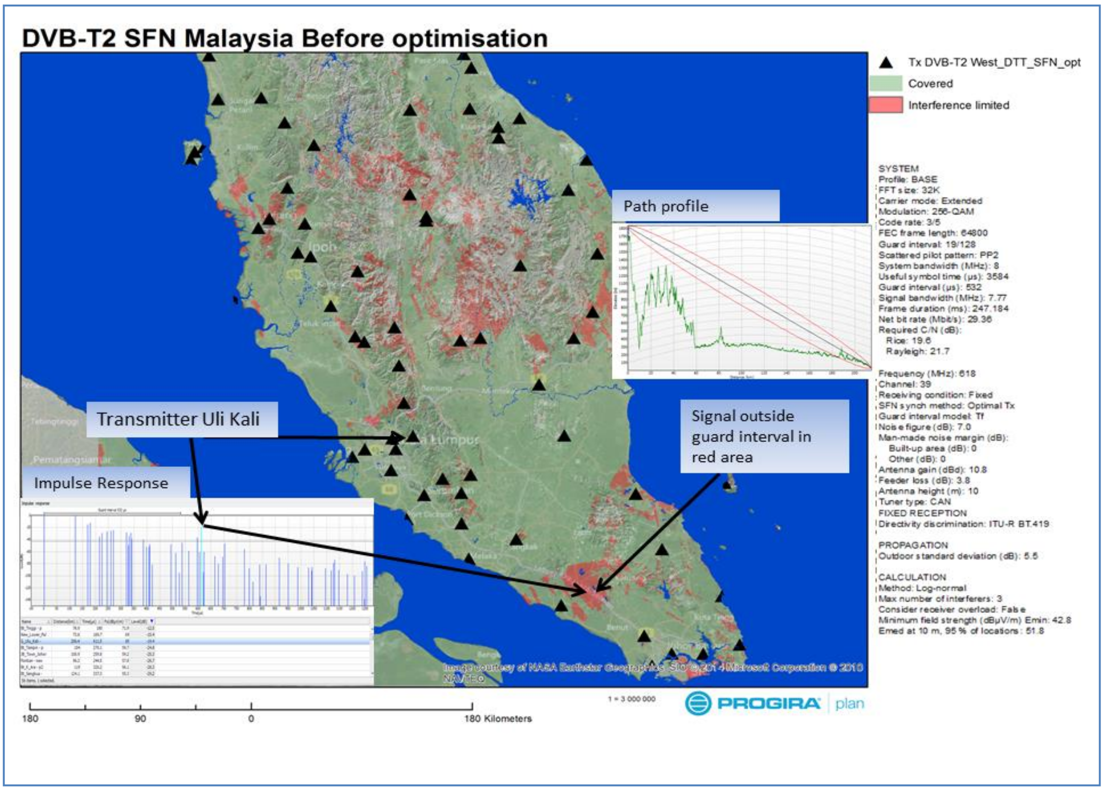
The main planning parameters were:

– 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 e.r.p.s between 1 kW and 60 kW.

FIGURE P2-81

Potential SFN self-interference areas in DVB-T2 SFN



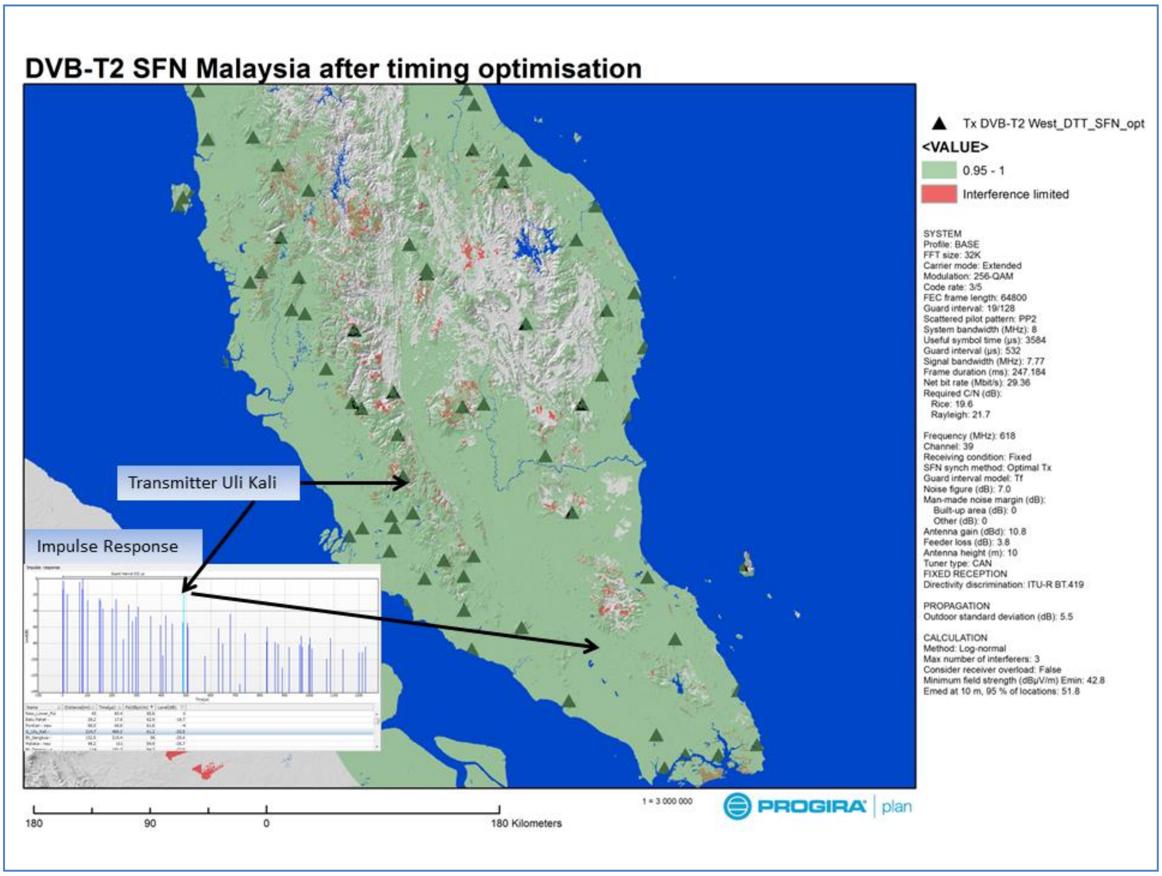
First the coverage was calculated using the nominal transmitter parameters assuming no timing offsets on the individual transmitters in the SFN. The result is given in Fig. P2-81 whereby coverage to 95% of the population was achieved, slightly below the requirement of 98%. When analysing the resulting 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 analysing the 1% time interfering signals where SFN self-interference areas are indicated in red in Fig. P2-81. 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 P2-81 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 1 700 m in some directions. The path profile from the transmitter to the area where self-interference may occur is also shown in Fig. P2-81.

FIGURE P2-82

Resulting DVB-T2 coverage after optimization of SFN self-interference. The problems with the out of guard interval signals are reduced with a combination of timing offsets and adjustments of antenna diagrams



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 Fig. P2-82. 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.

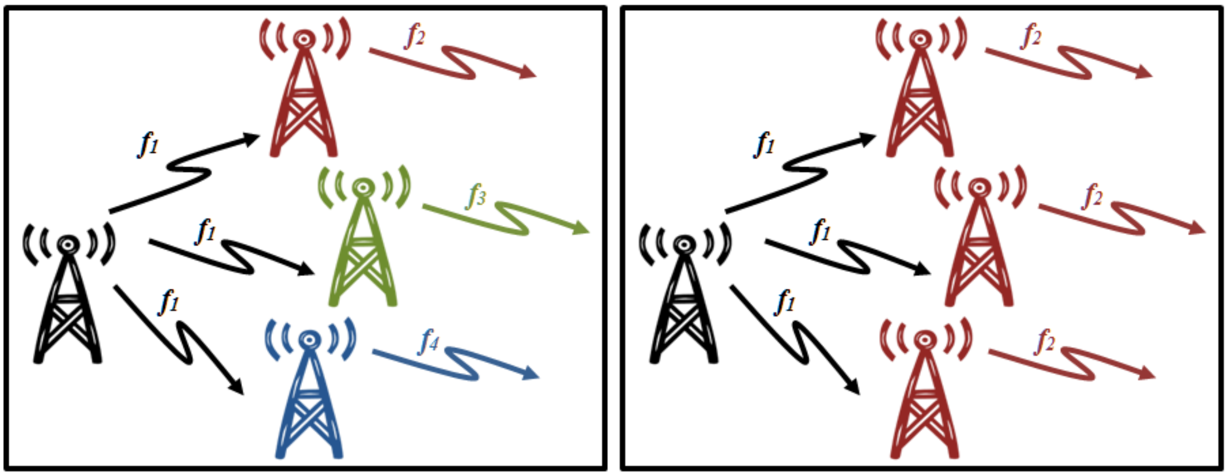
12.10 DVB-T2 SFNs Networks and an Extended T2-MIP: a BBC study

Introduction

The ideas below emerged from a discussion regarding the UK DVB-T and T2 networks.

A typical arrangement in the current UK network is shown in the left hand picture below. A parent transmitter operating on frequency f1 feeds a number of relays which receive its signal off-air and re-transmit it on frequencies f2, f3, f4. These relays are either full regenerative repeaters (demodulation followed by re-modulation) or, typically for lower power sites, frequency transposers (which perform a frequency shift only).

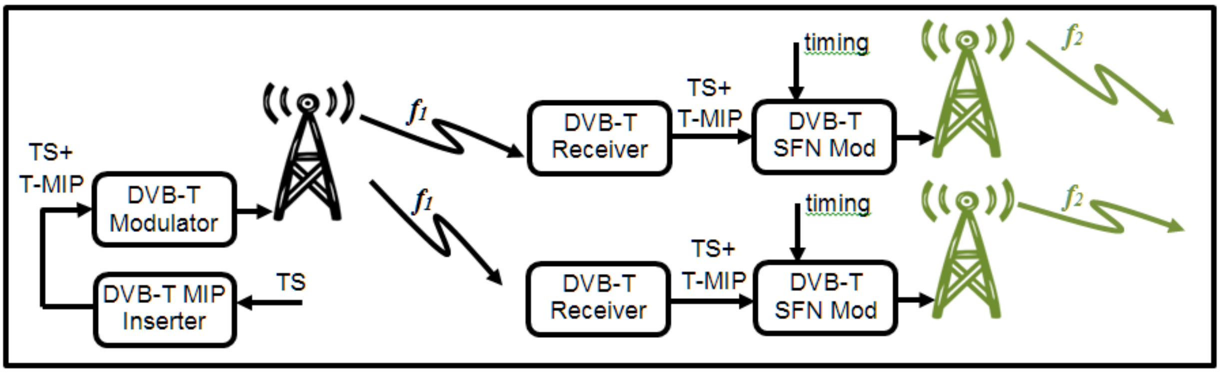
One way of increasing the spectral efficiency of the network might be for these relays to all re-transmit on the same frequency (f2) in a synchronised SFN as shown in the right hand picture. In order to achieve the highest signal quality in the resulting SFN, regenerative repeaters would be preferred over transposers. However, to achieve this requires the carriage of appropriate synchronisation information in the off-air signal used by the relays.



The differences between T and T2 mean that they present different challenges when deploying synchronised SFNs based on regenerative repeaters.

The differences between DVB-T and DVB-T2 SFNs

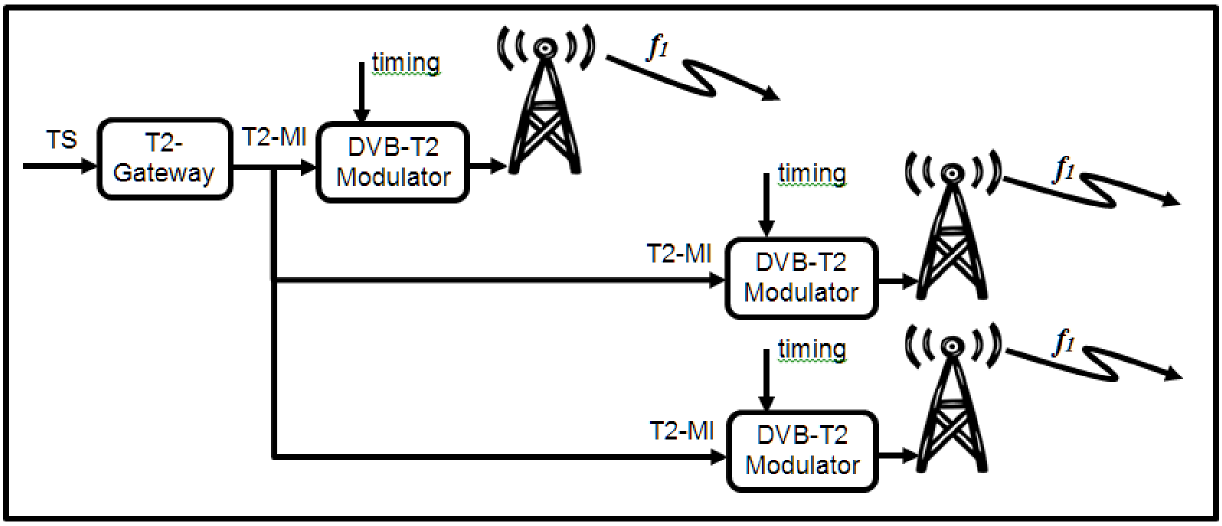
For DVB-T, there is a direct link between the mega-frame structure and the TS packets. The Transport Stream (TS) can be made into a complete and unambiguous description of the on-air signal by including Megaframe Initialization Packets ([T-]MIPs). The MIP is a TS packet that contains the timing information suitable for generating synchronised SFNs. Since this is a conventional TS packet, it is carried in the off-air signal along with the audio, video and SI. A conventional DVB-T receiver can decode the on-air signal and be connected directly to a SFN modulator to form a regenerative repeater as illustrated below.



For DVB-T2, there is no longer a fixed relationship between the packetization of the TS and the frame structure of the physical layer. Therefore the TS alone is not an unambiguous representation of the off-air signal meaning that it is not, on its own, suitable for the formation of T2 synchronised SFNs.

A new entity, the T2-Gateway, is required in the network that takes at its input the audio/video transport stream and generates at its output the T2 modulator interface (T2-MI)[23]. The T2-MI provides the unambiguous representation of the on-air DVB-T2 signal as a combination of BBFrames and L1 signalling. Timing information can also be conveyed by the T2-MI and, since the T2-Gateway has carried out the framing once, this can be used to form synchronised T2 SFNs from multiple transmitters. However, the T2-MI is not carried over-air but is instead used by a modulator to generate the on-air signal.

In the current UK DTT network, the synchronised T2 SFNs make use of a T2-Gateway at a parent transmitter after the output of a proprietary SI insertion device. The T2-Gateway generates a T2 Modulator Interface (T2-MI) signal that is then line-fed to the children as illustrated below.



The requirement for line feeding of the transmitters means that the cost is prohibitively high for generating T2 synchronised SFNs at smaller sites. In areas where it is not economic to provide line feeds, non-synchronised transposers are currently used and the resulting mush area regarded as an acceptable compromise.

T2 has its own version of the MIP defined as the T2-MIP (the T2 Modulator Interface Packet) that allows generation of synchronised SFNs from an off-air signal. Just as for DVB-T, this is a

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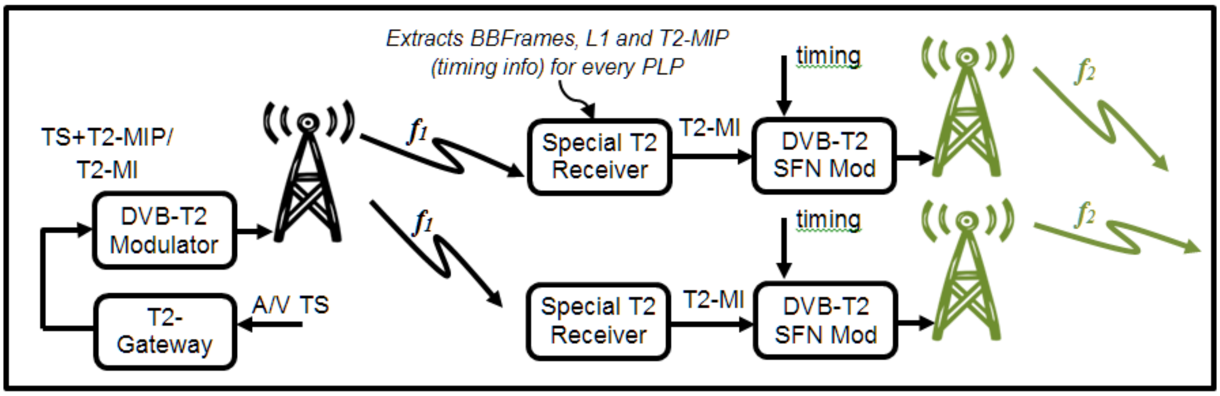
[23] The T2-MI packets are themselves carried in TS for compatibility with existing distribution networks.

conventional TS packet that carries timing information and is carried in the on-air signal along with the audio, video and SI. The T2-MIP indicates the timing of the start of emission of the physical layer super-frame in which the packet is carried.

However, a special receiver is required that is capable of outputting the physical layer framing of the T2 by generating T2-MI in the form of Baseband frames and the L1 signalling along with the timing information derived from the T2-MIP packet (see below).



A further issue occurs when multiple PLPs are used since this special receiver also needs to be able to receive all of the PLPs whereas a conventional T2 receiver is only required to receive two PLPs simultaneously[24].

Up until now, the necessity to have this special receiver has meant that this setup hasn't been possible and we don't believe that such a device currently exists on the market.

Possible Solutions

In principle, what is required is a full regenerative repeater, able to receive the T2 signal off air, extract the BBFRAMEs, L1 signalling and T2-MIP and either use these to generate T2-MI to feed a T2-MI-capable modulator, or generate the DVB-T2 signal directly.

However, such a piece of equipment is complicated and specialised, and for many applications a simpler solution may be possible.

For the simplest modes of DVB-T2 where every Baseband frame is fully allocated (as currently used in the UK), each T2 frame always contains the same number of Baseband frames and where only single PLPs are in use, the relationship between the TS packets and physical layer frames is simpler to define.

In fact, all that would be required is for the T2-MIP to be extended to signal the offset (in bits) from the start of the first BBFrame to the start of the packet. This would be a so-called extended MIP (T2-eMIP). With this packet, a conventional receiver could be used to receive the TS off-air. A separate (relatively simple) device could then use the offset and timing information contained in the T2-eMIP to re-construct the physical layer framing (BBFrames) in an unambiguous way and output a T2-MI signal suitable for use in forming a subsequent synchronised SFN.

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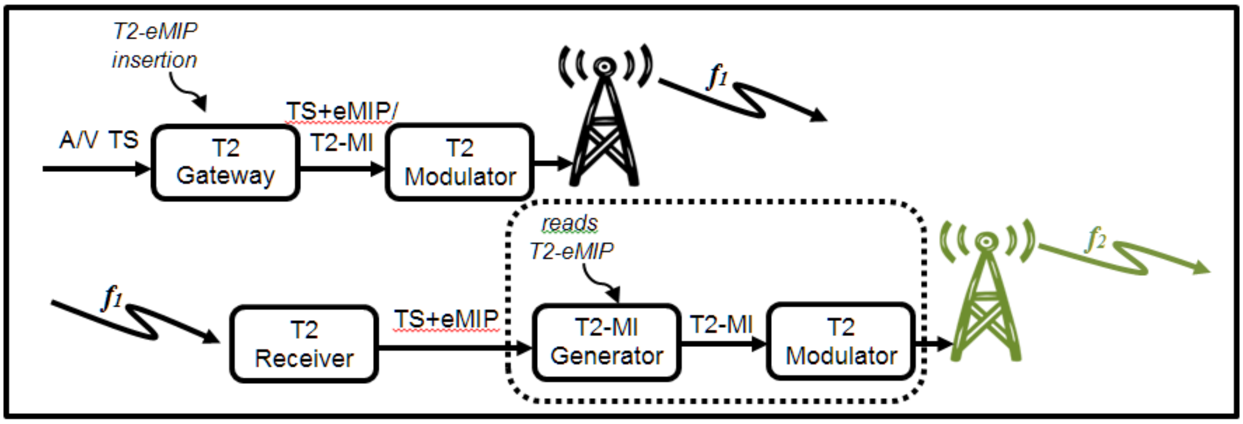
24 Simultaneous reception of one data plus one common PLP is mandated by the T2 specification.



This re-construction of the T2-MI could be carried out either in software or in a relatively simple hardware.

The standalone T2-MI Generator could be fairly simple. It would not even be necessary to read the L1 information of the off-air input signal since this could be manually configured on each device in the same way that T2 modulators are currently configured in the DTT network. For a more general solution, it would be possible to include the necessary configuration information in the T2-eMIP or another packet to be defined. The most obvious way to do this would be to transmit some or all of the L1 signalling.

The T2-eMIP could be created by making use of the rfu_bytes fields defined in Annex B of ETSI TS 102 773 v1.3.1. Alternatively, a new T2-MIP could be defined using a new synchronization_id. In either case, this could be standardised through DVB/ETSI by issuing a new version of TS 102 733.

Depending on the use cases and requirements, it might be necessary or advisable to make the T2-eMIP work for a wider range of configurations.

A possible outline for the information to be carried might include:

– All the information currently in the existing T2-MIP.

– An indication of the offset in packets and bits, relative to the start of the T2-eMIP, of the first bit of the data field of the first BBFRAME of each Interleaving Frame (it might be possible to indicate only every superframe if certain other constraints are imposed, particularly regarding padding).

– A concise way of indicating the pattern of BBFrame padding.

– A method of carrying the L1 pre- and configurable L1-post signalling as needed (once per superframe should be sufficient).

– A method to carry a copy of the dynamic L1 signalling for each T2-Frame.

Consideration would be needed as to how to support multiple PLPs. One option would be to include a T2-eMIP in each PLP's Transport Stream, possibly using a common PLP

There might be a trade-off in making the system flexible enough to meet the requirements whilst avoiding making it as complicated as the full T2-MI solution.

Conclusion

The T2-MIP can be used to re-create subsequent synchronised T2 SFNs that are re-generated from an off-air signal. However, up until now, the necessity to have a special device capable of re-uniting the TS packets with the relevant physical layer T2 frame has made this approach unattractive and we are not aware of any commercial devices that are available to perform this function.

The T2-MIP also relies on access to separate knowledge about how the TS was mapped into BBFRAMEs and Interleaving Frames as well as about the scheduling and allocation of PLPs to the T2-frame structure.

An extension to the existing T2-MIP definition (the so-called eMIP), could offer a simpler solution for off-air regeneration of a T2 signal in an MFN. It would also allow a DVB-T2 signal to be generated deterministically from an input TS in other applications. These could potentially include local content insertion.

DAB SFN

13 Impact of T-DAB parameters on SFN performance

With the term T-DAB is intended the reference to the EUREKA 147 system regardless the modulation adopted, MPEG-1-layer 2 (DAB) or AAC+ (DAB+).

13.1 General

Several of the conclusions drawn in the previous chapter on the impact of DVB-T parameters on SFN performance are equally valid also for the T-DAB case. For reasons of a balanced presentation they are partly repeated in the present chapter on T-DAB properties.

13.2 Constellation

All T-DAB modes use QPSK (4-QAM) modulation. QPSK provides a low data capacity but it does provide a very rugged service for mobile reception.

13.3 Code rate

Different code rates can be used to trade bit rate versus ruggedness, e.g. the signal strength required and interference protection required.

Five protection levels are available for audio (forward error correction (code rate) ranges from 1/3 to 3/4) and eight protection levels are available for data services through using punctured convolutional coding.

In the case of an audio signal, greater protection is given to some source-encoded bits than others, following a pre-selected pattern known as the unequal error protection (UEP) profile. The average code rate, defined as the ratio of the number of source-encoded bits to the number of encoded bits after convolutional encoding, may take a value from 1/3 (the highest protection level, giving the lowest useful data capacity) to 3/4 (the lowest protection level which provides the highest data capacity). Different average code rates can be applied to different audio sources, subject to the protection level required and the bit rate of the source-encoded data.

Because different segments of the data stream for each programme service have different protection levels and therefore require different code rates, it is not possible to precisely specify the overall code rate for each programme service or for the overall multiplex of programme services and data. The code rate thus depends slightly on the data rate used for each programme service (or data service).

13.4 FFT

The DAB system has four alternative modes which allow for the use of a wide range of transmitting frequencies up to 3 GHz. These transmission modes have been designed to cope with Doppler spread and delay spread, for mobile reception in presence of multipath (passive) echoes and active echoes created by co-channel gap-fillers or transmitters in a single frequency network.

Mode I is most suitable for a terrestrial SFN in the VHF range, because it allows the largest distances between transmitters as it has the longest guard interval.

Mode II is most suitable for local radio applications requiring one terrestrial transmitter and hybrid satellite/terrestrial transmission up to 1.5 GHz. Mode II can also be used for a small-to-medium SFN at 1.5 GHz.

Mode III is most appropriate for satellite and complementary terrestrial transmission at all frequencies up to 3 GHz. Mode III is also the preferred mode for cable transmission up to 3 GHz.

Mode IV, a new mode, bridging the gap between Modes I and II, which is also optimized for operation at 1.5 GHz has been added with key values in a binary relationship to the previously developed modes. This mode provides for a longer constructive echo delay for easier SFN implementation, while keeping the effect of the Doppler spread at high vehicle speed within reasonable bounds.

TABLE P2-30

Main characteristics for the four DAB transmission modes

		Mode I	**Mode IV**[25]	**Mode II**	**Mode III**
Typical use		Terrestrial VHF	Terrestrial Urban L-Band	Terrestrial L-Band	Satellite L-Band
Number of carriers	n	1536	768	384	192
Approximate Carrier spacing	Δf	1 kHz	2 kHz	4 kHz	8 kHz
Useful symbol duration	T_U	1 μsec	500 μsec	250 μsec	125 μsec
Guard Interval	Δ	246 μsec	123 μsec	62 μsec	31 μsec
Total symbol duration	$T_S = T_U + \Delta$	1246 μsec	623 μsec	312 μsec	156 μsec
Max. speed (mobile) VHF	v_{max}	260 / 390 km/h	520 / 780 km/h	n.a.	n.a.
Max. speed (mobile) L-Band	v_{max}	40 / 60 km/h	80 / 120 km/h	160 / 240 km/h	320 / 480 km/h

13.5 Guard interval

In an SFN each transmitter is required to radiate the same OFDM symbol at the same time.

This comes from the fact that echoes (natural or artificially generated by co-channel transmitters) shall be confined in the guard interval period. The OFDM receiver has to setup a time window during which it samples the on-air OFDM signal. The objective is to synchronize this time-window with the useful period of the OFDM symbol. Accordingly, it will ignore the signal during the guard interval period where the receiver signal is made of a mixture of two or more OFDM symbols. If the transmitters deliver the same OFDM symbol at the same instant, or with a sufficiently small time delay, the differential propagation path delay to the OFDM receiver will remain inside the guard

[25] Mode 4 is an extension of the original ETSI standard specification to improve multipath performance of L-Band SFN in urban areas, hence the table does not follow a natural sequence.

interval period. Accordingly, the sum of the received signals will be constructive because they constitute the same OFDM symbol (no inter-symbol interference).

The T-DAB specification offers one system guard interval, i.e. 1/4 times the duration of the active symbol duration. This is shown in Table P2-30 above.

The selection of this guard interval parameter affords resilience against delayed, interference–causing signals for mobile reception. The guard interval value has a major implication on the topology of the SFN: as the guard interval duration governs the maximum echoes delay admissible by the system. It therefore governs the maximum possible distance between co-channel transmitters (producing active echoes). Mode I allows setting up large SFN networks having a great distance between transmitter sites.

For Mode I, when the transmitters are situated less than 75 km apart, the permissible signal delay times are greater than the actual signal delay between adjacent transmitters.

Transmitter spacing can be increased beyond that defined by the guard interval by varying the radiated power, transmission polarisation and the relative transmitter timing. Effective planning of the required radiated power and transmission polarisation at the secondary site(s) will optimise SFN performance and provide effective management to eliminate most potential interference problems.

There is no limit on transmitter spacing providing the secondary site has a directional antenna transmitting away from the main site utilising an appropriate delay. However, where two transmit sites are radiating towards each other careful planning is required.

13.6 Data rate versus guard interval

In each of the specified modes of T-DAB operation the guard interval is a set fraction, one fifth, of the overall symbol period. Whilst both the symbol period and the number of carriers transmitted vary between modes the total number of symbols over a given period is the same. As a result the transmitted data rate is only affected by a change in the error protection level used.

Table P2-31 indicates the net bitrate in Mbit/s for various error protection code rates.

TABLE P2-31

Net bit rate in Mbit/s for various error protection code rates

Protection Level	Corresponding approximate Code Rate	Approximate Bit-Rate (Mbits/s)
1	0.34	0.78
2	0.43	0.99
3	**0.50**	**1.15**
4	0.60	1.38
5	0.75	1.73

14 DAB case studies

14.1 Italy implementation

14.1.1 DAB SFNs in Trentino Alto Adige region

In 2010, the Italian Administration issued a new set of laws for the digital radio choosing DAB+ as modulation technique and SFN mode for the fulfilment of the network.

Few operators were already operating DAB network in SFN mode and the widest network was the one of RAS in Alto Adige region. RAS is a regional radio television broadcaster which guarantees the public service in German for the minority community of the Alto Adige area.

In 2013 also Rai Way began to implement its national DAB+ SFN. The new network will be operating on the same block all over Italy but, at this time, the frequencies assigned to DAB have not been yet released.

The development of the new DAB+ network started from Trentino Alto Adige.

FIGURE P2-83

Italy and Trentino Alto Adige region

Trentino Alto Adige is a mountainous region located in northern Italy bordering Austria. In the northern part of the region, Alto Adige, there is the RAS network on 10B block shared with Rai Way; in the southern part of the region, Trentino, there is the Rai Way network on 12B block.

The RAS network is composed by twenty-seven transmitters, each one with a different identification code. As the region is not very wide (around 7 400 km^2), there is no need to have different static delays.

FIGURE P2-84

RAS DAB SFN coverage

The technical information of the network is detailed in the table below.

TABLE P2-32

RAS DAB SFN

Transmitter site	Altitude	Antenna height	e.r.p.	TII-Main 0-69	TII-SubTable 1-23	MNSC 65535
Mut – Mutta	1 264	32	1.0 kW	1	1	101
St. Leonhard – S. Leonardo	1 286	31	0.4 kW	1	2	102
St. Pankraz – S. Pancrazio	1 090	46	0.4 kW	1	3	103
St. Gertraud – Santa Gertrude	1 775	29	0.05 kW	1	4	104
Penegal	1 740	45	3.2 kW	2	1	201
Plose – Plose	2 023	22	1.6 kW	3	1	301
Lajen – Laion	1 142	58	0.13 kW	3	2	302

TABLE P2-32 *(end)*

Transmitter site	Altitude	Antenna height	e.r.p.	TII-Main 0-69	TII-SubTable 1-23	MNSC 65535
Meransen – Maranza	1 370	20	0.2 kW	3	3	303
Kronplatz – Plan Corones	2 258	69	0.5 kW	4	1	401
Luttach – Lutago	1 415	31	0.5 kW	4	2	402
Innichen – San Candido	1 690	46	0.25 kW	4	3	403
Rein – Riva di Tures	1 767	37	0.03 kW	4	4	404
Mühlwald – Selva dei Molini	1 510	29	0.05 kW	4	5	405
St. Konstantin – S. Costantino	917	16	0.2 kW	5	1	501
Sarntal – Sarentino	1 242	27	0.16 kW	5	2	502
Hohe Scheibe – Cima Capra	2 556	15	0.25 kW	5	3	503
Obervinschgau – Alta Val Venosta	1 962	56	1.0 kW	6	1	601
St. Martin am Kofel – S. Martino di Laces	1 703	45	0.63 kW	6	2	602
Graun – Curon Venosta	1 515	41	0.25 kW	6	3	603
Unser Frau in Schnals – Madonna di Senales	1 872	12	0.2 kW	6	4	604
Freienfeld – Campo di Trens	1 340	42	0.5 kW	7	1	701
Kematen – Caminata (Val di Vizze)	1 810	59	0.02 kW	7	2	702
Grödnerjoch – Passo Gardena	2 280	16	0.32 kW	8	1	801
Grödental – Val Gardena	2 006	45	0.32 kW	8	2	802
Abtei – Badia	1 702	33	0.02 kW	8	3	803
Paganella	2 098	56	3.2 kW	9	1	901
Kardaun – Cardano	932	29	0.13 kW	Gapfiller		

The multiplex contains twelve programs, some in DAB+ and some in DAB, some in Italian other in German: Rai Radio1 (DAB+, Italian); Rai Radio2 (DAB+, Italian); Rai Radio3 (DAB+, Italian); Rai Südtirol (DAB+, German); WDR KIRAKA (DAB+, Radio for children, German); Radio Swiss Classic (DAB+, German); Radio Swiss Pop (DAB+, German); Deutschlandradio Kultur (DAB+, German); RSI Rete 2 (DAB+, Italian); BR BAYERN 3 (DAB, German); BR-KLASSIK (DAB, German) and BR B5 aktuell (DAB, German).

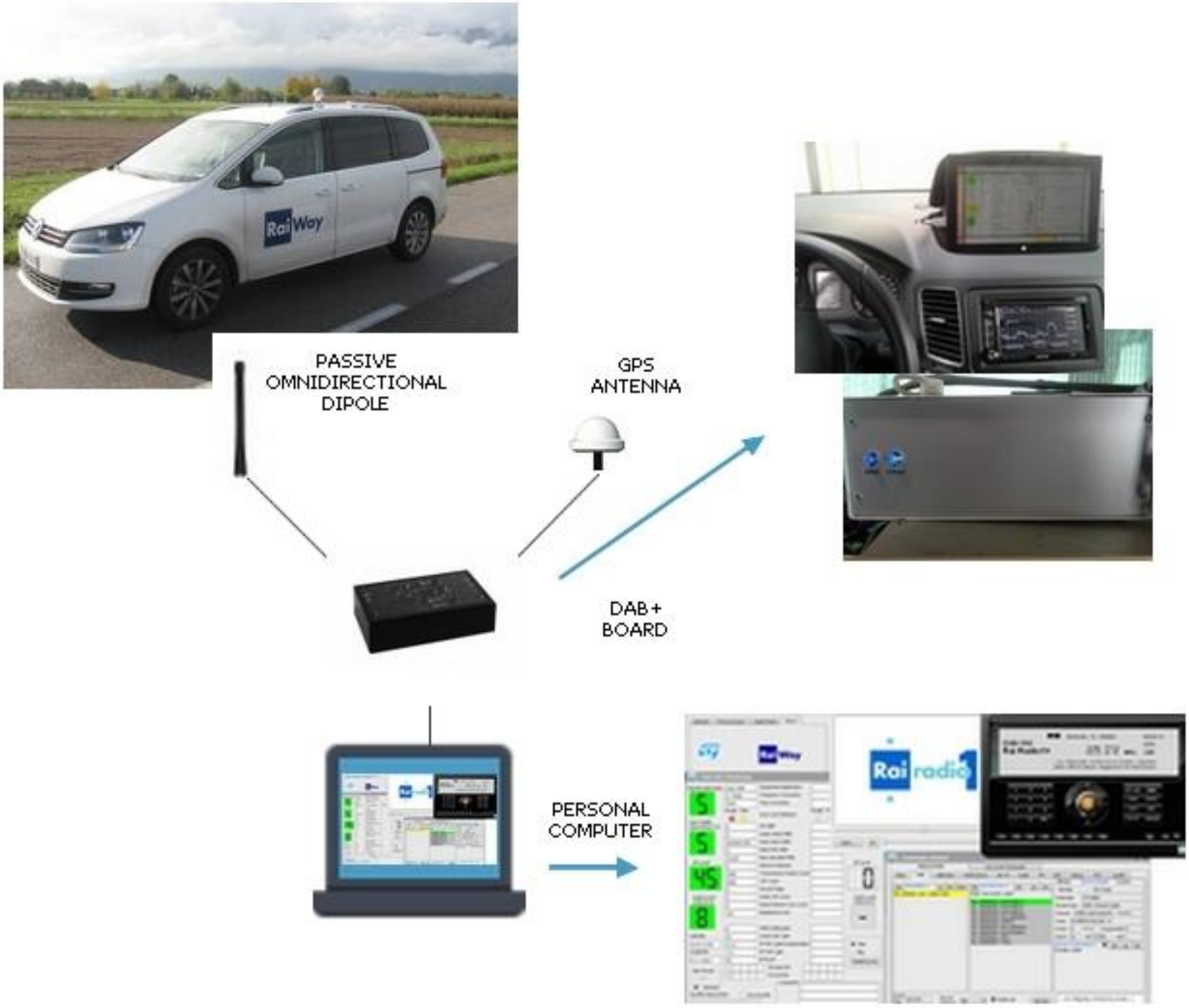
A measurement campaign were performed in order to evaluate the quality of service for mobile reception.

The measures were achieved with an equipped vehicle with a DAB+ commercial radio and an "ad hoc" board developed in partnership with a world leader in providing electronic components and semiconductor solutions. This equipment allowed to detect the Transmitter Identification Information, TII, and to evaluate the coverage, the quality of service and the performance of the SFN.

The following figure shows the measure set up.

FIGURE P2-85

Measure set up



The service quality is estimated with FIC parameter in the following way:

good service FIC < 5 * 10^{-3}

poor service 5 * 10^{-3} ≤ FIC <5 * 10^{-2}

no service FIC ≥ 5 * 10^{-2}

In the following figures the results of the measurements are shown.

FIGURE P2-86

TII map

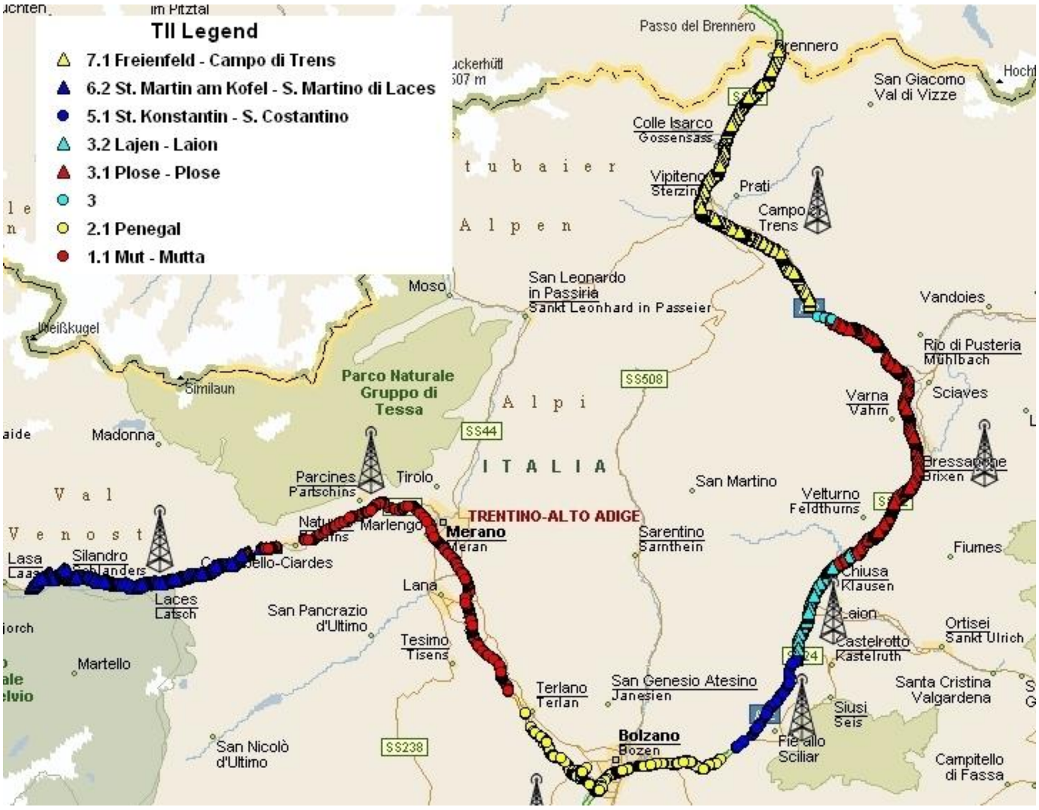


FIGURE P2-87

RF level map

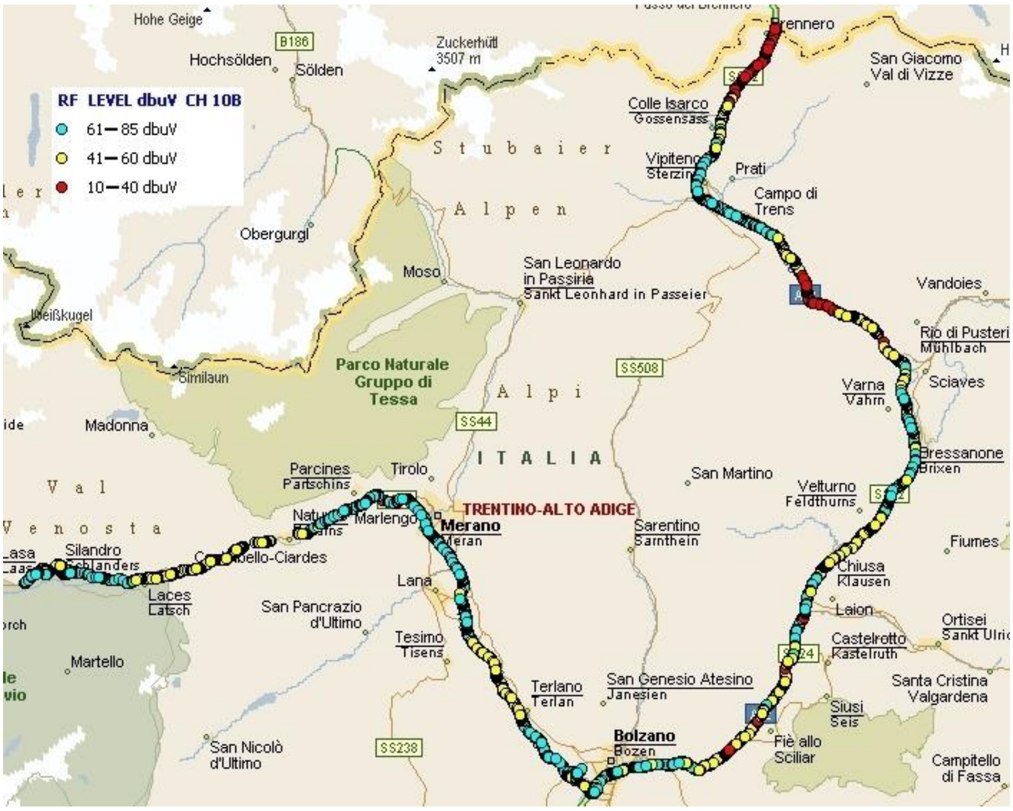
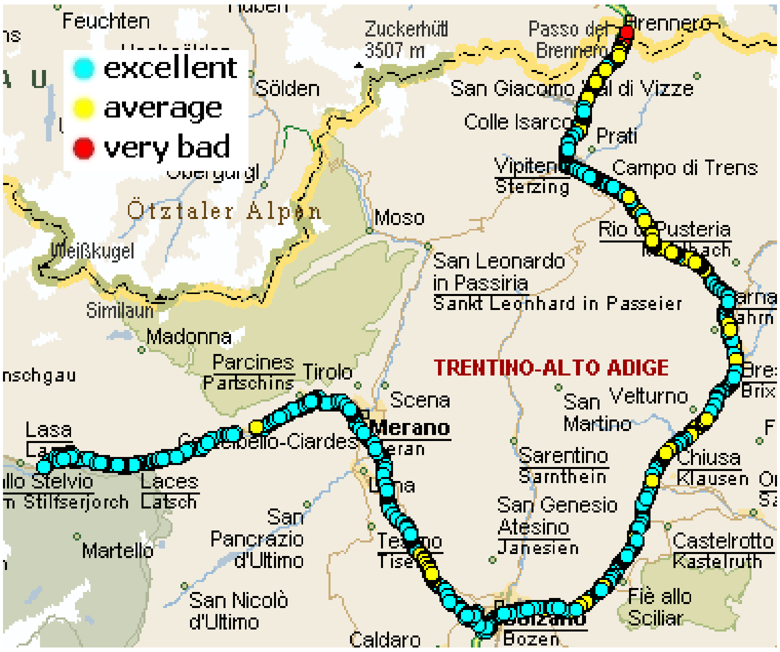


FIGURE P2-88

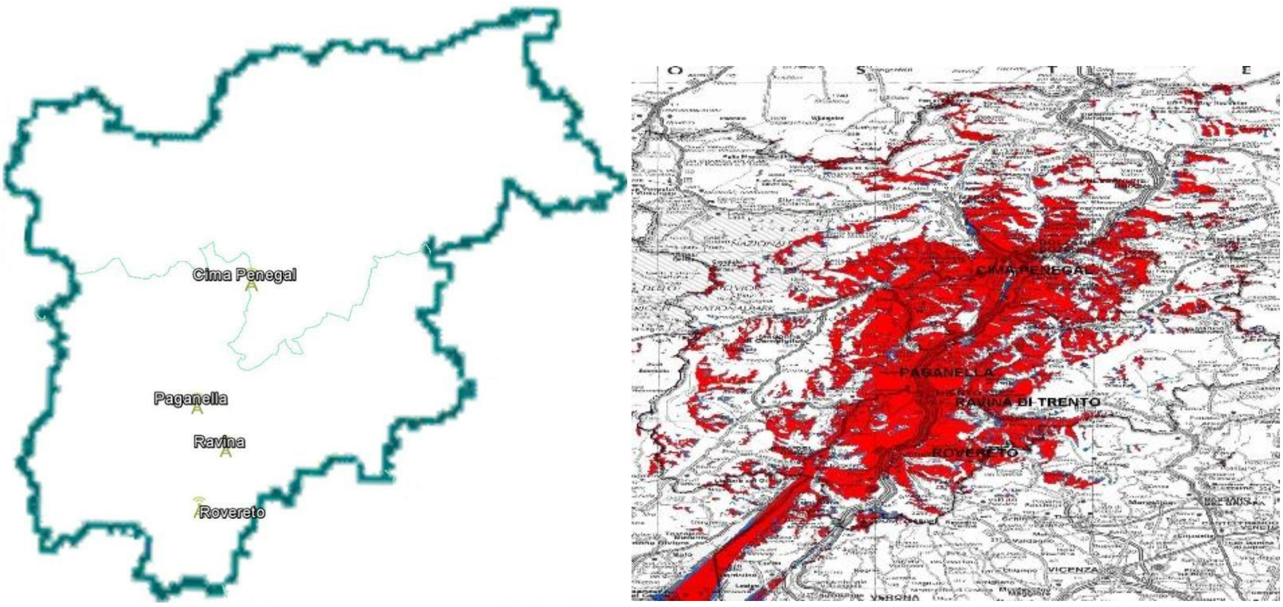
FIC BER map



The Rai Way network of Trentino is newer and, at the moment, is composed only by four transmitters: Paganella (0.25 KW and TII 55.16); Ravina di Trento (0.15 KW and TII 4.2); Rovereto (0.50 KW and TII 4.1); Cima Penegal (0.60 KW and TII 55.11) that cover the main valley.

FIGURE P2-89

Rai Way DAB transmitters and coverage



This multiplex contains only DAB+ programs: Radio1 (mostly news, national content); Radio1 TAA (regional content); Radio2 (mostly entertainment, national content); Radio2 TAA (regional content); Radio3 (mostly cultural programs); Südtirol (regional content in German); Radio Filodiffusione 5 (classical music programs); Radio Filodiffusione 4 (jazz and modern music programs); GR Parlamento (news and political programs); Isoradio (traffic information of the main roads); WebRadio6; WebRadio7 and WebRadio8. As the DAB+ technique allows to broadcast data contents, too, almost all the programs have their own data services: Slideshow, SLS, and Dynamic Label Segment, DSL.

FIGURE P2-90

SLS and DSL during Italy Cycling Tour 2013

FIGURE P2-91

Level and FIC BER map

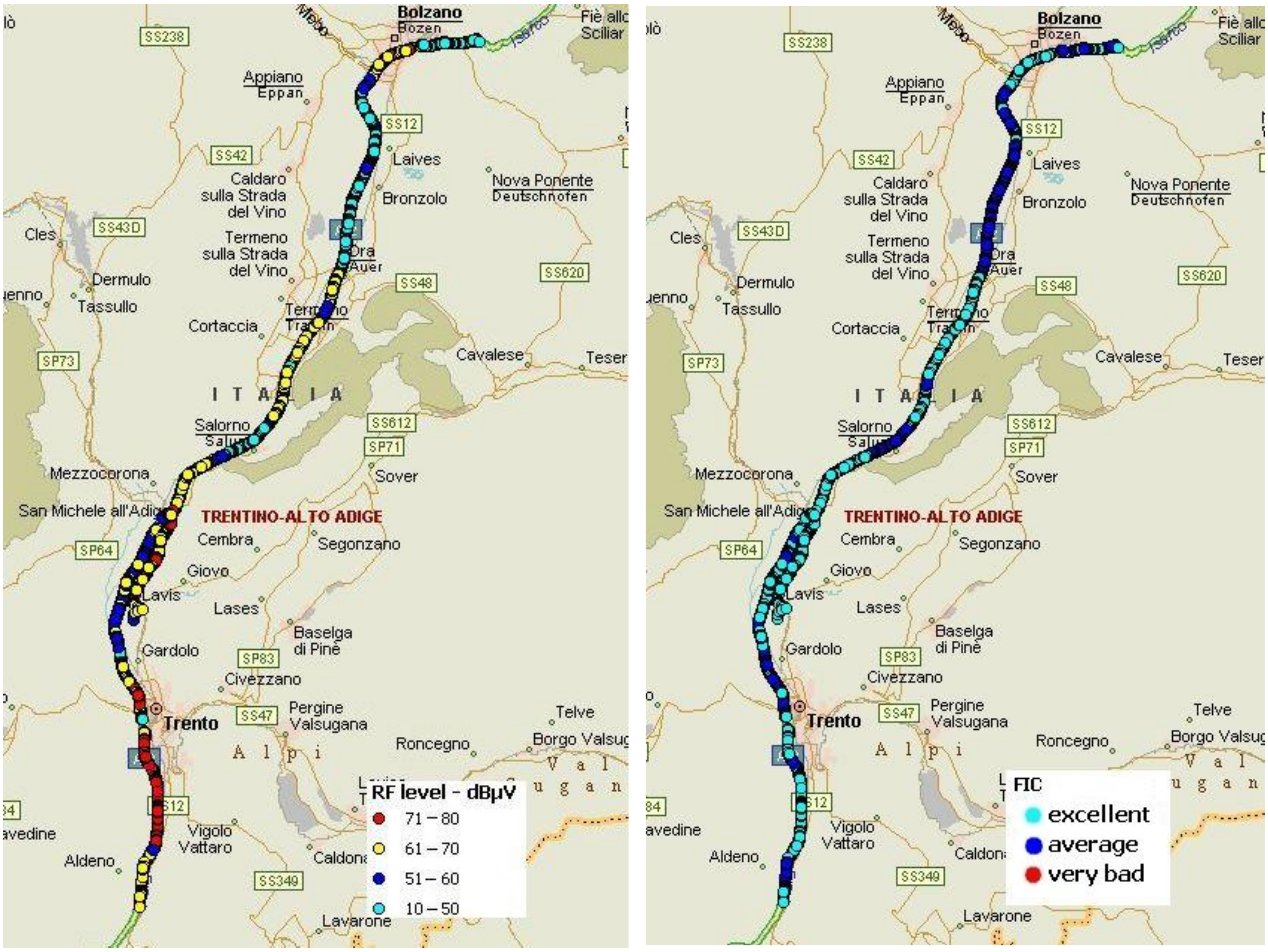
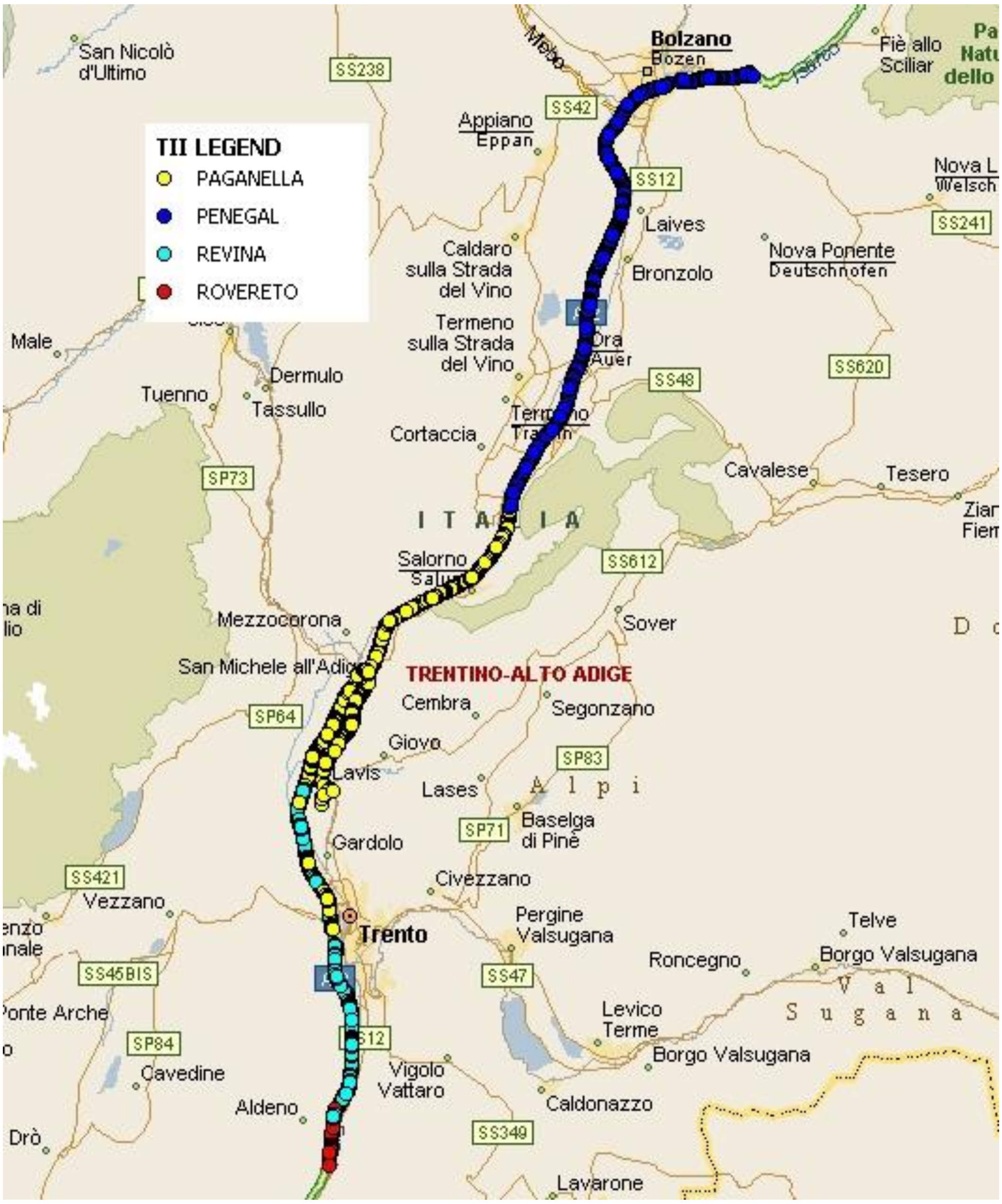


FIGURE P2-92

TII map



14.1.2 Tests on DAB receivers

In order to better optimize the network, tests on receivers were performed, too.

Two kind of tests were achieved: one in laboratory and the other in the service area.

Laboratory tests proved that receivers are more performing than the theory states. In fact, applying the theory, in presence of signals outside the guard interval, which for mode I is 246 μsec, the protection ratio needed are:

Protection ratio dB	**Delay μsec**
20	265
19	270
18	276
17	283
16	292
15	304
14	317
13.5	325
12	353

Laboratory tests fulfilled with five different receivers established the following values:

Protection ratio dB	**Delay Δ μsec**
0	$0 \leq \Delta \leq 246$
4	$246 < \Delta \leq 350$
13.5	$\Delta < 0 \div \Delta > 350$

The results obtained in the laboratory were proved in the service area.

Tests were performed in the service area of the Monte Venda and Campalto transmitters which were operating on block 12D. Acting on the transmitters power and delay, different configuration were obtained.

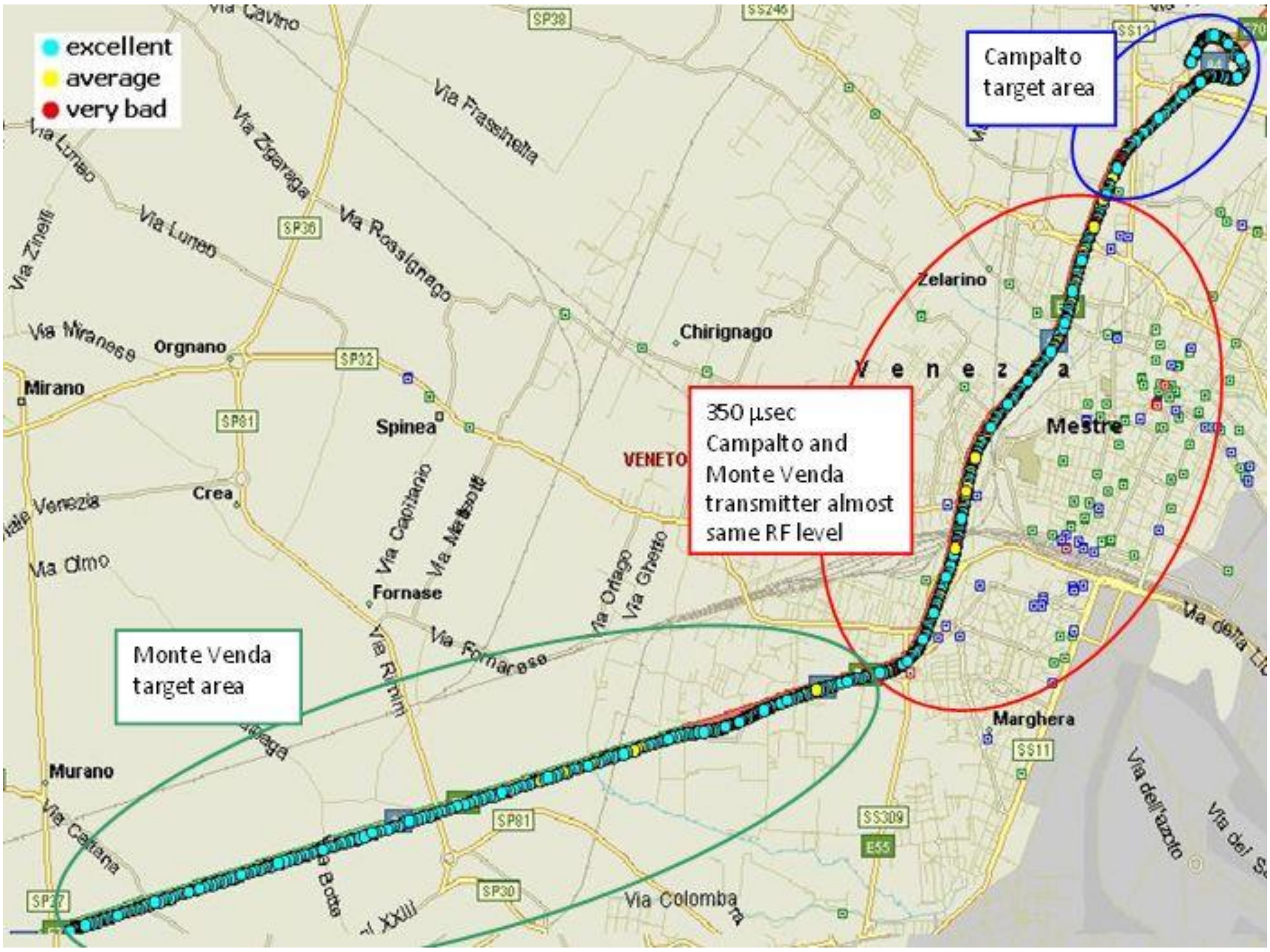
The measurements were achieved in specific point and also with an equipped vehicle travelling in the city and on the highway.

Summarizing, receivers were able to demodulate properly even when the two signals had the same RF level and the delay between the two was around 350 μsec. It is important to underline that receivers lost the signal when the delay was between 350 μsec and 400 μsec but they started to demodulate again when the delay reached 320 μsec.

In the following picture the audio quality travelling on highway is shown.

FIGURE P2-93

Audio quality measured travelling on highway



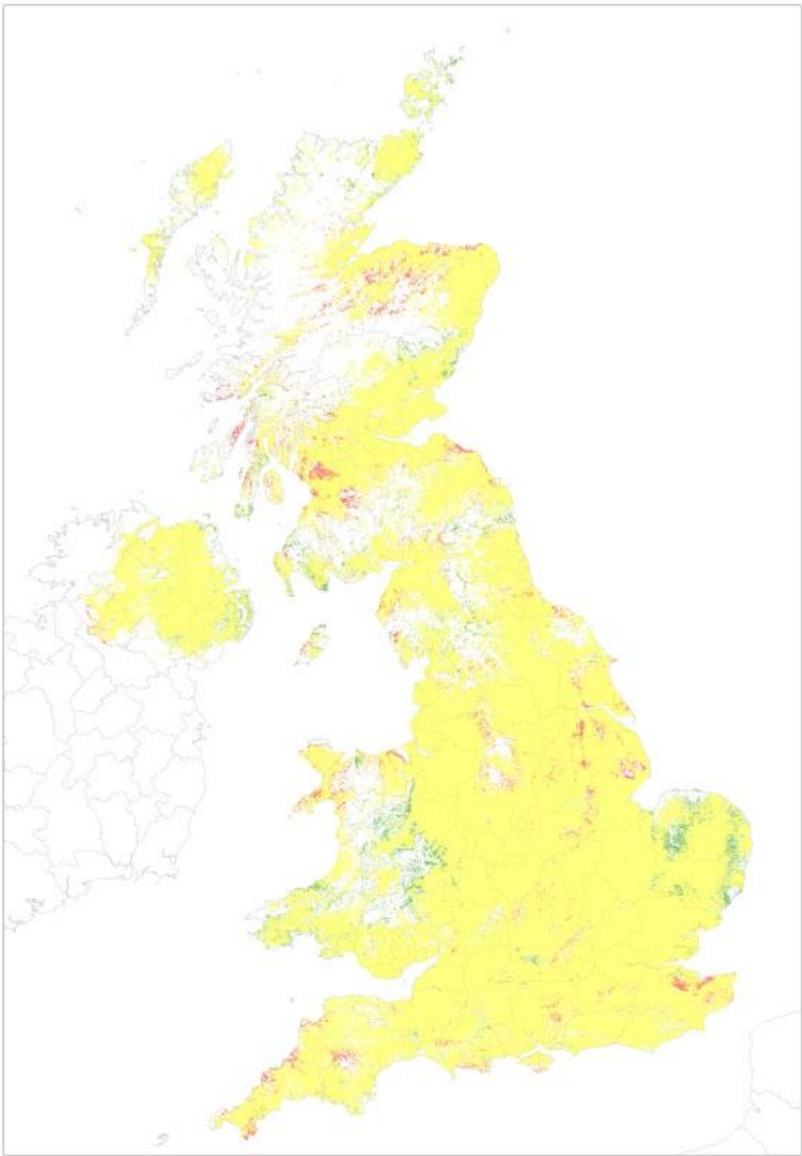
14.2 Static timing in the UK DAB network

The UK has two DAB networks which operate as national SFNs. Their predicted coverage is shown in Fig. P2-94 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.

FIGURE P2-94

The benefits of static timing in the UK T-DAB network (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)



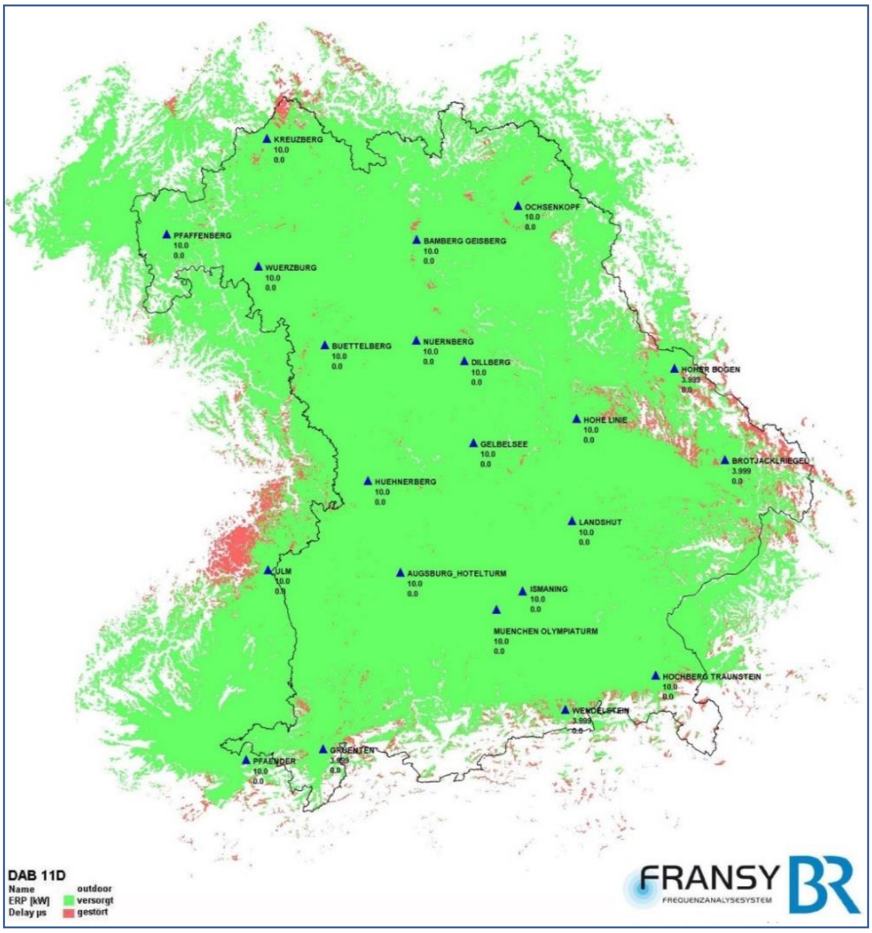
14.3 Static timing in the Bavarian DAB+ network

A further example of delay time tuning is given with the DAB+ network in Bavaria at stage of implementation 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 P2-95 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.

FIGURE P2-95

Coverage of the DAB+ network in Bavaria - without static delay time optimization – Transmitter sites, transmitter e.r.p. (kW) and the initial static delay (0 µs) are indicated



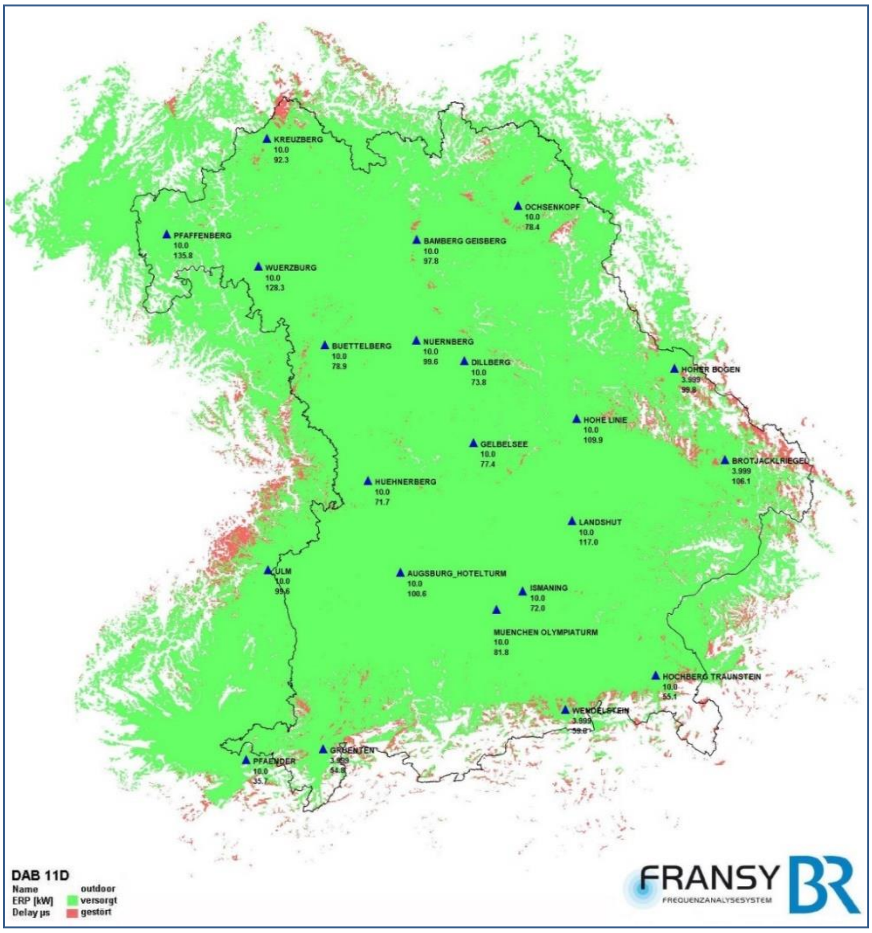
These remaining areas of interference could be reduced by a static time delay optimization, as can be seen in Fig. P2-96, where the individual delays are indicated in the coverage plot. Still there remain regions where self-interference occurs. This is due to the fact that time delay optimization may be a means to improve a self-interference situation but cannot totally eliminate it.

Figure P2-97 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 Fig. P2-98.

FIGURE P2-96

Coverage of the DAB+ network in Bavaria – with static delay time optimization – Transmitter sites, transmitter e.r.p. (kW) and individual static delays (µs) are indicated



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.

FIGURE P2-97

DAB+ network in Bavaria – Difference plot – Locations where static delay time optimization improved the coverage

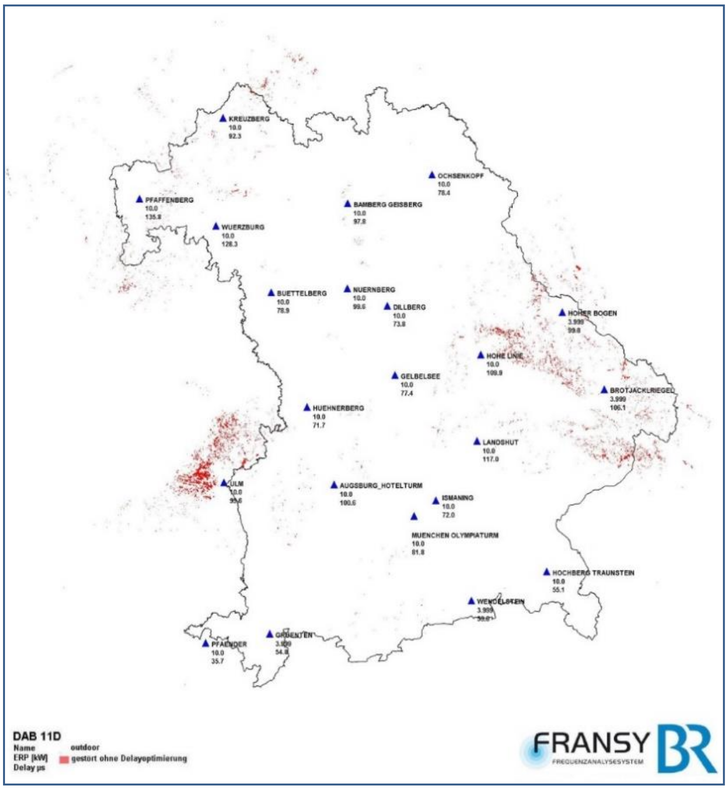
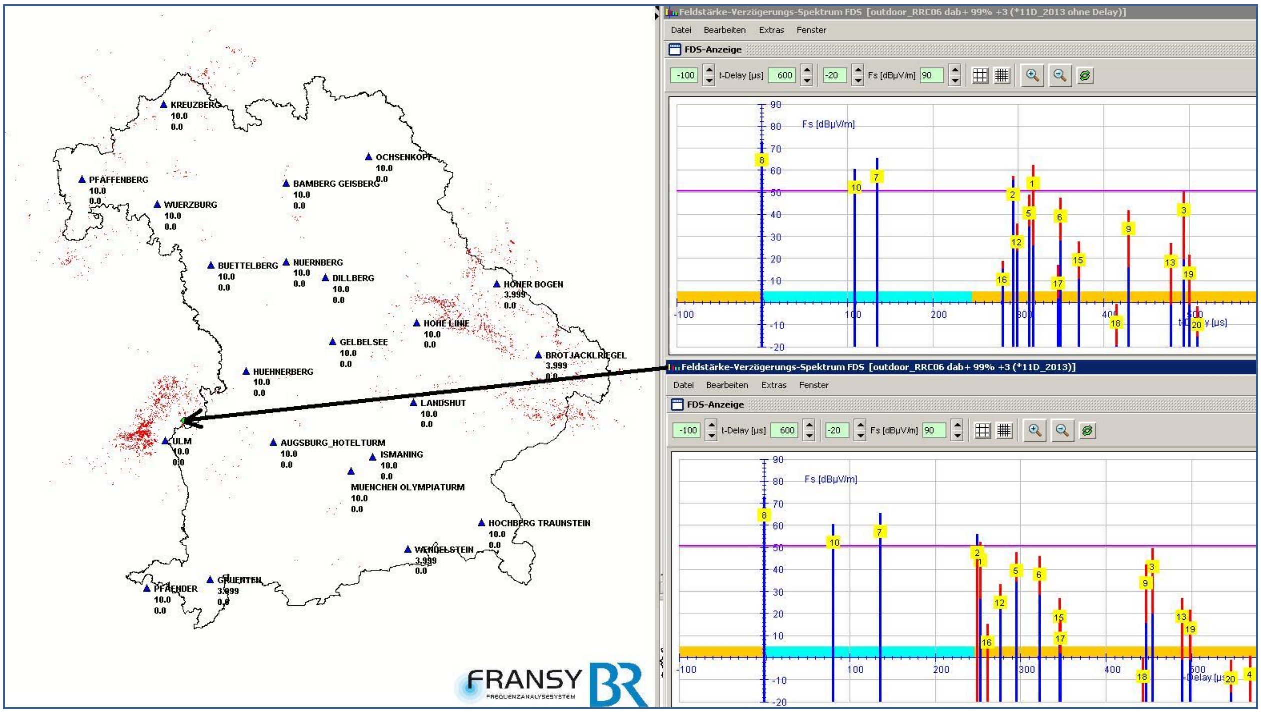


FIGURE P2-98

Time delay spectra at a typical self-interference situation before and after optimization



Part 3

SFN application and implementation of ISDB system

1 Principle of SFN reception

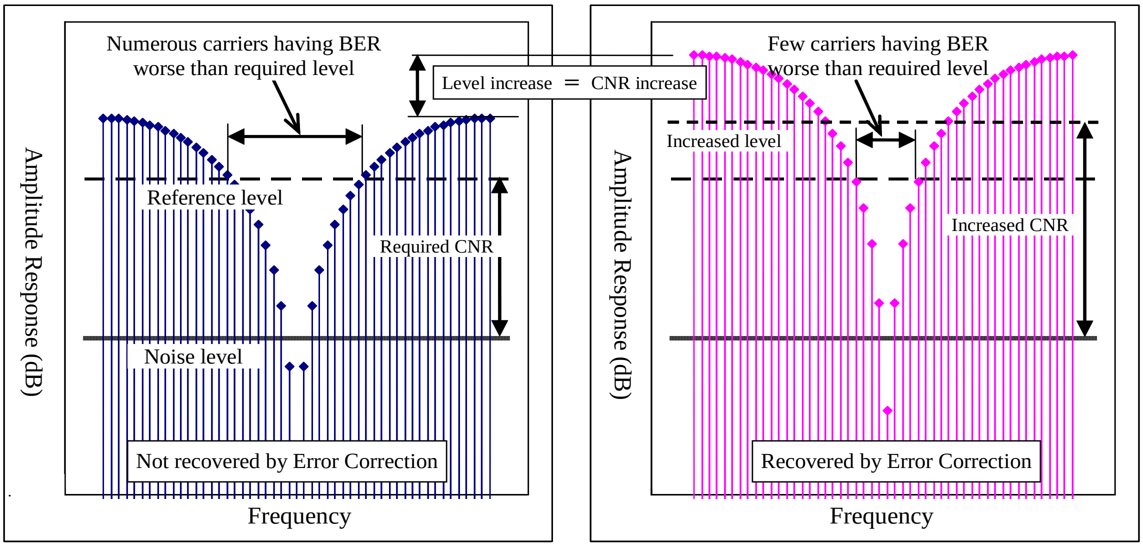
The Report ITU-R BT.2209 gives the detailed theoretical considerations concerning the SFN reception conditions, as well as the required receiver characteristics. The calculation model given by the Report has been successfully applied in the design and implementation of SFNs in Japan. A summary of the model follows.

The received signal exhibits ripples in frequency response when a desired signal is received with SFN waves. In this case, bit error rates (BERs) of the OFDM carriers positioned at peaks in the frequency response improve, because the input signal levels are high for those carriers. On the other hand, BERs of the carriers positioned at dips in the frequency response worsen, because the input levels are low. We can estimate the occurrence of SFN reception failure by calculating the BERs for every carrier, and the overall figures be used to check whether the total BER is worse than the required value.

Figure P3-1 gives an example of frequency response of the received signal. Figure P3-1a is a case where the desired signal is just at the level that gives the required carrier-to-noise ratio (CNR). In this example, it is assumed that the total BER is worse than the required value, as there are many carriers where BER is worse than the reference value. If the levels of both the desired and SFN signals are increased at the same time, the number of carriers having worse BER is decreased, and the signal is correctly received, as shown in Fig. P3-1b. Thus, the required CNR (or CNR threshold) increases with the existence of SFN waves, resulting in reception failure in critical areas.

FIGURE P3-1

Example of received signals



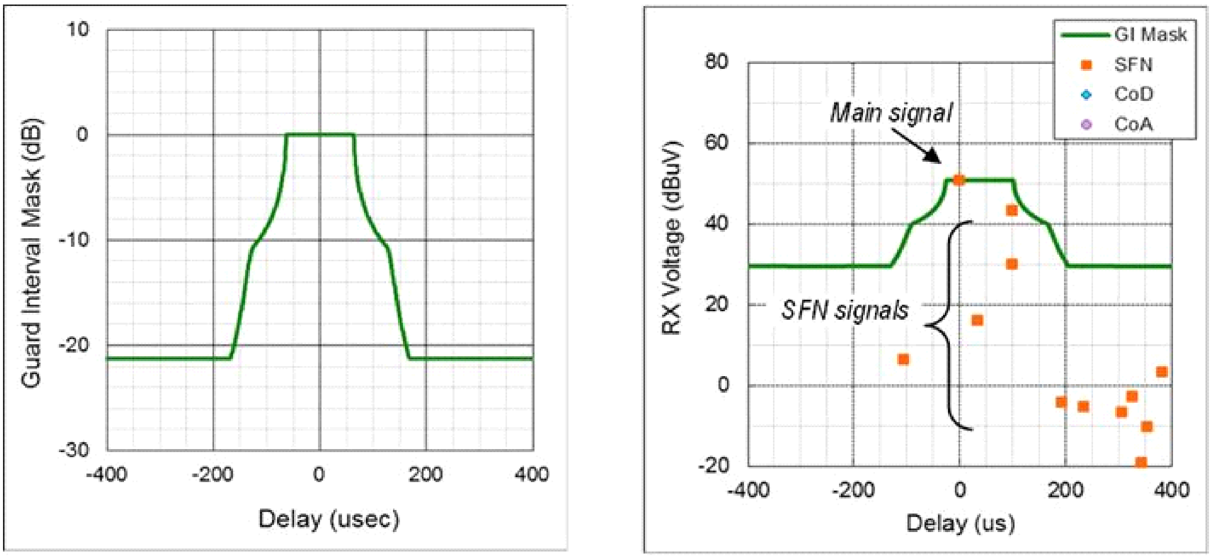
(a) Reference signal level (b) Increased signal level

The required DUR (desired-to-undesired ratio) increases with the delay difference between the main and SFN signals. Figure P3-2 (a) shows the Guard Interval Mask, which represents the relationship of allowable SFN signal levels against delays (both relative to the main signal). SFN reception failure occurs when one or more SFN signals exceed this mask. Figure P3- 2 (b) shows an application of the Guard Interval Mask, where the received signals are plotted in the form of delay profile together with the Guard Interval Mask. This graph is very useful in designing and optimizing an SFN, to the extent that any transmitting station causing SFN reception failure can be easily identified, while the network can be optimized by adjusting the transmission timing delay and antenna radiation pattern of the station.

For details of the theory and calculation model on SFN reception, see Report ITU-R BT.2209.

FIGURE P3-2

Example of Guard Interval Mask



(a) Guard Interval Mask (b) Delay profile of reception signal

2 Case study for Japan

In Japan, DTTB started in 2003 using the ISDB-T system. Analogue television broadcasts ceased in 2012. Approximately 12 000 broadcasting channels are assigned to DTTB transmitting stations to cover Japan using the 470-710 MHz frequency band (channels #13 – #53). Each of the 128 television broadcasters in Japan has its own broadcasting network. The majority are prefecture-based, while there are also some regional and nationwide networks.

Figure P3-3 shows a large-scale SFN the Kinki region (outlined in yellow) for NHK Educational TV. The coloured dots in red, yellow, green, etc. depict the reception failure probabilities. The SFN covers an area of 250 km by 250 km. The blue diamonds indicate the transmitting stations of the network. There are 120 transmitting stations, 40 of which operate in the SFN. In addition, there are 69 gap-fillers for small districts and community-antenna reception systems (very small-scale cable systems) in mountainous areas. The network is reliable, even in fading or abnormal propagation conditions.

Figure P3-4 shows the reception situation when the synchronization for SFN operation is lost.

FIGURE P3-3

Example of SFN in Kinki Region

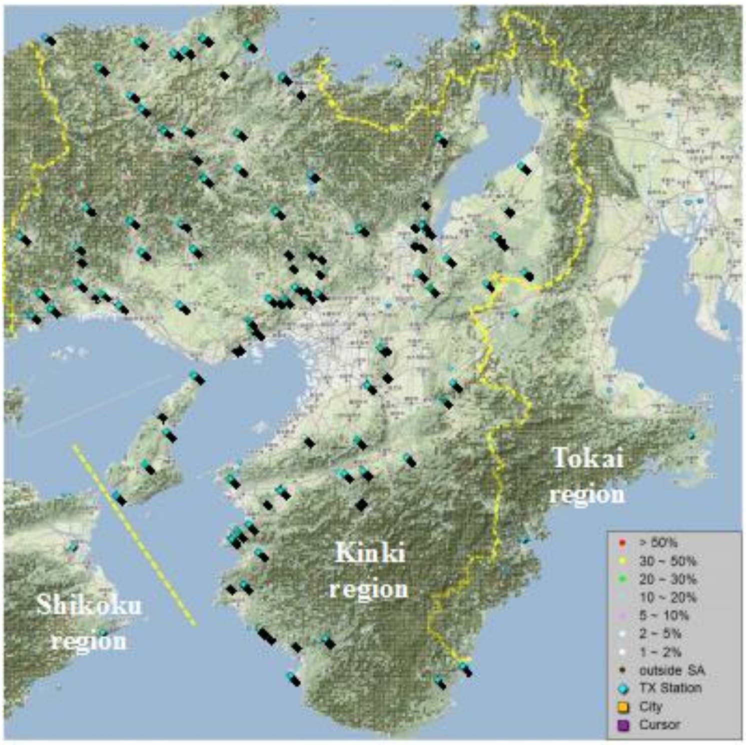
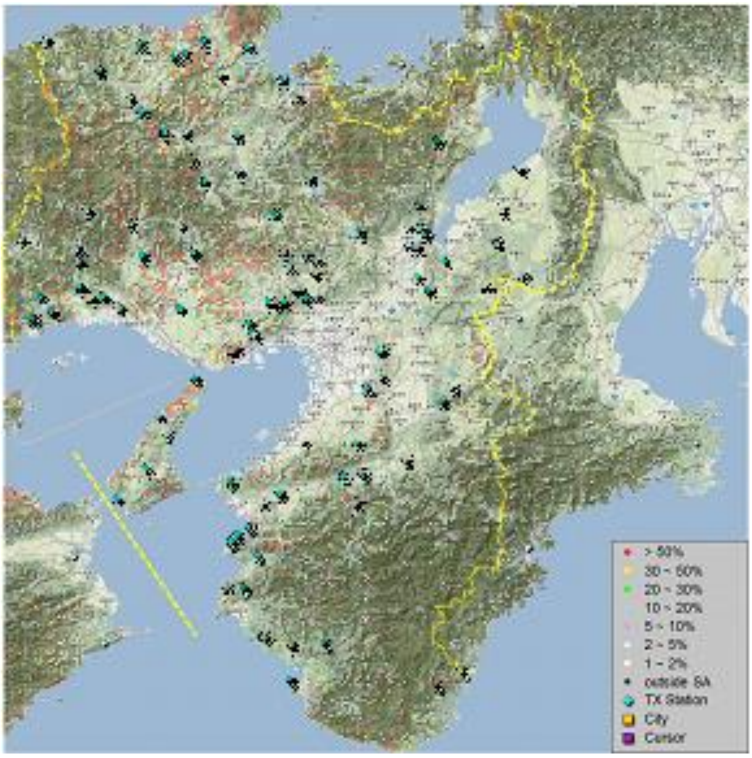


FIGURE P3-4

Example of SFN without synchronization



The red in Fig. P3-4 shows the places with severe reception failure when there is no synchronization. Thus, synchronization is indispensable in an SFN. When designing a network, the transmission timing adjustment, in particular, must be carefully studied and calculated, taking into account the actual propagation characteristics.

3 Design of SFN

In designing a broadcasting network, a number of technical characteristics for every transmitting station must be optimized. The major characteristics are site location, e.r.p., antenna radiation pattern, and transmission timing adjustment.

3.1 Site location

Many of the digital stations occupy the same site as the previous analogue station. This is only reasonable since:

– the analogue stations were situated at optimal locations in order to cover the service area, e.g. mountain tops or tall antenna towers in city centres;

– viewers' reception antennas were positioned for the analogue transmitting stations; and

– most of the facilities for analogue broadcasts (e.g. the station building, antenna tower, power supply system, etc.) were able to be re-used for DTTB.

When starting to design a network, it is desirable to take into account the existing sites, using them as the transmitting stations, and calculating the coverage, interference, implementation costs, and suchlike, accordingly. New transmitting sites can be added or some of the existing sites can be removed, if necessary, for the network to achieve its objectives.

3.2 Effective radiation power

The effective radiation power (e.r.p) for DTTB stations can initially be assumed to be proportional to that of the analogue stations. The proportional value is the required field strength of digital signal to the analogue, e.g. –10 dB. The area covered by the all of the transmitting stations in the SFN is calculated, and the e.r.p. for each station is then adjusted to ensure coverage. Each station need not provide coverage in its particular area, because the TV receivers will receive signals from all of the stations in the SFN.

3.3 Antenna radiation pattern

Antenna radiation pattern control is one of the useful methods to avoid SFN reception failure. SFN reception failure tends to occur in limited areas where the signal emitted from a particular station exceeds the Guard Interval Mask.

In such cases, the signal of interest can be decreased by reducing the radiation power of the transmitting station. This need only be done in the direction of the relevant area in order to have the signal level below the mask, keeping the reception conditions in the other areas unchanged.

3.4 Transmission timing adjustment

Transmission timing adjustment is the most effective and important technique in the design and implementation of a network. Figure 5 shows the transmission timing adjustment.

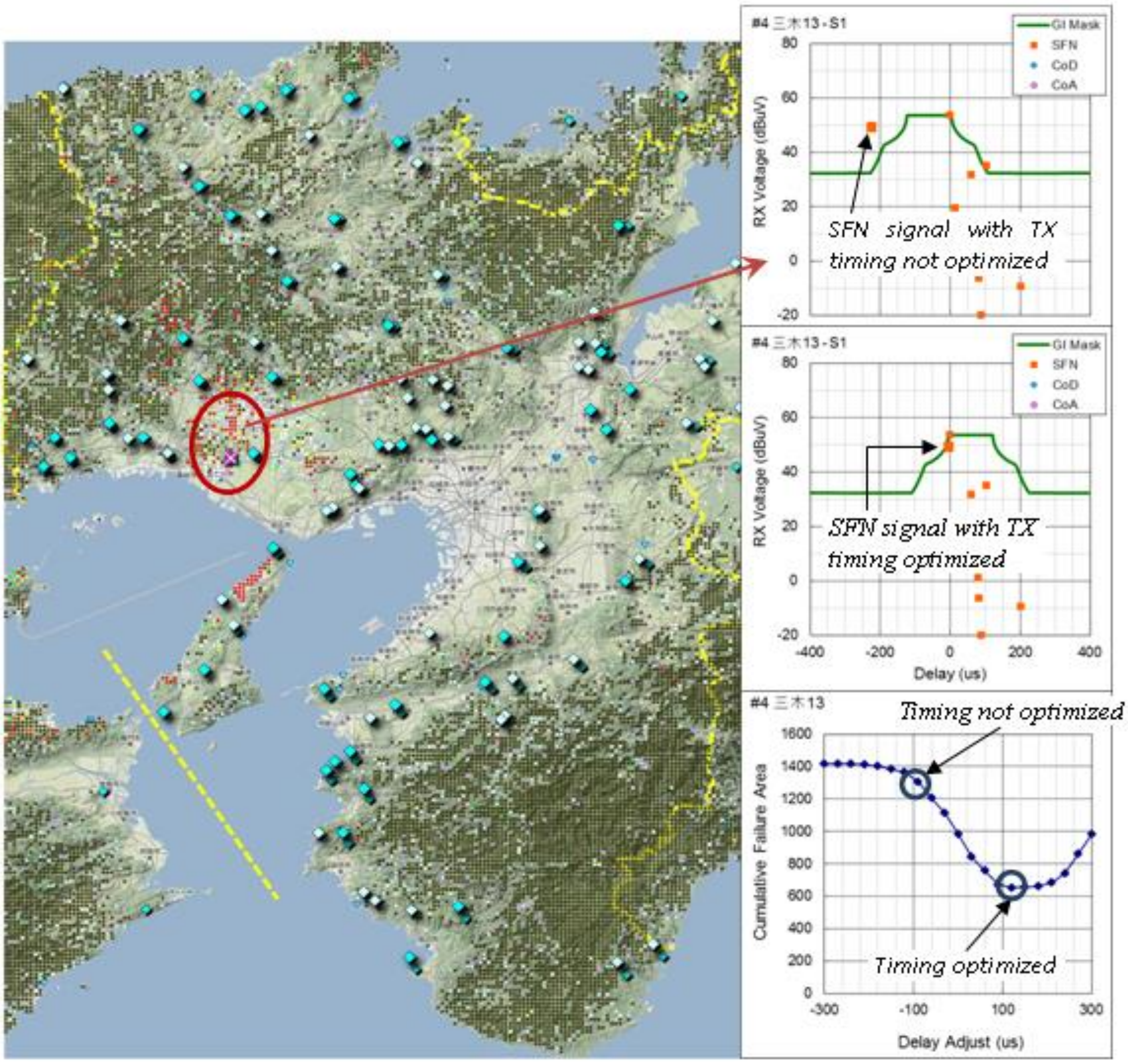
Figure 5 shows reception failure probability in an area circled in red experiencing reception failure. The graph at the top-right shows the delay profile and corresponding Guard Interval Mask at the reception failure location, where an SFN signal exceeds the Mask.

The graph at the centre-right shows the delay profile when the transmission timing of the interested station is delayed to make the reception signal below the mask. The delay adjustment eliminates the reception failure, as shown in Fig. P3-3.

The graph at the bottom-right expresses the relationship of number of failure locations (sum of the failure probabilities over the whole area) against transmission timing. Note that in adjusting the timing of a transmitting station, the calculation of reception failure should be conducted for a wide area rather than the area of interest. This is because SFN failure may take place at locations far away from the transmitting station concerned, especially in fading or abnormal propagation conditions, which often appear in the UHF band. The delay time setting for each transmitting station in the SFN followed the maximum delay time adjustment method described in Report ITU-R BT.2294 *Construction technique of DTTB relay station network for ISDB-T*.

FIGURE P3-5

Example of transmission timing adjustment in an SFN



3.5 Tools for network design

The design of SFN is complicated, especially in the transmission timing adjustment. Hence it is essential to use the right calculation tools, which include:

– precise field strength calculation based on the point-to- point prediction method;
– reception voltage calculation taking into account the reception antenna characteristics, including the algorithm for pointing the antenna at the optimum direction;
– antenna radiation pattern control and transmission timing adjustment for every transmitting station;
– calculation of reception failure probability at every reception location, based on the calculation model described in Report ITU-R BT.2209; and
– on an optional level, the automatic optimization algorithm for transmission timing adjustment.

A calculation tool named “Digital Reception Simulator” was developed and successfully used in the channel planning study, as well as in designing and implementing networks.

Part 4

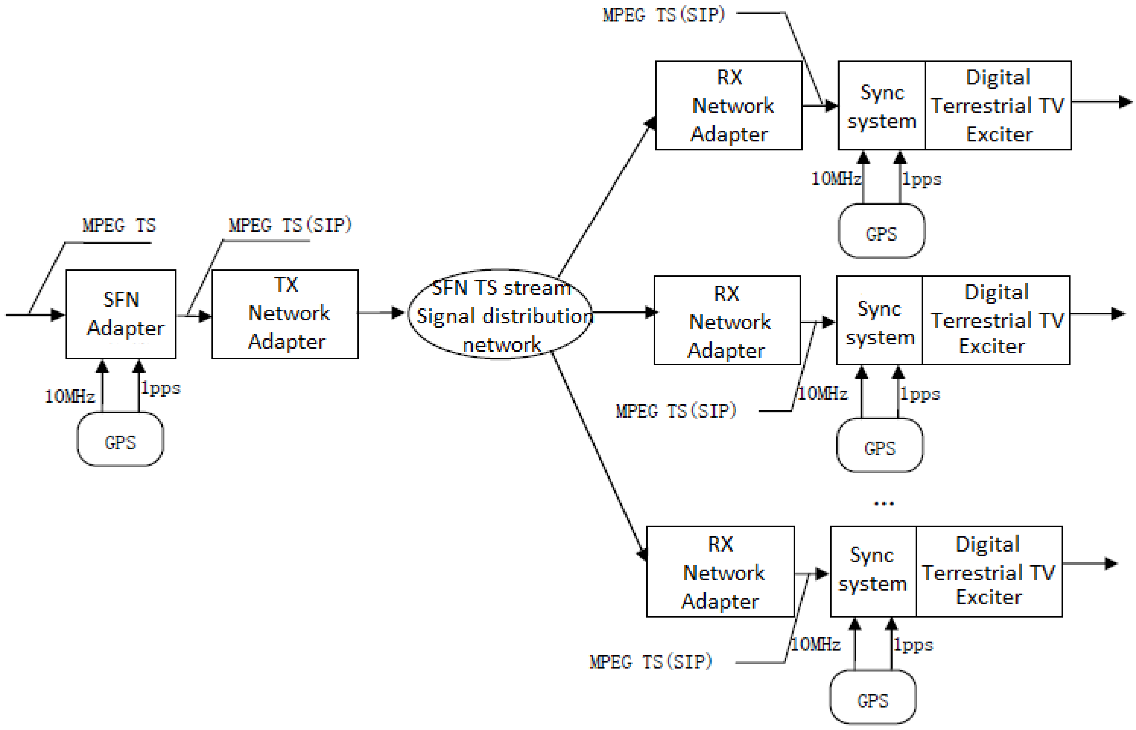
SFN application and implementation of DTMB system

1 Overview

Single Frequency Network refers the digital TV coverage network consist of several synchronized transmitters at different location. Each transmitter within the network transmits the same TV signal using the same frequency at the same time, to achieve more reliable coverage for the specific service area. For the DTMB-based SFN, TS from the multiplexers were firstly sent to SFN adapter to form streams that contain SIP, then delivered to transmitter via program distribution network and finally converted into radio frequency (RF) signals. The structure of DTMB-based SFN is shown in Fig. P4-1.

FIGURE P4-1

The structure of DTMB SFN in digital terrestrial television broadcasting.



The Signal Frame is the basic element of the frame structure for DTMB system. A Signal Frame consists of two parts, Frame Header and Frame Body. Frame Header uses Pseudo-random Noise (PN) sequences which can be used for fast synchronization and accurate and highly efficient channel estimation/equalization. There are three options for the Frame Header length in dealing with multi-path interference with different multi-path delay spread, as shown in Table P4-1.

TABLE P4-1

Frame Header mode (8 MHz RF bandwidth)

Frame Header mode	Symbols in Frame Header	Length of Frame Header
Mode 1 (PN420)	420	55.56 μs
Mode 2 (PN595)	595	78.7 μs
Mode 3 (PN945)	945	125 μs

A longer Frame Header can help deal with longer echoes, but will decrease the payload data rate of the system. In general, the longer Frame Header is suitable for large area SFN operation.

Remote control of distributed transmitters

DTMB standard supports over three hundred different operation modes or configurations of the modulator: for the SFN application scenario, it might become difficult, given these conditions, to ensure that all the modulators are coherently configured. The simplest way to deal with this problem is to remotely control these modulators from the unique broadcasting center. Utilizing the service information data in SIP package is one example of the remote control and synchronization.

The primary distribution network (including TX and RX adapter) transports the MPEG-TS (SIP) to the digital terrestrial TV modulator from the broadcasting center transparently. The MPEG-TS (SIP) keeps invariant for the same payload data rate of the modulator. So all the input of MPEG-TSs (SIP) to those modulators within the network are identical.

In the digital terrestrial TV modulator, SYNC system will recognize the SIP from the input MPEG-TS and provide propagation time compensation by comparing the inserted SIP with the local time reference (1 pps) and calculate the extra delay needed for SFN synchronization. In other words, all the modulators in the network will transmit Signal Frame including SIP at the time instant set in SIP after the absolute time reference (1 pps). The maximum delay spread (depending on the different time delay of the network) that SYNC system can deal with is one second. Modulators divide the input stream into data packets for modulation based on the recognized SIP. The first bit of SIP will also be the first bit of data packet so that all the modulators are bit synchronized. The operation modes of the modulators depend on the SI in the SIP (SI-SIP) so that all the modulators are working in the same mode. The working delay of the modulators should be stable.

As shown in Fig. P4-1, the SFN adapter and all the modulators need to use the 10 MHz frequency reference and 1 pulse per second (1 pps) time reference provided by GPS receiver as the absolute time reference. The network adapters especially the RX network adapters also use the GPS 10 MHz frequency reference. This will ensure all the modulators to be frequency, time and "bit" synchronized. The 10 MHz system clock is assumed to be available for all the nodes within the network.

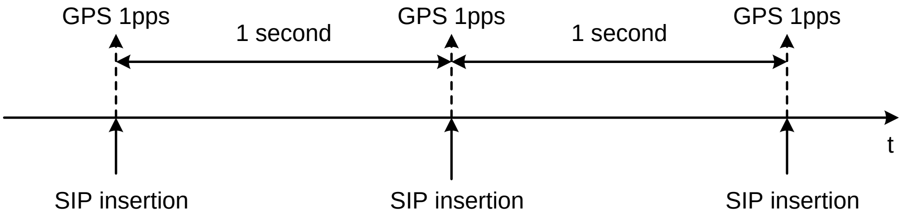
Second-frame and Second-frame Initialization Package

In the SYNC system described above, the SFN adapter inserts a Second-frame Initialization Package (SIP) every one second. This is based on the following reasons: according to the digital terrestrial TV broadcasting system specified in DTMB, there are 8 Super Frames in one second which is called Second Frame; the number of Signal Frame in one Super Frame is always an integer regardless of the constellation mapping mode, Frame Header mode and FEC code rate. Either the number of Signal Frames or TS packages in one second is integer.

The SFN adapter inserts one SIP to the TS stream every one second aligned with 1 pps, as shown in Fig. P4-2.

FIGURE P4-2

Insertion of SIP



The SIP package is MPEG-2-TS package consist of 4 bytes package header and 184 bytes data, as shown in Fig. P4-3. Package header is used to identify SIP. Maximum delay time prescribes the delay time between the modulated Signal Frame including SIP and the 1 pps. Individual adjusting time prescribes the individual extra delay for each modulator in the SFN network. SI-SIP includes the SI of the operation modes for all modulators. Broadcasting addressing information is used to address the modulators in the network.

FIGURE P4-3

SIP structure

1	2	3	4	5-6	7-9	10-11	12-14	15-17	18-19	20-188
0x47	0x40	0x15	0x10	SI-SIP	Maximum delay time	Broadcasting addressing	Individual adjust time	Frequency offset	Power control	Padding bytes

2 Case study for DTMB

2.1 Local area SFN

2.1.1 Deployment of DTMB in Single Frequency Network of Hong Kong

Hong Kong Special Administrative Region (HKSAR) of the People's Republic of China has adopted DTMB for its Digital Terrestrial Television (DTT) services. The first transmitting station of the DTT SFN was launched at the end of 2007 covering about 50% of the population. As of early 2011, the DTT SFN has been extended to cover about 90% of the population with 20 transmitting stations.

2.1.1.1 Executive Summary

Hong Kong Special Administrative Region (HKSAR) of the People's Republic of China has adopted for its digital terrestrial television (DTT) services. The DTMB SFN deployment was formally launched with 50% population coverage by a single DTT transmitting station at the end of 2007 and was extended to about 90% population coverage in January 2011 by 20 DTT transmitting stations.

This subsection introduces DTMB deployment in the Single Frequency Network of Hong Kong, including assessment of DTMB, DTMB SFN design criteria, challenges to implement DTMB SFN, and update on implementation of DTMB SFN.

Most information provided in this Report is based on information available from the Office of the Telecommunications Authority website (www.ofta.gov.hk) and HKSAR government Digital TV website (www.digitaltv.gov.hk).

In selecting the DTT technical standard for HKSAR, the HKSAR Government adopted a market-led approach under which the two incumbent broadcasters proposed the preferred standard for assessment by the Telecommunications Authority (TA). The TA, taking into account the technical proposals of the incumbent broadcasters, issued the Statement setting out his views and decisions on the transmission standard and receiver specification for DTT service.

2.1.1.2 Criteria of Assessment for Transmission Standard

In selecting the DTT technical standard for HKSAR, the TA has taken into consideration the following criteria:

a) The selected standard should facilitate the provision of sufficient channel transmission capacity (e.g. able to support SFN transmission) to meet new demand for broadcasting services during and after the simulcast period.

b) The selected standard should support mobile reception;
The channel bandwidth adopted by the selected standard should be compatible with the 8 MHz channel bandwidth that is currently used in HKSAR for terrestrial television broadcasting.

c) The selected standard should preferably be widely adopted internationally. There should be a full range of consumer products such as set-top boxes and integrated television sets based on the selected standard available in the market at competitive prices.

d) It would be advantageous for the selected standard to be interoperable with other broadcasting services delivered by different transmission platforms such as satellite or cable. The commonality in the system design of the relevant broadcasting equipment and television receivers may lead to cost savings in both network rollout and network operation.

2.1.1.3 Assessment on Technical Performance of Transmission Standard

To verify the suitability of deploying the National Standard DTMB in the local environment, which is characterised by hilly terrain, high-rise buildings and tidal harbour with long waterfront, a field trial for the National Standard DTMB was conducted in HKSAR in late 2006.

The field trial covered receptions under a variety of propagation conditions, such as line-of-sight, non-line-of-sight and tidal fading. The field trial demonstrated the superiority of the National Standard over analogue transmission (PAL-I). In particular the picture and sound quality delivered by DTT signal was satisfactory under non-line-of-sight conditions using only one tenth of the transmitting power of its analogue counterpart. Satisfactory results were obtained for all the following test items:

a) Line-of-sight reception

b) Reception in hill shadow

c) Reception at roof level in building shadow

d) Reception at ground level in building shadow

e) Reception under tidal fading

f) Indoor reception

g) Standard definition television (SDTV) / HDTV reception

h) Mobile reception

i) Tests on SFN / MFN, and

j) Test on In-building Co-axial Cable Distribution System (IBCCDS).

As demonstrated in the field trial, the National Standard DTMB supports spectrum-efficient operations including SFN deployment, multi-channel programming (several programme channels carried in one frequency multiplex) and conveyance of HDTV content. Regarding the frequency characteristics, the 3 dB bandwidth of a frequency multiplex is 7.56 MHz, which fits well within the 8 MHz channel currently used for terrestrial television broadcasting in HKSAR.

2.1.1.4 DTMB Technical Parameters adopted in HKSAR

The specification HKTA 1108 issued by the TA covers the technical standard of DTMB receiver requirements in HKSAR. The RF Characteristic, Channel Demodulation and Decoding are shown Table P4-2.

TABLE P4-2

HKTA 1108 technical standard of DTMB receiver

Item No.	Description	Reference / Detail
2	RF Characteristics, Channel Demodulation and Decoding	
2.1	Frequency Band	470 MHz – 862 MHz
2.2	Transmission channel bandwidth	8 MHz
2.3	Channel demodulation and decoding	Transmitted DTT signals will comply with GB 20600-2006 (‘the National Standard’) which includes some 300 combinations of options. Mode – C = 3780 Modulation – 64QAM, 16QAM and 4QAM Frame Header – PN 945 Code Rate – 0.4 and 0.6 Symbol Interleaving – Mode 2 i.e. B = 52 and M = 720 symbols. Receivers shall be capable of correctly Interpreting the system information given in the frame body in accordance with Annex G of the National Standard.
2.4	Channel offset	The nominal centre frequency of each channel is given by : fc = 474 + (I – 21)*8 MHz Where I is the channel number which is an integer between 21 and 69. The receiver shall be capable of tuning to transmissions with a channel offset of + 1/6 MHz.
2.5	Operation in Single Frequency Network (SFN)	Receivers shall be able to operate properly in SFN environments.

2.1.1.5 Challenges to build DTMB SFN

SFN is a broadcast network where several transmitters simultaneously send the same signal over the same frequency channel. Once there is a loss of synchronization of SFN in any one of the transmitting stations, the un-synched signal becomes an interference signal, and the SFN coverage in overlapping service areas may collapse if the interference signals level exceeds the co-channel interference protection ratio. Hence, the overlapping service areas of SFN coverage should be minimized. If there are many overlapping areas, it is very difficult to add the gap filling stations which create even more overlapping areas.

In most foreign countries, the distance between SFN transmitting stations are widely separated so that the overlapping area is relatively small comparing with the main service areas and do not create significant reception problem. Basically, in order to keep the SFN in working condition, there are two essential key elements of working criteria:

1) synchronization in transmitting frequency with identical signal of all SFN transmitting stations with the frequency precision accuracy within 1 Hz, and

2) to keep arriving time of the entire signals in the service area within the guard interval to prevent symbol errors

HKSAR topographic situation is mountainous and complicated in radio wave propagation because of densely built high rise buildings. Due to the basic considerations as mentioned above, it would be appropriate to minimize the overlapping coverage areas of the SFN transmitting stations to reduce the loss of synchronization signal. Furthermore, echo mixed with pre-echo and long post-echo would cause reception difficulty. With reference to the factors mentioned above, the DTMB SFN transmission network has been carefully designed to minimize overlapping from each DTMB SFN transmitting stations by means of tailor-made antenna radiation pattern.

2.1.1.6 Implementation Update of DTMB SFN

HKSAR adopted a phased implementation approach for DTMB. The following table shows the technical parameters of individual transmitting stations and their accumulated population coverage. The 12 stations completed by the end of 2009, and their coverage areas are set out in Annex A.

TABLE P4-3

e.r.p. of 12 DTMB SFN stations, including principal and fill-in stations

SFN Station name	Maximum e.r.p.	Polarization	Station type	Accumulated population coverage
Temple Hill	1000 W	H	Principal station	~ 50% of HKSAR population
Golden Hill	320 W	H	Principal station	~ 75% of HKSAR population by 7 stations
Kowloon Peak	320 W	H	Principal station	
Castle Peak	320 W	H	Principal station	
Cloudy Hill	1 000 W	H	Principal station	
Lamma Island	150 W	V	Principal station	
Mt. Nicholson	10 W	V	Fill-in station	
Sheung Yeung Shan	0.6 W	V	Fill-in station	~ 85% of HKSAR population by 12 stations
Sai Wan Shan	10 W	H	Fill-in station	
Piper’s Hill	10 W	H	Fill-in station	
Brick Hill	10 W	H	Fill-in station	
Beacon Hill	0.2 W	H	Fill-in station	

By the end of 2010, eight more DTMB SFN fill-in stations were competed. With the rollout of these fill-in stations, the coverage was extended to about 90% of the population. The e.r.p. of the

8 DTMB SFN stations is shown in Table P4-4. The covered areas of the eight fill-in stations are set out in Annex B. The locations of the 20 SFN transmitting stations are set out in Annex C.

TABLE P4-4

e.r.p. of 8 DTMB SFN fill-in stations

SFN Station name	Maximum e.r.p.	Polarization	Station type	Accumulated population coverage
Hill 374 (Yuen Long)	5 W	V	Fill-in station	~ 90% of HKSAR population by 20 stations
Pottinger Peak	10 W	H	Fill-in station	
Stanley	10 W	H	Fill-in station	
Cheung Chau	2 W	V	Fill-in station	
Hill 141 (Tai Lam Chung)	0.2 W	V	Fill-in station	
Tai Po Tsai	0.5 W	V	Fill-in station	
Robin's Nest	10 W	V	Fill-in station	
Tai O	0.7 W	V	Fill-in station	

As in January 2011, there were 20 transmitting stations launched for DTMB SFN services, the location of the DTT Stations and the estimated coverage can be found in Annex E. It is planned that nine more DTMB SFN fill-in stations will be constructed by the end of 2011.

2.1.1.7 DTT take-up rate

The viewing public in HKSAR has been taking up DTT services at a steady pace. According to the latest public survey conducted in September 2010, about 61% of the families in HKSAR (representing some 1.4 million television households territory-wide) receive DTT services via set-top boxes, integrated digital TV (iDTV) sets (i.e. TV sets with built-in decoders) and computers. The details of the take-up situation from early 2008 to September 2010 with the use of set-top box, iDTV or computer are set out in Annex D.

2.1.1.8 Conclusion

During the implementation of DTMB SFN transmission network in HKSAR, invaluable experience was gained in overcoming reception problems caused by the difficult topographic situations (which is mountainous, dense built-up urban areas and tidal changes along harbour-front). Such experience would also be invaluable to the deployment of DTMB SFN in other cities.

Annex A

SFN Transmitting Stations completed by the end of 2009

No.	Station name	Coverage Areas (note)	Estimated population served
1	Temple Hill	Quarry Bay, North Point, Wan Chai, Central & Western, Yau Tsim Mong, Kowloon City, Wong Tai Sin, Sham Shui Po, Sha Tin, Cheung Chau, Discovery Bay	~ 50% of Hong Kong Population
2	Kowloon Peak	Siu Sai Wan, Chai Wan, Shau Kei Wan, Sai Kung, Tseung Kwan O, Yau Tong, Kwun Tong	~25% of Hong Kong Population
3	Golden Hill	Lai Chi Kok, Kwai Chung, Tsing Yi, Tsuen Wan, Ting Kau, Sham Tseng, Tsing Lung Tau	
4	Castle Peak	So Kwun Wat, Tuen Mun, Lam Tei, Yuen Long, Tin Shui Wai, Tung Chung	
5	Cloudy Hill	Ma On Shan, Ma Liu Shui, Tai Po, Fanling, Sheung Shui, Lo Wu	
6	Lamma Island	Repulse Bay, Wong Chuk Hang, Ap Lei Chau, Aberdeen, Pok Fu Lam, Lamma Island	
7	Mount Nicholson	Happy Valley, Causeway Bay, Wan Chai	

No.	Station name	Coverage Areas (note)	Estimated population served
8	Sheung Yeung Shan	Tseung Kwan O, Sheung Yeung, Ha Yeung, Sheung Sze Wan	~ 10% of Hong Kong Population
9	Sai Wan Shan (Chai Wan)	Chai Wan, Siu Sai Wan	
10	Piper's Hill	Cheung Sha Wan, Sham Shui Po	
11	Brick Hill	Aberdeen, Shouson Hill, Repulse Bay, Chung Hom Kok	
12	Beacon Hill	Hin Tin, Tai Wai	

Note: The regions listed are covered entirely or partially by the DTT signals.

Annex B

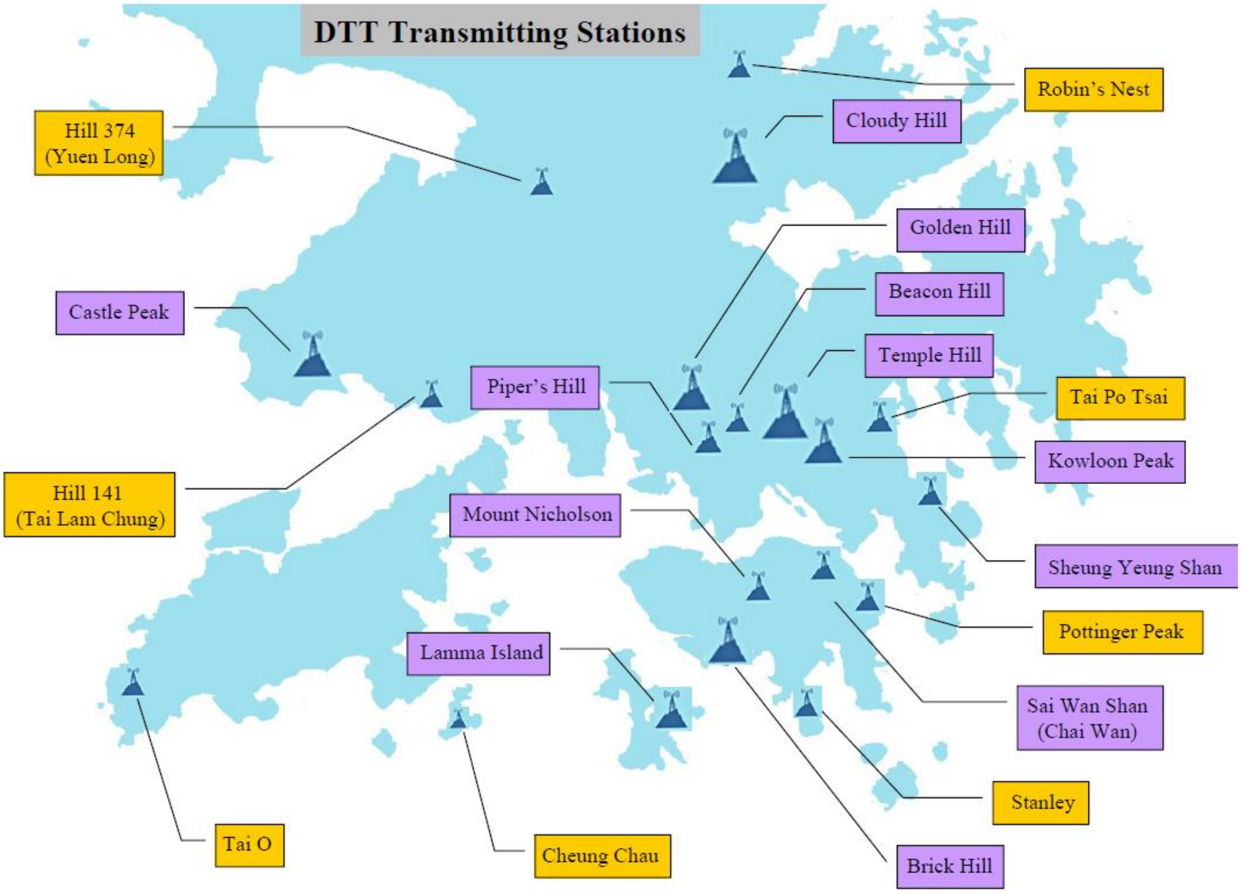
DTT Fill-in Stations Launched in Late 2010 / Early 2011

No.	Station name	Coverage Areas (note)	Estimated population served
1	Hill 374 (Yuen Long)	Yuen Long, Mong Tseng Wai, Shui Bin Tsuen	~ 4% of Hong Kong Population
2	Pottinger Peak	Shek O, Hok Tsui (Cape D'Aguilar)	
3	Stanley	Stanley, Red Hill	
4	Cheung Chau	Cheung Chau	
5	Hill 141 (Tai Lam Chung)	Tai Lam Chung	
6	Tai Po Tsai	Tai Po Tsai	
7	Robin's Nest	Shan Tsui, Yim Liu Ha, Luk Keng, Ping Che , Kwan Tei	
8	Tai O	Tai O	

Note: The regions listed are covered entirely or partially by the DTT signals.

Annex C

Location of 20 DTMB SFN Stations (12 stations in pink refer to Annex A; 8 stations in yellow refer to Annex B).

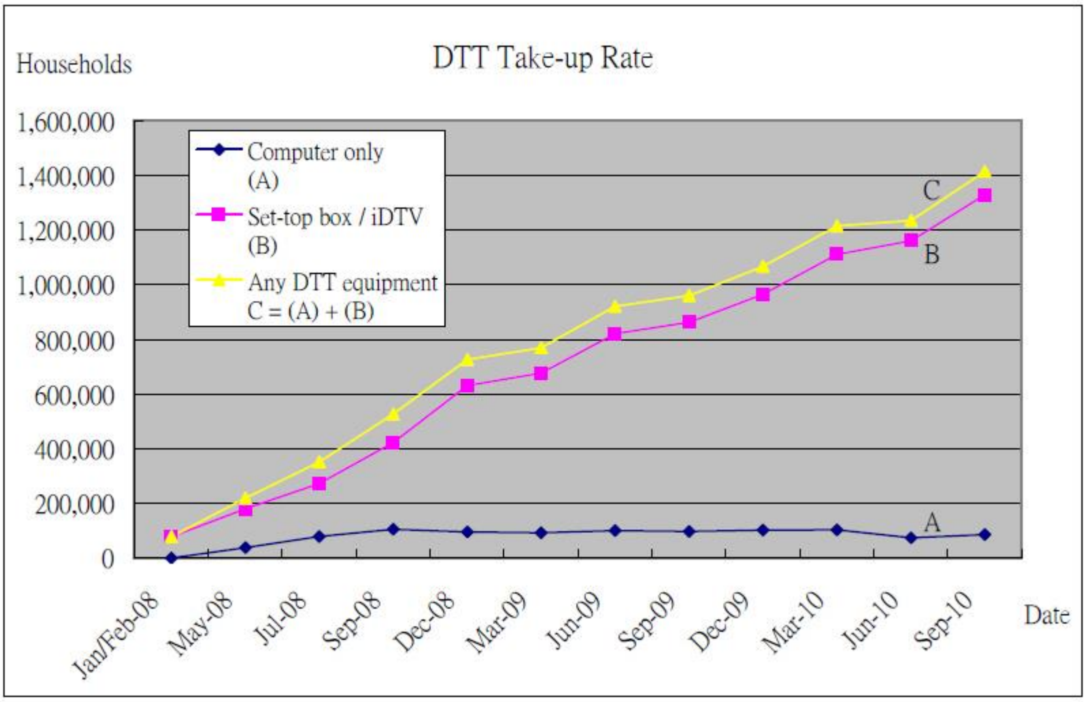


Annex D

Digital Terrestrial Television (DTT) Take-up Rate (January 2008 - September 2010)

Total Hong Kong households (2008) = 2,251,900
Total Hong Kong households (2009) = 2,293,200
Total Hong Kong households (2010) = 2,317,500

	DTT Households receiving DTT via (note)					
	Computer only (A)		Set-top box / iDTV (B)		Any DTT equipment C = (A) + (B)	Take-up Rate (%)
Jan/Feb-08	N/A	N/A	78,156	3.5%	78,156	3.5%
May-08	38,260	1.7%	180,474	8.0%	218,734	9.7%
Jul-08	78,833	3.5%	272,321	12.1%	351,154	15.6%
Sep-08	104,782	4.7%	422,181	18.7%	526,963	23.4%
Dec-08	95,744	4.3%	631,205	28.0%	726,949	32.3%
Mar-09	92,670	4.0%	676,941	29.5%	769,611	33.6%
Jun-09	100,435	4.4%	820,604	35.8%	921,039	40.2%
Sep-09	97,833	4.3%	862,612	37.6%	960,445	41.9%
Dec-09	102,033	4.4%	965,232	42.1%	1,067,265	46.5%
Mar-10	103,342	4.5%	1,111,607	48.0%	1,214,949	52.4%
Jun-10	74,035	3.2%	1,160,572	50.1%	1,234,606	53.3%
Sep-10	85,243	3.7%	1,329,281	57.4%	1,414,525	61.0%

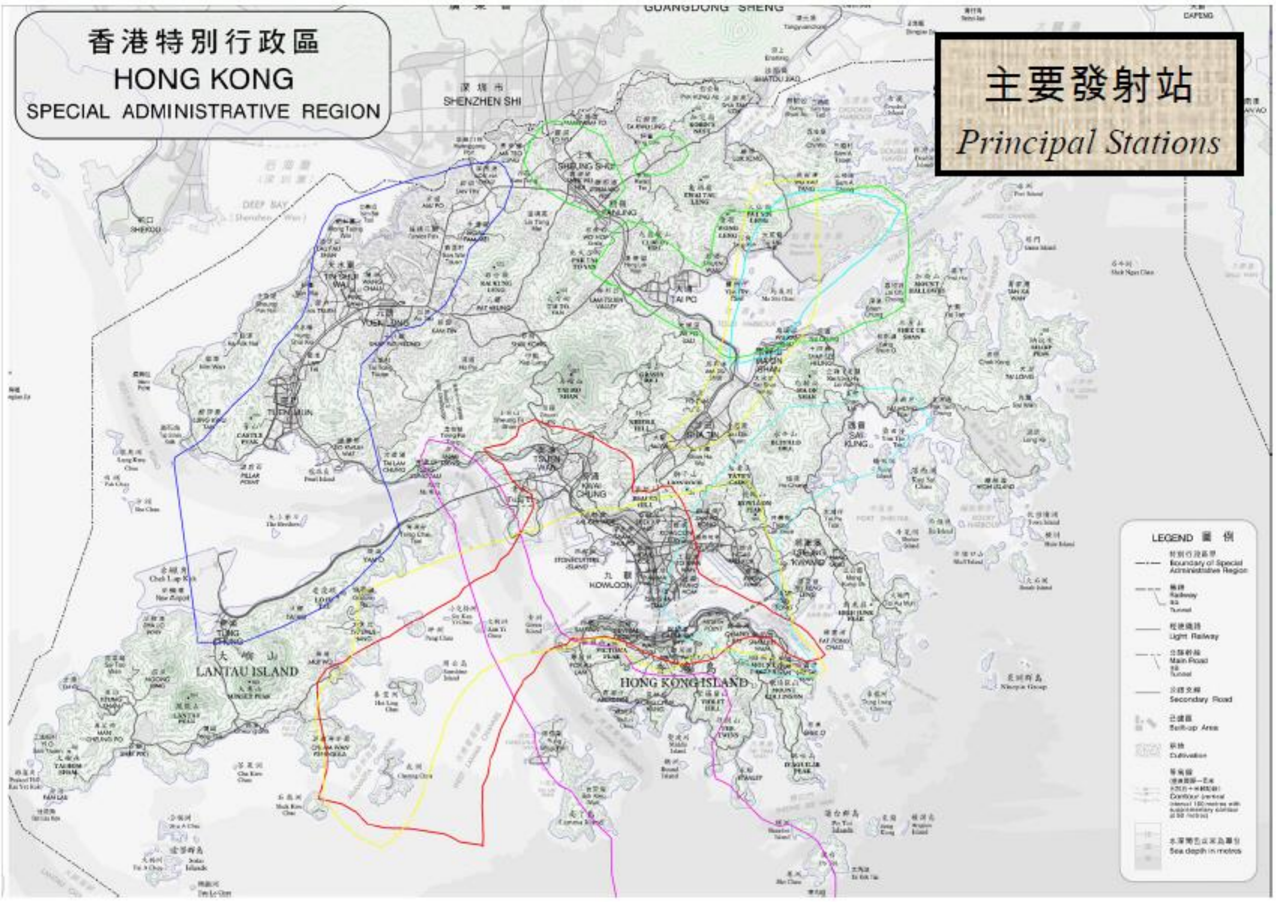


Note: Projected number of households based on the survey result of an average sample size of 1000 households randomly selected by computer aided telephone interviewing.

Annex E

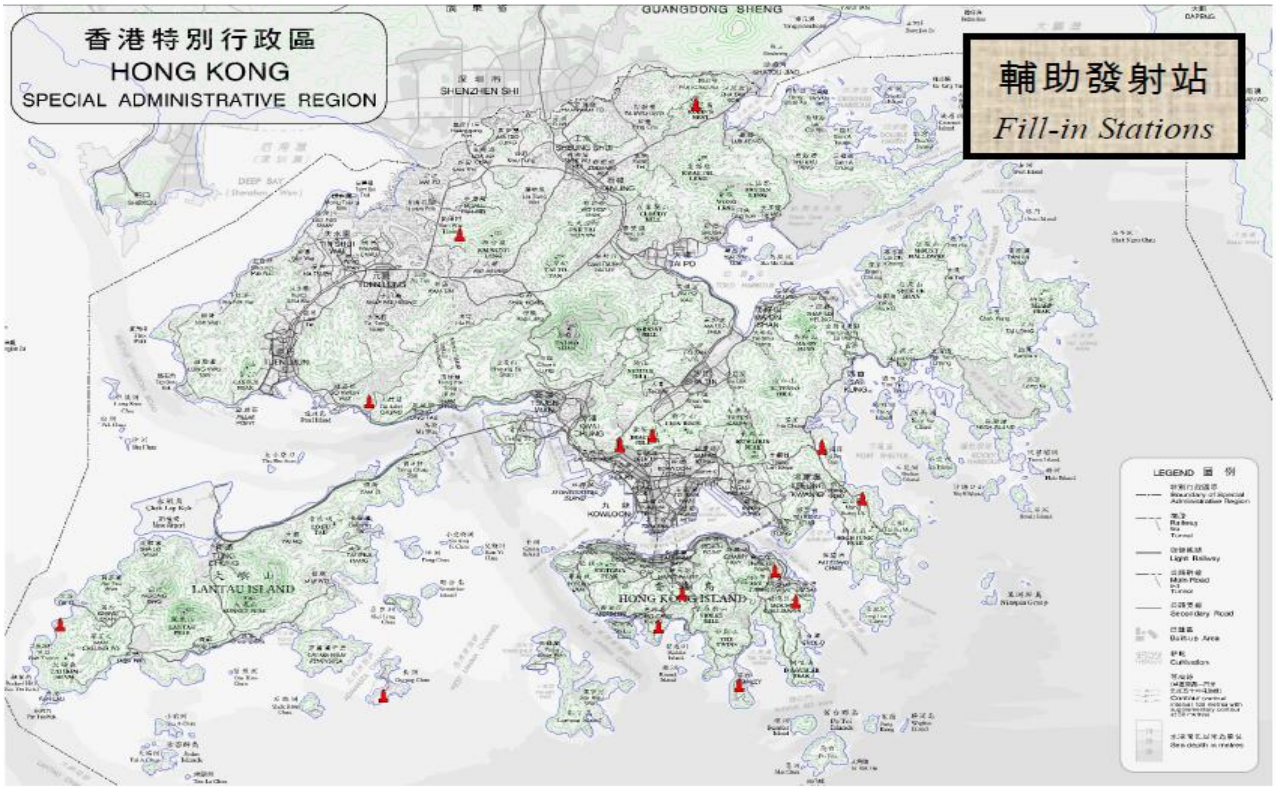
Location of the Digital Terrestrial Television (DTT) Stations and the estimated coverage (January 2011)

There are totally 20 transmitting stations launched for DTT services, including 6 principal stations and 14 fill-in stations. The location of the transmitting stations and the map of estimated coverage and areas are illustrated by the following diagrams and tables respectively. The listed diagrams and tables are prepared for reference as rough estimation of DTT coverage. It is planned that nine more DTMB SFN fill-in stations are to be constructed by the end of 2011.



Estimated coverage shown in the above diagram is composed by the signals broadcast by the following principal transmitting stations.

(yellow)	慈雲山	Temple Hill
(cyan)	飛鵝山	Kowloon Peak
(red)	金山	Golden Hill
(blue)	青山	Castle Peak
(green)	九龍坑山	Cloudy Hill
(magenta)	南丫島	Lamma Island



Location of fill-in stations

數碼地面電視廣播的估計覆蓋範圍
Estimated Coverage of Digital Terrestrial Television (DTT) Broadcast

數碼地面電視發射站 **DTT Stations**	**覆蓋範圍** Coverage Areas							**發射站啟播時間表** **Official Launch of DTT Station**
慈雲山 **Temple Hill**	鰂魚涌 Quarry Bay 深水埗 Sham Shui Po	北角 North Point 沙田 Sha Tin	灣仔 Wan Chai 長洲 Cheung Chau	中西區 Central & Western 愉景灣 Discovery Bay	油尖旺 Yau Tsim Mong	九龍城 Kowloon City	黃大仙 Wong Tai Sin	2007 年 12 月 31 日 31 December 2007
飛鵝山 **Kowloon Peak**	小西灣 Siu Sai Wan	柴灣 Chai Wan	筲箕灣 Shau Kei Wan	西貢 Sai Kung	將軍澳 Tseung Kwan O	油塘 Yau Tong	觀塘 Kwun Tong	2008 年 7 月 July 2008
金山 **Golden Hill**	荔枝角 Lai Chi Kok	葵涌 Kwai Chung	青衣 Tsing Yi	荃灣 Tsuen Wan	汀九 Ting Kau	深井 Sham Tseng	青龍頭 Tsing Lung Tau	2008 年 7 月 July 2008
青山 **Castle Peak**	掃管笏 So Kwun Wat	屯門 Tuen Mun	藍地 Lam Tei	元朗 Yuen Long	天水圍 Tin Shui Wai	東涌 Tung Chung		2008 年 7 月 July 2008
九龍坑山 **Cloudy Hill**	馬鞍山 Ma On Shan	馬料水 Ma Liu Shui	大埔 Tai Po	粉嶺 Fanling	上水 Sheung Shui	羅湖 Lo Wu		2008 年 8 月初 Early August 2008
南丫島 **Lamma Island**	淺水灣 Repulse Bay	黃竹坑 Wong Chuk Hang	鴨脷洲 Ap Lei Chau	香港仔 Aberdeen	薄扶林 Pok Fu Lam	南丫島 Lamma Island		2008 年 8 月初 Early August 2008
聶高信山 **Mount Nicholson**	跑馬地 Happy Valley	銅鑼灣 Causeway Bay	灣仔 Wan Chai					2008 年 8 月初 Early August 2008
上洋山 **Sheung Yeung Shan**	將軍澳 Tseung Kwan O	上洋 Sheung Yeung	下洋 Ha Yeung	相思灣 Sheung Sze Wan				2009 年 12 月 31 日 31 December 2009
西灣山 (柴灣) **Sai Wan Shan (Chai Wan)**	柴灣 Chai Wan	小西灣 Siu Sai Wan						2009 年 12 月 31 日 31 December 2009
琵琶山 **Piper's Hill**	長沙灣 Cheung Sha Wan	深水埗 Sham Shui Po						2009 年 12 月 31 日 31 December 2009
南朗山 **Brick Hill**	香港仔 Aberdeen	壽臣山 Shouson Hill	淺水灣 Repulse Bay	舂坎角 Chung Hom Kok				2009 年 12 月 31 日 31 December 2009
筆架山 **Beacon Hill**	顯田 Hin Tin	大圍 Tai Wai						2009 年 12 月 31 日 31 December 2009
元朗 374 山 **Hill 374 (Yuen Long)**	元朗 Yuen Long	輞井圍 Mong Tseng Wai	水邊村 Shui Pin Tsuen					2010 年 12 月 31 日 31 December 2010
砵甸乍山 **Pottinger Peak**	石澳 Shek O	鶴咀 Hok Tsui (Cape D'Aguilar)						2010 年 12 月 31 日 31 December 2010

數碼地面電視廣播的估計覆蓋範圍
Estimated Coverage of Digital Terrestrial Television (DTT) Broadcast

數碼地面電視發射站 DTT Stations	覆蓋範圍 Coverage Areas					發射站啟播時間表 Official Launch of DTT Station
赤柱 Stanley	赤柱 Stanley	白筆山 Red Hill				2010 年 12 月 31 日 31 December 2010
長洲 Cheung Chau	長洲 Cheung Chau					2010 年 12 月 31 日 31 December 2010
大欖涌 141 山 Hill 141 (Tai Lam Chung)	大欖涌 Tai Lam Chung					2010 年 12 月 31 日 31 December 2010
大埔仔 Tai Po Tsai	大埔仔 Tai Po Tsai					2010 年 12 月 31 日 31 December 2010
紅花嶺 Robin's Nest	山咀 Shan Tsui	鹽寮下 Yim Liu Ha	鹿頸 Luk Keng	坪輋 Ping Che	軍地 Kwan Tei	2011 年 1 月 7 日 7 January 2011
大澳 Tai O	大澳 Tai O					2011 年 1 月 7 日 7 January 2011

註：數碼地面電視訊號覆蓋全部或部分上述地區
Remarks: The regions listed above are covered entirely or partially by the DTT signals

二零一一年一月
January 2011

2.1.2 Deployment of DTMB SFN in Shanghai

With the release of DTMB standard, the application of terrestrial digital TV in Shanghai began to schedule in 2009.

Shanghai is the largest city in china full of high buildings and skyscrapers. Total area of whole city is about 300 square km. Only one broadcasting station cannot provide enough coverage and the SFN application of DTMB seems to be a unique solution. Besides, the wireless channel of Shanghai is very complex, especially in the overlapping area between two adjacent stations.

2.1.2.1 Executive summary

After the release of DTMB standard and the specification of DTMB receiver, some modes with good lab test results can be applied for the SFN in Shanghai. Evaluations and experiments had been carried out to promote the application. With the help of radio network planning tool, a SFN network with six stations had been successfully deployed since 2009.

This Report provides introduction of DTMB trial in Shanghai for mobile TV by the SFN Transmission Network System. Firstly, technical parameters of DTMB SFN in Shanghai are given; secondly, DTMB SFN implementation for different stages is introduced; finally, a result of technical methods suitable in the SFN is given.

2.1.2.2 Technical parameters of DTMB SFN in Shanghai

To fully utilize the analogue station infrastructure, building and steel tower, the design of DTMB SFN system in Shanghai was based on the existing station. Oriental Pearl, the main SFN station, and five other SFN stations (HongQiao, Education TV, Oriental TV, Daning and West Nanjing Road) formed the whole SFN transmission network system of DTMB.

After release of DTMB standard, some modes of DTMB had shown attractive testing results. One mode of DTMB was tried for the SFN application of DTMB in Shanghai.

Transmission parameters

Modulation of DTMB is C = 1, 4 QAM, PN = 595, Code rate 0.8 and Data rate is 10.396 Mbps, which is shown in Table AE-1.

TABLE AE-1

Parameters of one mode used in Shanghai

Mode	Single-Carrier Mode with the number of carriers (C= 1)
Modulation	4QAM,
Frame Header	PN 595
Code Rate	0.8
Symbol Interleaving	Mode 2 i.e. B = 52 and M = 720 symbols

2.1.2.3 Implementation and results of DTMB SFN

The whole construction was in three stages.

Stage 1: Operated the two stations (Oriental Pearl and HongQiao) individually and got the coverage of the two stations respectively by field testing around the broadcasting station. With the help of field testing, a planning tool designed for DTMB SFN network was used to get the overlapping coverage area.

Stage 2: Some field testing for these overlapping areas were conducted with the two stations broadcasting synchronized. With the guide of lab testing results and help of planning tool, some adjustment of time delay and powers were made.

Stage 3: By extending the experience of two station SFN network and with the further help of the planning tool, the whole DTMB SFN network with six stations was successfully deployed. The testing of whole SFN network had shown a good result.

Stage 1 implementation

At the implementation of Stage 1, broadcasting signals by single station at Oriental Pearl station and HongQiao station individually to get the overlapping coverage area. The Oriental Pearl station is the highest TV tower in Shanghai and located in the eastern Shanghai, while HongQiao station is located in the western Shanghai and also plays a role in the broadcasting.

Some new platforms on the tower were setup with antenna mounting structure, which was designed to provide space for DTMB equipment accommodation, steel platform on top of building for antenna (Normal & Standby) installation. The equipments and facilities of optical fiber transmission were installed for the adaptor of SFN network, steel pole on top of the steel platform for accommodation the common GPS antenna system, which was necessary for the DTMB SFN network.

The period for Stage 1 lasted one month. The overlapping area for the two main stations was successfully figured.

DTMB coverage maps formed by Oriental Pearl station and HongQiao station individually are shown below in Fig. AE-2 and Fig. AE-3. The overlapping areas were marked in Fig. AE-4 by calculating the difference of Receiving Signal Level (RSL) between the two stations.

FIGURE AE-2

DTMB Coverage map – only with the broadcasting of Oriental Pearl station

NOTE – Green is representing for the RSL from –65 dBm to –20 dBm.
Blue is from –72 to –65 dBm.
Orange is from –78 to –72 dBm.
Yellow is from –85 to –78 dBm.
Red is from –100 to –85 dBm.

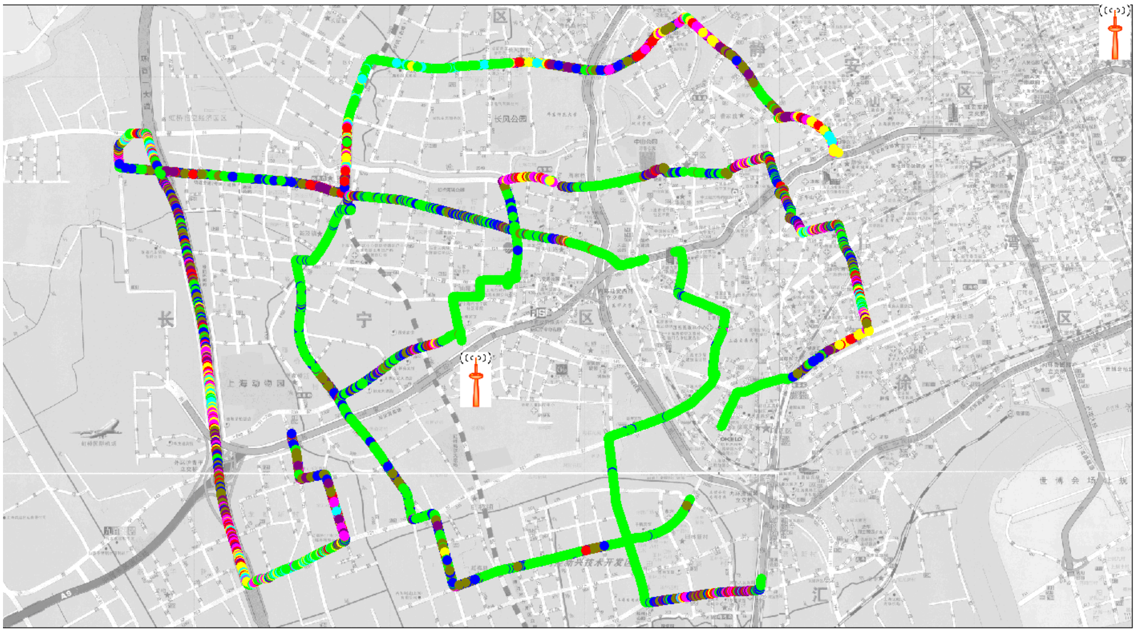
FIGURE AE-3

DTMB Coverage Map – only with the broadcasting of HongQiao station

NOTE – Green is representing for the RSL from –65 to –20 dBm.
Blue is from –72 to –65 dBm.
Orange is from –78 to –72 dBm.
Yellow is from –85 to –78 dBm.
Red is from –100 to –85 dBm.

FIGURE AE-4

DTMB Coverage map– for the RSL difference between the two stations



NOTE – Grass Green is representing for the RSL difference from 9 to 35 dB.
Azure is from 6 to 9 dB.
Yellow is from 3 to 6 dB.
Pink is from 1 to 3 dB.
Red is from –1 to 1 dB.
Purple is from –3 to –1 dB.
Khaki is from –6 to –3 dB.
Blue is from –9 to –6 dB.

The overlapping area is defined to be those areas where the absolute difference of RSL between two stations is less than 5 dB.

Stage 2 implementation

The SFN network of two stations must have equipment, the SFN adaptor. In Stage 2, the two stations were broadcasting synchronized. Based on the lab test report and analysis from the planning tool, some adjustments for the time delay and power of the two stations were made.

The initial transmitter parameters of the two stations are listed as below in Table AE-2.

TABLE AE-2

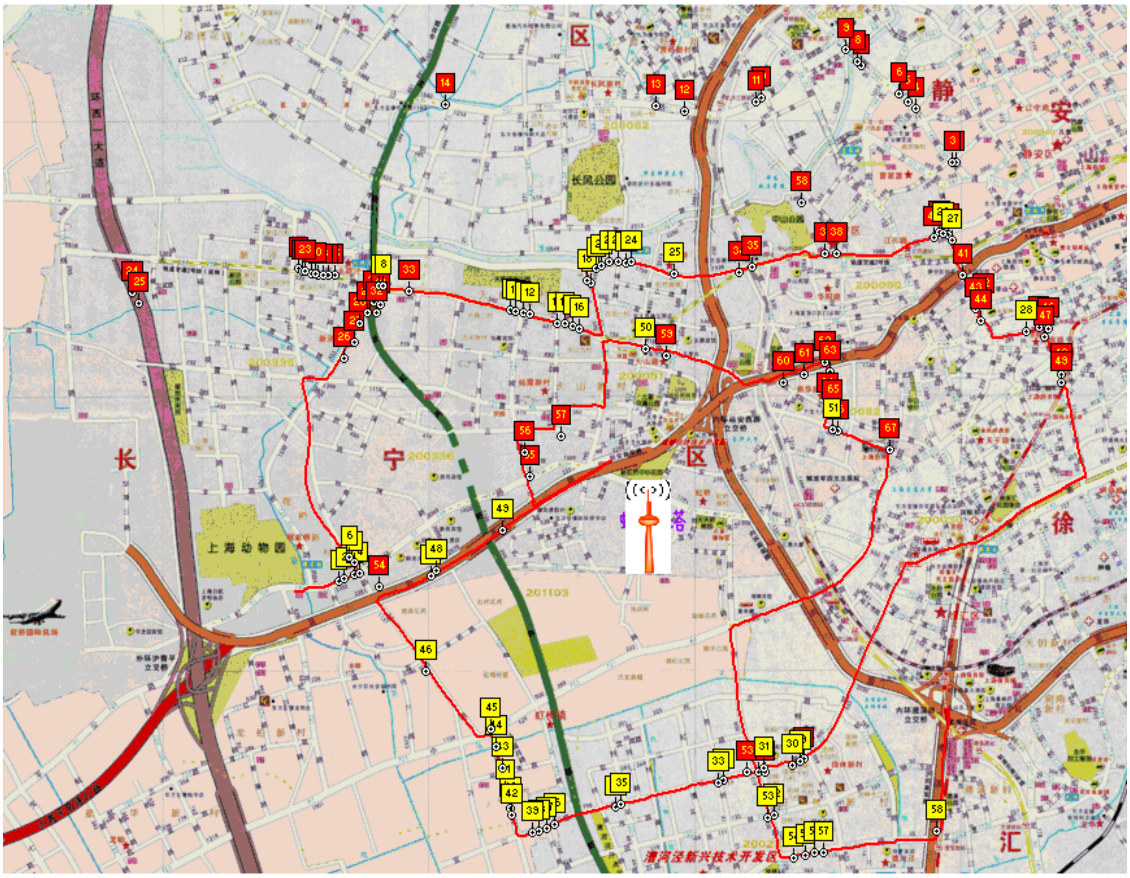
Initial transmitter parameters of the two stations

Transmitter Location	Power (w)	Delay (us)	Antenna height (m)
Oriental Pearl	1 000	0	420
HongQiao	800	0	150

Field test examples in the overlapping area without the adjustment of time delay and power are shown below in Fig. AE-5.

FIGURE AE-5

DTMB Reception Performance –without the adjustment of time delay and power for the SFN network with two stations



NOTE – The yellow labels indict failure reception spots in the overlapping area.

With the guide of planning tool, some adjustment of time delay and powers were made. The adjusted transmitter parameters of the two stations are listed as below in Table AE-3.

TABLE AE-3

Adjusted transmitter parameters of the two stations

Transmitter Location	Power (w)	Delay (us)	Antenna height (m)
Oriental Pearl	1 000	0	420
HongQiao	700	14	150

Field test examples in the overlapping area after the adjustment are shown below in Fig. AE-6.

FIGURE AE-6

DTMB Reception Performance – after the adjustment of time delay and power for the SFN network with two stations

NOTE – The yellow labels indict failure reception spots in the overlapping area.

From the Fig. AE-6, it is clear that the reception performance in the overlapping area had been greatly improved.

Stage 3 implementation

In Stage 3, additional four stations were deployed to cover the whole Shanghai. Information of these six stations is listed in Table AE-4, including the final adjustments of time delay and power. The location map of DTMB SFN stations is shown in Fig. AE-7. With a careful design, the SFN network of DTMB in Shanghai had achieved good coverage and reception performance, which are shown in Fig. AE-8 and Fig. AE-9.

TABLE AE-4

Technical parameters of six principal stations in Stage 3

Transmitter Location	Transmitter Power (W)	Delay (µs)	Antenna height (m)
Oriental Pearl	1 000	0	420
HongQiao	700	14	150
Oriental TV	1 000	2	140
DaNing	500	9	100
Education TV	600	5	130
West Nanjing Road	400	5	130

FIGURE AE-7

Location Map of DTMB SFN Stations

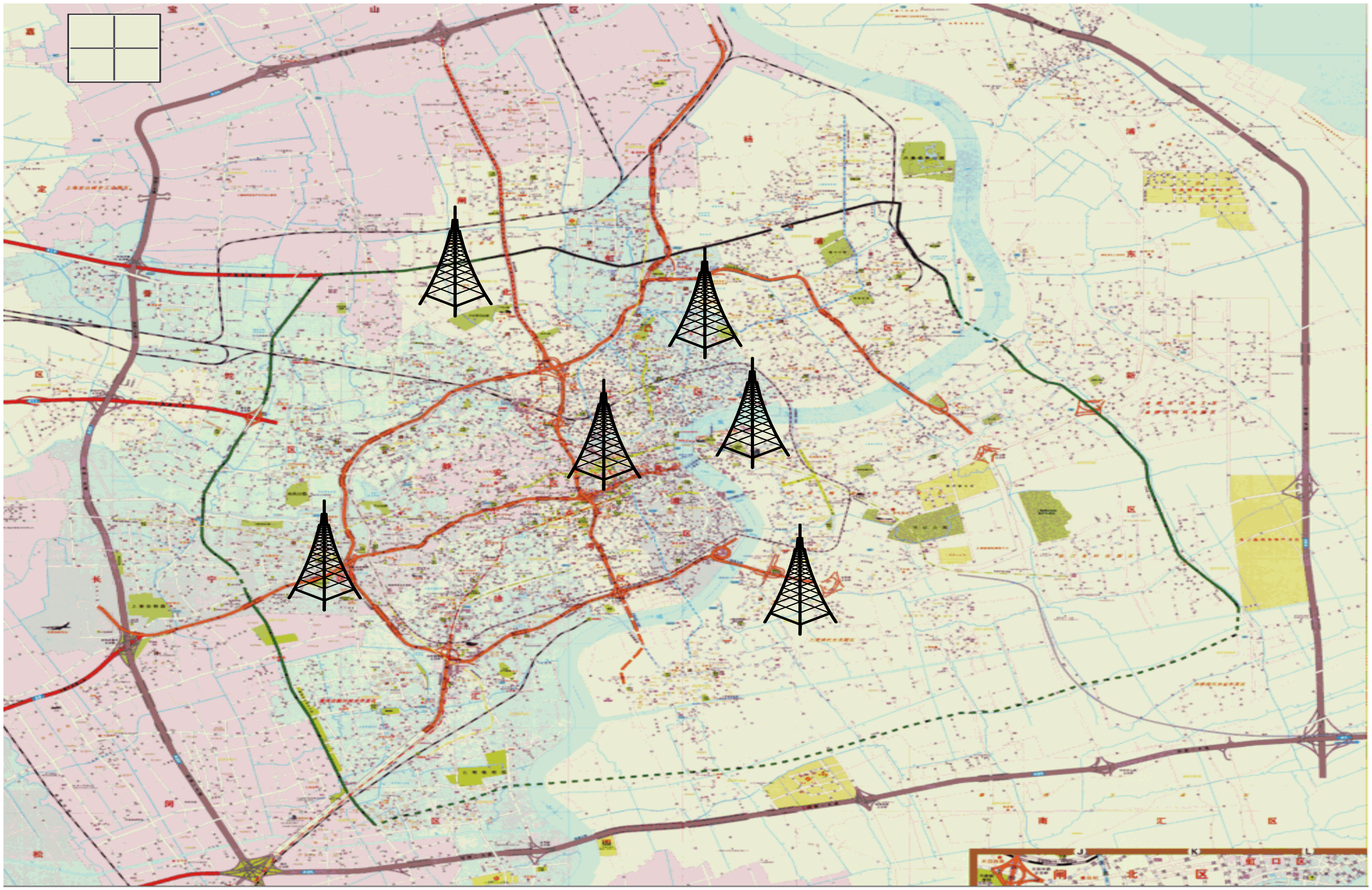
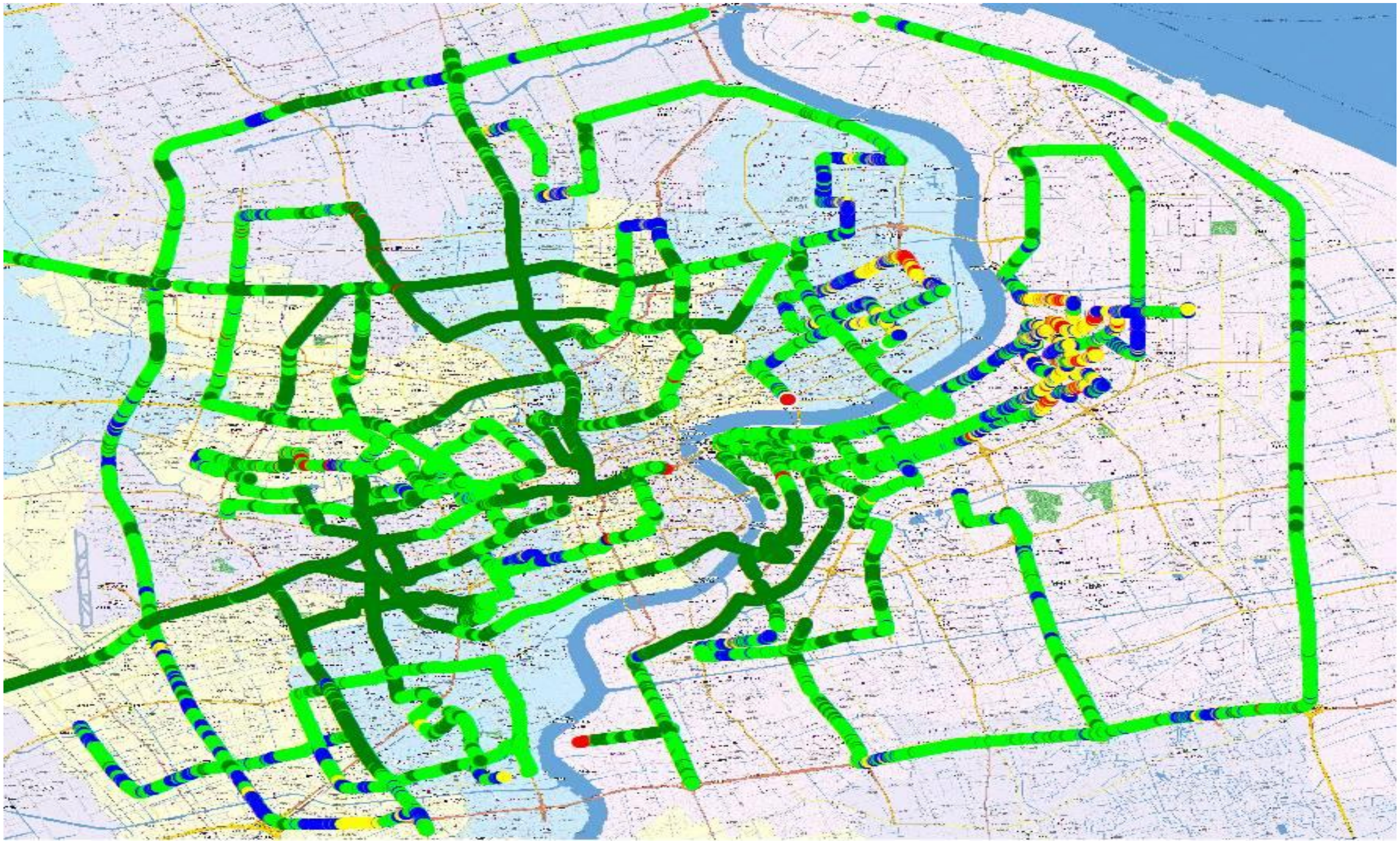


FIGURE AE-8

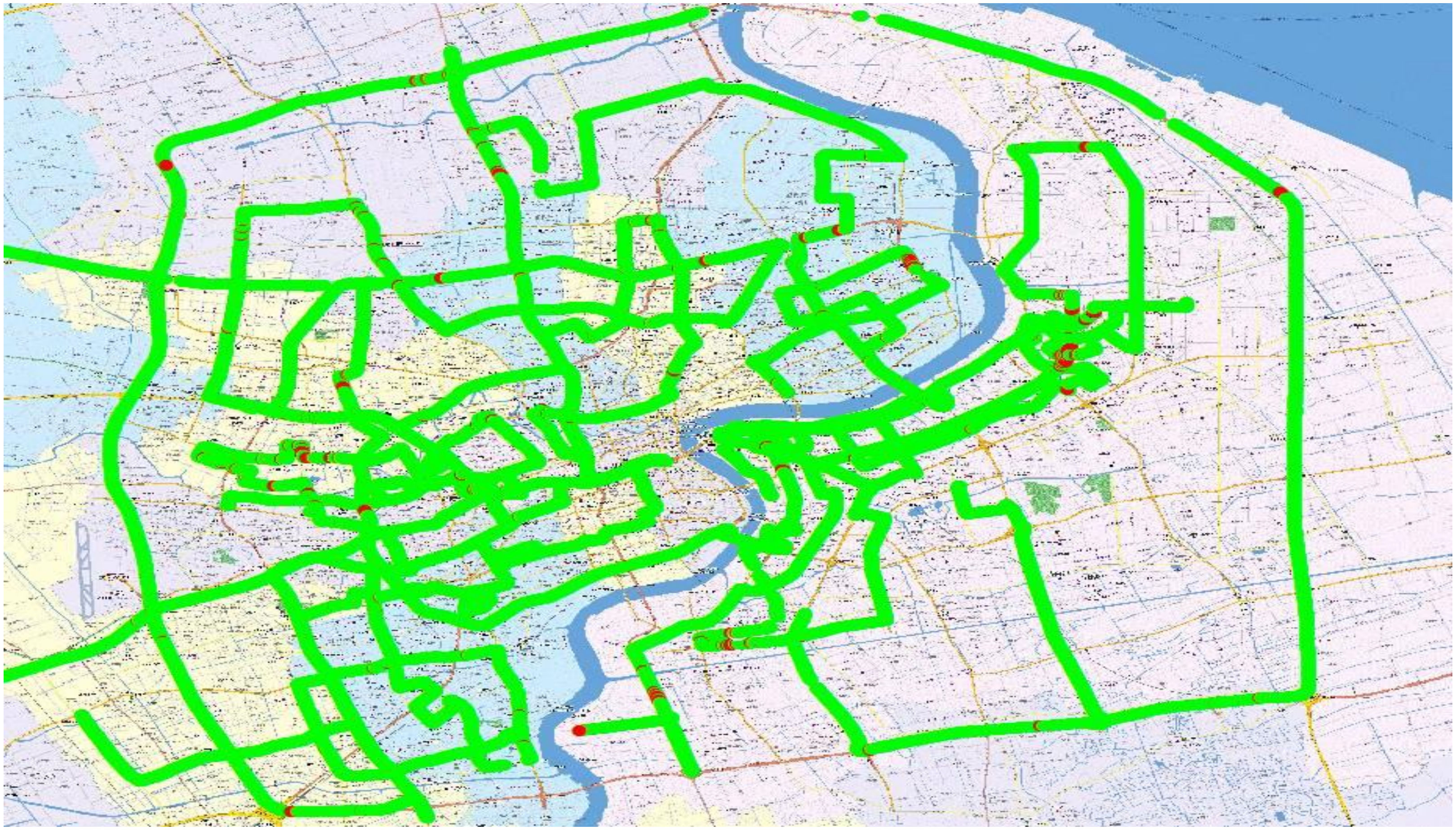
DTMB Coverage map – with six broadcasting stations



NOTE – Dark green is representing for the RSL from –60 to –20 dBm
Green is from –70 to –60 dBm
Blue is from –75 to –70 dBm
Red is from –100 to –75 dBm.

FIGURE AE-9

DTMB Reception Performance – with six broadcasting stations



NOTE – Green is representing for the successful reception and Red is for the failure reception.

2.1.2.4 Conclusion

During the trial implementation of DTMB SFN transmission network in Shanghai, invaluable experience was gained in overcoming reception problems caused by the difficult topographic situations (which is multiple broadcasting stations and dense skyscraper area). Such experience would also be invaluable to the deployment of DTMB SFN in other cities.

2.2 Deployment of DTMB SFN based on satellite program distribution networks

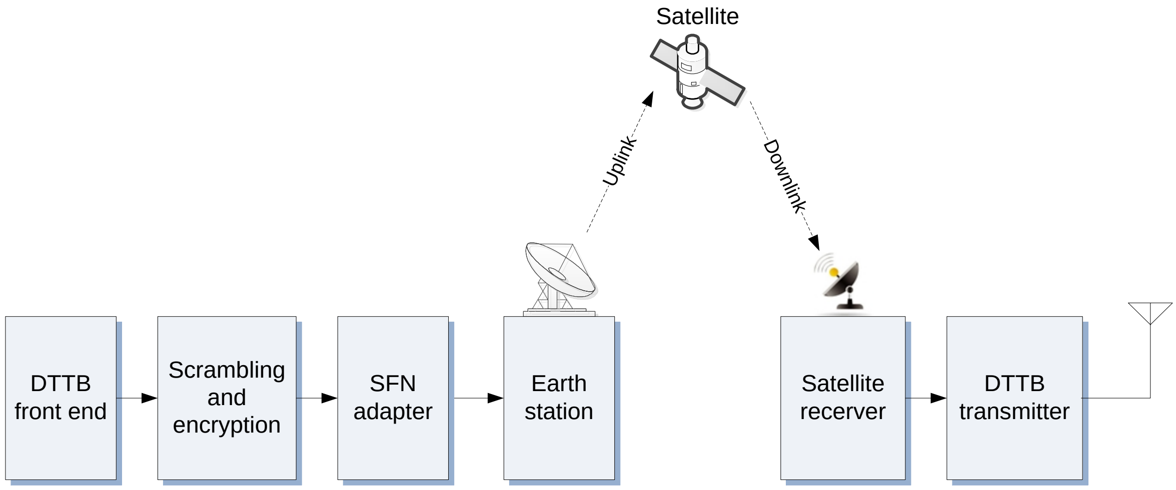
2.2.1 System Structure

The SFN based on satellite distribution networks consists of DTT front-end system, scrambling and encryption, SFN adapter, satellite distribution link and DTTB transmitting system. The SFN structure is illustrated in Fig. AE-10.

The DTT front-end system performs the video and audio compression coding using AVS+ and DRA standards, and generates one TS by multiplexing. Then, the TS is fed to the SFN adapter for SFN adaption after scrambling and encryption. After that, the adapted TS is transmitted to the satellite earth station for satellite distribution. The satellite receiver demodulates the received satellite signal and recovers the transmitted TS. Then, the recovered TS is transformed to the DTTB signal by DTTB transmitters.

FIGURE AE-10

The DTTB SFN structure based on satellite distribution networks



2.2.2 Satellite Distribution Networks

The satellite distribution link is comprised of signal transmission and connection system, uplink transmitting system and downlink receiving system. The signal transmission and connection system transmits the TS from the SFN adapter to the satellite earth station through DS3 signal format. The uplink transmitting system completes the satellite signal modulation, up-conversion, high power amplifying and RF output. The downlink system receives the satellite signal, demodulates, descrambles and recovers the original TS signal.

The signal transmission and connection system includes network terminal, digital optical transmission hub station, dual-route cable protection ring network, digital microwave link and transmission adapter. The DS3 signal is input to the dual-route cable protection ring through the network terminal, and then distributed to the satellite earth stations through the dual-route cable protection ring and the digital microwave link. The uplink systems at the earth stations receive the distributed DS3 signal and transmit to the satellite transponder.

The uplink system completes satellite signal modulation, up-conversion, signal amplification and RF output to the satellite transponder. At the same time, the DTTB station should have the satellite receiving antenna and satellite IRD with AVS+ decoder, after demodulation and descrambling, the TS was sent to DTTB transmitter/exciter.

The synchronization module inside the DTTB transmitter/exciter identifies the second initialization packet (SIP) embedded in the received TS and analyzes the TS transmission delay. Furthermore, the transmitter will also identify the working mode from the System Information part in the SIP and adjust it operation mode. According to the local reference signal supplied by GPS or BDS timing receiver, the transmitter/exciter adjusts the transmitting time so that all the transmitters in the SFN can send the same signal at the same time.

However, the transmission data rate of the satellite modulator will be slightly higher than the data rate of the DTMB system. So additional null packets will be inserted into the adapted SFN TS by satellite modulator, which will change the original structure of the adapted SFN TS. Therefore, the DTTB modulator must distinguish the null packets inserted by satellite modulator and SFN adapter, and should eliminate the null packets inserted by satellite modulator to keep the TS same as output of SFN adapter. In addition, traditional satellite modulator will modify the PCR data in the TS. It maybe causes the out of synchronization of audio and video. So the PCR data information should be recovered by the DTTB transmitter or the satellite receiver. Furthermore, long transmission delay and jitter problems will be introduced when using satellite transmission links, further experimental verifications is needed to check the influence on SFN.

Accordingly, there are two technical difficulties that should be overcome using satellite link as the distribution network. Firstly, the satellite transmission equipment must guarantee the TS structure unchanged from the SFN adapter. Secondly, the DTTB transmitters must be able to complete the synchronization adjustment according to the synchronization reference information in the SFN adapted TS under the long transmission delay caused by satellite distribution and encrypting.

2.2.3 SFN Adapter

The SFN adapter is the key equipment in the SFN. The SFN adapter have two functions, SIP packet insertion and data rate adaptation to match the payload data rate of the corresponding DTMB working mode.

According to the reference signals (10MHz clock and 1PPS signal) provided by GPS/BDS timing receiver, the SFN adapter inserts SIP packet to the TS with the period of 1 second. Because satellite distribution link is adopted, it is required that the SIP and null packets inserted by SFN adapter must have special tags in order to distinguish from the null packets involved by satellite modulator. Otherwise, it will cause the processing error at each DTTB station and make the SFN networking failure.

Consequently, the format of null packet inserted by SFN adapter needs to be modified. At the same time, special indication bytes and CRC check bytes are introduced to the padding data of the SIP.

2.2.4 Laboratory and Field Tests

In order to verify the feasibility and effectiveness of the proposed DTMB SFN scheme, laboratory verification and field trial was conducted based on satellite distribution networks.

1) Laboratory Test Results

The TS distribution link is very important for SFN networking. Besides the wireless transmission delay, additional processing delay will be introduced by the satellite modulator and demodulator in the satellite distribution link. So, the transmission characteristics and the processing delay of the satellite transmission link should be verified.

The laboratory test system diagram for the measurement of satellite transmission delay is shown in Fig. AE-11.

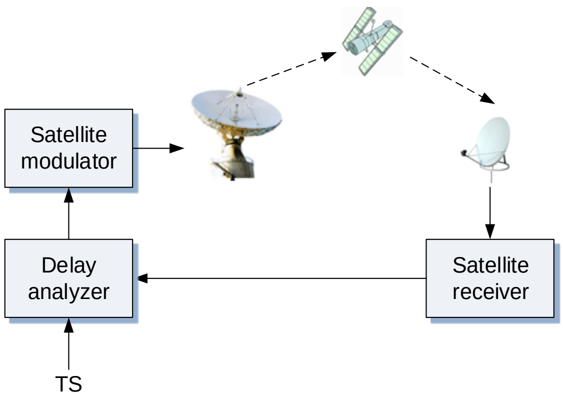
The delay analyzer will insert special timing tag to the measured TS, and then the TS will be modulated and transmitted to the satellite. The satellite demodulator receives the forwarded signal and demodulates the TS to the delay analyzer. Then, the transmission delay is calculated by comparing the timing tags between the transmitted and received TS.

The test site is selected at the satellite earth station. TS signal with 3 AVS+ HDTV programs passing through the delay analyzer, and then modulated by uplink satellite modulator. Local satellite receiver at the same earth station demodulated the signal and fed back the TS to the delay analyzer.

Test results show that the satellite transmission delay is about 250 ms (248.5~249.3 ms) for different satellite receivers. The transmission jitter is also not obvious during laboratory tests. So the transmission delay of the satellite distribution link can satisfy the DTTB SFN requirement of 1 second transmission delay even taking into account different DTTB stations with different geography locations.

FIGURE AE-11

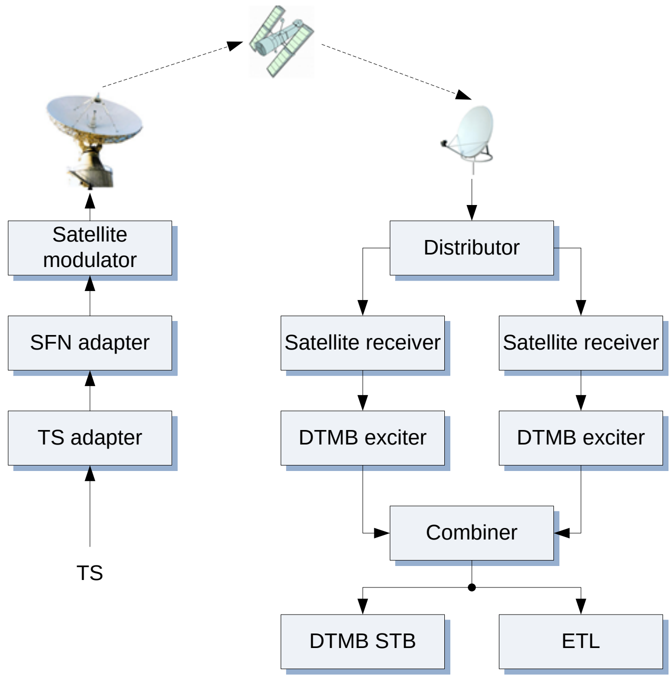
Transmission delay measure



Networking experiment with multiple exciters is an important verification step before SFN field trial. The diagram of test system is shown in Fig. AE-12. The receiving antenna receives the transmitted signal from satellite distribution link and sends the signal to two satellite receivers by distributor. Two satellite receivers demodulate and descramble the received signal and send the demodulated TS signal to DTTB exciters. The modulated RF signals from the DTTB exciters are combined with a power combiner. Combined signal is transmitted to digital television analyzer (ETL) and DTTB set-top-box. ETL can analyze the SFN networking parameters and set-top-box can monitor the reception quality directly.

FIGURE AE-12

Laboratory SFN networking test



Part of the test scenarios are shown in Fig. AE-13.

FIGURE AE-13

Laboratory test scenarios

Laboratory networking test results show that the distribution network based on satellite links can support the SFN synchronizations effectively. The spectrum and corresponding time domain channel impulse response of the combined RF signal are shown in Fig. AE-14 (a) and (b) respectively. Furthermore, cross tests indicate that the SFN networking is successful using different SFN adapter and DTTB exciters of different brands. Therefore, laboratory test verified the feasibility of the proposed SFN structure using satellite distribution networks.

2) Field Trial Results

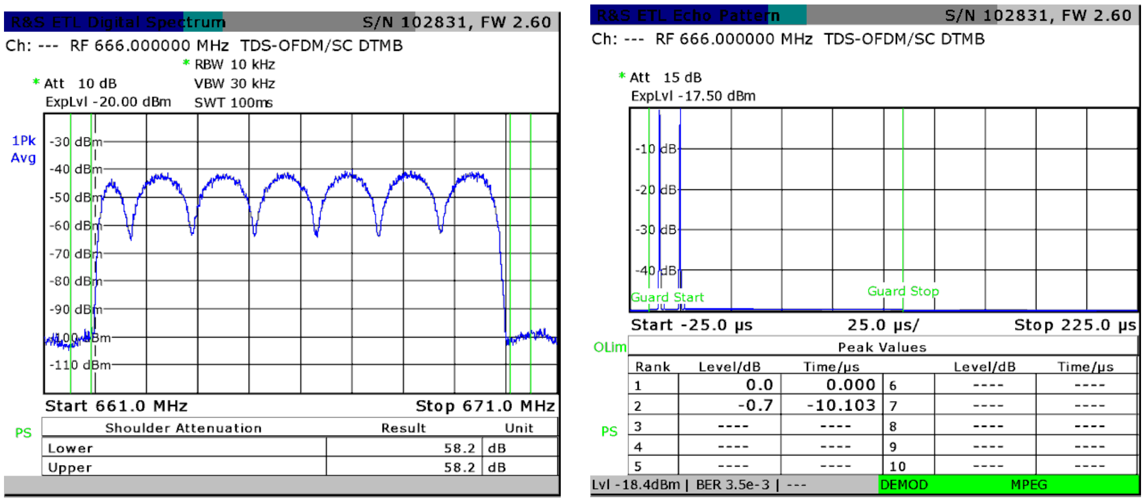
The field trials are performed based on laboratory tests to further validate the proposed SFN scheme with the coordination of CCTV tower, satellite earth station and CCTV.

The field trail is completely constructed according to the actual system architecture. CCTV provides one scrambled TS signal including 6 AVS+ programs. The TS signal is then transmitted to the satellite earth station and passed through the SFN adapter and satellite modulator to generate the uplink satellite signal. At the DTTB station, the TS signal is recovered by satellite receiver. DTTB transmitter receives the recovered TS and converts it to DTMB RF signal. Two DTTB stations are selected, i.e. CCTV tower and one transmitting station around Beijing. Channel 32 with centre frequency of 666 MHz is used, and the transmitting power is 1KW for both stations. DTMB working mode is PN945, C=3 780 (multi-carrier mode), 16QAM and LDPC rate 0.6.

Before field trial, the coverage is calculated using frequency planning software according the real parameters. Calculated results show that the coverage overlapping area mainly exists between the east Ring 3 and Ring 5. Therefore, the main road of east Ring 3 and Ring 5 is selected for the reception test.

FIGURE AE-14

Signal characteristics of the combined signal



(a) spectrum (b) impulse response

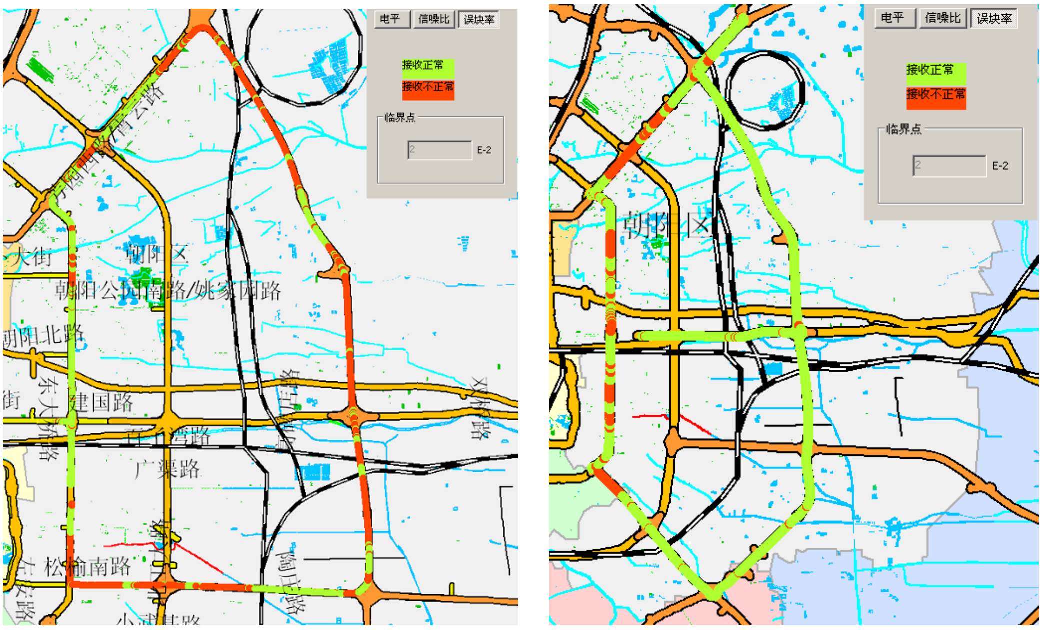
The field trail results for single transmission station are shown in Fig. AE-15 (a) and (b) respectively, in which the LDPC block error rate is used to indicate the mobile reception quality. It is clear from Fig. AE-15 that there exists an obvious service blind area when using single transmission station (red section in Fig. AE-15).

Figure AE-16 illustrates the coverage test results in the case of two transmission stations working on nonsynchronous condition. It is obvious that both transmission stations generate severe interference to each other, and the coverage area is decreased evidently compared with single transmission station mode.

Under the condition of SFN mode with both transmitters synchronous to each other, the field trail results are shown in Fig. AE-17. From Fig. AE-17 it is clear that the service availability exceeds 98% when both transmitters are working synchronously to form SFN. The coverage effect is much better compared with single transmission station, which proves the feasibility and effectiveness of the satellite based distribution link in practical application environments.

FIGURE AE-15

Coverage test results of single transmission station



(a) CCTV tower (b) the other station

FIGURE AE-16

Coverage test results of nonsynchronous transmission stations

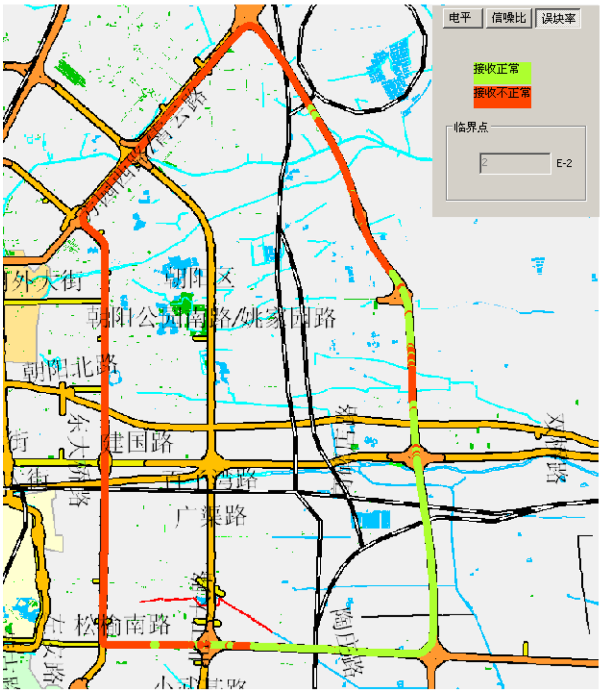
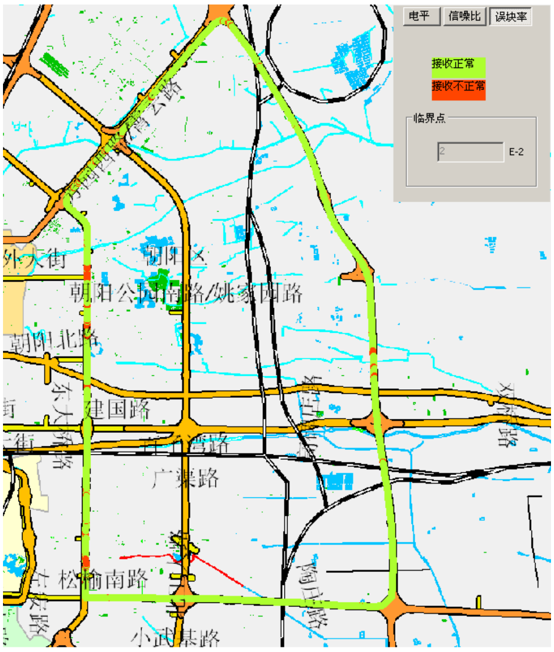


FIGURE AE-17

Coverage test results of SFN mode



2.2.5 Conclusion

A novel DTTB SFN scheme is proposed based on satellite distribution networks. The advantages of the satellite link are fully utilized in the proposed scheme so that the program distribution network will not be affected by the regional restrictions. Therefore, it is suitable for constructing national wide or large area DTTB SFN networks. Test result indicates that the transmission delay of the satellite distribution link satisfies the SFN networking requirement. Both laboratory test and field trial show that the proposed SFN structure can support practical applications.

References

[1] Recommendation ITU-R BT.1306 *Error correction, data framing, modulation and emission methods for digital terrestrial television broadcasting*

[2] Technical Standard for Digital Terrestrial Television Broadcasting, Statement of the Telecommunications Authority, 4 June 2007 (http://tel_archives.ofca.gov.hk/en/tas/others/ta20070604.pdf)

[3] Technical Specification for Digital Terrestrial Television Baseline Receiver Requirements, OFTA (http://tel_archives.ofca.gov.hk/en/standards/hktaspec/hkta1108.pdf)

[4] Location of the Digital Terrestrial Television (DTT) Stations and the Estimated Coverage (January 2011), OFTA http://www.digitaltv.gov.hk/general/pdf/coverage.pdf

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