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High and Low Tower Broadcast Networks

A study comparing network topologies and spectrum efficiency for high tower and low tower broadcast networks commissioned by Broadcast Networks Europe (BNE)

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1 Executive Summary

Terrestrial broadcasting services are delivered by networks based on high power transmissions from high towers and masts. This is a cost-efficient solution to simultaneously deliver the same audio visual content to many receivers spread over a large geographical area. The higher the tower or mast, the larger the coverage area, meaning that a modest number of high power transmitters can be used to cover very large areas and populations.

To investigate the feasibility of different network configurations for the transmission of digital terrestrial television (DTT), alternative network architectures with different power levels and transmitting antenna heights (300 m, 50 m and 30 m) have been studied for fixed reception with rooftop antennas. In all cases Single Frequency Network (SFN) design and DVB-T2 technology was used. The antenna heights and power levels considered are representative of the alternative options available.

The Impact of Network Architecture on Number of Sites

A general reduction in site height and power for a network inevitably leads to an increase in the number of sites required. Accordingly, a very large number of sites are needed for low tower (LT) networks to achieve equivalent coverage and capacity when compared with the high tower (HT) alternative. The table below shows calculated inter-site distances for the noise limited case, average service area per site and the number of low tower sites to replicate the coverage area achieved by a single HT site (the site multiplier factor).

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

HT/LT	Antenna height (m)	ERP (W)	Inter-site distance (km)	Service area per site (km^2)	Site multiplier factor
HT	300	50 000	104	7 123	1
LT	50	50	12.8	108	66
LT	50	500	21.6	308	23
LT	50	5 000	34.6	790	9
LT	30	50	10.0	66	108
LT	30	500	17.0	191	37
LT	30	5 000	27.4	495	14

Applying these results to Sweden, as an illustration, shows that country-wide area coverage would require 63 high tower sites with antennas at 300 meters and ERP 50 kW versus 4 161 low tower sites with antennas at 30 meters and ERP 50 W. Alternatively, 2 360 sites with antennas at 30 meters and ERP 500 W, or 1 462 sites with antennas at 50 meters and ERP 500 W would be required.

Real networks are often designed to include margins to allow for certain interference from neighbouring coverage areas, and the site multiplier factors will for this case turn out even higher.

Co-channel Separation and Network Design

The same frequency can be reused in two geographically separated areas provided that mutual interference levels are acceptable. The network architecture determines the amount of unwanted outgoing interference from one service area to another service area, thus influencing the minimum geographic separation distance between areas using the same frequency.

The required distance between such areas has been calculated for reference SFN networks. The table below summarizes the co-channel separation distances for the different network architectures assuming a 3 dB interference margin and land-only propagation. For instance, the required co-channel separation distance for HT networks (50 kW, 300 m) is 195 km.

HT/LT	Antenna height (m)	ERP (W)	Co-channel separation distance (km)
HT	300	50 000	195
LT	50	50	44
LT	50	500	80
LT	50	5 000	148
LT	30	50	38
LT	30	500	75
LT	30	5 000	146

For LT networks the separation distances are shorter, but still in the order of several tens of kilometers. This emphasises that even with LT networks it is necessary to use different frequencies in adjacent areas to avoid large exclusion zones.

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

Frequency Re-use and Potential Efficiency Gains

With the frequency allotment areas presently used in Europe, based on high tower architecture and DVB-T technology, typically around 7 frequencies are needed per national network coverage layer. This study however indicates that this could be improved, for HT networks as well as for LT networks.

Without changing the existing infrastructure (High Tower) less RF channels per national coverage layer could be required provided that larger SFNs are introduced and all services are delivered utilizing DVB-T2. For instance, the results indicate that if individual SFN areas are larger than approximately 200 km, then high tower based networks with on average 4 RF frequencies per national layer may be realized. In general the achievable frequency reuse factor is independent of network architecture (HT or LT) as long as the SFN areas are large enough.

The minimum number of frequencies per layer depends on the specified planning conditions and a range of key parameters, most notably coverage requirements, population distribution, propagation conditions, size and shape of coverage areas, minimum co-channel separation distance, requirement for regional services, etc. To provide continuous full coverage in a real environment across a country, including border areas, without any exclusion zones and allowing for regional content, at least 4 RF frequencies per national layer are needed. This requirement is equally valid for HT and LT networks.

It should also be noted that the planning conditions are determined by the requirements of the broadcast services and that broadcast service areas vary in size and shape, even within the same country. Where there are cases of SFN areas that are not regular in size and shape or terrain conditions are unfavourable, additional frequencies per layer could be required.

In addition, any major change in the DTT frequency usage, whether based on existing high tower infrastructure or on low tower infrastructure, involves international frequency replanning and coordination. In the present GE06 Plan[1] frequency allotment sizes are generally smaller than 200 km and hence significant replanning will be needed to implement larger SFN areas. With the introduction of DVB-T2 this is technically feasible, although excessively large SFNs require system parameters that reduce the available bitrate and limit the possibilities to provide local and regional services.

It can be concluded that frequency efficiency could be improved, also for high tower networks, through introduction of DVB-T2 and increased use of large SFNs. However, full SFN adoption will not be feasible due to the need to optimise coverage, capacity, regionality and international frequency coordination aspects.

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[1] The GE06 Agreement defines the frequency plans and usage for DTT in Europe, Middle East and Africa.

In order to maximise the outcome of any such replanning this would need to be coordinated at a European level based on agreed and common policy goals.

Implications on Service Provision

Terrestrial broadcast networks using high towers are designed to efficiently deliver broadcast content to a mass audience and to meet the requirements of broadcasters. A fundamental change of the network architecture would mean a hugely complex and costly process for consumers as well as broadcast network providers.

If the existing high tower based network configuration were to be changed to a low tower architecture this would imply

- Many more sites
- Much higher costs expected (more sites, more transmitters, more backhaul connections, more equipment for redundancy, more backup power units, higher maintenance costs)
- Greater environmental impact (more sites, higher total power consumption, etc.)
- Consumer disruption, e. g. a large number of consumers will have to redirect their roof-top antennas

All these aspects need to be taken into account if a change to an alternative network architecture were to be considered.

2 Background

Existing terrestrial broadcasting networks are based on high power transmissions from high towers and masts. The high tower infrastructure is usually supplemented by in-fill transmitters using low to medium height towers to cover areas where the high tower transmissions do not reach, for instance due to terrain irregularities and shadowing. Additional sites are also sometimes needed to tailor coverage areas to deliver regional broadcast content.

Using high towers and masts is a cost-efficient solution to provide broadcasting services, i.e. where the same content is consumed simultaneously by a large audience over a large area. The higher the mast, the larger the coverage area, meaning that a limited number of high power transmitters can be used to cover very large areas and populations. In practice there is a limitation of the maximum height of a mast for technical and cost reasons. Most European countries use broadcasting masts and towers with heights in the range 150-300 meters to efficiently provide the required coverage. The optimal height depends on surrounding terrain, coverage requirements, cost considerations, the need for regional services and other national or local conditions.

For many years the broadcasting infrastructure was the only nationwide terrestrial infrastructure to provide radiocommunication services to the general public. However, when public mobile networks were rolled-out they were generally established using low tower infrastructures. The two main reasons were that mobile cell sizes are limited by the available output power of the handsets and that cell sizes need to be small enough to provide the necessary capacity to serve all active users in each cell.

Based on the almost universal availability of low tower infrastructure for mobile networks it has been suggested that this infrastructure may also be used for broadcasting purposes, possibly replacing the traditional high tower broadcasting infrastructure. A number of important issues will need to be analysed and addressed in this context.

In this study two key aspects are considered; number of sites and potential spectrum gain; for comparison of high tower (HT) based architecture with low tower (LT) based architecture for terrestrial broadcasting. The results should in general be representative for broadcast networks in Europe. However, real case studies may prove beneficial to verify the results.

To fully address all issues and questions related to a potential switch to an alternative network architecture, additional studies will be needed.

3 Assumptions and Methods

The aim is to compare different infrastructure options for the transmission of digital terrestrial television (DTT). Several network architectures are evaluated, based on assumptions and parameters expected to be relevant for DVB-T2 high and low tower networks in a European perspective.

3.1 DTT System and Planning Parameters

Even though most DTT networks in operation in Europe today are using the DVB-T standard, it is assumed that DVB-T2 will be the most deployed technology in the future. Therefore, DVB-T2 has been assumed throughout this study.

DVB-T2 is currently the most advanced DTT system. It is much more flexible, robust, and efficient than any previous DTT systems. It uses OFDM modulation, and offers a wide range of different modes, making it a very flexible standard. DVB-T2 uses the latest modulation and coding techniques which results in efficient use of the scarce spectrum resource.

Due to the multi-path immunity of OFDM, DVB technology allows implementation of single frequency networks, SFNs. An SFN is a network of transmitters radiating identical and synchronized signals on exactly the same frequency. DVB-T2 enables the possibility to build much larger SFNs than is possible for other DTT systems. For example, with a system bandwidth of 8 MHz, DVB-T allows a maximum transmitter separation distance of 67 km while DVB-T2 allows up to 160 km. The allowed DVB-T2 intersite distance is far beyond the radio horizon and compared to DVB-T there is scope to include more distant transmitters in the SFN without causing self-interference.

It should be noted that larger SFNs also have some drawbacks. They require use of system parameters that reduce the available bit rate. Large SFNs also limit the possibilities to provide regional services.

Increased use of SFNs does however not preclude that supplementary in-fill transmitters continue to be operated on separate frequencies (MFN) for instance for cost efficiency reasons.

The DVB-T2 parameters used in this study have been selected to enable large SFNs with high bit rate signals. The chosen system parameters are listed in Table 1 and the planning parameters are given in Table 2.

To simplify the study all radio propagation is assumed to be over land only and with flat terrain. Of course, in a real case the radio propagation can be over both land and sea, and terrain irregularities may influence results. However, the chosen approach should provide results that are generally applicable.

Table 1: DVB-T2 system parameters used in this study

Modulation	256-QAM
FFT	32K
Carrier Mode	Extended
Code Rate	2/3
Pilot Pattern	PP2
FEC Frame Length	64 800
Guard Interval	19/128 (532 µs)
Required C/N (Rice)[2]	21.2 dB
Capacity	32.7 Mbit/s

Table 2: Planning parameters

Frequency	698 MHz
Reception Type	Fixed rooftop at 10 m
Radio Propagation Model	ITU-R P.1546-4 (Land)
Radio Propagation Standard Deviation	5.5 dB
Location Probability Target	≥ 95%
Receiving Antenna Direction	Strongest transmitter
Antenna Directivity	Rec. ITU-R BT.419-3
Guard Interval Model	Cliff edge
Lognormal Summation Method	Schwartz and Yeh
Minimum Median Field Strength[3]	57.1 dBµV/m

As the radio channel is time variant, useful signals are calculated for 50% of time whereas interfering signals are calculated for 1% of time, i.e. the standard propagation parameters used in broadcasting planning.

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[2] ETSI TS 102 831 V1.1.1 (2010-10). Required raw $(C/N)_0$ is taken from Table 44. For the mode used this value is 18.4 dB. Assumed additional C/N to achieve BER=10E-7 before BCH decoding is 0.1 dB. Correction for pilot boosting is 0.4 dB. Penalty for real channel estimation is 2 dB. Back-stop noise margin @ -33 dBc is 0.28 dB.

[3] The required minimum median field strength is given by the link budget as described in Annex 1.

3.2 Network Structures

In order to study infrastructure options for terrestrial television, representative parameters for high tower (HT) networks and various low tower (LT) networks have been defined. In this context “tower” covers all kinds of site structures, including towers and masts.

The possible coverage from a transmitter is ultimately limited by the radio horizon since terrestrial broadcast frequencies are quickly attenuated beyond the radio horizon. Transmitter and receiver antennas have their own radio horizon. Co radio horizon is the distance where the two horizons just touch. In Figure 1 the co radio horizon is given for a receiving antenna height of 10 meter and transmitter antennas in the range 30 to 300 meter. For example, with a transmitting antenna height of 300 meter and receiving antenna height of 10 meter the co-radio horizon is 84 km.

Most countries in Europe use broadcasting masts and towers with heights in the range 150-300 meter to efficiently provide the required coverage. The optimal height depends on terrain, coverage requirements, cost considerations, the need for regional service provision and other national or local conditions. In this study an antenna height of 300 meter has been selected for the high tower calculations. The ERP (Effective Radiated Power) is chosen to be 50 kW, which is considered to be typical for a 300 meter site.

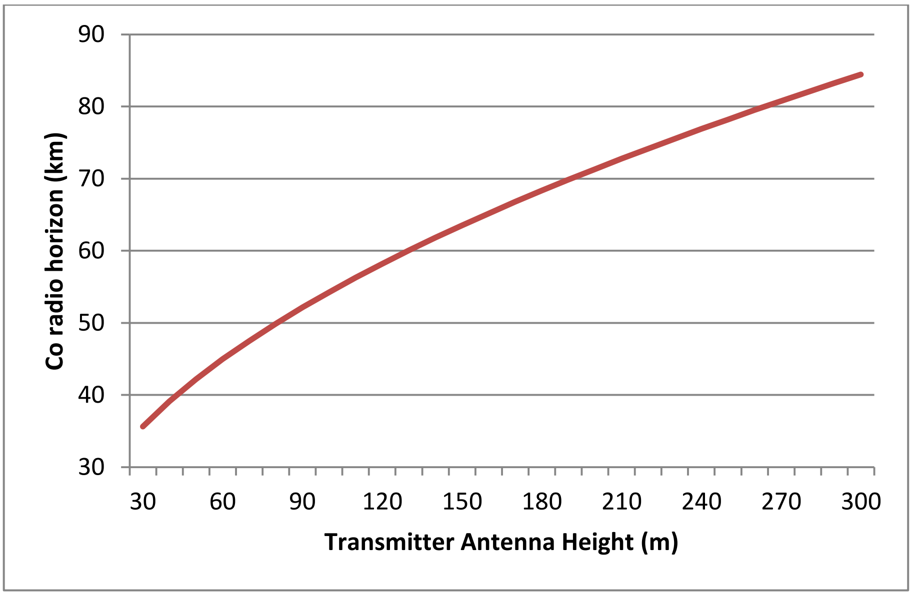

Figure 1: Co radio horizon for different transmitter antenna heights and a receiving antenna height of 10 meter

For low towers the parameters chosen are intended to represent typical sites used in mobile networks. The average height of the antenna on a mobile site varies across Europe and two different heights have therefore been chosen for the studies, namely 30 and 50 meters. It is assumed that an operator implementing a broadcast network on such infrastructure would like to use a relatively high ERP for cost efficiency reasons. However, there may be restrictions since the mobile infrastructure in many cases is located very close to houses. In order to provide a relevant range of results, low tower ERPs of 50, 500, and 5 000 W, have been used in the calculations.

It is clear that in a real network not all sites use exactly the same operating parameters and high tower based networks normally include in-fill transmitters using low to medium height towers. However, in order to provide general results this study is based on standardised HT and LT sites only.

A summary of the selected network structure combinations, i.e. the different combinations of antenna height and ERP values, are given in Table 3.

Table 3: Network structure options.

HT/LT	Antenna height (m)	ERP (W)
HT	300	50 000
LT	50, 30	50, 500, 5 000

3.3 Reference Networks

In order to analyse the different network structures so called reference networks have been defined. Reference networks are assumed to adequately represent real SFN networks for the various network structure options, even though they do not exactly correspond to real network implementations.

Reference networks can also be used to represent outgoing interference and susceptibility to incoming interference in compatibility calculations between SFN areas or frequency allotments. As an example reference networks were used for compatibility calculations in the process of creating the GE06 Plan[4].

In general a reference network can be designed for arbitrary sizes of service areas. The reference network assumes a high degree of geometrical symmetry and may use the same transmitter parameter values for all involved transmitters.

The reference networks used in this study are open networks, i.e. all transmitters have omnidirectional antennas. They consist of seven identical transmitters. Six of them are located at the vertices of a hexagon and one transmitter is located in the centre of the hexagon. The geometries and service area of the reference network are defined in Figure 2 below.

The size of the reference networks is optimised by finding the maximum site separation distance provided that all pixels within the service area are covered.

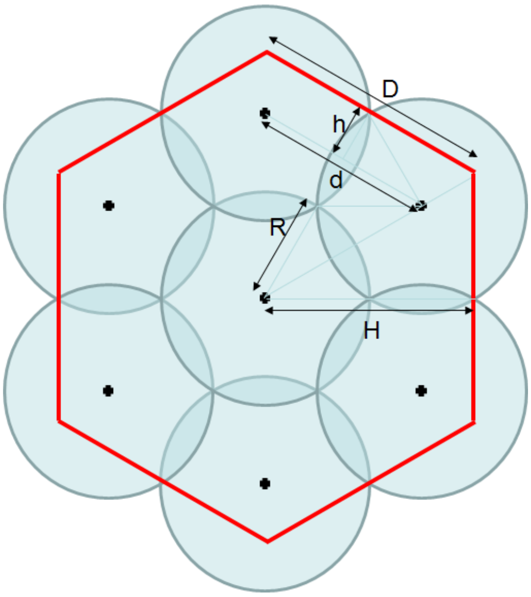

Figure 2: Geometry of reference networks used in this study.

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[4] The GE06 Agreement defines the frequency plans for DTT, including usage conditions, in Europe, Middle East and Africa.

The red hexagon represents the service area for the reference network[5]. The coverage radius for each transmitter (**R**), and thus the site separation distance (**d**), is calculated so that continuous coverage within the service area is ensured. The distance from the centre of the hexagon to the edge of the service area is the location where the circles of the outer transmitters are crossing each other, i.e. the distance indicated by **H** in the figure above.

The radius of each circle, **R**, can be derived from the Law of Cosines:

$$R = \frac{d}{\sqrt{3}} \tag{1}$$

H, **h**, and **D** can be defined by the Pythagorean Theorem:

$$H = \frac{2}{\sqrt{3}} d \tag{2}$$

$$h = \frac{d}{2\sqrt{3}} \tag{3}$$

$$D = \frac{4}{3} d \tag{4}$$

The area of the hexagon (the service area) can then be calculated as:

$$A = \frac{3\sqrt{3}}{2} D^2 = \frac{8}{\sqrt{3}} d^2 \tag{5}$$

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[5] It can be noted that the service area for the reference networks that are used in GE06 are a bit smaller than the ones used in this study – in GE06 D = 1.15*d.

3.4 Calculation Methods

The field strength from each transmitter is calculated on a regular grid of points, so called pixels. In this study a pixel size of 1 km x 1 km has been used.

Within the area of a pixel the field strength level varies significantly. These fluctuations are described in statistical terms and can be approximated by a log normal distribution. The radio wave propagation model is used to calculate the median value of the field strength level for each pixel and then the statistical variation is calculated using the specified standard deviation of 5.5 dB.

The resulting location probability is calculated for each pixel. This probability represents the percentage of receiving locations which can receive a satisfactory signal level within the pixel. The pixel is assumed to be covered if the probability is higher than 95%.

In an SFN, identical signals are transmitted by many transmitters simultaneously and at the same frequency. The individual useful and interfering field strength contributions from all transmitters are assumed to be random variables with lognormal distributions calculated in each pixel and combined to a resulting signal. This resulting signal, the C/(N+I), is the quotient between the sum of useful signal powers and the sum of the receiver noise and interfering signal powers.

In an OFDM based system, the received signal power from an SFN transmitter can contribute to both the useful and the interfering signal depending on the time of arrival at the receiver. In SFN radio network planning this can be modelled in several different ways. In this study we have used the so called cliff edge model where a signal is considered to be useful if it is within the guard interval and interfering if it arrives outside the guard interval. A simple receiver that synchronises on the arrival of the first received signal is assumed.

The summation of signals with log normal distribution is approximated using the Schwartz and Yeh method[6].

The coverage probability in a pixel is the probability that the distribution of C/(N+I) exceeds a system specific planning value. Noise limited coverage probability is defined as the probability that the combined signal strength from the wanted transmitters exceed the receiver noise floor with at least the required carrier-to-noise ratio. Composite coverage probability is defined as the probability that combined useful signal strength exceeds combined interfering signal strengths and receiver noise floor with at least the required carrier-to-noise ratio. A more detailed description of coverage probability calculations can be found in Annex 2.

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[6] S. C. Schwartz and Y. S. Yeh, “On the Distribution Function and Moments of Power Sums With Log-Normal Components”, The Bell System Technical Journal, September 1982, pp. 1441-1462.

4 Coverage Calculations for HT and LT Networks

Reference networks for the various network structures as described in Section 3.3 have been constructed. For each reference network the resulting inter-site distance and the corresponding service area have been calculated for noise limited coverage. Comparing these service areas provides an estimate of how many sites are needed to cover a certain area with the respective network topologies.

Noise limited coverage is achieved when the location probability is not lower than 95% in any pixel within the service area, see Figure 3 below. Thus, the maximum inter-site distance is exceeded when the location probability at any point is below 95%.

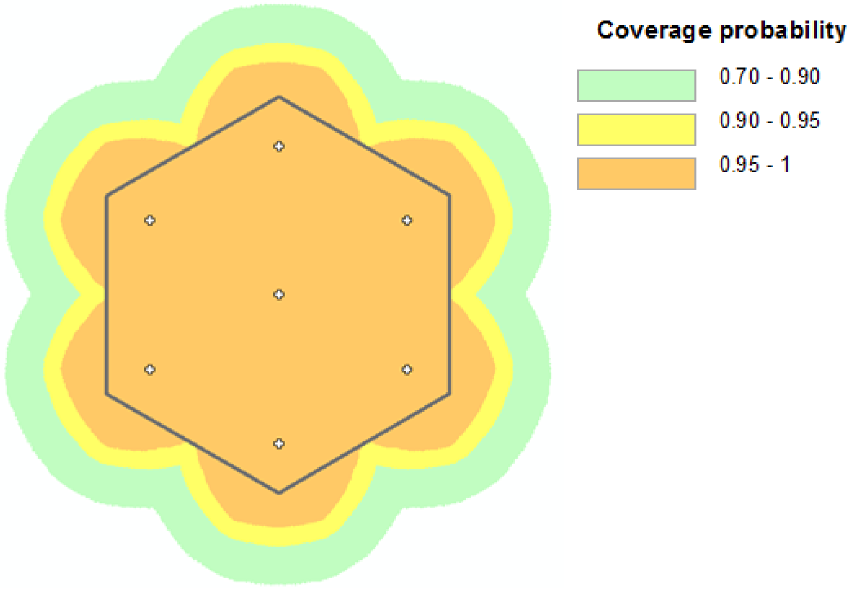

Figure 3: Maximum inter-site distance is found so that the location probability for each pixel within the service area is at least 95%.

In Table 4-6 the inter-site distances and the resulting service areas for the different network structures are presented. The last column in Table 5 and 6, (Site multiplier factor), shows the ratio between the number of LT sites and the number of HT sites required to achieve the same service area. For example, about 108 times more LT sites with antennas at 30 m and ERP 50 W (10.0 km inter-site distance) would be needed to cover an equivalent geographic area as the corresponding high tower network. About 37 times more LT sites using antenna heights of 30 meter and ERP 500 W are required and for a network using antennas at 50 meters and ERP 500 W, 23 times more sites are needed.

Table 4: Reference network for HT, ERP 50 kW and antenna height 300 meter.

ERP (W)	Inter-site distance (km)	Service area (km^2)	Service area per site (km^2)
50 000	104	498	7 123

Table 5: Reference networks for LT, antenna height 50 meter.

ERP (W)	Inter-site distance (km)	Service area (km^2)	Service area per site (km^2)	Site multiplier factor
50	12.8	757	108	66
500	21.6	2 155	308	23
5 000	34.6	5 529	790	9

Table 6: Reference networks for LT, antenna heights 30 meter.

ERP (W)	Inter-site distance (km)	Service area (km^2)	Service area per site (km^2)	Site multiplier factor
50	10.0	462	66	108
500	17.0	1 335	191	37
5 000	27.4	3 468	495	14

Figure 4 summarises the maximum inter-site distances (line diagram) and service area per site (bar diagram) for each LT configuration.

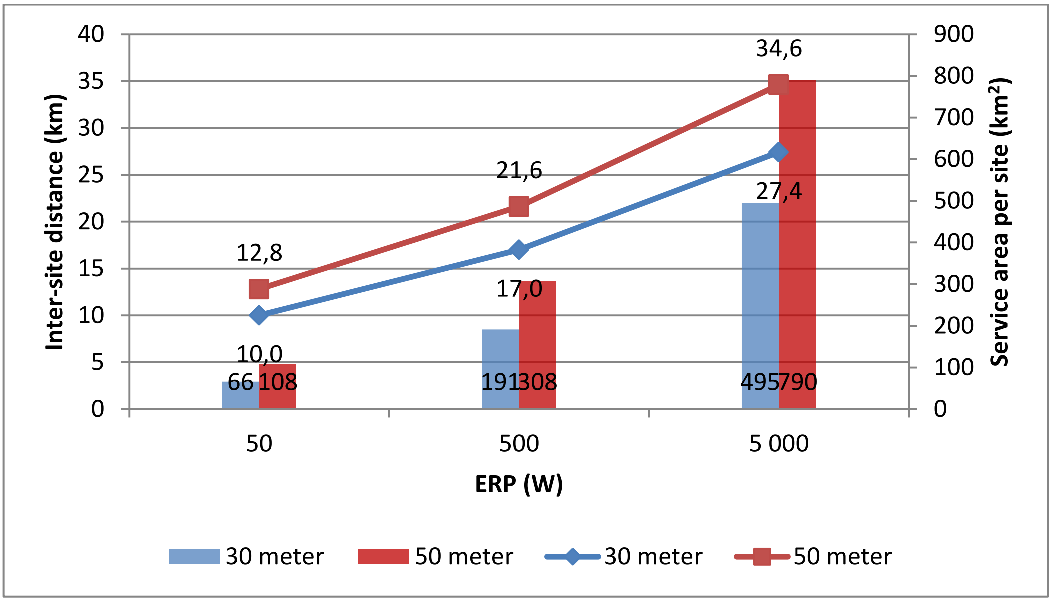

Figure 4: Maximum inter-site distances and service area per site for each LT configuration.

To illustrate what this could mean in practice, with the assumptions made, the number of transmitters required to cover some selected European countries have been calculated and are presented for each reference configuration in Table 7 below. It should be noted that in reality the typical parameters for high tower transmissions vary somewhat between the countries and that in general not 100% of the country area is covered. The calculated figures should therefore be seen as indicators for comparison only.

Table 7: Number of sites needed, for the noise limited case, to provide full area coverage in some European countries.

Country	Area (km^2)	HT 300 m 50 kW	LT 50 m 50 W	LT 50m 500 W	LT 50 m 5 000 W	LT 30 m 50 W	LT 30 m 500 W	LT 30 m 5 000 W
Germany	357 000	50	3 301	1 160	452	5 409	1 872	721
Spain	506 000	71	4 679	1 644	641	7 667	2 653	1 021
France	551 000	77	5 095	1 790	698	8 348	2 889	1 112
Italy	301 000	42	2 783	978	381	4 561	1 578	608
Sweden	450 000	63	4 161	1 462	570	6 818	2 360	908
UK	244 000	34	2 256	793	309	3 697	1 279	493

It is clear that a very large number of LT sites are needed to cover the same area compared to the HT case. For example, to achieve full area coverage in Sweden[7] with the given assumptions, there would be a need for 63 high tower sites versus 4161 low tower sites with antenna height 30 m and ERP 50 W. Alternatively, 2 360 low tower sites with 30 m antenna height and ERP 500 W, or 1 462 low tower sites with 50 m antenna height and ERP 500 W would be required.

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[7] In the real case the area coverage for DTT in Sweden is not 100%, since there are large unpopulated areas, and the number of existing high tower sites is 54.

5 Minimum Co-channel Separation Distances

In network planning it is imperative to use the available frequencies as efficiently as possible to achieve the specified reception quality and coverage targets. The same frequency can be reused in two geographically separate areas if the mutual interference levels are acceptable. The type of network architecture influences how far apart such co-channel areas need to be separated. This distance is called the minimum co-channel separation distance, or the reuse distance (see also Figure 5). Generally the required separation distance is higher if ERPs and antenna heights are higher. The separation distance also depends on reception mode[8], frequency, system parameters, coverage and capacity requirement, etc.

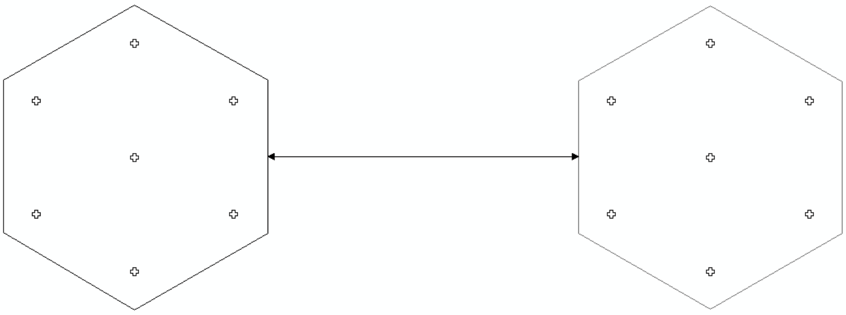

Figure 5: Definition of co-channel separation distance for reference networks

If networks are planned to include a certain margin to allow for higher interference levels the required separation distance will be shorter than for noise limited networks. The drawback is that the networks then need to be denser or have higher ERPs, thus increasing the cost.

Co-channel separation distances have been calculated for the different network architectures under study, both for noise limited networks and for networks with an extra interference margin of 3 dB. The interfering signals were summed using the Schwartz and Yeh method. In all cases only one interfering reference network has been taken into account. The results are provided in Section 5.1 and 5.2 below.

It should be noted that for all calculations only land propagation is assumed. If sea paths are involved the required co-channel separation distance will be larger.

5.1 Noise Limited Networks

For noise limited networks all pixels within the service area have a location probability of at least 95% in the absence of external interference. For this case the minimum co-channel

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[8] DTT networks can be designed for various reception modes, such as rooftop reception, portable reception or mobile reception.

separation distance between two networks is achieved when the composite coverage probability is reduced by one percentage unit in the weakest pixel within the service area. This corresponds to the weakest pixel within the service area achieving a 94% coverage probability with the interference taken into account.

The calculated co-channel separation distances for the various reference networks as specified in Section 4 are given in Table 8 below.

Table 8: Co-channel separation distances for HT and LT noise limited networks

HT/LT	Antenna height (m)	ERP (W)	Co-channel separation distance (km)
HT	300	50 000	266
LT	50	50	90
LT	50	500	142
LT	50	5 000	202
LT	30	50	72
LT	30	500	119
LT	30	5 000	203

5.2 Networks with Interference Margin 3 dB

Real broadcast networks are often interference limited rather than noise limited. The re-use distance will be shorter for interference limited networks. In order to illustrate how the site separation distances are influenced if networks are designed with an inherent interference margin, all reference networks under study have been recalculated to include an interference margin of 3 dB (as in the GE06 reference networks).

Inter-site distances are first calculated for each new reference network using an ERP reduced by 3 dB, so that location probability is not lower than 95% in any pixel within the hexagon service area. Then the ERP is brought back to the original level, resulting in denser reference networks with 3 dB margin. The data for the new reference networks are given in Table 9-11 below. It can be noted that compared to the noise limited case the site multiplier factors are even larger here.

Table 9: HT reference network with 3 dB interference margin, antenna height 300 meter.

ERP (W)	Inter-site distance (km)	Service area (km^2)	Service area per site (km^2)
50 000	95.0	41 685	5 955

Table 10: LT reference networks with 3 dB interference margin, antenna height 50 meter.

ERP (W)	Inter-site distance (km)	Service area (km^2)	Service area per site (km^2)	Site multiplier factor
50	10.6	519	74	80
500	18.1	1 513	216	28
5 000	29.8	4 102	586	10

Table 11: LT reference networks with 3 dB interference margin, antenna height 30 meter.

ERP (W)	Inter-site distance (km)	Service area (km2)	Service area per site (km^2)	Site multiplier factor
50	8.5	334	48	125
500	14.7	998	143	42
5 000	23.3	2 508	358	17

The resulting co-channel separation distances for these new reference networks have then been calculated. In this case the separation distance is achieved when the location probability is reduced to 95% in the weakest pixel within the hexagon service area. The results are presented in Table 12.

Table 12: Co-channel separation distances for networks with 3 dB interference margin.

HT/LT	Antenna height (m)	ERP (W)	Co-channel separation distance (km)
HT	300	50 000	195
LT	50	50	44
LT	50	500	80
LT	50	5 000	148
LT	30	50	38
LT	30	500	75
LT	30	5 000	146

Hence, the required co-channel separation distance for HT networks (50 kW, 300 m) is 195 km. Whilst for LT networks the separation distances are shorter, but still in the order of several tens of kilometers. This emphasizes that even with LT networks it is necessary to use different frequencies in adjacent areas to avoid large exclusion zones.

6 Frequency Planning and Implementation Aspects

Broadcast networks are planned to provide the required coverage and capacity within a country or a region of a country. As of today the networks are based on high power transmissions from high towers and masts, supplemented by in-fill transmitters using low to medium height towers. Frequencies are used in Multi-Frequency Network mode (MFN) or Single Frequency Network mode (SFN) or a mixture of both.

6.1 Frequency Reuse and Potential Efficiency Gains

SFNs are often planned using so called allotments, that is areas where a particular frequency is used in SFN mode. Allotment shapes and sizes are determined by the requirements of the broadcast service, in particular with regard to coverage, capacity, regional content requirements and country borders. Generally, allotments vary in size and shape, also within the same country. If the separation distance between two allotments is large enough these can use the same frequency as illustrated in Figure 6.

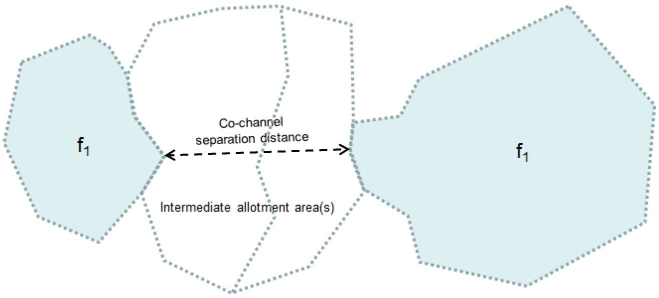

Figure 6: If the co-channel separation distance is large enough two allotment areas can use the same frequency

With the frequency allotment areas presently used in Europe typically around 7 frequencies are needed per network coverage layer. However, if larger SFNs are introduced and all services are delivered utilizing DVB-T2 less frequencies per coverage layer could be achieved.

The spectrum requirement depends on the specified planning conditions and a range of key parameters, such as coverage requirements, population distribution, propagation conditions, size and shape of coverage areas, minimum co-channel separation distance, requirement for regional services, etc.

To provide continuous full coverage in a real environment across a country, including border areas, without any exclusion zones and allowing for regional content, at least 4 RF frequencies per layer are needed (see also Annex 3). This is independent of network architecture and is thus valid for HT as well as LT networks. In cases where allotments are not regular in size and shape and where terrain variations are considered, the frequency requirement per layer may be higher.

The relation between necessary theoretical co-channel allotment separation distance, D_{sep}, and allotment size has been calculated for two different frequency reuse patterns where the allotment areas are represented by a regular lattice of hexagons and based on rooftop reception.

As shown in Annex 3, under the given assumptions frequency planning with respectively 4 and 7 frequencies per coverage layer is feasible provided that the following relations between allotment diameter (d_{all}) and separation distance (D_{sep}) are fulfilled:

$d_{all} \geq D_{sep}$ (4 frequencies per layer)

$d_{all} \geq 0.65 * D_{sep}$ (7 frequencies per layer)

In other words, to achieve a frequency reuse factor of 4 the allotment diameters must be greater than the co-channel separation distance. To achieve a frequency reuse factor of 7 the allotment diameters must be greater than 0.65 times the co-channel separation distance. The numbers 4 and 7 should be seen as examples only. Other numbers could also be feasible, in particular taking real world conditions into account.

In summary, the analysis shows that a particular frequency reuse pattern can be achieved if the allotment diameters are large enough. As a general rule this is valid for both high tower networks and low tower networks.

Furthermore, applying the above factors for the various network architectures, and corresponding minimum co-channel separation distances as calculated in Section 5, the results given in Table 13 are obtained. The minimum allotment sizes indicate how large the allotments in general need to be for a particular frequency re-use pattern.

Table 13: Minimum allotment sizes to enable frequency planning with respectively 4 and 7 frequencies per coverage layer

HT/LT	Antenna height (m)	ERP (W)	D_{sep} (km)[9]	Min allotment diameter (km)	
				Reuse 4	Reuse 7
HT	300	50 000	195	195	127
LT	50	5 000	148	148	97
LT	50	500	80	80	52
LT	50	50	44	44	29
LT	30	5 000	146	146	95
LT	30	500	75	75	49
LT	30	5 000	38	38	25

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[9] From Table 12 in Section 5 above (networks with interference margin 3 dB)

Based on these results it can be concluded that with sufficiently large SFN allotment areas more efficient frequency planning can be realised, also without changing the basic high tower infrastructure. For instance, when allotment diameters are larger than 195 km a frequency reuse factor of 4 may be realised, also for HT networks.

It should be noted that the minimum allotment diameters for HT networks, as given in Table 13, in many cases exceed the allotment sizes in the GE06 Plan. Therefore, replanning will generally be needed to implement these larger SFN areas. Such replanning needs to be based on DVB-T2. Furthermore, any major change in the DTT frequency usage, whether based on existing high tower infrastructure or on low tower infrastructure, involves international frequency replanning and coordination.

The appropriate SFN sizes and shapes in a real network are subject to national conditions. Coverage requirements are different from country to country. Terrain conditions, population distribution, and requirements to provide regional content vary from area to area. Countries with large coastal areas may benefit from increased distance to neighbouring countries in their frequency planning but may also need to take sea path radio propagation into account. High mountain areas at country borders may also be beneficial for frequency planning.

Real networks will of course not be implemented exactly as the reference networks used in this study. However, the reference networks are assumed to provide representative values for outgoing interference and interference susceptibility. The results in Table 13 should therefore be seen as indicative of what could be achieved in reality.

6.2 Implications on Service Provision

It is recognized that low tower based networks do provide more flexibility in the network planning process, since re-use distances are shorter, but this should be compared with high associated costs for an alternative network structure.

The results presented in Section 4 show that a very large number of sites will be needed if the already existing high tower infrastructure should be replaced with a low tower architecture. For SFNs the sites generally need an individual transmission link and a higher number of sites will result in a much higher cost for the content distribution network. Furthermore, if the reliability of the existing network is to be replicated each site needs to be equipped with backup power and spare transmitters which will further increase the costs. Also maintenance will be much more expensive if the number of sites is significantly increased.

Changing the basic infrastructure will also require a large number of viewers to redirect their receiving antennas. Such changes to consumer antenna installations are costly, need extensive information campaigns and will be very complex to handle. How the related costs should be covered will certainly become a significant problem with no obvious solution.

So, if the existing high tower based network configuration were to be changed to a low tower architecture this would imply

- Many more sites
- Much higher costs expected (more sites, more transmitters, more backhaul connections, more equipment for redundancy, more backup power units, higher maintenance costs)
- Greater environmental impact (more sites, higher total power consumption, etc.)
- Consumer disruption, e.g. a large proportion of consumers will have to redirect their roof-top antennas

All these aspects need to be taken into account if a change to an alternative network architecture were to be considered.

7 Conclusions

A reduction in site height and power for a network inevitably leads to an increase in the number of sites required. Accordingly, a very large number of sites are needed for low tower (LT) networks when compared with the high tower (HT) alternative. For example, this study suggests that at least about 37 LT sites with antenna height 30 meter and ERP 500 W are needed to achieve the same coverage as one HT site (antenna height 300 meter and ERP 50 kW).

Network design has an impact on the minimum distance between two service areas using the same frequency. For HT networks the calculated minimum separation distance is around 200 km, assuming land-only propagation. For LT networks the minimum separation distances are shorter, but still in the order of several tens of kilometers. This emphasises that even with LT networks it is necessary to use different frequencies in adjacent areas to avoid large exclusion zones.

There is scope to reduce spectrum requirements per coverage layer without changing the existing infrastructure, provided that larger SFNs are introduced and all services are delivered utilizing DVB-T2. The results in this study indicate that if individual SFN areas are larger than approximately 200 km then high tower networks with on average 4 RF frequencies per national layer may be realized. In general the achievable frequency reuse factor is independent of network architecture (HT or LT) as long as the SFN areas are large enough.

The minimum number of frequencies per coverage layer depends on the specified planning conditions. To provide continuous full coverage in a real environment across a country, including border areas, without any exclusion zones and allowing for regional content, at least four frequencies per layer are needed.

However, whilst there is scope to reduce spectrum requirements through the increased utilisation of SFNs, full SFN adoption may not be feasible due to the need to optimise coverage, capacity, regionality and international frequency coordination aspects. In order to maximise the outcome of any replanning activity this would need to be coordinated at a European level based on agreed and common policy goals.

A fundamental change of the network architecture would mean a hugely complex and costly process for consumers as well as broadcast network providers. Alongside the technical aspects considered in this report there are a host of policy, economic and consumer issues that are worthy of detailed consideration.

Annex 1 – Link Budget

The minimum median equivalent field strength calculation is described in the step-by-step procedure given below.

Step 1: Calculate receiver noise input power P_n (dBW):

$$P_n = F + 10\log_{10}(kT_0B) \tag{1}$$

where:

F: Receiver noise figure (dB)
k: Boltzmann's constant (Ws/K)
T_0: Absolute temperature (K)
B: Receiver noise bandwidth (Hz)

Step 2: Calculate minimum required receiver input signal power $P_{s\,min}$ (dBW):

$$P_{s\,min} = P_n + C/N \tag{2}$$

where:

P_n: Receiver noise input power (dBW)
C/N: Required signal to noise ratio (dB)

Step 3: Calculate effective antenna aperture A_a (dBm^2):

$$A_a = G_I + 10\log_{10}(\lambda^2/4\pi) \tag{3}$$

where:

G_I: Receiver antenna gain (dBi)
λ: Radio wave length (m)

Step 4: Calculate minimum power flux density ϕ_{min} (dBW/m^2):

$$\phi_{min} = P_{s\,min} - A_a + L_f \tag{4}$$

where:

$P_{s\,min}$: Minimum required receiver input signal power (dBW). See *Step 2*.
A_a: Effective antenna aperture (dBm^2). See *Step 3*.
L_f: Antenna feeder loss (dB).

Step 5: Calculate location correction factor C_l (dB):

$$C_l = \mu * \sigma \qquad (5)$$

where:

μ: Log-normal distribution factor.
σ: Standard deviation of log-normal fading (dB).

Step 6: Calculate minimum median power flux density ϕ_{med} (dBW/m^2)

$$\phi_{med} = \phi_{min} + C_l \qquad (6)$$

where:

ϕ_{min}: minimum power flux density (dBW/m^2). See *Step 4*.
C_l: Location correction factor (dB). See *Step 5*.

Step 7: Calculate minimum median equivalent field strength (dBμV/m):

$$\mathrm{E}_{med} = \phi_{med} + 120 + 10\log_{10}(120\pi) \qquad (7)$$

where:

ϕ_{med}: minimum median power flux density (dBW/m^2). See *Step 6*.

Table A.1 presents the parameter values that are used to calculate the minimum median equivalent field strength according to the procedure described above.

Table A.1: Parameter values for calculation of minimum median equivalent field strength

F	Receiver noise figure (dB)	7.0
K	Boltzmann's constant (Ws/K)	1.38E-23
$\mathbf{T_0}$	Absolute temperature (K)	290
B	Receiver noise bandwidth (Hz)	7.77E6
$\mathbf{P_n}$	Receiver noise input power (dBW)	-128.1
C/N	Required signal to noise ratio (dB)	21.2
$\mathbf{P_{s\ min}}$	Minimum required receiver input signal power (dBW)	-106.9
$\mathbf{G_D}$	Antenna gain (dBd)	11.3
$\mathbf{G_I}$	Antenna gain (dBi)	13.45
C	Speed of light (m/s)	3E8
F	Frequency (Hz)	698E6
λ	Wave length (m)	0.4
$\mathbf{A_a}$	Effective antenna aperture (dBm^2)	5.1
$\mathbf{L_f}$	Receiver feeder loss (dB)	4.3
$\boldsymbol{\varphi_{min}}$	Minimum power flux density (dBW/m^2)	-107.6
$\mathbf{p_{loc}}$	Location probability (%)	95
μ	Distribution factor	1.6449
σ	Standard deviation of log-normal fading (dB)	5.5
$\mathbf{C_l}$	Location correction factor (dB)	9.0
$\boldsymbol{\varphi_{med}}$	Minimum median power flux density (dBW/m^2)	-88.6
$\mathbf{E_{med}}$	Minimum median equivalent field strength (dBμV/m)	57.1

Annex 2 – Coverage Probability Calculation

Let P = {P_1, P_2, …, P_N} denote the set of received signal powers from the SFN transmitters.

Let U={U_1, U_2, …, U_M} denote the set of received signal powers from interfering transmitters.

Let N denote the noise power of the receiver.

Let w denote the weighting function, which is used to determine how much of the received signal power are considered to be useful and interfering.

$$w(\Delta t) = \begin{cases} 1 & if\ \Delta t < T_g \\ 0 & otherwise \end{cases} \tag{1}$$

Let C denote the sum of useful signal powers:

$$C = \sum_{i=1}^{N} w(\Delta t_i) P_i \tag{2}$$

Let I denote the sum of interfering signal powers:

$$I = \sum_{i=1}^{N} [1 - w(\Delta t_i)] P_i + \sum_{j=1}^{M} U_j \tag{3}$$

The CNIR can then be defined as:

$$\xi = \frac{C}{N + I} = \frac{\sum_{i=1}^{N} w(\Delta t_i) P_i}{N + \sum_{i=1}^{N} [1 - w(\Delta t_i)] P_i + \sum_{j=1}^{M} U_j} \tag{4}$$

To achieve the coverage probability in a pixel, p, we need to calculate the probability that the distribution of CNIR exceed a system specific planning value.

$$p = P\{\xi \geq \alpha\} \tag{5}$$

Annex 3 – Co-channel Allotment Separation

SFN frequency planning is often based on allotments, i.e. areas where a particular frequency is used in SFN mode. If the separation distance between two allotments is large enough these allotments can use the same frequency (see Figure A.1).

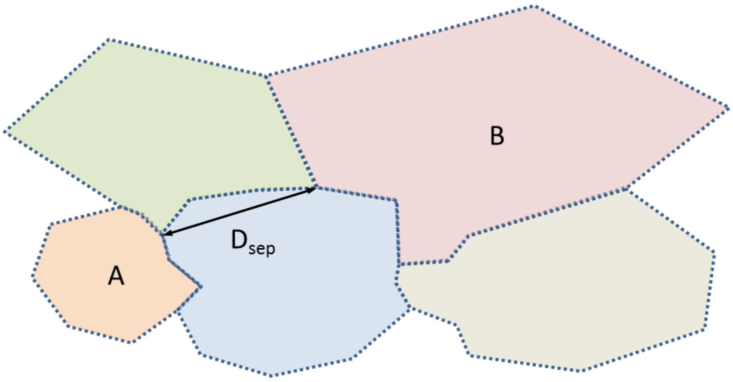

Figure A.1: Allotment areas vary in size and shape. If D_{sep} is large enough two areas can use the same frequency.

The co-channel allotment separation distance is one of the factors that influence how much spectrum is needed for a particular network. A short separation distance implies that a frequency can be more frequently reused across a country.

For networks providing continuous full coverage, based on essentially regular allotment areas and taking national borders into account, the minimum number of frequencies needed for one network layer is in the general case 4. This is in line with the conclusions of the four colour theorem. For real networks, where allotments are not regular in size and shape and where terrain variations are considered, this figure may be higher. In particular, the GE06 Plan typically uses 6-8 frequencies per layer across Europe. However, the introduction of DVB-T2 allows the use of larger SFNs than previously possible with DVB-T, providing a possibility to increase spectrum efficiency. It could also be noted that if only local non-continuous coverage is needed, then fewer frequencies per network layer may be feasible.

The necessary co-channel allotment separation distance, $D_{sep,}$ can be determined for various frequency reuse patterns using a regular hexagonal lattice that represents the allotment areas. This has been done for frequency reuse factor 7 and 4, as shown in Figures A2 and A3. It should be noted that the given relations are generic for a particular frequency reuse pattern and they do not depend on network structure or reception mode, even though D_{sep} varies with these parameters.

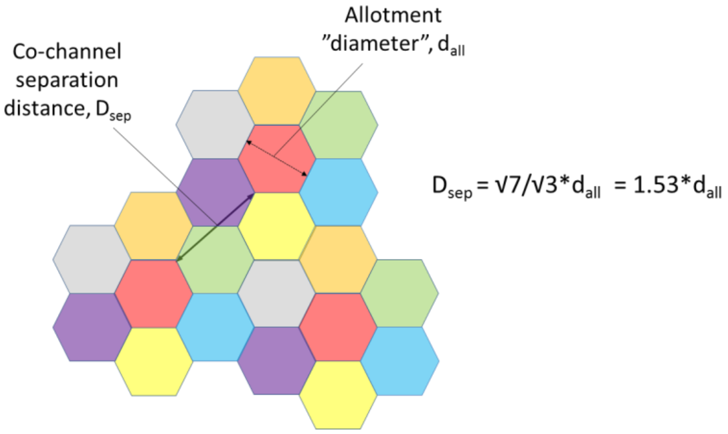

Figure A.2: Minimum co-channel allotment separation distance, D_{sep}, for a regular network with frequency reuse factor 7.

The minimum co-channel allotment separation distance, D_{sep}, for a regular hexagonal lattice with frequency reuse factor 7 (Figure A.2) can be calculated according to:

$$D_{sep} = \sqrt{7/3} * d_{all} = 1.53 * d_{all} \qquad (1)$$

This means that frequency planning with reuse factor 7 is feasible provided that allotment diameters satisfy the following condition:

$$d_{all} \geq 0.65 * D_{sep} \qquad (2)$$

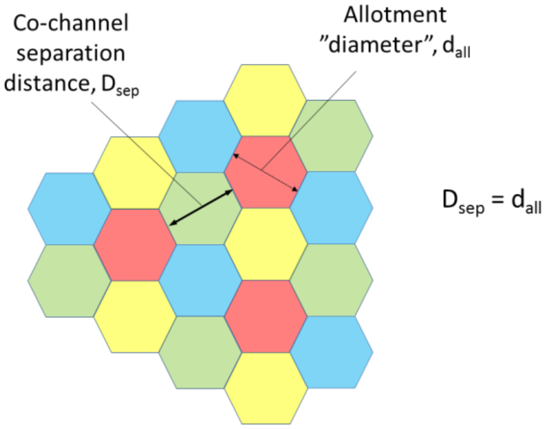

Figure A.3: Minimum co-channel allotment separation distance, D_{sep}, for a regular network with frequency reuse factor 4.

The minimum co-channel allotment separation distance, D_{sep}, for a regular hexagonal lattice with frequency reuse factor 4 (Figure A.3) can be calculated according to:

$$D_{sep} = d_{all} \qquad (3)$$

This means that frequency planning with reuse factor 4 is feasible provided that allotment diameters satisfy the following condition:

$$d_{all} \geq D_{sep} \qquad (4)$$