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TV DISTRIBUTION VIA CELLULAR NETWORKS PART 1: SPECTRUM CONSUMPTION

ROLAND BRUGGER, IRT
and ALEXANDER SCHERTZ, IRT

ABSTRACT

The concept of distributing linear broadcast content via cellular mobile broadband networks has been discussed for several years. Whereas the distribution of mass TV content by means of a unicast mode of mobile broadband systems is still of some restricted usefulness, the introduction of a broadcast mode in cellular 'Long Term Evolution' (LTE) has opened the door for more promising approaches. This operational mode employs the single frequency network (SFN) concept and is called eMBMS (multimedia broadcast multicast service) or MBSFN mode.

This article analyses mobile broadband studies dealing with TV distribution via cellular LTE networks for different reception scenarios, uses findings from these studies to evaluate the spectrum efficiency of these approaches and compares them with classical broadcast approaches using DVB-T2. For this purpose a generalized notion of spectral efficiency is derived.

This article is based on material partially published and distributed earlier in EBU and CEPT working groups. It also takes into account some additional recently-published studies, which modify some of the previous results.

INTRODUCTION

The concept of distributing linear broadcast content via cellular mobile broadband networks has been discussed for several years - see, e.g., [1, 2, 3]. Whereas the distribution of mass TV content by means of a unicast mode of mobile broadband systems is still of some restricted usefulness, the introduction of a broadcast mode in LTE (eMBMS) [4] has opened the door for more promising approaches. This operational mode employs the single frequency network (SFN) concept and is also called MBSFN mode.

Several studies have been published recently [5, 6, 7, 8, 9, 10, 11] which describe TV programme delivery by means of cellular LTE networks in MBSFN mode. Various reception scenarios are investigated, comparisons with broadcast transmission systems (ATSC, DVB-T) are made and case studies for metropolitan areas are performed. These investigations have come to the attention of many national regulatory authorities.

Quite naturally, this new approach has also attracted the broadcasters' attention. At the EBU this field is intensively investigated in the Strategic Programmes 'CTN' (Cooperative Terrestrial Networks) and 'SMR' (Spectrum Management and Regulation).

The scope of this article is twofold. Firstly, it analyses studies of the mobile broadband community on the delivery of TV programmes by means of cellular LTE networks in MBSFN mode. Secondly, it uses the findings of these investigations to evaluate the spectral efficiency of these approaches and compares them with classical broadcast approaches. For this purpose, a generalized concept of spectral efficiency is applied.

This article is Part 1 of an investigation on TV distribution via cellular networks. Part 2 analyses economic aspects.

LOW POWER – LOW TOWER LTE MBSFN NETWORKS

METHODOLOGY

The methodology applied in the cited studies to evaluate the spectral efficiency of LTE MBSFN networks is as follows. Based on link budget considerations for the different reception scenarios and on LTE MBSFN system properties, single frequency networks (SFN) with a smaller or larger number of base stations for the provision of broadcast content are simulated. These networks employ a cellular topology (Low Tower – Low Power: LTLP), as is usual with this technology.

A major aspect in these network simulations is the occurrence of self-interference which is not an issue in today's LTE networks since these are planned for individual communication and are therefore operated in a unicast mode which allows for a sophisticated treatment of inter-cell interference. In a broadcast SFN mode this is not possible since terminals are not addressed individually. As a consequence, the spectral efficiency of an MBSFN network is quite sensitive to factors which influence self-interference – i.e. the size of the network, guard interval of the employed OFDM mode and the typical distance between two neighbouring base stations (inter-site distance: ISD). As usual, spectral efficiency is defined as available data rate per frequency unit, measured in "bit/s/Hz".

The networks are assumed to be large compared with the inter-site distance, and the guard interval is fixed for MBSFN usage (33.3 µs)[i]. It is therefore natural to characterize an MBSFN network by means of its spectral efficiency as a function of the inter-site distance. Such a characterization gives information on the implementation effort - i.e. the required base station

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[i] In LTE terminology the guard interval is called cyclic prefix. A value of 33.3 µs for the cyclic prefix is not available in present LTE eMBMS implementations. The currently available maximum value is 16.7 µs. However, the value of 33.3 µs is already foreseen in present LTE releases [4]. It can be expected that it will be made available when broadcast eMBMS implementations are envisaged. A cyclic prefix of 33.3 µs is therefore used throughout the studies investigated here, apart from [10] where 16.7 µs is used.

density in order to provide the intended data rate; or, considering this the other way round, information can be gained about how much data rate is available in a given network implementation.

System	OFDM
Modulation	4-, 16-, 64-QAM
Guard Interval	33.3 μs (or 16.7 μs)
Base station antenna height	32 m
ISD	up to 10 km
Typical power	20 W amplifier, about 0.6 kW ERP
No. of base stations	from 19 to more than 100

TABLE 1: Typical LTE MBSFN system and network parameters

LTE MBSFN characteristics and typical cellular network parameters which are relevant for such investigations and which have been employed in the analysed studies are given in Table 1.

RECEPTION SCENARIOS

Different reception scenarios are considered in the studies: fixed reception, investigated in [5]; in-car reception, investigated in [6]; mobile and portable outdoor reception, investigated in [11]; light indoor reception, investigated in [7, 8, 9, 10, 11]; and deep indoor reception, investigated in [6, 10]. Fixed, mobile, portable outdoor and light indoor reception scenarios are typical broadcast planning scenarios. Also in-car reception is sometimes considered in the broadcast field, whereas deep indoor reception is usually not a planning option for broadcasting.

The studies are not homogeneous with regard to their applied reception parameters. For example, typical values as they are used by [5, 6, 7] are collected in Table 2.

	Reception scenario			
	Fixed [5]	light indoor [7]	in-car [6]	deep indoor [6]
Penetration loss / dB	0	8	6	20
Body loss / dB	0	0	3	3
Rx noise figure / dB	9	9	9	9
Rx antenna height / m	10	1.5	1.5	1.5
Antenna type	Yagi	built-in, diversity	built-in, diversity	built-in, diversity

TABLE 2: Typical reception parameters for LTE MBSFN

Standard propagation models, as they are used in the simulation of mobile or broadcast networks, are applied and LTE terminals are assumed to be equipped with diversity antennas which have about the same performance as (external) dipole antennas for portable broadcast reception.

It should be noted that usually coverage calculations for mobile networks do not apply a differential coverage probability criterion - as it is normally used in a broadcast context – which requires a certain minimum coverage probability for each location ("pixel") of the service area. Rather they use an integral criterion which requires a certain minimum percentage of the service area to be covered. For the same probability value, this latter criterion is less demanding than the former one.

SPECTRAL EFFICIENCY OF LTE MBSFN NETWORKS

The results for spectral efficiency which were obtained in the various studies for different reception scenarios are summarized in Figure 1.

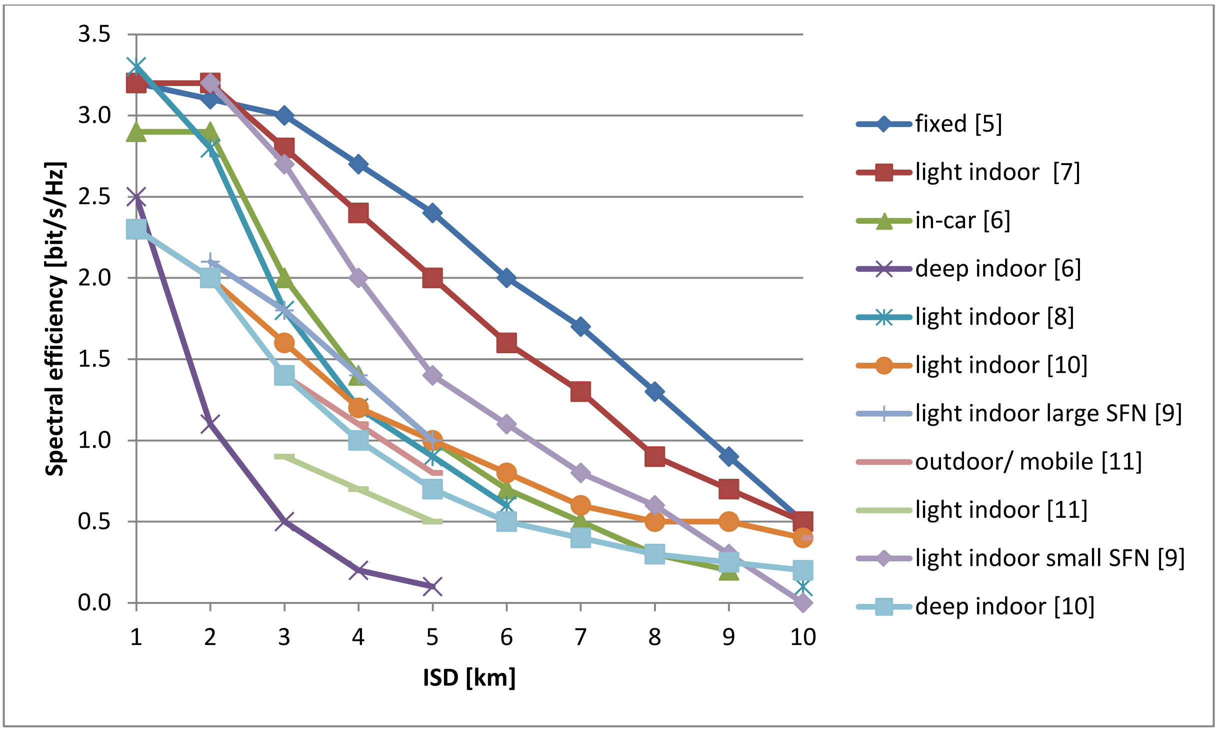

FIGURE 1: LTE MBSFN Spectral Efficiency vs. Inter-Site Distance (ISD) for various reception modes *(results taken from [5, 6, 7, 8, 9, 10, 11])*

For all scenarios strong performance degradation can be observed with increasing ISD. The differences, however, between the various scenarios are remarkable.

At very small ISD the spectral efficiency is around 3 bit/s/Hz for most scenarios. This is a system-imminent upper bound of LTE due to the available modulation schemes. In the case of deep indoor reception, for ISD larger than 1 km, strong performance degradation is observed. This can mainly be attributed to a lack of field strength rather than self-interference, since in these simulations power restrictions for the base stations due to, among other things, EMC considerations, are already taken into account. Also for the large SFN case, the limit of 3 bit/s/Hz is not met at very small ISD due to self-interference effects. For the other reception scenarios, degradation starts at an ISD of about 2 – 4 km, which is the value where it is expected that self-interference becomes significant for smaller network types as well. Spectral efficiency falls below 0.5 bit/s/Hz in all simulations for all reception modes beyond an ISD of 10 km.

The results of two studies [5, 7] stand out with remarkably better spectral efficiency values. In these studies the authors assume a detailed model of the system's degradation behaviour "beyond the guard interval" as it is typically applied in the broadcast field. However, the improvement which is reported in [5] as compared to the standard model amounts to about 100% which is surprising, since in broadcast simulations these gains are found to be much smaller. It is therefore presumed that the results of [5, 7] are optimistic.

For the following considerations spectral efficiency as a function of ISD is a crucial parameter. From the presented studies, however, no unique data can be derived. Therefore approximate average values of the spectral efficiency for three ISDs (2 km, 5 km and 10 km) are assumed, the authors being aware of the remarkable spread of the available data. In particular, further confirmation for the value of ‘fixed reception/ISD = 5 km’ would be desirable.

Thus the chosen values are given in Table 3.

ISD [km]	Spectral efficiency [bit/s/Hz] Fixed reception	Spectral efficiency [bit/s/Hz] Mobile / Light indoor reception
2	3.0	3.0
5	1.5	1.0
10	0.5	0.2

TABLE 3: Assumptions on spectral efficiency as a function of ISD for LTE MBSFN

HIGH POWER - HIGH TOWER DVB-T2 NETWORKS

In order to make a comparison with broadcast technologies, the same scenarios are investigated for DVB-T2. Reception parameters for DVB-T2 as typically applied in broadcast coverage considerations are given in Table 4.

	Reception scenario		
	Fixed reception	(light) Indoor	Outdoor/mobile
Penetration loss / dB	0	11	0
Rx noise figure / dB	6	6	6
Rx antenna height / m	10	1.5	1.5
Antenna type	Yagi	dipole	dipole
Antenna gain / dB	11	0	0
Feeder loss / dB	4	0	0
Standard deviation for location correction / dB	5.5	8.1	5.5
Minimum coverage probability per pixel	95%	95%	95% portable 99% mobile

TABLE 4: Typical reception parameters for DTT (see for example [12])

DVB-T2 is specifically designed for the terrestrial distribution of linear broadcast content. It shows, in general, higher spectral efficiency as compared to LTE MBSFN. This is true in particular for fixed reception. In Table 5, spectral efficiency figures for a selection of DVB-T2 modes are given. These values are achieved by DVB-T2 in a “High Tower – High Power” (HTHP) network topology.

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

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

For a cellular network topology with an ISD of 2 km, DVB-T2 achieves spectral efficiency values of about 6 bit/s/Hz for all reception scenarios; for an ISD of 5 km, values between 3 and 4 bit/s/Hz are achieved [13]. However, such scenarios are hypothetical since no LTLP implementations for DVB-T2 are envisaged as yet.

COMPARISON OF SPECTRAL EFFICIENCIES

REQUIREMENTS FOR BROADCAST CONTENT DELIVERY

At present, a broadcast TV multiplex typically carries 6 programmes in the fixed reception scenario and 4 programmes in the portable reception scenario in a TV channel of 8 MHz. This remains a broadcast requirement in the future for HD quality. Therefore, if an HD programme requires 6.0 Mbit/s (which is realistic for current source coding schemes), a multiplex for fixed reception should provide a data rate of about 36 Mbit/s (in 8 MHz bandwidth); the figure would be about 24 Mbit/s for portable reception. In other words, a spectral efficiency of about 4.5 bit/s/Hz for the former scenario and about 3 bit/s/Hz for the latter one, would be desirable.

COMPARISON OF MOBILE BROADBAND AND BROADCAST TECHNOLOGIES

Spectral efficiencies, as produced by DVB-T2 are shown in Table 5 in the previous section. These are valid for an HTHP network topology, and hold for a hypothetical LTLP topology, also.

In contrast, Figure 1 shows that LTE MBSFN does not provide a mode with a spectral efficiency of 4.5 bit/s/Hz which would be desirable for fixed reception. For portable reception, 3 bit/s/Hz is the benchmark value which can be provided by a cellular LTE MBSFN network with a base station distance of 1 to 2 km. Such dense mobile networks are available in metropolitan areas but do not exist in rural areas. Rural areas typically show a base station density with an ISD between 5 and 10 km. For these ISD values, the spectral efficiency of LTE MBSFN is between 0.2 and 1.5 bit/s/Hz, depending on the LTE network topology and the reception mode.

NETWORK TOPOLOGY AND LAYER SPECTRUM EFFICIENCY

In the above discussion of broadcast and broadband technologies, only the spectral efficiency figures are compared. In this comparison, for linear content delivery, i.e. for a point-to-multipoint (P2M) service, existing broadcast technology is definitely superior to existing broadband technology. But a further aspect, to be taken into account when the consumption of spectrum is to be assessed, is the network topology.

Usually, broadcast technology (DVB-T2) is associated with an HTHP network topology, and broadband technology (LTE MBSFN) is associated with a cellular LTLP network topology. The following considerations are based on these assumptions.

The network topology plays a crucial role in the question of 'frequency re-use'. Transmission systems together with their associated network topology are often characterized by the minimum required number of channels to cover a large area. This figure is called the frequency re-use; and this number of channels has to be made available, even if not all channels are used in all locations.

However, the frequency re-use figure is a rough metric which does not realistically assess the spectrum consumption of a transmission system. In the case of LTLP networks, 3 to 4 channels might be needed in principle and have to be made available, but this does not mean that all these channels are blocked everywhere in the considered area. Pedantically, of course, one channel is blocked since it is used by the intended service; but, in general, only a fraction of this area is blocked for the other channels. Thus, there remains a part of the area where the other channels may be 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, rather than the frequency re-use figure.

In Annex 1, an approach is described how such a blocking factor may be defined. It is called the 're-use blocking factor' (RBF). Annex 2 describes, with Germany as an example, how the re-use blocking factor can be calculated.

Based on these considerations, a generalization of the concept of spectral efficiency is used in the following investigation, and this is explained in detail in Annex 1. It allows for a more realistic comparison of the spectrum load of different P2M transmission systems. The concept is called 'layer spectrum efficiency' (LSE). Basically, the LSE value is given by the ratio of spectral efficiency SE to re-use blocking factor RBF:

LSE = SE/RBF

The larger the re-use blocking factor is, the smaller is the layer spectrum efficiency; and the larger the spectral efficiency is, the larger is the layer spectrum efficiency.

This concept is now applied to the MBSFN and DVB-T2 scenarios described in the sections above.

For DVB-T2, a re-use blocking factor RBF of 7.0 is assumed for the multi-frequency network (MFN) approach[ii]; and for the medium SFN approach, an RBF of 5.0 is used - as calculated in the example for Germany in Annex 2 for a re-use distance of 120 km. For large and very large SFN, values for RBF of 4.0 and 2.1 apply. Very large SFN are required for the case of national service areas.

ii Often it is claimed that for MFN smaller RBF can be achieved. This is true if area coverage of less than 100% is intended. But in this investigation, full area coverage is assumed for the sake of comparability.

For LTE MBSFN, small re-use distances as calculated in [9] are used, and the resulting RBF values are given in Annex 2.

The resulting values of the layer spectrum efficiency for both systems, DVB-T2 and LTE MBSFN, are shown in Tables 6 and 7.

DVB-T2 **network type**	**reception mode**	**Spectral efficiency SE [bit/s/Hz]**	**Re-use blocking factor RBF**	**Layer spectrum efficiency LSE [bit/s/Hz]**
HTHP MFN	fixed	5.0	7.0	0.71
HTHP Large SFN	fixed	4.2	4.0	1.05
HTHP Medium SFN	portable outdoor / mobile	3.3	5.0	0.66
HTHP Large SFN	portable outdoor	3.3	4.0	0.83
HTHP Medium SFN	portable indoor	2.2	5.0	0.44
HTHP Medium SFN	(deep) portable indoor	1.6	5.0	0.32
LTLP Large SFN (ISD = 2 km)*	portable / mobile	6.0	1.7	3.53

TABLE 6: Layer spectrum efficiency of various DVB-T2 scenarios - regional layer
(This scenario is hypothetical. A larger value of RBF than for the corresponding LTE case applies here since in DVB-T2 a higher modulation scheme is used.)*

LTE MBSFN ISD [km]	**Re-use blocking factor RBF**	**Layer spectrum efficiency LSE [bit/s/Hz]**	
		fixed reception	**mobile / light indoor reception**
2	1.4	2.14	2.14
5	1.4	1.07	0.71
10	1.5	0.33	0.13

TABLE 7: Layer spectrum efficiency of various LTE MBSFN scenarios – regional layer (spectral efficiency SE values from Table 3)

The comparison of LTLP LTE MBSFN and HTHP DVB-T2 in the light of layer spectrum efficiency is instructive. Tables 6 and 7 show that

- a (hypothetical) DVB-T2 network with LTLP topology has the best (= highest) LSE value,
- very dense LTE networks with an ISD of 2 km also have a very good performance, significantly better than HTHP DVB-T2 networks,
- LTE networks with an ISD of 5 km have about the same performance for fixed reception as DVB-T2 HTHP (SFN); they show still a (slightly) better performance than HTHP DVB-T2 networks for portable/mobile reception,
- LTE networks with an ISD of 10 km are significantly worse than DVB-T2 HTHP networks.

A similar comparison has been performed for a national layer scenario (very large SFN), too. Table 8 contains the results. RBF values as calculated in Annex 2 are used. The comparison of DVB-T2 and LTE MBSFN for this case gives a similar result as for the regional layer case, where now the figures for LTE MBSFN, ISD = 5 km, are worse than those for DVB-T2 HTHP - in particular for the fixed reception case.

	Re-use blocking factor RBF	Layer spectrum efficiency LSE [bit/s/Hz]	
		fixed reception	mobile / light indoor reception
LTE MBSFN ISD = 2 km	1.09	2.75	2.75
LTE MBSFN ISD = 5 km	1.10	1.36	0.91
LTE MBSFN ISD = 10 km	1.14	0.44	0.18
DVB-T2 (HTHP - SFN)	2.10	2.00	1.05

TABLE 8: Layer spectrum efficiency of DVB-T2 and LTE MBSFN scenarios – national layer

The general and most relevant finding is that the large differences between the various scenarios with regard to their LSE values, which finally determine the spectrum consumption, are due to the different network topologies, LTLP or HTHP, rather than to the transmission systems, LTE MBSFN or DVB-T2.

With regard to spectrum consumption: very dense LTLP networks with an ISD of 2 km are clearly superior to HTHP networks; cellular networks with an ISD of 5 km are similar to HTHP networks in their performance; cellular networks with an ISD of 10 km are much worse than HTHP networks.

EXAMPLE: THE CASE OF GERMANY

To give a definitive example, the case of Germany is investigated in more detail. Whereas in the previous section the more abstract quantity ‘layer spectrum efficiency’ was evaluated, now the more concrete quantities ‘blocked spectrum space’ and ‘spectrum to be made available’ are considered.

In Germany, DTT is planned for portable/mobile reception. In the following exercise, we do not distinguish between rural and urban areas, even if the density of existing base stations is different for rural and urban areas, and the data rate requirements are different for rural and urban areas as well.

NUMBER OF BASE STATION SITES

Germany has an area of 357000 km^2. To cover 98% of the population, which is the public broadcaster’s requirement, coverage of an area of about 90% is required, which corresponds to an area of 321000 km^2. For this coverage, a certain number of base stations is required, depending on the size of a base station cell. These numbers are given in Table 9.

ISD [km]	No. base station sites
2	92859
5	14877
10	3760

TABLE 9: Number of base station sites to cover 90% of the area of Germany with an LTLP approach

At present there exist about 20000 base station sites per operator, several of them being jointly used by different operators.

Typically, an LTE base station operates with frequency blocks of 10 MHz. In principle, broader frequency blocks are possible, but for the following consideration it is practical to use a block unit of 10 MHz. The conclusions of this section do not depend on this assumption. The data rate which is available at each location of a layer depends on the achievable spectral efficiency which is given in Table 3. A coverage layer condition is defined which requires one unit frequency block to be available at each location of the area which is to be covered.

In Germany, public broadcasters operate three multiplexes for portable/mobile reception. With DVB-T2 these multiplexes will carry approximately 24 Mbit/s each, which amounts to a total data rate of about 72 Mbit/s.

Thus the number of required MBSFN layers, each with 10 MHz bandwidth, or, equivalently, the total required bandwidth as a multiple of 10 MHz, to carry the data rate of 72 Mbit/s can be calculated. The result is given in Table 10. Here it is neglected that fractional layers do not exist and in reality only an integer number of layers can be implemented.

ISD [km]	No. MBSFN LTLP layers Mobile / Light indoor reception
2	2.4
5	7.2
10	36.0

TABLE 10: Number of MBSFN LTLP layers with 10 MHz bandwidth to provide a data capacity of 72 Mbit/s

BLOCKED SPECTRUM SPACE

With the information of the previous section, the ‘blocked spectrum space’ (BSS) can be evaluated. The concept of blocked spectrum space describes for a particular area, how much spectrum is blocked. It is explained in detail in Annex 1, where BSS is given by equation (A1.2):

BSS = Bandwidth x Area x RBF.

In Germany, terrestrial TV is planned for portable / mobile reception with a regional structure for the service areas. For the calculation of the blocked spectrum space, LSE values are taken from Tables 6 and 7. The calculation is made for the required data rate of 72 Mbit/s.

The results are given in Tables 11 and 12. Again, we have not taken into consideration here that in practice spectrum is only available in integer multiples of channel raster blocks - 8 MHz for DTT; and 5, 10 or 20 MHz for LTE. For the latter a basic bandwidth of 10 MHz is assumed. For smaller or larger bandwidths the results differ only slightly.

Network type	Reception mode	System bandwidth [MHz]	Re-use blocking factor RBF	No. of Layers	Blocked spectrum space BSS [MHz x km^2 x 10^6]
HTHP Medium SFN	Portable outdoor / mobile	8	5.0	2.7	39.00
HTHP Medium SFN	Portable indoor	8	5.0	4.2	60.57

TABLE 11: Blocked spectrum space for a data capacity of 72 Mbit/s with a DVB-T2 HTHP network

Network type	Reception mode	System bandwidth [MHz]	Re-use blocking factor RBF	No. of Layers	Blocked spectrum space BSS [MHz x km^2 x 10^6]
LTLP ISD = 2 km	mobile / portable indoor	10	1.4	2.4	10.79 LTLP
LTLP ISD = 5 km	mobile / portable indoor	10	1.4	7.2	32.36 LTLP
LTLP ISD = 10 km	mobile / portable indoor	10	1.5	36.0	173.34

TABLE 12: Blocked spectrum space for a data capacity of 72 Mbit/s with an LTE LTLP network

Absolute values of BSS do not give a feeling for assessing the quality of a scenario; it is the relative values of the different scenarios as compared to each other which enable an assessment of their quality with regard to spectrum consumption.

This comparison shows that:

- LTE LTLP with ISD = 2 km blocks by far the lowest amount of spectrum space,
- LTE LTLP with ISD = 5 km has a slightly smaller blocking potential than DVB-T2 HTHP for portable outdoor / mobile reception and shows a definitely better performance than DVB-T2 HTHP for portable indoor reception,
- LTE LTLP with ISD = 10 km shows a remarkably poorer performance than DVB-T2 HTHP.

As is explained in Annex 1, the amount of blocked spectrum space and a hypothetical amount of “blocked spectrum” derived from this are different from the amount of spectrum that has to be made available for the coverage of a layer.

SPECTRUM TO BE MADE AVAILABLE

For an LTLP approach, 3 to 4 channels have to be made available for one layer. From the previous sections of this article it is clear that these 3 or 4 channels are not in use at all locations of the service area, but at least for some locations they have to be made available. This final section looks for the number of channels that have to be made available in this sense or, equivalently, the total spectrum that has to be made available.

Tables 11 and 12 give the number of layers that are required to provide the envisaged data rate of 72 Mbit/s. The resulting amount of spectrum that has thus to be made available is given in Table 13, where the frequency re-use figures for DVB-T2 and LTE MBSFN are assumed to be 6.5

and 3.5, respectively, as average values out of 6 and 7 for DVB-T2 and out of 3 and 4 for LTE MBSFN (see Annex I, section A1.1). Again 10 MHz are taken as the basic bandwidth for MBSFN. Smaller or larger values would modify the result slightly.

Network	ISD [km]	Reception mode	Spectrum to be made available [MHz]
LTLP MBSFN	2	mobile / light portable indoor	84
LTLP MBSFN	5	mobile / light portable indoor	256
LTLP MBSFN	10	mobile / light portable indoor	1260
HTHP DVB-T2	50	mobile / portable outdoor	173
HTHP DVB-T2	50	light portable indoor	218

TABLE 13: Spectrum to be made available to provide a data rate of 72 Mbit/s

Again, the comparison of LTLP / LTE MBSFN and HTHP / DVB-T2 is instructive:

- LTE MBSFN with ISD = 2 km requires by far the lowest amount of spectrum to be made available,
- LTE MBSFN with ISD = 5 km has about the same spectrum requirement as the DVB-T2 HTHP approach, at least when a larger basic bandwidth than 10 MHz is chosen,
- LTE MBSFN with ISD = 10 km is much worse than the HTHP approach.

FURTHER CONSIDERATIONS

In two of the analysed mobile broadband studies [5, 7] a comparison with existing broadcast technologies is made as well, and case studies for two metropolitan areas are performed. Fixed reception is investigated in the San Francisco Bay Area and compared with ATSC [5]; portable indoor reception is considered in the Cologne Area and compared with DVB-T [7].

In principle, a performance comparison of a novel, not even implemented mobile broadband system (LTE MBSFN) with existing and about 20 years old broadcast transmission systems (ATSC and DVB-T) is not appropriate. The outcome is obvious and in favour of the novel system.

In addition, in the comparison of the required spectrum, for DVB-T and ATSC, all available channels for broadcast usage in the country are compared with the spectrum required to cover the metropolitan areas with LTE MBSFN only. Of course, this comparison is again in favour of the mobile broadband system, but nonetheless it is inadequate, since in these metropolitan areas the broadcast systems do not use all of the available channels either. An analysis of the blocked spectrum space as presented in this article would be more appropriate.

Unfortunately, in the regulatory sphere, this inadequate comparison is sometimes taken as a proof of the superiority of mobile broadband systems.

CONCLUSIONS

Studies on mobile broadband technology supporting TV distribution via cellular LTE networks for different reception scenarios have been analysed here, with the LTE networks deploying a Low Tower – Low Power (LTLP) topology. The objective of the analysis was twofold: firstly, to understand the mobile broadband approach on the delivery of TV programmes by means of cellular LTE networks in MBSFN mode; secondly, to use the findings of these studies to evaluate the spectrum consumption of these approaches, and to compare them with classical broadcast approaches. For this purpose, a generalized concept of spectral efficiency (SE) was applied.

The analysed studies present spectral efficiency figures of simulated LTE MBSFN networks for various reception scenarios. The results show a relatively large spread. For our investigation approximate average values of the spectral efficiency taken from these studies were assumed. A comparison with DVB-T2, which is typically operated on a High Tower – High Power (HTHP) topology was performed. A crucial parameter for the spectral efficiency of LTE MBSFN networks is the Inter-Site Distance (ISD), the distance between two neighbouring base stations.

Our results show that DVB-T2 exhibits a higher spectral efficiency. Only very dense LTLP LTE networks with an ISD of 2 km or less exhibit a competitive performance. Hypothetical DVB-T2 LTLP networks show an even higher spectral efficiency than the HTHP networks.

However, the simple comparison of spectral efficiencies does not reveal the benefits of LTLP networks with regard to real spectrum consumption. LTLP networks allow for a smaller frequency re-use figure, which is an advantage as compared with HTHP networks. Therefore, an alternative metric for the comparison has been derived and applied - based on the concept of ‘layer spectrum efficiency’, an extension of the notion of spectral efficiency for point-to-multipoint transmission systems.

The comparison has been repeated on this basis, and it is shown here that: LTE LTLP networks with a (very) high density of base stations have the lowest spectrum consumption; LTE LTLP networks with ISD of around 5 km have still a slightly better performance than DVB-T2 HPHP networks; LTE networks with an ISD of 10 km are significantly worse.

The comparison shows that the large differences in spectrum consumption between the various scenarios are due to the different network topologies (LTLP, HTHP) rather than the transmission systems used (LTE MBSFN or DVB-T2).

The major conclusion of the investigation is that, at least for today’s cellular network infrastructure, and even with new state-of-the-art mobile technology, it is not reasonable to provide linear TV content via cellular networks for reasons of spectrum resource usage. To achieve a significantly better spectrum usage, for cellular networks with nation- or region-wide coverage, much higher base station densities would be needed; such base station densities would currently be available only in metropolitan areas.

Nevertheless, a converged network that is capable of transmitting broadcast and unicast content could be very promising. Therefore it is suggested that further investigations are needed to look at the possibility of extending the eMBMS/MBSFN network approach by, for example, adding HTHP components to the LTLP networks while maintaining or even improving the efficient use of the spectrum.

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ANNEX 1:

How to assess spectrum consumption?
Frequency Re-use and Re-use Blocking Factor
Blocked Spectrum Space and Layer Spectrum Efficiency

A1.1 FREQUENCY RE-USE

In the section on Network Topology, it was pointed out that the spectral efficiency figure of a P2M transmission system alone does not reveal its real spectrum consumption. The network topology which is associated with the transmission system plays an important role, too. Annex 1 analyses that aspect and investigates an approach which may be understood as a generalization of the concept of spectral efficiency. Here it is called **layer spectrum efficiency**.

It is closely related to the concept of spectrum utilisation efficiency which is well-known in spectrum management; see ITU-R Rec. SM.1046 [15].

A channel cannot be used in adjacent service areas if different content is to be delivered in those areas because of mutual interference between the two adjacent networks. This holds true for both transmission systems, DVB-T2 as well as LTE MBSFN[iii]. But the potential interference into the neighbouring service area depends very much on the applied network topology. An LTLP network shows a much lower interference potential than an HTHP network. Therefore the distance beyond which a channel may be re-used is much smaller in an LTLP approach than in an HTHP approach. The minimum distance that is to be kept is called the **re-use distance**. Typical re-use distance values for HTHP DVB-T2 networks are between 80 km and 120 km, whereas for an LTLP LTE MBSFN network values between 10 and 20 km may be realistic. Such values are achieved in interference-limited scenarios which are typical for broadcast implementations.

This difference between LTLP and HTHP networks induces a huge effect with regard to the number of channels that are required to fully cover a large area or territory which consists of several or many individual service areas. The larger the re-use distance, the larger is the number of different channels before the original channel can be re-used. Quite often transmission systems together with their associated network topology are characterized by the minimum required number of channels to cover a large area. This figure is called the **frequency re-use**. This number of channels has to be made available even if not all channels are used in all locations.

Apart from the re-use distance, the geometry of the layout of the service areas is a crucial factor for the required number of channels. The smaller the ratio of “re-use distance vs. typical linear extension of a service area” is, the smaller is the number of required channels.

The limiting case of (nearly) 0 km re-use distance can be described by reference to the mathematical 4-colour theorem which states that four colours (channels) are sufficient to colour (cover) a map with many non-interfering (service) areas.

[iii] Sometimes it is argued that in LTE adjacent cells can use the same channel while providing different content. This is true in unicast mode where the capacity of one channel is shared by several users/cells. The statement here refers to the total capacity of the channel in an LTE MBSFN network.

In this sense, since re-use distances of LTLP topologies are in general much smaller than broadcast/multimedia service areas, LTLP networks are sufficiently well described by the 4-colour theorem, i.e. their frequency re-use is 4. Moreover, the cellular character of an LTLP network allows for a flexible definition of (technical) service areas. Thus quite often it is possible to reduce the frequency re-use factor to 3, for example by designing small stripe-like service areas along borderlines.

HTHP re-use distances are much larger. Consequently, the required number of channels to cover a large area is higher. For example, the GE06 frequency plan for DTT requires 39 channels for 6 layers. A layer designates full coverage of the planning area with one multiplex. Hence, the frequency re-use in the GE06 plan (which was agreed at the ITU Regional Radiocommunication Conference RRC-06 in Geneva in 2006) is between 6 and 7.

A1.2 RE-USE BLOCKING FACTOR

However, the frequency re-use figure is a rough metric which does not realistically assess the spectrum consumption of a transmission system. In the case of LTLP networks, 3 to 4 channels might be needed in principle and have to be made available, but this does not mean that all these channels are blocked everywhere in the considered area. Pedantically, of course, one channel is blocked since it is used by the intended service; but, in general, only a fraction of this area is blocked for the other channels. Thus, there remains a part of the area where the other channels may be 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, rather than the frequency re-use figure.

In the following it is described how such a blocking factor may be defined and calculated. Basically, this factor is determined by the ratio of the area where a channel is blocked, i.e. where it cannot be used for other purposes, as compared with the area to be served by a P2M service. This blocking factor also depends crucially on the re-use distance and the layout of the service areas and to some extent to the distribution of the channels to the service areas. To be specific, we call this factor **re-use blocking factor RBF**. It is a global and characteristic property of a frequency plan for a P2M transmission system.

In detail, the re-use blocking factor can be determined in the following way:
If A is the total area of a layer that is to be covered by the P2M service, and A_k are the individual service areas within this layer, then a channel f_i is attributed to each of these service areas. A certain number of channels are required to allocate the channels in such a way that no interference occurs between the service areas A_k. This number depends on the re-use distance of the P2M transmission system and the geometry of the service areas. In the following it is assumed that the minimum required number of channels is allocated. It is a combinatorial optimization problem to find this number. The channel which is allocated to a service area cannot be used for other purposes within this service area. Moreover, this channel cannot be used for other purposes beyond the border of this service area within the range of the re-use distance. Its usage is blocked.

If now a_i is the area within A that is blocked by the channel f_i, and n channels f_i, i=1…n, are needed, then the re-use blocking factor RBF is defined as the sum of all a_i normalized to the total area A of the layer:

$$\mathrm{RBF} = \frac{1}{\mathrm{A}} \times \sum_{i=1}^{n} a_i \ ,$$

Note that several service areas A_k may use the same channel f_i, which means that a_i is not (necessarily) the simple extension of a single service area A_k.

According to calculations made for Germany, which are described in more detail in Annex 2, for a typical LTE MBSFN network the re-use blocking factor is between 1.1 and 1.5 as compared to a frequency re-use factor of 3 to 4.

A similar behaviour is found for the HTHP case. Even if in one part of the planning area the maximum number of channels is required ("hot spot"), it does not mean that everywhere in the planning area all these channels are blocked. Famous "hot spots" in this sense in the GE06 plan are the region around Luxembourg, the Adriatic and the Baltic Sea. The re-use blocking factor for the regional subdivision of Europe as assumed in the GE06 plan is between 4 and 5 as compared to a frequency re-use of 6 – 7; for a national layer the re-use blocking factor is around 2. The results of the calculations for the case of Germany can be found in Annex 2.

Later in this annex the re-use blocking factor is used to generalize the concept of spectral efficiency.

A1.3 BLOCKED SPECTRUM SPACE

The considerations of the previous section on RBF are based on the more general concept of spectrum space which is well-known in spectrum management, see, e.g. [14, 15]. In the assessment of spectrum consumption this concept takes the three dimensions of spectrum usage into account: frequency bandwidth, geometrical space and time. **Spectrum space**, which can be considered under the aspects of being used or being blocked, is defined as the product of:

Spectrum Space = Bandwidth × Space × Time.

In ITU Recommendation SM.1046 [15] this quantity is called spectrum utilisation factor.

In the context of broadcasting, Space reduces to Area, and Time is a constant since broadcasting is a 24/7 service and can therefore be taken out:

Spectrum Space = Bandwidth × Area (in the case of broadcasting).

This is the general, abstract description of spectrum space. In the previous section the concrete case of blocked spectrum is considered when covering a layer with channels such that one channel of bandwidth b is available at each location of the layer. Thus, the **Blocked Spectrum Space** BSS in this case is:

$$\mathrm{BSS} = \mathrm{b} \times \sum\nolimits_{\mathrm{all}\ \mathrm{f_i}} \mathrm{a_i} \ ,$$

where a_i is the area within the layer where channel f_i cannot be used for other purposes, i.e., is blocked. Here it is assumed that the used bandwidth b is identical with the blocked bandwidth, i.e., that no adjacent channel interference occurs. However, adjacent channel interference could easily be incorporated into the concept.

Since the re-use blocking factor, as described in the previous section, is defined as

$$\mathrm{RBF} = \frac{1}{\mathrm{A}} \times \sum\nolimits_{\mathrm{all}\ \mathrm{f_i}} \mathrm{a_i} \ ,$$

where A is the area of the entire layer, BSS can be expressed as:

$$BSS = b \times A \times RBF. \qquad (A1.1)$$

An example of the calculation of blocked spectrum space is given in the article in the example of Germany.

A1.4 LAYER SPECTRUM EFFICIENCY

Blocked spectrum space describes the resource consumption of a P2M transmission system when covering a layer. Yet, there is still an aspect missing in order to describe how efficient a transmission system uses this blocked resource. This quantity is the spectral efficiency as described at the beginning of this article.

Spectral efficiency is defined as

$$SE = D / b,$$

where D = data rate; and b = bandwidth.

Substituting b in equation (A1.1) by D/SE gives

$$BSS = D/SE \times A \times RBF,$$

or

$$BSS = D \times A / (SE/RBF).$$

This last version of the equation can be read in the following way:

In order to provide a layer of area A with a given data rate D a certain amount of spectrum space BSS is blocked which depends on the ratio SE/RBF, which in turn is determined by the transmission system, the network topology and the design of the individual service areas.

The ratio SE/RBF is the characteristic quantity to describe the spectrum consumption of a P2M transmission system with its associated network topology. In this sense, the ratio SE/RBF can be understood as a generalized spectral efficiency which we call **layer spectrum efficiency** LSE:

$$LSE = SE / RBF.$$

A more detailed introduction to the concept can be found in [16]. LSE is a better and more realistic metric of the spectrum consumption of a P2M transmission system together with the associated network topology than the simple notion of spectral efficiency. The larger the re-use blocking factor is, the smaller is the layer spectrum efficiency; and the larger the spectral efficiency is, the larger is the layer spectrum efficiency. Moreover, the larger LSE, the smaller is the amount of blocked spectrum space:

$$BSS = (D \times A) / LSE. \qquad (A1.2)$$

The layer spectrum efficiency LSE is the relevant factor to evaluate the spectrum consumption of a P2M transmission system and should therefore be used for a comparison of P2M transmission systems.

The corresponding quantity in ITU Recommendation SM.1046 [15], which is called **spectrum utilisation efficiency** SUE, is defined in a slightly different way. LSE and SUE are related by

SUE = LSE / A.

In [15] it is also described how the aspect of population density may be introduced into the concept.

A word of caution is required at this point. BSS divided by A gives a quantity with the dimension "frequency" and might be understood as "blocked spectrum". This is formally correct. However, this amount of "blocked spectrum" must not be confused with the amount of spectrum that is to be made available for a service in order to provide a certain amount of multimedia content and which is characterized by the frequency re-use figure. Usually, there is a difference between these two quantities. The former gives the percentage which is blocked within the latter; the difference may be used by other services. These further services have to accommodate themselves to the geometrical and spectral usage pattern determined by the original service. A well-known example is the usage of TV white spaces by PMSE applications.

In this context it is also to be mentioned that re-use distances as required in the methodology of the layer spectrum efficiency depend on the characteristics of these further services. Here it was assumed that these further services have the same compatibility characteristics as the original DVB-T2 and LTE MBSFN systems. This is a generic assumption which is to be refined when a particular further service is considered. Its specific compatibility properties have then to be used to determine in more detail the specific LSE value of the considered scenario.

ANNEX 2:

Re-use Blocking Factor for DTT
A case study for a DTT layer in Germany

In this annex the re-use blocking factor is evaluated for a particular scenario in Germany. It is assumed that the service areas in Germany are built (mainly) from the political regions ("Länder"). Technically, this means medium to large SFN are envisaged. Such a structure for one layer has been planned during the GE06 process within the VHF band. This case is taken as an example for the calculation of the RBF, although in the end this particular band III scenario was not realized for DTT since Germany now uses all band III for DAB+.

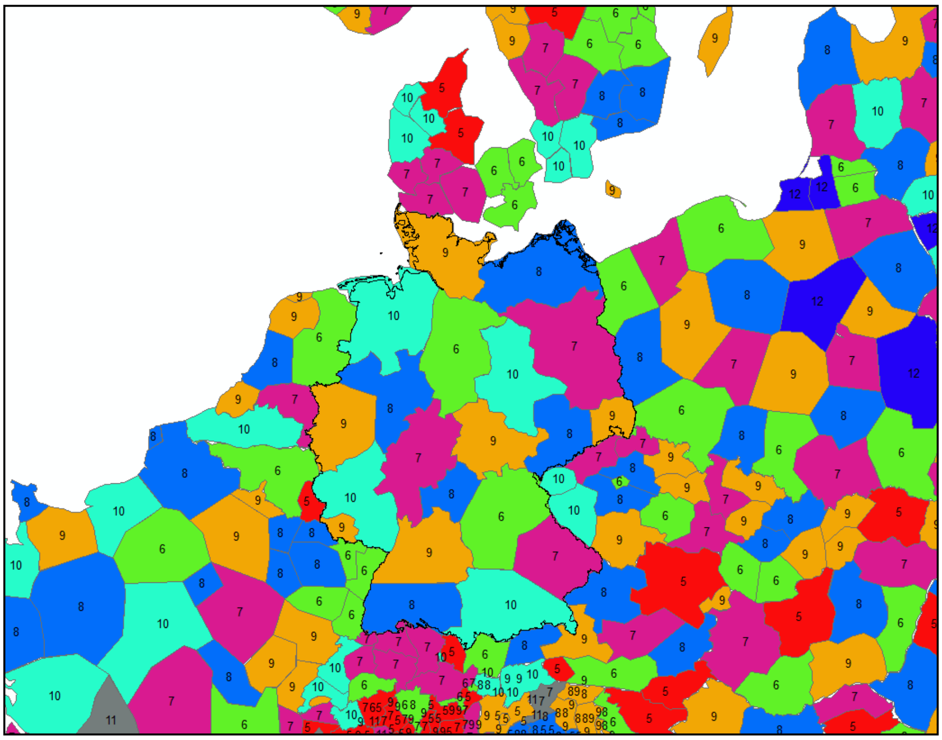

FIGURE A2.1: Example frequency plan for Central Europe – Large re-use distance

Since the frequency distribution and assignments of the neighbouring countries are relevant for the computation of the RBF, they are used in the analysis as given in the GE06 planning process. Figure A2.1 gives an overview of the scenario including an indication of the VHF channels used.

RBF is calculated according to the description in Annex 1. The calculation is performed for three re-use distances, 80 km, 100 km and 120 km, which are typical values for DVB-T2. For illustration purposes, Figure A2.2 shows the blocked areas in Germany for one channel (channel K8). Blue areas are channel K8 service areas and light green areas together with the blue service areas are the areas where channel K8 is blocked.

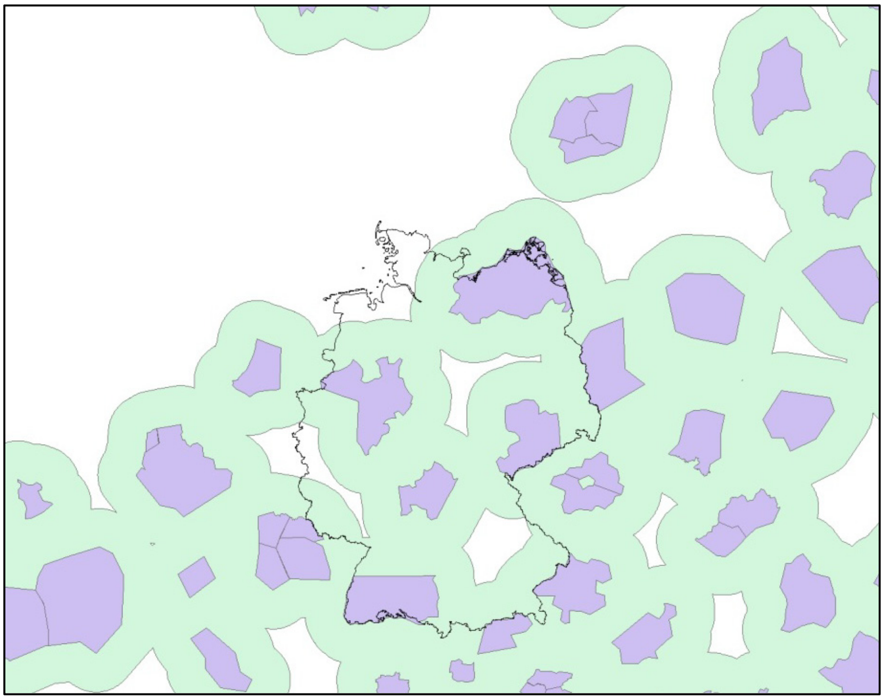

FIGURE A2.2: Areas blocked by channel K8 – Large re-use distance

The results of the analysis are given in Table A2.1. Depending on the re-use distance, the RBF was found to have a value between 4.1 and 5.0.

Re-use distance [km]	RBF
80	4.1
100	4.7
120	5.0

TABLE A2.1: Re-use blocking factors RBF for the scenario of Figure A2.1

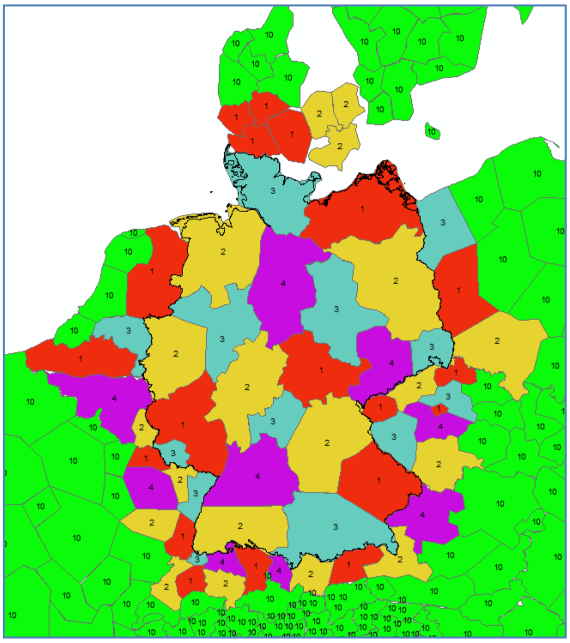

FIGURE A2.3: Example frequency plan for Germany + neighboring areas – Small re-use distance

For a P2M transmission system with a small re-use distance, a different frequency distribution would be chosen for the service area layout of Figure A2.1. Such a distribution using four channels is described in Figure A2.3. The frequency allocations in neighbouring countries at a distance beyond the re-use distance from the German border are not relevant for the determination of the RBF for Germany. They are formally set to channel K10 in this example. Re-use distances as calculated in [9] are used.

The results for the scenario of Figure A2.3 are given in Table A2.2.

Re-use distance [km]	RBF
9.5	1.4
10.5	1.4
13.5	1.5

TABLE A2.2: Re-use blocking factors RBF for the scenario of Figure A2.3

A similar calculation was performed for a scenario where national service areas are assumed, .i.e., each national territory in Europe gets one channel. The resulting RBF figures are summarized in Table A2.3.

Re-use distance [km]	RBF
9.5	1.09
10.5	1.10
13.5	1.14
80	1.8
100	1.9
120	2.1

TABLE A2.3: Re-use blocking factors RBF for a national layer scenario

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AUTHOR BIOGRAPHIES

ROLAND BRUGGER

Dr Roland Brugger is Head of the Frequency Management Section of the Institut für Rundfunktechnik (IRT) in Germany.

Roland has been involved in the planning of digital broadcasting systems for 20 years. During this time he has been working on stochastical optimisation of frequency plans and the development of planning techniques for digital broadcasting networks. He actively participated in the frequency planning conferences in Wiesbaden 1995, Chester 1997, Maastricht 2002 and Geneva 2006.

Presently, Roland is involved in the preparation of WRC-15 at national and international levels and the European discussion on the digital dividend. He is member of CEPT Task Group TG6 and project manager of EBU project group SMR-BNP.

Dr Brugger holds a Diploma and PhD degree in physics from Ludwig-Maximilians-Unversität in Munich.

ALEXANDER SCHERTZ

Alexander Schertz is a member of the research staff in the Frequency Management Section of the Institut für Rundfunktechnik (IRT) in Germany.

Alexander was born in Saarbrücken (Germany) in 1953. He joined the Institut für Rundfunktechnik (IRT) in 1981, and has been involved in the planning and management of digital communications systems for many years. Alexander specialises in the distribution of broadcast content via mobile radio, and has expertise in both terrestrial broadcasting standards such as DVB-T2 and mobile communication standards such as Long Term Evolution (LTE).

Alexander Schertz gained a Diploma in physics from the University of Saarbrücken in the German state of Saarland, in 1979.

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Editor-in-Chief: Simon Fell

Managing Editor: Roger Miles (ad interim)

E-mail: miles@ebu.ch