Deliverable 6.1

Authors	T. Owens, C. Zhang, T.Itagaki (Brunel), Jan Outters (IRT), J Lauterjung (R&S), M. Martucci (PUSP), D. Bouquet, B. Mazieres, J. Prudent (TDF), P. Christ, Ingo Gaspard, Stefan Ritscher, Gerd Zimmermann, P. Christ (T-Systems)
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Glossary

ANFR	Agence Nationale des Fréquences
CSA	Conseil Supérieur de l'Audiovisuel
CEPT	European Conference of Postal and Telecommunications Administrations
DECT	Digital Enhanced Cordless Telecommunications
DTT	Digital Terrestrial Television
DVB-T	Digital Video Broadcasting - Terrestrial
DVB-H	Digital Video Broadcasting -Handheld
E-GSM	Enhanced GSM
GSM	Global System for Mobile Communications
IMT-2000	International Mobile Telecommunications 2000
PAL	Phase Alternation Line
PMR	Private Mobile Radio
PAMR	Public Access Mobile Radio
SAB	Services Ancillary to Broadcasting
TACS	Total Access Communications System
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System (3G mobile standard)
VCR	Video Cassette Recorder
VHF	Very High Frequency

Chapter 1 Introduction

One of the core objectives of Work Package 6 is to study and define new network planning rules (frequency allocation, cell size, cell bit rates) that will support the deployment of denser and localized broadcast networks.

Deliverable D6.1 defines by means of simulations and measurements network engineering rules that will enable an efficient use of broadcast spectrum. They will contribute to the definition of protection ratio and frequency allocation management.

Chapter 2 identifies frequencies available for DVB-T/H broadcast in several European countries and in Brazil. It does this by stating the current frequency planning with respect to the simulcast stage of analogue and digital TV in the transition to digital TV in these countries and by presenting the possible network topologies for DVB-T/H broadcast and highlighting the consequences for frequency planning of each of these topologies.

In chapter 3 the cell ranges for different DVB-T/-H reception modes are given for different transmitter heights / powers and for rural as well as for urban environments.

For different single frequency network (SFN) structures coverage probability predictions are done and analysed. For multi-frequency networks (MFN) characterized mainly by their frequency reuse or cluster size different approaches are analysed.

In mobile telecommunication networks sectorizing of cells is applied to increase capacity without additional base station locations and down-tilting the antennas of the radio network's transmitters is heavily used, especially in small cells, to effectively lower the cell range in areas were high capacity is demanded and to have a sharp transition at the cell border with the neighbouring cells. To investigate network topologies for DVB-H MFNs that are similar to mobile telecommunication network topologies sectorization of hexagonal cells into 6 x 60° sectors and 3 x 120° sectors and antenna down-tilting are considered.

Combining the benefits of SFNs with the cellular layout of MFNs to distribute more localized content leads to the idea of illuminating the hexagonal cell area by an SFN whose transmitters are located in the corners of the hexagon. The case where 3 transmitters with 120° sector antennas in every second corner of the hexagonal cell are used to illuminate the cell is considered as a means of lowering the cluster size thus lowering the number of frequencies required to deliver full area coverage.

Chapter 4 presents a theoretical evaluation of the gain in network coverage due to a SFN network to appraise the added coverage area compared to an MFN network.

Chapter 5 attempts to determine, at a broadcast operator investment cost level, what is the best configuration for a DVB-H SFN network deployment. Results of simulations made with the TDF proprietary radio planning tool for several configurations, that due to a TDF proprietary cost function based on CAPEX are known to lead to similar investment costs, with working assumptions close to future deployments, are presented.

Chapter 6 presents cositing issues between the DVB-H system and mobile telecommunication services (GSM900, GSM1800, and UMTS). The main topic is Electro-Magnetic Compatibility (EMC) between radio systems.

Chapter 7 presents a basic approach to modelling DVB-T/H network coverage planning and investigates the dimensioning criteria in a wide area SFN network.

In Chapter 8 to validate the performance of the RF front-end incorporated in the DVM400 test probe developed in WP6 Task 3, and to verify some of the conclusions for network planning, a number of tests are reported that were carried out in accordance with the test methodology described in the DVB-H Validation Task Force final report [ETSI TR 102 401 v1.1.1 (2005-06)].

The overall conclusions are presented in Chapter 9.

Chapter 2 Frequency Planning

2.1 Background

2.1.1 Aim of this chapter

- To identify frequencies available for DVB-T/H broadcast in several European countries.

2.1.2 Objectives of this chapter

- To state the current spectrum usage in some of EU countries, namely the United Kingdom, Germany, France and The Netherlands, of analogue and digital TV. To state as an example of the current spectrum usage of analogue and digital TV in an emerging economy the current spectrum usage of analogue and digital TV in Brazil.
- To state the current frequency planning with respect to the simulcast stage of analogue and digital TV in the transition to digital TV.
- To present the possible network topologies for DVB-T/H broadcast and highlight the consequences for frequency planning of each of these topologies.

Following disappointing growth in 2001 and 2002, the European DVB-T market exhibited large subscriber growth in 2003. During 2003 the DVB-T market grew in the United Kingdom, Sweden, Finland, Italy, Netherlands and Germany. At the end of 2003, there were 3.9 Million DVB-T households viewing DVB-T services in Europe of which about 3 Million are viewers of Freeview services in the United Kingdom. Berlin-Brandenburg is the only region in Europe where analogue TV has been switched off. In some German cities like Berlin, Cologne, Düsseldorf, Bonn, Munich, Hannover, Hamburg, the analogue signal is already partially switched off and will completely be switched off in the near future.

Because the progress of the rollout of digital TV in the countries of Europe is different, this chapter focuses on the frequency usage in three countries with large home markets, the United Kingdom, Germany and France, together with The Netherlands as its approach to digital roll-out has some particularly distinctive features. The progress of the rollout of digital TV in Brazil is considered as an example of digital roll out in an emerging economy. For the countries considered, this chapter highlights the frequency usage of terrestrial analogue TV, the penetration of terrestrial digital TV, and the arrangements for the transition to the terrestrial analogue TV switch-off.

2.2 Frequencies used for television channels

Frequencies used for analogue TV are mainly in the bands III, IV and V. Therefore, to identify the spectrum used by analogue TV in the countries considered, the frequency allocation schemes in bands III to V will be examined first.

2.2.1 Frequency usage in the United Kingdom

2.2.1.1 Spectrum allocation

In the United Kingdom the channels used by analogue broadcasters, and thus subject to release when the digital switchover is complete, are the 46 frequency channels 21 to 68, with the exception of channels 36 and 38; Channel 36 is used for radar and VCRs, and Channel 38 is used for radio astronomy. The existing digital services are interleaved between the analogue services. Therefore, there is 368 MHz to be re-planned for the continuation of digital television and for other possible uses. There is no band III television in UK. Figure 2.1 gives a more clear view of the television channel distribution in UK

Table 2.1 shows the frequency usage in the UK above band III (condensed from [14] and [15]).

Table 2.1 Frequency usage in UK above band III.

BAND	Sub-band (MHz)	Current UK use
Band III	174-217.5	Mobile (PMR and PAMR)
	217.5-230	Broadcasting and Mobile services on a no interference to Broadcasting basis.
	230·0-328·6	Fixed Mobile. Radiolocation. Radio Astronomy. Mobile-Satellite.
	328·6-335·4	Aeronautical-Radio-Navigation.
	399·9-400·05	Radio Navigation-Satellite.
	400.05-400.15	Standard frequency and time signal satellite (400.1 MHZ)
	400.15-401	Meteorological-satellite. Space research. Mobile-Satellite. Meteorological aids. Space Operations.
	401-406	Meteorological aids. Space Operation. Fixed Mobile except: Aeronautical. Meteorological-Satellite (Earth to space).
	406-406.1/	Mobile-Satellite (Earth to

	399·9-400·05	space).
	230-235/ 335·4-399·9/ 406-470	Fixed Mobile. Mobile-Satellite. Radiolocation.
Band IV –V	470-590	TV Broadcasting (channels 21-35). Some SAB use.
	590-598	Airport radars, also used in some geographic regions for broadcasting (channel 36).
	598-606	TV Broadcasting, channel 37.
	606-614	Radio astronomy.
	614-854	TV Broadcasting, channels 39-68.
	854-862	SAB.
GSM	880-890/ 917-925	E-GSM band, some residue TACS use.
	890-915/ 925-960	GSM core band, fully-utilised.
	1710-1785/ 1805-1880	GSM 1800 band, fully utilised except for the top 3.5 MHz (DECT guard band).
IMT-2000	1900-1980/ 2010-2015/ 2110-2170	IMT-2000.

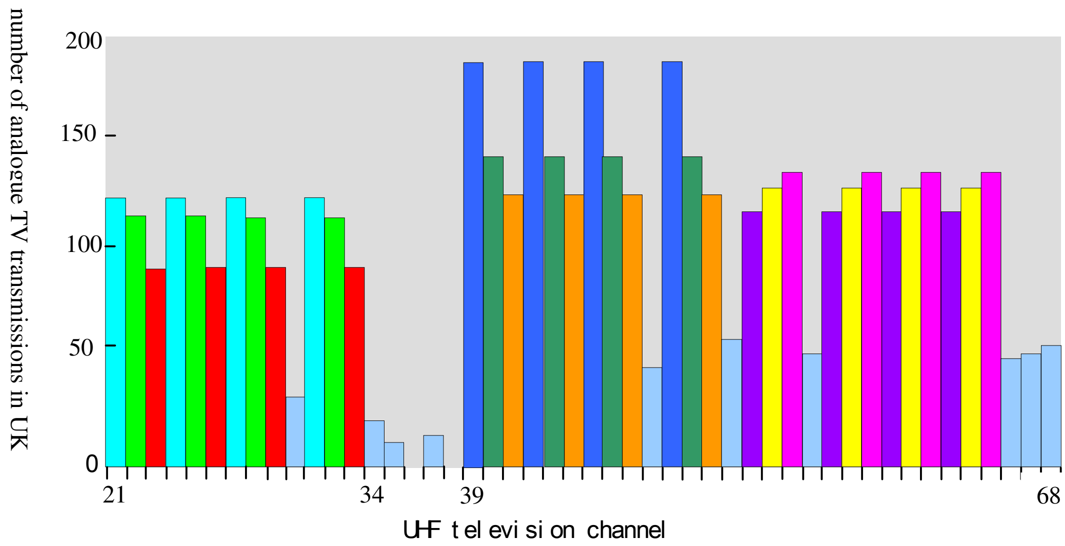


Figure 2.1: Distribution of UK television transmission in Band IV/V [23]

The total number of television transmissions in the UK is about 6350 analogue and DTT (from the 1100+ transmitting stations, plus 350 self-help schemes believed to be on-air). On average, each channel is re-used 138 times throughout the UK [23]

2.2.1.2 Present analogue television coverage

The broadcasters provide 4/5 national network analogue television services to a regulated minimum level of service based on using an outdoor receiving aerial at rooftop height (10 metres).

In practice, nearly all UK households can receive the four national network analogue services and around 80% a fifth national service.

The white areas in Figure 2.2 indicate the areas in the UK where there is no service. These areas are sparsely populated. Frequency channels are reused as indicated by the colour scheme in Figure 2.2.

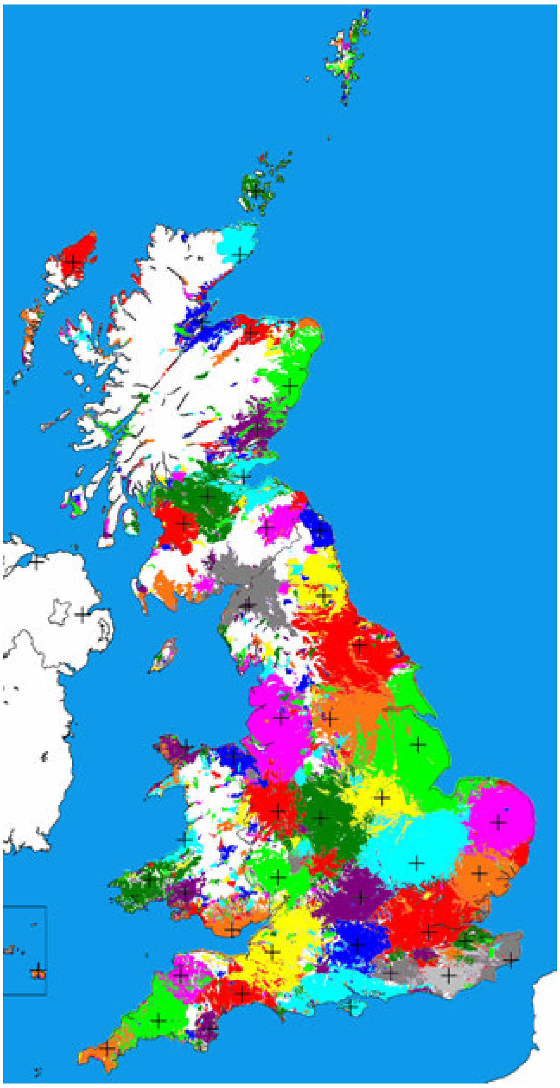


Figure 2.2: Present UK analogue TV coverage [23]

2.2.1.3 Digital terrestrial television (DTT)

Digital terrestrial television is transmitted on multiplexes, each of which uses one frequency channel (8MHz) of spectrum. Each multiplex can support six, or possibly seven, broadcast services at a quality similar to that of analogue.

Note: 2.1.3.1 to 2.1.3.8 are adapted from [23].

2.2.1.4 Planning basis for DTT in the UK

Each DVB-T station uses 6 multiplexes, which means 6 UHF channels. 80 DVB-T stations are co-sited with exiting analogue TV stations for ease of implementation and low infrastructure costs.

44 channels in Bands IV and V are used in DTT.

The DTT network is a multi-frequency network (MFN). The spectrum used by DVB-T is shared with analogue television and interleaved in the network with an 8MHz channel for each multiplex. The maximum effective radiated power of a DVB-T transmitter is about 20dB below that of an analogue transmitter. The planned covered area assumes fixed reception but will provide some portable reception as well.

Table 2.2 below shows the UK DTT multiplex licensees and their mode of operation. (72% of households are able to receive all 6 multiplexes, assuming ideal receiving aerials.)

Table 2.2 UK DTT Situation [16] [23]

Multiplex Licence	1	2	A	B (Freeview)	C (Freeview)	D (Freeview)
Operator	BBC	D3&4 (ITV+C4)	SDN (C5+S4C+ntl)	BBC	Crown Castle	Crown Castle
DVB-T Mode	16QAM	64QAM	64QAM	16QAM	16QAM	16QAM
Coverage	87%	81%	79%	85%	81%	72%

2.2.1.5 The DTT transmitter network

DTT was launched in 1998 with 80 transmitting stations on-air. There have since been many small changes to the network to improve coverage.

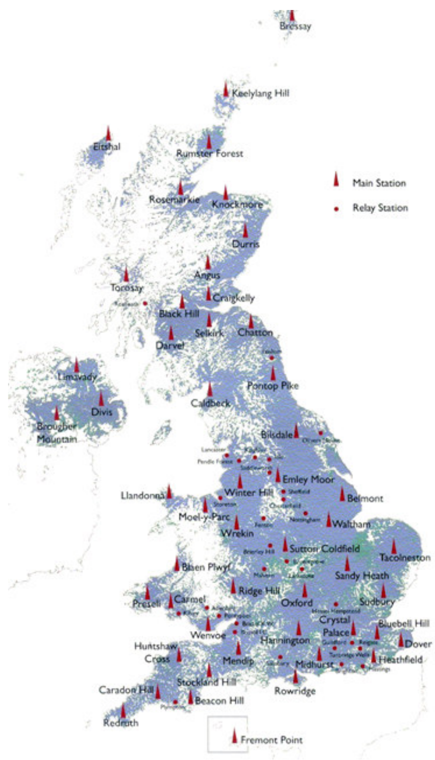


Figure 2.3 DTT transmitters in UK [23]

2.2.1.6 DTT Multiplex coverage equalisation

The initial network plan provided Mux BBC to 81% of UK households but Mux D, which was ITV Digital, to only 64% of UK households. The 'core' coverage was only 56%, that is, where all 6 multiplexes could be received. Following the launch of DTT in the UK it became clear that the 'core' coverage effected the take up of DTT. Work proceeded to equalise the coverage, by increasing the transmitter powers where possible. [Figure 2.4]

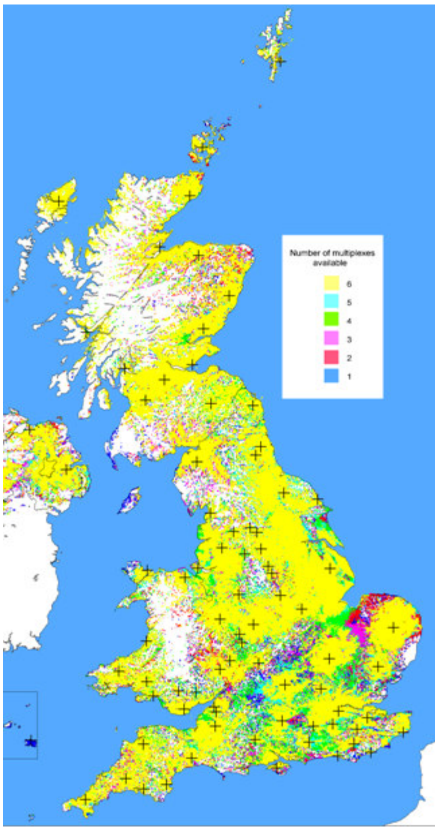


Figure 2.4: UK DTT Multiplex coverage equalisation [23]

2.2.1.7 Network choices (SFN/MFN)

It is recognised that SFNs can offer improved spectrum efficiency with a typical saving of 1/3 but they require a free VHF/UHF channel over the whole of the target service area. SFNs also can give greater uniformity of coverage for portable reception, but a relatively dense network of lower-power transmitters is required.

In the UK there were no free channels for regional SFNs. The prime requirement was for fixed rooftop reception. MFNs allowed DTT transmissions to be interleaved with analogue channels making use of adjacent channels to analogue from most TV stations.

2.2.1.8 DVB-T channel interleaved planning

The planning is based on the planning scenario 1 in the TG 6/8 report [24].

“The primary assumption made for this scenario is that all existing or planned analogue assignments1 would need to be protected by every new digital requirement for the indefinite future. However, the analogue assignments will continue in use without any changes and their coverage areas will be effected only to a certain extent by new digital requirements.” [24]

“DVB-T can make use of channels adjacent to analogue transmission at a given station. Considering the fact that adjacent channel analogue/analogue transmissions interfere with each other, adjacent analogue/DVB-T transmissions can be co-sited because DVB-T is lower power (won’t interfere with analogue) and it is more rugged (analogue won’t interfere with DVB-T). Adjacent channels are extensively used in the UK plan.

Nevertheless, not all DVB-T channels can be located adjacent to the analogue service, other channels had to be found to provide 6 multiplexes at some stations and these channels may give different coverage resulting in unequal coverage between multiplexes.

It is not possible to achieve universal DTT coverage whilst the analogue network remains in service” [23]

2.2.1.9 Channels used at a single transmitting station

“Most of the channels are used in groups of 4 for the 4 national analogue services (BBC One, BBC Two, ITV 1 and ‘Channel 4’). The ‘Five’ service was planned separately (and much later) and is accommodated mainly in Channel 35 and Channel 37. Each analogue service or DTT multiplex requires one frequency channel so some transmitting stations radiate 11 different television transmissions (others fewer, and some even more than 11).” [23]

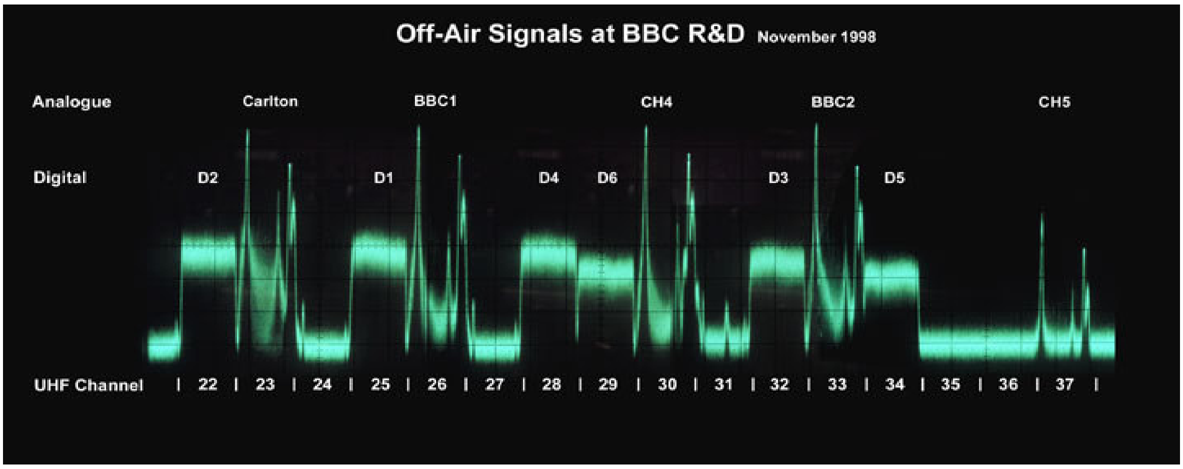


Figure 2.5: Off-Air Signals at BBC R&D [23]

D1-D6 (the square wave) represents the 6 digital channels, the spikes reprents the anologue TV signals.

2.2.1.10 Co-ordination of DTT after Chester 97

"The UK had rules on which to base our negotiations with European neighbours. Other countries started planning DVB-T services – the UK could now make bilateral agreements on a station for station basis. Nevertheless, Chester 97 rules are too strict to allow the UK and its neighbours achieve their required coverage.

Relaxations have been agreed bilaterally and detailed planning methods adopted to achieve the desired objectives including terrain based predictions and complicated antenna designs" [23]

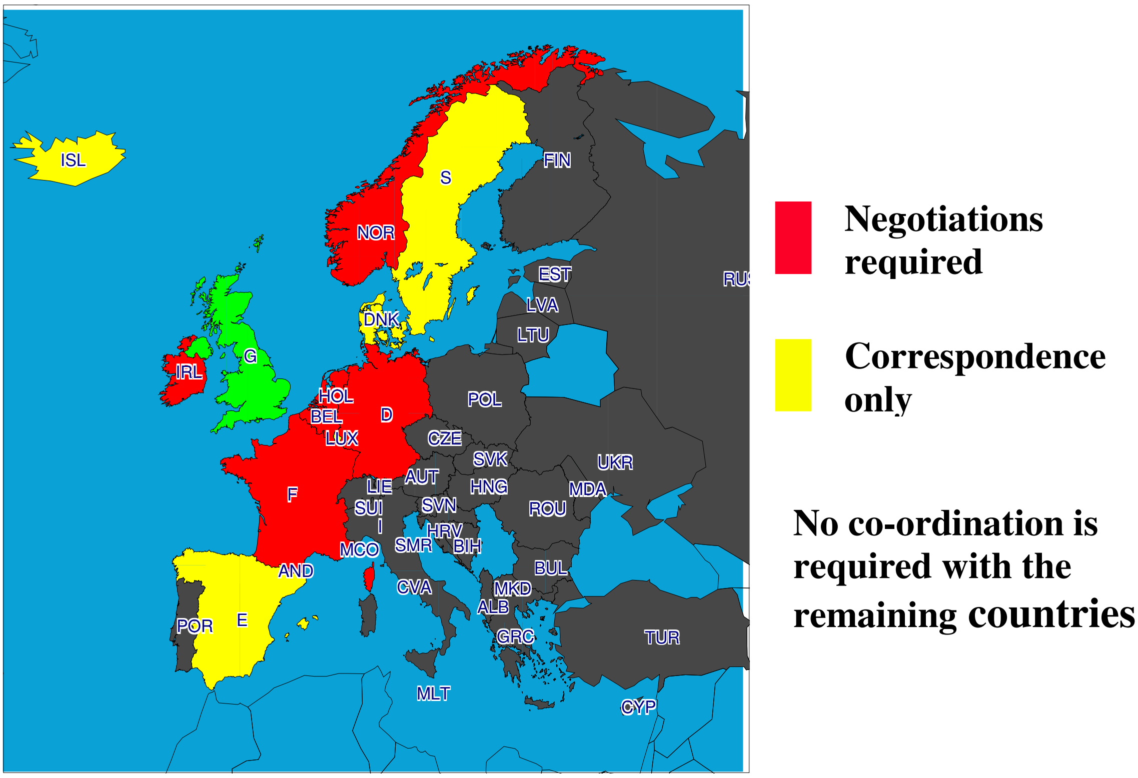


Figure 2.6: Co-ordination of UK DVB-T with neighbouring countries

2.2.1.11 ITU Regional Radiocommunications Conference, May/June 2006

RRC-06 scope

1. Digital broadcasting planning in the bands:
   174-230 MHz (Band III)
   470-862 MHz (Band IV and V, Channels 21 to 69)
2. Sound and television broadcasting
3. Other radio services having international status

4. RRC-06 impact upon UK:
   - T-DAB in Band III (current use and planned future use)
   - Mobile radio services in Band III

- DVB-T in Bands IV and V
- Aeronautical radars in Ch 36
- Radio astronomy in Ch 38
- Spectrum designated for release following digital switchover (the “digital dividend”)
- Programme-making servies in Bands III, IV and V , including Ch 69;

2.2.1.12 Spectrum trading and liberalisation in UK

“Spectrum trading and liberalisation has been introduced in bands traditionally used for telecommunications. However, the distinction between broadcasting and communications is becoming less clear as services continue to converge and some broadcasting services are likely to appear in non-traditional bands in the future.

Mobile media is an important concept in that a handheld terminal can combine broadcast reception with 3G connectivity and services. As is typical in such initiatives, there is international standardisation activity. Some proposals for spectrum envisage fitting DVB-H within a DVB-T framework but a standalone channel is an alternative. The flexible spectrum regime which the UK is trying to create opens up the possibility of acquiring a channel for mobile media. However, if it is to be combined with 3G to make converged services, then for international roaming it would help if there was some international spectrum harmonisation.

Changing spectrum use is a very slow process and the shortcomings in assigned spectrum are overcome by expensive engineering methods and innovative technologies. Using more appropriate spectrum could have as great an impact as a major technology step.

Ofcom is changing from Command and Control to Market Mechanisms plus some Licence-Exempt use. The Market Mechanisms are that the regulator partitions spectrum and ownership and use are driven by market forces.”[29]

Allocation and Management Methods

1. “On –demand” assignment
2. Band plans/ harmonisation
3. “Beauty contests”
4. Administered Incentive Pricing
    - Regulator can over-recover costs
    - Price based on value compared with alternatives
    - Price should influence usage
5. Auctions
    - Fairest method of assignment.
    - Auction design difficult (or may distort outcome)
    - New/Existing operator difference
    - UK 3G auction excessive payments
    - Normal allocation method for new spectrum in future
6. Spectrum trading
    - Based on economic ideas (market mechanisms)

- Permits changes in ownership and use
- Started in December 2004 in UK
- Transfers of licences
- Liberalisation of use of permitted
- Ofcom forecasts 72% of spectrum allocated by trading approach by 2010

"Spectrum trading and liberalisation has been introduced in bands traditionally used for telecommunications and gives greater flexibility. The distinction between broadcasting and communications is becoming less clear. Services continue to converge and some services are likely to appear in non-traditional bands in future."[29]

2.2.1.13 The UK Government's 'vision' for a digital future

The Government has not specified explicitly what it expects to be in place before analogue television can be switched off, but it expects:

- digital coverage (of one form or another) to match the present coverage of public service analogue television
- affordable digital receiving equipment 'accessible' to 95% of consumers
- switch over to occur between 2006 and 2010
- penetration (at least 70% of the UK population)

The Government has issued a 'Digital Television Action Plan' which has mandated the setting up of a spectrum planning group to produce plans that would allow 'DTT only use of the spectrum' (bands IV and V).

The Government acknowledges that switch over will be a sequence in time with geographical phasing.

The likely end result will be a mix of different platforms, although the terrestrial platform will be a principal concern because most viewers still rely on it. [23]

2.2.2 Frequency usage in Germany

2.2.2.1 Currently used spectrum

From [3]:

"In Germany bands I, III and IV/V are currently being used for the transmission of analogue terrestrial television. In band I these are channels 2 to 4 and in band III channels 5 to 11 each with a bandwidth of 7 MHz. This corresponds to a bandwidth of 70 MHz. Channel 12 was assigned to digital sound broadcasting T-DAB in the Wiesbaden Plan 1995 and is no longer used by television in Germany. In Band IV/V channels 21 to 60 are used for analogue television. In total, 50 channels are currently being used by analogue terrestrial television in Germany."

Figure 2.7 gives a general view of the frequency allocation for analogue and digital TV in channels 05 to 65 in Berlin. Table A1 lists the detailed frequency allocation in the VHF-UHF band in Germany.

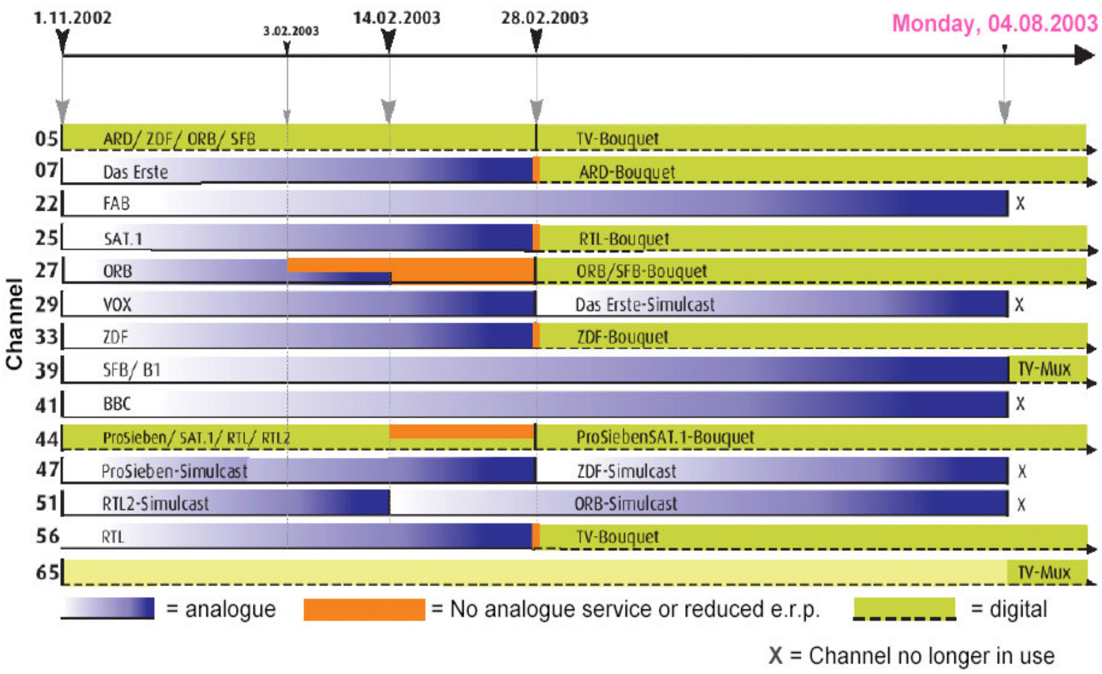


Figure 2.7: Channel Usage in Berlin [25]

2.2.2.2 Future spectrum needs after the analogue switch-off

From [3]:

“Due to the digitalisation of television transmission broadcasters will no longer need band I and can make channels 2 to 4 - corresponding to 21 MHz - available to the spectrum management authorities for other purposes. Also, two further channels in band III are intended to be used additionally to Plan WI 95 for T-DAB. Therefore, in the VHF-band around 35 MHz (5 channels) will no longer be used in future for terrestrial television and can be released for other services.

To facilitate the transition from analogue to digital broadcasting, channels 64 to 66 are available for DVB-T. Unlike in some other European countries, channels 61 to 63 and 67 to 69 will not be available for broadcasting in Germany in the medium term although they could become available in the long-term. Moreover, radio astronomy services must be protected in channel 38 and its use for broadcasting is highly restricted or not possible. Within the VHF- and UHF- bands 49 channels are available in total for DVB-T.

Spectrum needs for DVB-T depend primarily on the number of programmes and envisaged service goals and hence on the expansion of DVB-T networks. In Germany requirements for DVB-T are expected for 24 to 30 programmes or 6 multiplexes with the aim of portable indoor or outdoor reception, i.e. without rooftop aerials. This is to improve the acceptance of terrestrial television, which has been strongly diminished over the past few years due to the relatively small number of programmes available. Mobile reception also serves this purpose and hence is part of the strategic considerations for DVB-T. To achieve this envisaged goal, a preferably robust transmission mode has to be selected. A compromise must be found between transmittable data capacity and susceptibility to interference. Hence, Germany has opted for the DVB-T variant 16QAM with code rate 2/3. Higher-level modulation such as 64QAM (code rate 7/8) can enable almost twice the data rate but is very sensitive to interference and therefore is at best suitable for reception via rooftop aerials. With the chosen 16QAM (R=2/3) variant one can accommodate 4 PAL quality TV programmes in an 8 MHz TV channel. Given that one needs around 7 TV channels for full area coverage in Europe, this means 6-7 multiplexes. With the selected DVB-T variant one could realise the envisaged 24 to 28 programmes. This would approximate the number of analogue programmes that are transmitted by cable today and ought to suffice for an improved acceptance of terrestrial television."

Most of the German "Länder" have now published their digital TV rollout plans. The experience of the successful introduction of DVB-T in Berlin will be used in most "Länder" as the model with a short simulcast phase. In Berlin digital TV was offered with sufficient transmission power for the private and public broadcasters in November 2002. After less than 6 months analogue TV from private broadcasters was switched off. The released spectrum was used for another multiplex and to improve the coverage and reliability of digital services. For the wider Berlin area the SFN topology was used which required 2-3 transmitter sites for each frequency. In August 2003 the analogue transmission of the public broadcast services ended. The released spectrum was used to further improve the coverage and to pilot data services (DVB-H/T). By the end of 2003, more digital receivers had been sold in Berlin than there had been households depending on analogue terrestrial TV in 2001. This success was mainly due to the availability of cheap receivers (e.g. 69 Euro), the very good coverage of DVB-T (portable indoor and mobile reception) right from the beginning, and the coordination of all major players (public and private broadcasters, network operators, manufacturers) together with the Landesmedienanstalt (media board) of Berlin.

The transition to digital TV will be finalised for the major 15 urban areas of Germany by 2006. The last analogue TV transmitter should be switched off 2010. By 2010 there should be stationary reception for 95% of the population. Nevertheless, the final coverage of DVB-T will depend on the market success of DVB-T and there are no concrete rollout plans for Germany as a whole.

2.2.2.3 Digital terrestrial television

Figure 2.8 and Table 2.3 show the current reception area of DTT in Germany.

An example of Channel allocation in the Frankfurt area is given in Figure 2.9. One channel (Ch 8) is in the VHF band, the others are all in the UHF band. Ch 8 and Ch 22 carry 3 programmes plus a MHP data service each. The other channels carry 4 programmes. Ch 64 will be operational in spring 2005. Here, 1 programme is replaced by a media service.

Table 2.3: Overview of the areas in Germany where DVB-T signals can be received

Area	Start of DVB-T switch-over	Date of switch-off of analogue services	Number of multiplexes
Verbreitungsgebiet	Umstellungsbeginn	Analogabschaltung	Multiplexe
Berlin	1. November 2002	4. August 2003	erst 2, jetzt 7
Bremen/Unterweser [1]	24. Mai 2004	8. November 2004	5, später 6
Hannover/Braunschweig			4, später 6
Köln/Bonn [1]		April 2005	5, später 6
Rhein-Main-Gebiet	4. Oktober 2004	6. Dezember 2004	2, später 6
Düsseldorf/Ruhrgebiet	8. November 2004	April 2005	5
Hamburg/Lübeck		März 2005	6/7
Kiel + Schleswig		März 2005	5, später 6
München + Nürnberg [1]	31. Mai 2005		je 5
Halle/Leipzig	2. Quartal 2005		3 bis 4
Erfurt/Weimar	2. Quartal 2005		2 bis 3
Rostock/Schwerin	geplant 2005, spätestens 2007		vorerst 2
Ludwigshafen/Mannheim	geplant 2005		5
Saarland	geplant 2006		6
Stuttgart [1]	Ende 2006		5, später 6

1. DVB-T in normal operation (analogue services switched off)
2. DVB-T operation started in 2004
3. DVB-T operation to start in 2005
4. DVB-T operation not before 2006

Figure 2.8: DVB-T reception areas: current situation in Germany Status of November 2004

DVB-T-Kanalbelegung im Rhein-Main-Gebiet ab 6. Dezember 2004

Kanal	Sender
8	Das Erste
	Arte
	Phoenix
	MHP Datendienst
22	ZDF
	Kinderkanal/ ZDF dokukanal
	ZDF infokanal/ 3sat
	MHP Datendienst
34	RTL
	VOX
	RTL II
	Super RTL
54	SAT 1
	PRO 7
	N 24
	Kabel 1
57	hessen Fernsehen
	Südwest Fernsehen
	Bayrisches Fernsehen
	Eins Festival
64**	CNN
	Eurosport
	Rhein-Main-TV
	Mediendienst

** spätestens im Frühjahr 2005

Figure 2.9: Channel allocation in the Frankfurt

2.2.3 Frequency usage in France

The CSA has opted for a mixed national digital network, basically, a bit of both models: MFN on the one hand and SFN on the other hand.

The planning of the frequencies is carried out within the UHF band used in parallel to analogue transmissions (channels 21 to 65), with the objective of minimising the frequency re-planning of gap-fillers necessary to ensure the continuity of service of the analogue reception. Frequency planning is made with the priority of using the main sites currently used to broadcast analogue television

Frequency reassignment:

An operational structure in charge of the realisation on a large scale of the analogue frequency re-channelling has been created by the CSA. This structure, called “GIE fréquences”, is using the ANFR re-farming fund. The re-channelling operations for 230 frequencies have already been made.

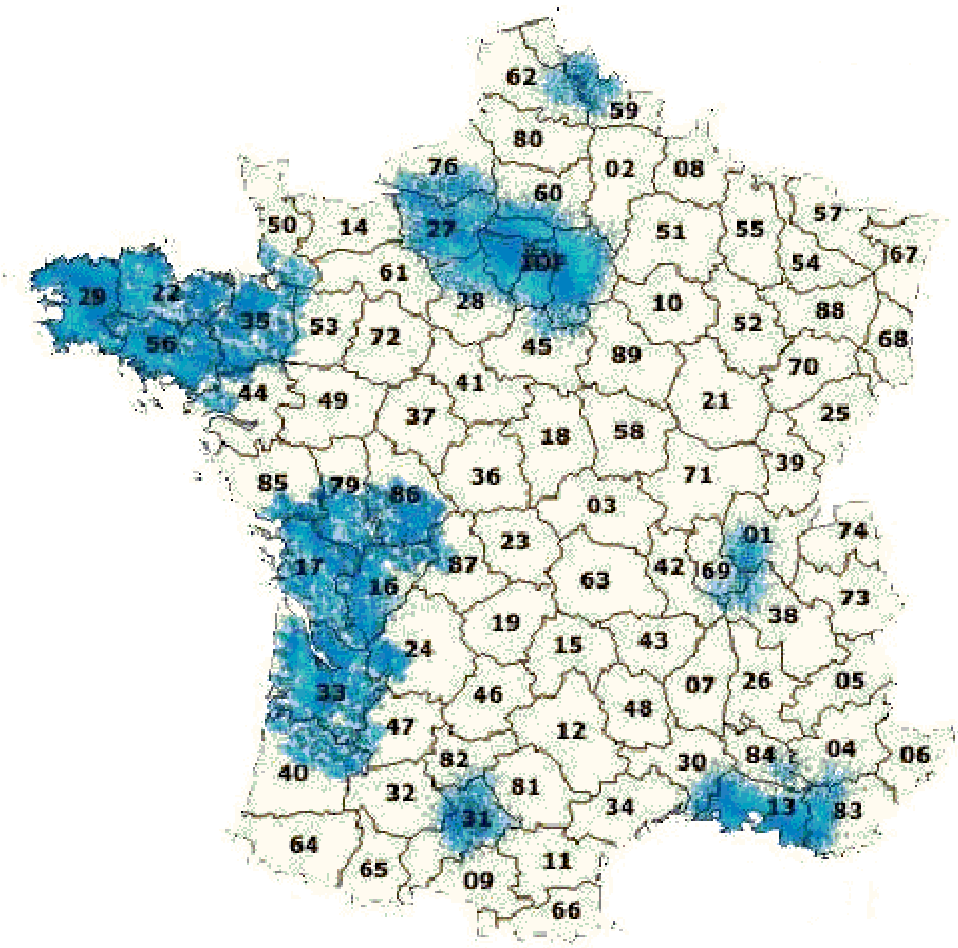
- "GIE Fréquences" represents analogue channels. It is negotiating with the French agency in charge of frequencies, ANFR, on the one hand and monitoring the contractors.
- There are 3 contractors: TDF handles the transmission side- Espace Numérique won the tender to handle Communication and reception. A third player is to handle the call centre.
- TDF has already reassigned over 260 frequencies between 2003 & 2004 to GIE.

The CSA believes that 1500 reassignments for the 105 designated areas will be necessary. For the first two DTT phases, about 400 reassignments will have to be made between now and September 2005.

The objective for terrestrial digital television is to reach coverage of 35 % of the French population by the 31st of March 2005 (17 sites).

Note:

The planning of the first sites is published with some details on the CSA server. Planning of the remaining sites is on going progressively.



French DTT pre-launch coverage (free-to-air programmes)

DTT Channels

From the 31st of March 2005, 14 free-to-air channels will be broadcast:

TF1, France 2, France 3, France 4, France 5, Canal + (non-encrypted broadcast), M6, Arte, Direct 8, W9, TMC, NT1, NRJ 12, La Chaîne parlementaire

The agreed composition of the multiplexes should be:

M1: France 2, France 3, France 4, France 5, Arte, and La Chaîne Parlementaire

M2: EUROPE 2 TV, Canal J*, Direct 8, TMC, BFM, Gulliver

M3: Canal +*, I télé, Sport+, CANAL+ Cinéma*, and Planète*

M4: W9, M6 music, TF6*, Paris Première*, NT1, and AB1*

M5: To be dedicated to DVB-H

M6: TF1, LCI(*), Eurosport*, TPS Star*, and NRJ 12

* Pay-TV, will start in September 2005

The composition of the multiplex can be subject to changes. A ministerial co-ordination group is established and is now meeting regularly with the participation of all the key players. Furthermore, an association for the promotion of DTT in France has been created.

The CSA finalised in June 2003, jointly with the selected applicants, the agreement between the CSA and each DTT service editor. Since, the editors holding user rights for the same radio resource jointly proposed a multiplex operator. The multiplex operators have been created by the DTT licence holders, sharing the same multiplex, and have received their authorizations for frequency usage.

Distributors who wish to market authorized service editors' programmes to the public will have to make a declaration to the CSA.

Service editors, authorised to operate television services, and requiring payment from users, must make the appropriate agreements, ensuring that each reception terminal receives all the programmes and all services relating to it. These agreements should be made within two months of the issuance of receipt of the declarations made by the commercial distributors. Service editors holding an authorisation will have to ensure that programmes begin on the date and in the conditions laid down in their authorisation. This date will be set by the CSA in consideration of the development and investment plans forecast, and allowing for the time needed to solve any pending issues.

The CSA will also collaborate in the implementation by the public authorities of measures enabling a smooth transition from analogue to digital television and to ensure the viable development of DTT.

The time schedule for starting the digital transmissions was set by the CSA.

The CSA has decided to dedicate the 5th multiplex to DVB-H.

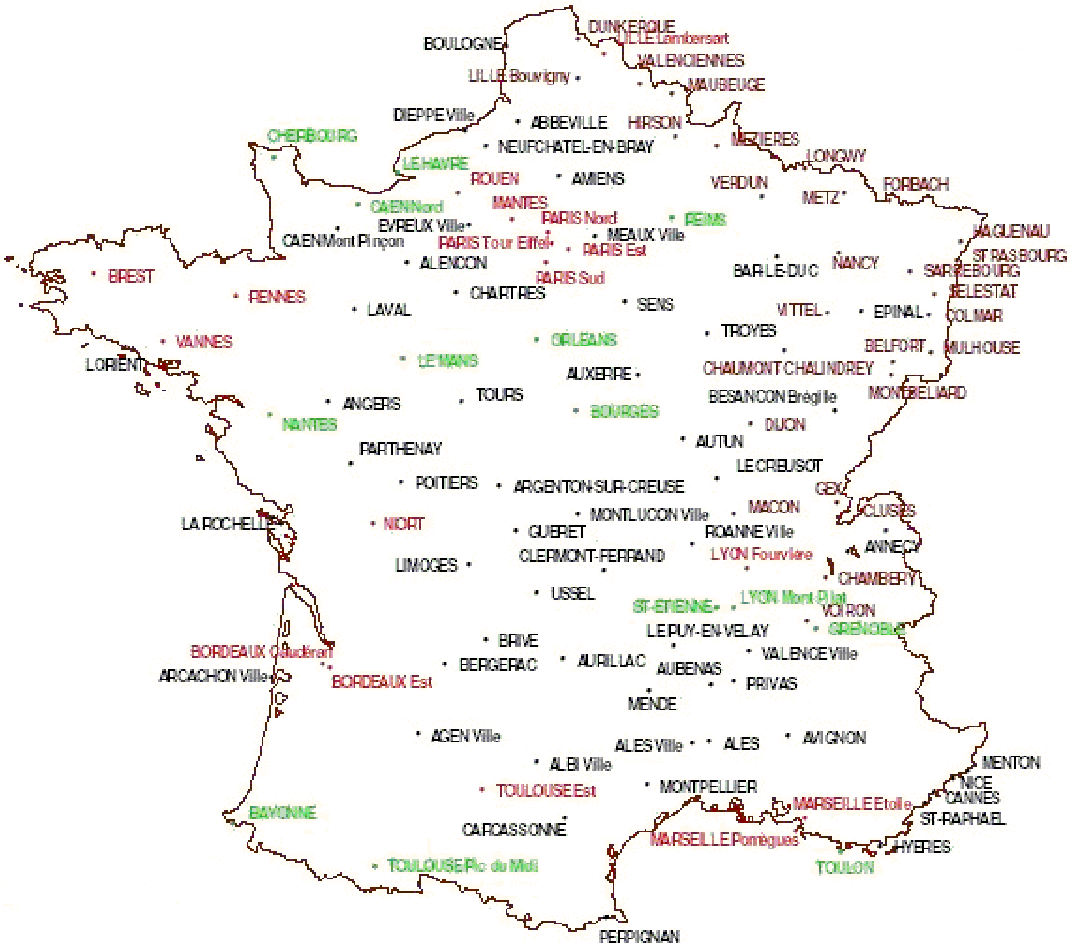
It has now been decided to operate the free to air programmes in MPEG-2 and the pay-TV programmes in MPEG-4/H-264. Hence the launch of pay TV may be delayed.

2.2.3.1 Future spectrum usage

The objectives for terrestrial digital television are to reach coverage of 50 % in September 2005 (32 sites), and in the long term, of 80 % to 85 % of the French population (105 sites). By The end of June 2005 500,000 receivers were sold.

From September 05, launch of commercial pay per view DTT (in a 6 month window) with the following channels:

AB1, Canal + (encrypted), Eurosport, LCI, Paris-Première, TF6,TPS Star



Sites for March 05
Sites for September 05
Other sites already planned
Sites for future planning phases

The objective for 2007 is 105 transmission sites covering nearly 85% of the population.

2.2.4 Frequency usage in The Netherlands [3]

2.2.4.1 Currently used spectrum

From [3]:

"On the 31st of January 2002 the State Secretary for transport, public works and water management, granted the licenses for use of frequency space for digital terrestrial television. The public license is given to the NOS, an organisation in the Netherlands which now exploits analogue public television (one multiplex). The license for commercial purposes is given to Digitenne Holding (four multiplexes).

The licenses are given on a basis of NIB (Non Interference Basis). The reason is that co-ordination is not ready for all the surrounding countries of the Netherlands. The licenses are given for a period of 15 years ending on 31st December 2016.

Digitenne and NOS started together in April 2003 with regular digital commercial transmissions in part of the so-called Randstad area and they are now in a position to finalise their multiplexes in the complete Randstad area."

2.2.4.2 Digital Switch-over

From [3]:

"A government appointed advisory commission proposed that a switch off should be realised around 2007, provided that some necessary conditions are fulfilled at that time.

Public broadcasters are now studying in detail how the transition to digital could take place in the fastest way. There is a proposal using the regional frequencies with the following schematic steps:

1) Simulcast the regional program in DVB-T on a temporary frequency.
2) After half a year analogue broadcasting will be switched off, and the frequency will then be used to transmit all 3 nationwide programs plus the regional program in DVB-T.
3) Step 2 is the beginning of the half-year simulcast for the 3 nationwide programs in that region.

Even this scheme would take a period of some 3-4 years to complete the switch over.

2.2.4.3 Cable interference

From [3]:

"The license holder, the cable operator and the Government will cover problems that can be solved by using good cable material. The Government will contribute an amount of 2.7 million Euros to solving such problems. The cost of solving problems that cannot be solved by using good cable material must be paid for by the license holder."

2.2.5 Frequency usage in Brazil

2.2.5.1 Current spectrum allocation

From [21]:

Sub-band (in MHZ)	Use in Brazil
54-72	Broadcasting of audio and video – transmission and retransmission of VHF signal.
72-76	Restrict radiation – radio command systems and listening aid devices
76-87.8	Broadcasting – basic channel distribution on VHF and UHF transmission.
87.8-88	Neighbourhood broadcasting.

88-108	Audio Broadcasting – basic channel distribution on FM transmission.
108-144	Aeronautical – radio – navigation space to Earth. Meteorological-satellite. Space research. Mobile-Satellite. Meteorological aids.
174-216	Broadcasting – basic channel distribution on VHF and UHF transmission and retransmission.
470-608	Broadcasting – basic channel distribution on VHF and UHF retransmission.
608-614	Radio – astronomy.
614-806	Broadcasting – basic channel distribution on VHF and UHF transmission and retransmission.

2.2.5.2 Plan of digital spectrum usage

From [22]:

"Channel planning
Channels:

1. Transition phase: "Simulcasting" of analogue and digital television in the UHF (preferentially) and the VHF high (channels 7 to 13) bands.
2. Digital phase: Digital TV only"

Digital TV is planned to be allocated channels 14 to 59 only considering the possibility of frequency re-utilisation. And, if the system hasn't full capacity of reuse, the channels between 60 and 69 could be used also. The basic plan foresees 1893 digital channels over all Brazilian states (From [22]).

2.2.6 Summary

In the UK if all the frequencies used by analogue TV are released for use by Digital TV, then 368MHz will become available for use by Digital TV. During the simulcast period, the frequencies available for Digital TV are more limited. However, as long as the interference to the existing services is below a certain level, a frequency can be used for Digital TV.

In Germany 50 channels are currently used for analogue TV (counting in channel 12). During the simulcast stage, additional channels 64 and 66 will be available for digital broadcasting. Therefore, within the VHF- and UHF- bands 49 channels will be available for DVB-T after the switch over.

In France 45 (21-65) channels are used for analogue TV and an additional UHF frequency band will be planned for DVB-T during the simulcast period.

The situation in The Netherlands in terms of the channel allocation is still under review as is the planned data for the switch over.

The UK, Germany and France have all planned switch over for 2010. However, Italy and Finland are planning switch over as early as 2006 and Belgium, Denmark, Portugal plan to switch over in 2007. Sweden has planned to switch over in 2008.

Brazil plans to use UHF and VHF bands in the transition phase. The digital TV is planned to be allocated channels 14 to 59. Channels 60-69 will also be used if the system hasn't full capacity of reuse.

2.3 Frequency planning after introducing DVB-T/H

2.3.1 Frequency planning in the simulcast stage

In the simulcast phase, to enable a soft transition from analogue to digital TV (in Germany there will be a short simulcast phase of less than one year. The transition will be complete for all major urban areas in Germany by 2006), as a rule, this phase will entail increased spectrum needs. If the frequency used for analogue TV is not changed, then additional channels must be assigned to transmit the digital TV signal. (Otherwise, DVB-T/H must use the same frequency with the exiting services as long as they do not interfere with each other.)

If spectrum will be available during this phase for DVB-H it is to be expected that there will be less available than when this phase is complete. This probably means that if DVB-H is to be delivered during this phase, its frequencies may need to be reassigned after this phase.

A major issue is that countries are not going through simulcast stage in phase. As each country comes out of simulcast and tries to re-assign frequencies this will have an impact on its neighbours.

2.3.2 Frequency planning in the switchover stage

The EU's Radio Spectrum Policy Group (RSPG) adopted an opinion in November 2004 on "The Spectrum Implications of Switchover to Digital Broadcasting"[27]

This recognised:

- The benefits of switchover- more efficient and flexible spectrum use, the spectrum dividend, and the contribution to the strategic goals of the "Lisbon Agenda"
- The importance of coordination between member states on spectrum management to assist a quick and efficient switchover
- The benefits of a common approach to the transition period
- The need for initiatives to promote consumer benefits
- The value of flexibility in planning for both broadcasting and other radio services, with a technology-neutral approach for the latter

Digital Dividend
When the analogue TV services have been closed down, there will be some spectrum that can be used for other purposes, such as for:

1. More digital TV services to roof-top antennas
2. Digital TV services to mobile/handheld devices
3. Digital HDTV
4. DAB services(in band III)
5. Non-broadcast services

UK has already declared “112MHz” (bands 31-35, 37, 39-48, 63-68) dividend, but no other country has quantified it yet. [28]

In Germany during the short simulcast phase there is no spectrum available for DVB-H services. It is expected that Berlin will auction a frequency for IP Datacast based on DVB-H in 2005. In Munich a half multiplex will be used for DVB-H experimentation. Finland has already assigned a frequency for data services.

Apart from frequencies that were originally used for analogue TV becoming available for DVB-T/H, for spectrum usage efficiency some re-planning may be put into practice.

Whether or not new frequencies will be introduced for digital broadcasting depends on the services broadcast, i.e., will digital TV need more channels to meet consumer demand, and other factors like interference and frequency usage in neighbouring countries.

2.3.3 Summary

The simulcast phase is a critical time in the digital TV rollout process because the frequency allocation is more complex than in the switchover phase. The long simulcast phases for UK, Spain, etc. will delay the re-allocation of spectrum after 2006. The Nordic countries (Finland, Sweden) will have enough frequencies during the simulcast phase to allow for data services.

Not only do additional frequency bands need to be used but frequency sharing with existing analogue services is also considered. The frequency planning may also depend on negotiations with neighbouring countries. This is a more flexible phase than switchover.

After the switchover, some spectrum is released and re-farming the whole frequency usage for DVB-T/H is needed for spectrum efficiency.

The higher frequencies starting from 806 MHz may be particularly “congested”; since the allocation of the band 806-862 MHz to IMT2000 is on the Agenda of the WRC2010.

2.4 Network topologies for DVB-T/H

The services planned to be delivered by the INSTINCT open platform as encompassed in WP3 can be classified into four delivery classes:

1. Through a DVB-T network;
2. Through a DVB-H network (IP Datacast with no backchannel);
3. Through a joint DVB-T/H network;
4. Through UMTS (providing a back channel) and DVB-T/H or DVB-H network.

The corresponding network topologies can be broadly divided into two classes, the first is DVB on top of or co-cited with the cellular telecommunications network, which could be UMTS, GPRS or GSM; the other is a dedicated DVB-T or DVB-H network. In the simulcast stage, DVB on top of an analogue network will also be considered.

2.4.1 Dedicated DVB-T and DVB-H network

The dedicated DVB-T network will normally take over the transmitter sites and corresponding coverage area of an analogue TV network. The frequency planning depends on the following factors:

a) Services to be broadcast (how many programmes should be broadcast?)

b) The network deployment method (Single Frequency Network (SFN) or Multiple Frequency Network (MFN))

c) Coverage area context (Isolated island or bordered by different countries?)

d) The frequencies already used in the covered area.

e) The user mobility type (high speed in-car or indoor portable device)

If the DVB-T network is using the analogue TV site, the transmitting power of the DVB-T transmitter is limited by the requirement that the digital TV transmission does not interfere with the analogue TV transmission, and the number of sites available for DVB-T transmission is limited to the analogue sites available.

A dedicated DVB-T network mainly focuses on national area coverage, while a dedicated DVB-H network focuses on local area coverage [Figure 2.9]. Though there is no existing dedicated DVB-H network, it is clear that several issues need to be addressed before deploying such a network:

a) A low transmitter power transmitter will be used for localised coverage.

b) Network densification will be used to improve the capacity and coverage in urban areas.

c) The frequency reuse pattern for a MFN network.

d) The user mobility profile.

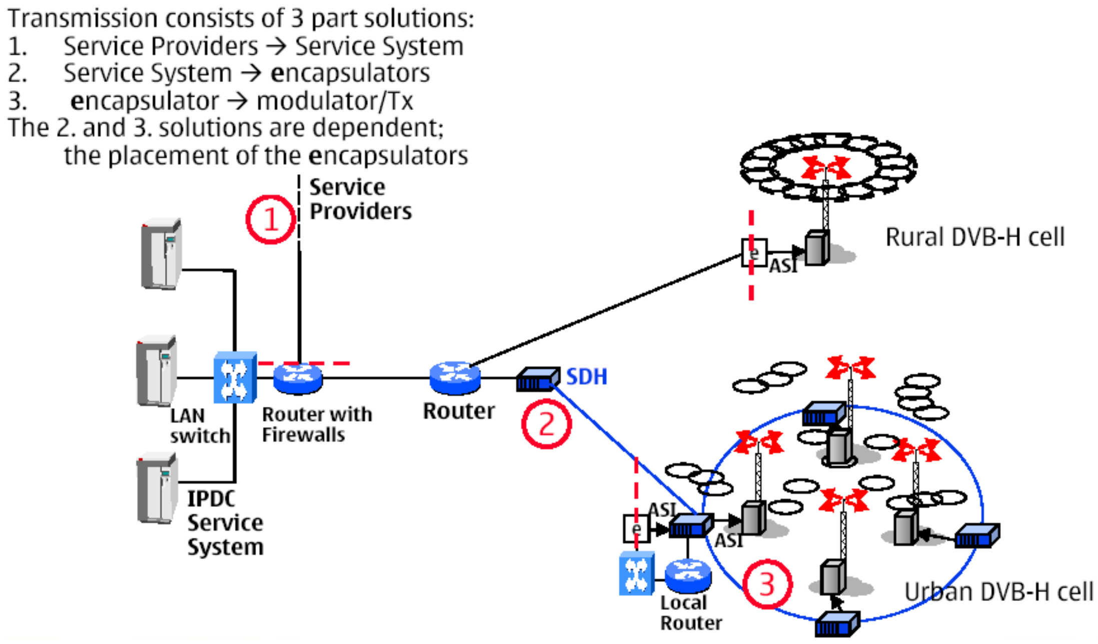


Figure 2.9: Dedicated DVB-H Network [4]

2.4.2 DVB-T/H co-cited with a cellular Telco network

In this scenario the cellular telecommunications network will provide a reverse channel to the user (Figure 2.10) for interactive services. If the DVB-T/H network is on top of the cellular network as [4] stated:

1. Mast height and power is limited
2. The cellular network is not always the "optimal" site of the broadcast network.

Before frequency planning for the DVB-T/H network begins several parameters should be set:

1. The cellular coverage area, what is the optimal site for the DVB-T/H transmitter? In [4], several types of coverage area are given:
   - Central business District
   - Urban Area, Tight blocks~ 5-6 floors
   - Suburban
   - Regional
   - Rural
   - Small provincial towns
   - Connecting main road to the remote towns
2. The protection ratio between the DVB transmitting power and the base station (BS) transmitting power
3. If DVB-T/H if planned as a MFN network, what is the reuse distance?

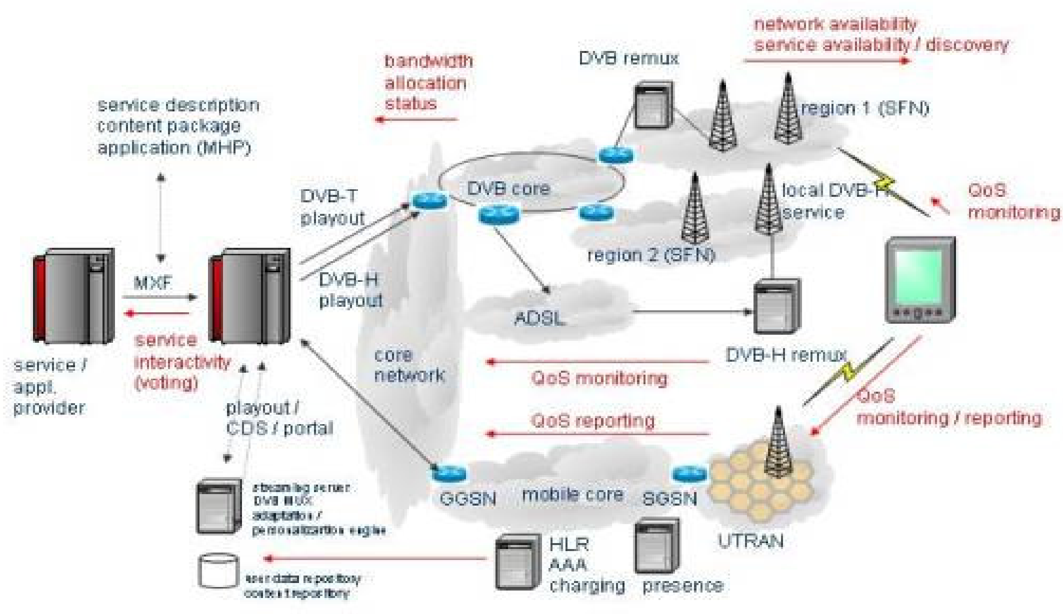


Figure 2.10: DVB-T/H Network and UMTS network convergence [7]

2.4.3 Existing DVB-T network and DVB-H sharing MUX

The DVB-H services are transmitted through the existing DVB-T Multiplex. Figure 2.11 shows this DVB-T/H co-sited network.

The factors effecting frequency planning for this network are the same as in 2.4.1 for a dedicated DVB-T network.

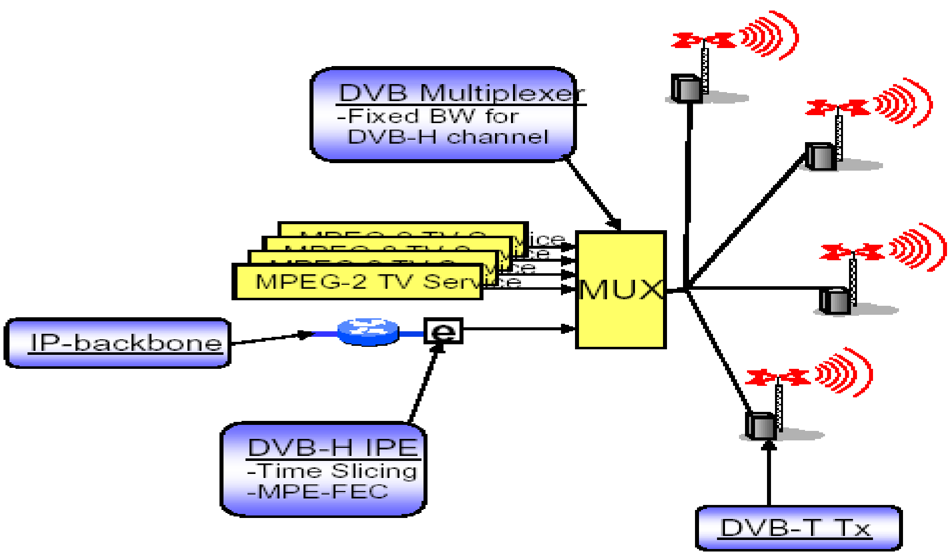


Figure 2.11: DVB-T/H co-siting network [6]

2.5 Protection ratio and Single Frequency Networks

2.5.1 Protection ratio

If the frequency band used for DVB-T/H is shared with other services and/or the neighbouring band is used by other services, some protection ratio must be provided. In [3], some guidance for determining the protection ratio for DVB-T is given, but for DVB-H the required protection ratio is not yet clear. A DVB-H signal may suffer from several sources of interference:

1. Other DVB-H signals
2. Analogue TV signals
3. T-DAB signals.

It should be noted that with the introduction of DVB-T into the broadcasting world, a decision on the revision for the Stockholm 1961 Regional Agreement (ST61) is ongoing (RRC04) and although some techniques and criteria for frequency planning have been proposed [1], the concepts and ideas of frequency planning for digital TV are still being developed.

2.5.2 Single Frequency Networks

From [8]: “SFNs offer the most spectrally efficient network architectures”. Significantly, the spectrum efficiency of DVB-H is higher than that of DAB unless large, e.g. nationwide, SFNs are envisaged [17].

From [17]:

“If the goal is to receive only data rates of less or a few 100 Kb/s, the DAB transmission system would be much superior to DVB-H with respect to processing power and reception performance.”

However, the Japanese experience of implementing a nationwide SFN for terrestrial digital TV broadcast stations is cautionary ([18-20]). In January 2001, the Japanese government launched a large project to shift the existing analogue UHF relay stations to another channel to make room for the digital SFN. The shift involves about 800 relay stations throughout Japan and its estimated cost is 1350 million euro funded by the government through RF licence charges.

Japan’s ISDB-T service was launched on 01 December 2003 in three major cities: Tokyo, Nagoya and Osaka. Nationwide coverage of digital TV services is expected by 2006, and the analogue switch-off is planned on 24 July 2011.

Commercial broadcasters in the Tokyo region have been having difficulty addressing the task of changing the current frequencies of analogue channels to prevent them from interfering with the frequencies for digital broadcasting. The result is that commercial broadcasters in the region cannot transmit strong digital waves. The broadcasters found it unavoidable to limit the number of households their digital broadcast signals can reach, in the initial stage to about 120,000 in central Tokyo.

2.6 Conclusions

Although the frequency left for DVB-T/H is mainly in Band III to V in Europe, the frequency planning for DVB-T/H is constrained by many factors as stated in Section 2.4. It can be stated during the simulcast period that less spectrum will be available for DVB-T/H than when the analogue TV is totally switched off. After the simulcast phase the frequency planning may also be re-farmed for spectrum efficiency. However, it is not clear that spectrum will be available for DVB-H services in all the countries of the European Union after the analogue switch-off. At the Spectrum Management in the field of Broadcasting Final Report Workshop under the aegis of the European Commission's DG INFOSEC UNIT B4 in Brussels on 30 June 2004 an EU initiative was recommended to make available at least 8 frequency channels in each member state for new services to be assigned on a market based technology and service neutral basis. In Brazil, an important example of an emerging economy adopting digital TV there is not anticipated to be shortage of spectrum for DVB-H.

First generation DVB-H receivers are specified only for frequencies 470-702 MHz (channel 21-49). When the cellular connection is implemented with GSM 900 technology, the higher channels are excluded to avoid radio interference between upper UHF channels and GSM 900. With other cellular technologies (e.g. GSM 1800, UMTS) higher parts of UHF V can also be used. The test channel 40 (626 MHz) is planned for the DVB-H pilot in Berlin. From the physical point of view, the VHF band would certainly be the most appropriate for high-speed reception. Nevertheless, first generation DVB-H receivers will support only UHF.

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[25]: Deutsche Telekom AG, TSI Media&Broadcast, Matthias Georgi; Practical experience gained during the introduction of digital terrestrial television broadcasting (DTTB) in Germany; BR Information Meeting on RRC-04/05, Geneva 2003

[26]: http://www.efis.dk/search/general

[27]Mike Goddard, "Developing the UK submission to RRC-06" , IEE seminar on Broadcasting Spectrum, London, 1 June 2005.

[28] Philip Laven, "RRC-06 and beyond", IEE seminar on Broadcasting Spectrum, London, 1 June 2005.

[29] Peter Ramsdale, "Trading and Liberalisation of Spectrum", IEE seminar on Broadcasting Spectrum, London, 1 June 2005.

Chapter 3 Densification and rules for "cellularized" DVB-T/H planning

With the new DVB-H standard a digital broadcast technology is available which is very well suited to be combined with mobile radio communication systems like GSM/GPRS or UMTS for delivery of IP datacast. Whereas radio network cell layout in broadcast and mobile communications was totally different in the past, e.g. large cells with high transmitters in broadcast systems and small cells down to "pico" cells with low power transmitters in mobile communication systems in dense urban areas, new network concepts for DVB-H transmitter networks have to be investigated which will allow the distribution of the new services enabled by datacast networks which combine the benefits of broadcast and mobile communication systems.

This chapter starts with a collection of predicted field strengths as a function of cell radius for different transmitter heights and powers based on the ITU-R P.1546-1 propagation model as it is used throughout the whole chapter.

The cell ranges for different DVB-T/-H reception modes are given for different transmitter heights / powers and for rural as well as for urban environments.

Coverage planning in the Berlin area was done for different radio network topologies.

In particular for different single frequency network (SFN) structures coverage probability predictions were done and analyzed. It turns out that large SFNs where the size of the whole network is large in comparison to the guard interval are possible without severe self-interference.

For multi-frequency networks (MFN) characterized mainly by their frequency reuse or cluster size different approaches were analyzed. Based on a hexagonal cell layout different C/I (carrier-to-interference) estimates are given for the use of omnidirectional transmit antennas. C/I values for different transmitter heights and cluster sizes are given for different cell radii and propagation environments at the terminal.

Sectorized cell layouts with 60° and 120° sectors are investigated and the estimated C/I values for different cluster sizes are tabulated.

As another means of reducing the required cluster size antenna down-tilting was investigated. It turns out that down-tilting will lower the required number of frequencies to deliver full area coverage, but it may be difficult to realize the required narrow elevation beamwidth of the transmit antennas.

As the most effective means of lowering the cluster size and thus obtaining the lowest number of frequencies required to deliver full area coverage, the illumination of MFN cells by SFNs consisting of three 120° sectorized transmitters is considered. Compared with the use of omnidirectional antennas in the cell centre there is no need for additional transmitter locations, but the cluster size can be reduced significantly at the expense of two additional transmitters and antennas at each transmitter site.

3.1 Introduction

Within Task 6.1 “Radio network engineering, dimensioning and resource management” of the INSTINCT project T-Systems performed planning exercises with respect to:

- Densification of networks and
- Identification of rules for “cellularized” DVB-T/H planning.

In a first step a catalogue of reachable cell ranges for different transmitter and receiver parameter sets for DVB-T as well as for DVB-H was produced based on ITU-R P.1546-1 propagation models [3]

By means of area coverage planning examples, comparisons of different MFN as well as SFN network topologies were made. The area coverage planning examples given in this chapter are for the Berlin area and are based on the planning tool *ruVIP* used within the Media&Broadcast Division of T-Systems for the planning of terrestrial broadcast transmitter networks.

If not noted otherwise, all calculations in this chapter are done for a frequency of 618 MHz (channel 39, band IV).

3.2 Cell range

3.2.1 Field strength propagation curves

To obtain an overview of the possible cell ranges for DVB-H as well as DVB-T a comprehensive catalogue of propagation curves was produced. These curves show the median predicted field strength values. The parameters varied for these curves were:

- Height of the transmitter: 20 m, 30 m, 50 m, 75 m, 150 m, 300 m.
- Power of the transmitter (ERP): 200 W, 300 W, 500 W, 1 kW, 10 kW, 20 kW, 50 kW.
- Environment of the terminal: Rural, Urban.

The propagation model is based on ITU-R P.1546-1 curves and takes into account correction for the terminal height as well as the environment around the terminal.

In Figure 3.1 the predicted field strength as a function of the distance between the transmitter and the terminal is given for a terminal antenna height of 1.5 m in a rural environment. Different transmitter antenna heights and different transmitter powers are considered.

In Figure 3.2 the predicted field strength for a terminal antenna height of 1.5 m is given for urban environment around the terminal. Again the transmitter height and the transmitter power are varied.

Figure 3.1 and Figure 3.2 show an additional loss of field strength in an urban environment in comparison to a rural environment as expected.

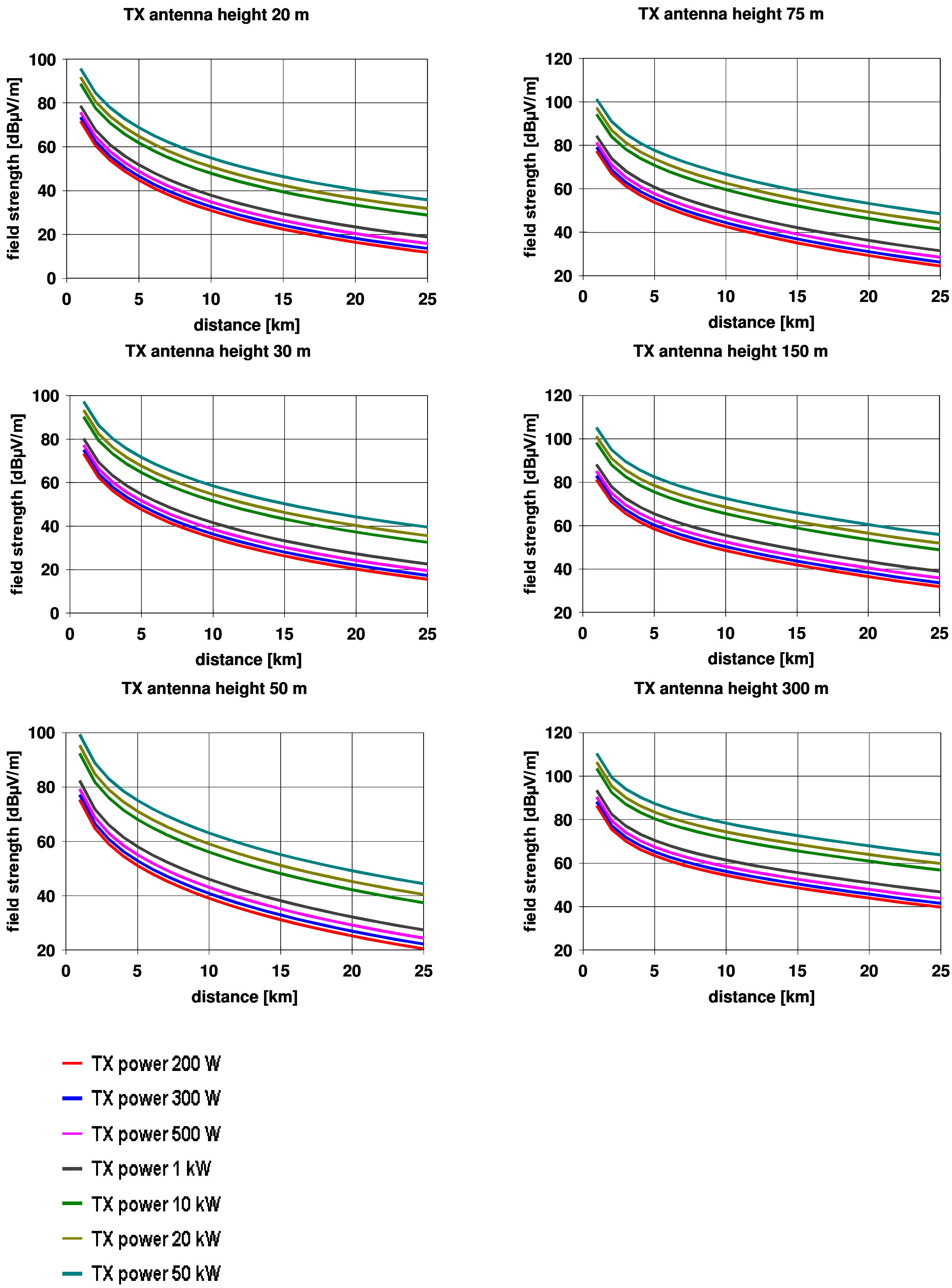


Figure 3.1: Field strength predicted using an ITU-R P.1546-1 based propagation model for a 1.5 m high terminal antenna in a rural environment for different transmitter heights and different transmitter powers.

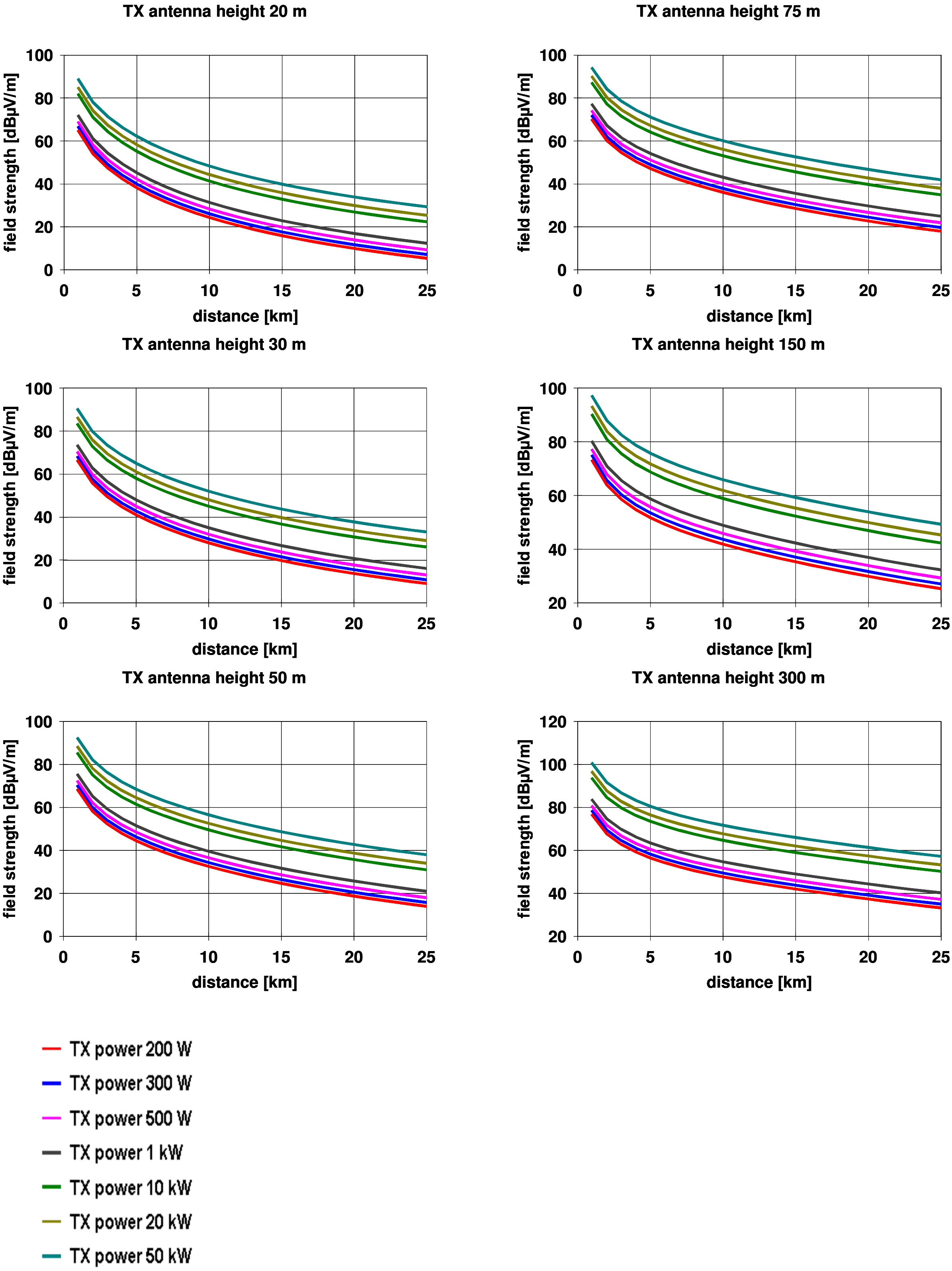


Figure 3.2: Field strength predicted using an ITU-R P.1546-1 based propagation model for a 1.5 m high terminal antenna in an urban environment for different transmitter heights and different transmitter powers.

3.2.2 Coverage range prediction

Based on the system-independent propagation curves in subsection 3.3.1 in this subsection, coverage ranges for DVB-T and DVB-H are calculated for the median field strength. In addition to the parameters varied for the propagation curves in subsection 3.2.1 the following parameters are considered here:

- Terminal class: class A, class B, class C, and class D in the case of DVB-H and indoor / outdoor for DVB-T.
- Coverage probability: 95 %, 99 %.

For a prediction standard deviation of 5.5 dB, the threshold for 95 % coverage probability is the predicted median value + 9 dB (1.64 x standard deviation) and for 99 % coverage probability is the predicted median value + 13 dB (2.33 x standard deviation).

For DVB-T and DVB-H the following system parameters are assumed for coverage calculations according to the Chester agreement and the ETSI draft TR 102 377 ("DVB-H implementation guidelines") [4]:

	8k OFDM mode, 16-QAM, inner coderate 2/3, guard interval 1/8					
	Chester DVB-T		**ETSI TR 102 377 DVB-H | MPE-FEC CR = 3/4**			
	Outdoor	Indoor	Class A	Class B	Class C	Class D
bandwidth B [MHz]	7,6	7,6	7,6	7,6	7,6	7,6
frequency f [MHz]	618	618	618	618	618	618
noise figure F [dB]	7	7	5	5	5	5
implementation loss [dB]	3	3	1	1	1	1
required C/N [dB]	14,2	14,2	15,1	15,1	18,1	18,1
antenna gain G [dBd]	0	0	-7	-7	-1	-7
cable loss L_f [dB]	0	0	0	0	0	0
man made noise Pmmn [dB]	0	0	0	0	0	0
height loss L_h [dB]	0	0	0	0	0	0
building penetration loss L_b [dB]	0	7	0	11	0	7
standard deviation [dB]	5,5	5,5	5,5	5,5	5,5	5,5
standard deviation (indoor) [dB]	0	6	0	6	0	0
k [Ws/K]	1,38E-23	1,38E-23	1,38E-23	1,38E-23	1,38E-23	1,38E-23
T_o [K]	290	290	290	290	290	290
c [m/s]	3,00E+08	3,00E+08	3,00E+08	3,00E+08	3,00E+08	3,00E+08
dBd -> dBi	2,14	2,14	2,14	2,14	2,14	2,14
L_h+L_b [dB]	0,0	7,0	0,0	11,0	0,0	7,0
Aa [dBm^2]	-15,1	-15,1	-22,1	-22,1	-16,1	-22,1
P_{n0} [dBm]	-105,2	-105,2	-105,2	-105,2	-105,2	-105,2
P_n [dBm]	-95,17	-95,17	-99,17	-99,17	-99,17	-99,17
$P_{s\ min}$ [dBm]	-80,97	-80,97	-84,07	-84,07	-81,07	-81,07
ϕ_{min} [dBm/m^2]	-65,84	-65,84	-61,94	-61,94	-64,94	-58,94
E_{min} [dBµV/m]	**49,92**	**49,92**	**53,82**	**53,82**	**50,82**	**56,82**
ϕ_{med} [dBm/m^2] 50%	-65,8	-58,8	-61,9	-50,9	-64,9	-51,9
E_{med} [dBµV/m] 50%	49,9	56,9	53,8	64,8	50,8	63,8
$P_{s\ med}$ [dBm] 50%	-81,0	-74,0	-84,1	-73,1	-81,1	-74,1
overall standard deviation	5,5	8,1	5,5	8,1	5,5	5,5
required coverage probability [%]	95,0	95,0	95,0	95,0	99,0	99,0
C_l [dB]	9,0	14,0	9,0	14,0	13,0	13,0
phi $_{med}$ [dBm/m^2]	-56,8	-44,8	-52,9	-36,9	-51,9	-38,9
E_{med} [dBµV/m]	**58,9**	**70,9**	**62,8**	**78,8**	**63,8**	**76,8**
$P_{s\ med}$ [dBm]	-72,0	-60,0	-75,1	-59,1	-68,1	-61,1

Table 3.1: System parameters of DVB-H and DVB-T for coverage prediction.

The last line in Table 3.1 gives the required received power threshold for the defined reception mode and the required coverage probability of 95 % or 99 % respectively.

Correspondent to the first column in Table 3.1 (DVB-T outdoor reception) Figure 3.3 shows the maximum distance between the transmitter and the receiver in an urban and a rural environment for a reception antenna at 1.5 m height as a function of transmitter power and as a function of transmitter height.

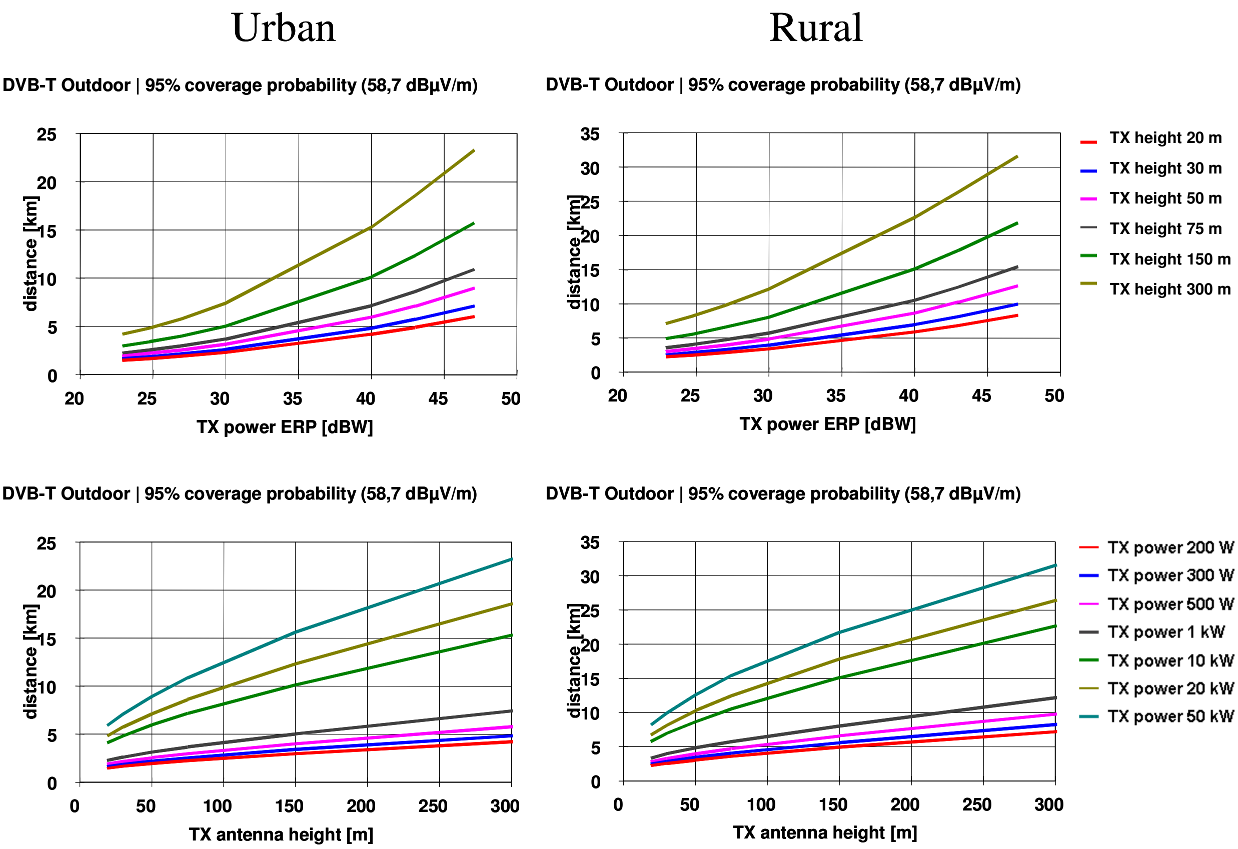


Figure 3.3: The maximum distance between the transmitter and the receiver for DVB-T outdoor reception in an urban (left) and a rural (right) terminal environment for different transmitter powers and heights

In Figure 3.4 the maximum distance between the transmitter and the receiver in an urban and a rural environment for DVB-T indoor reception correspondent to the second column of Table 3.1 is shown.

In Figure 3.5, Figure 3.6, Figure 3.7 and Figure 3.8 the maximum distances between the transmitter and the receiver in an urban and a rural environment for DVB-H reception with a terminal of class A, class B, class C and class D are depicted for different transmitter heights and powers. These figures correspond to columns 3 to 6 in Table 3.1.

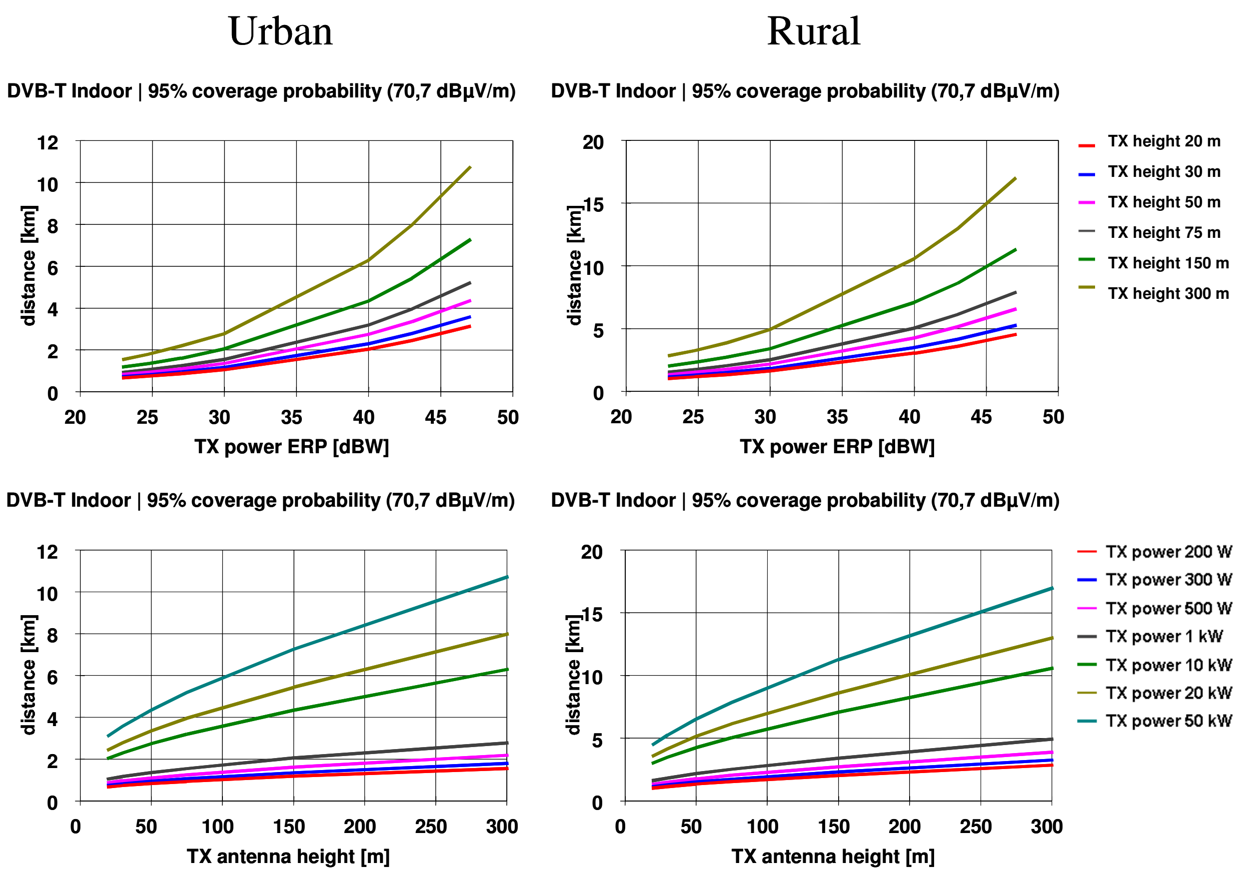


Figure 3.4: The maximum distance between the transmitter and the receiver for DVB-T indoor reception in an urban (left) and a rural (right) terminal environment for different transmitter powers and heights.

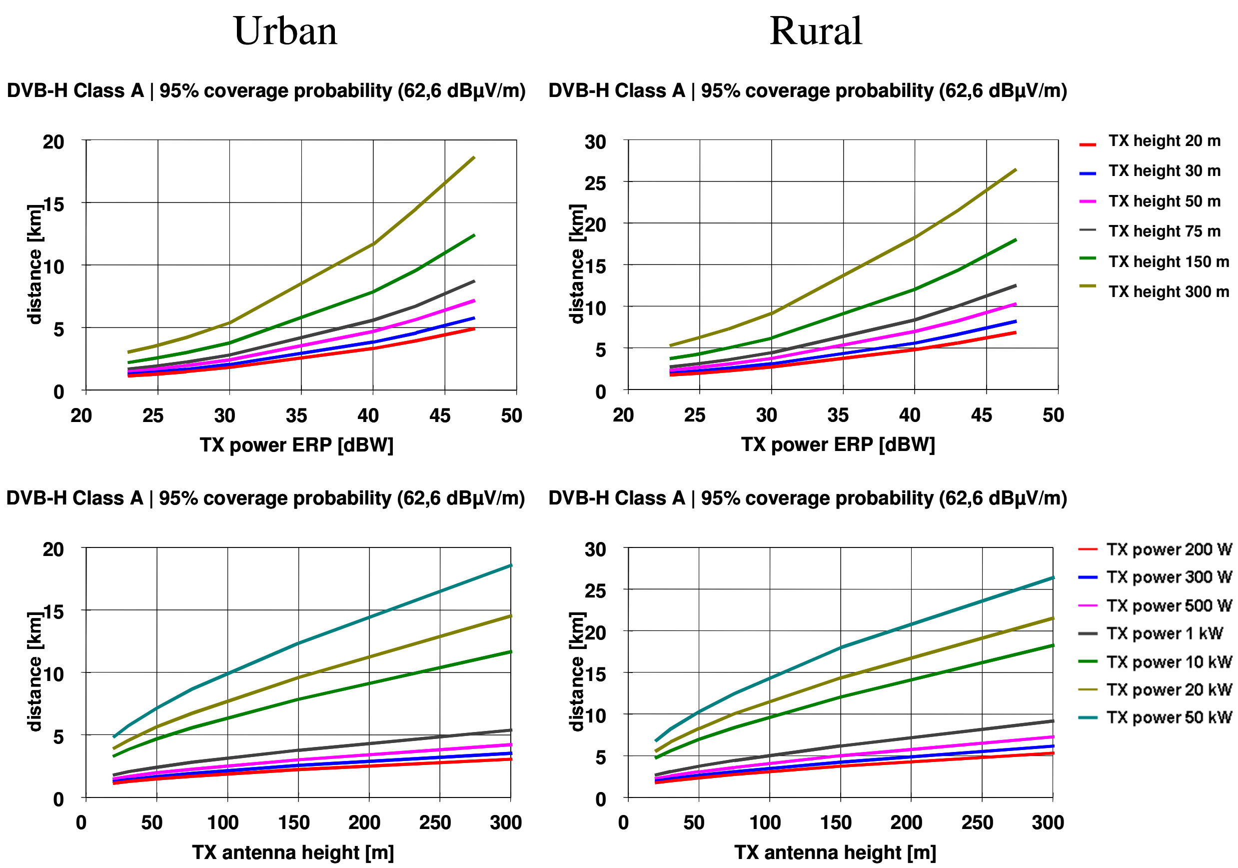


Figure 3.5: The maximum distance between the transmitter and the receiver for DVB-H, class A, reception in an urban (left) and a rural (right) terminal environment for different transmitter powers and heights.

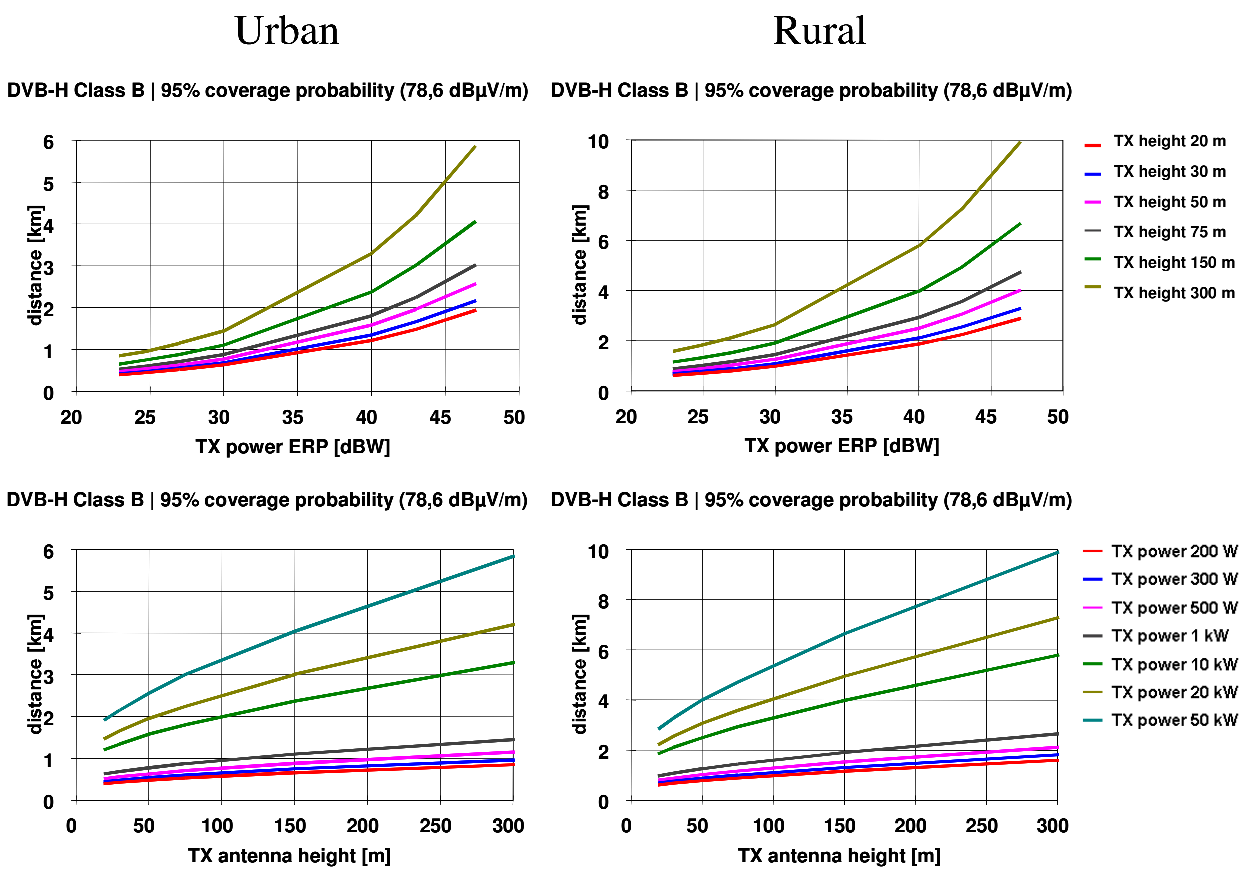


Figure 3.6: The maximum distance between the transmitter and the receiver for DVB-H, class B, reception in an urban (left) and a rural (right) terminal environment for different transmitter powers and heights.

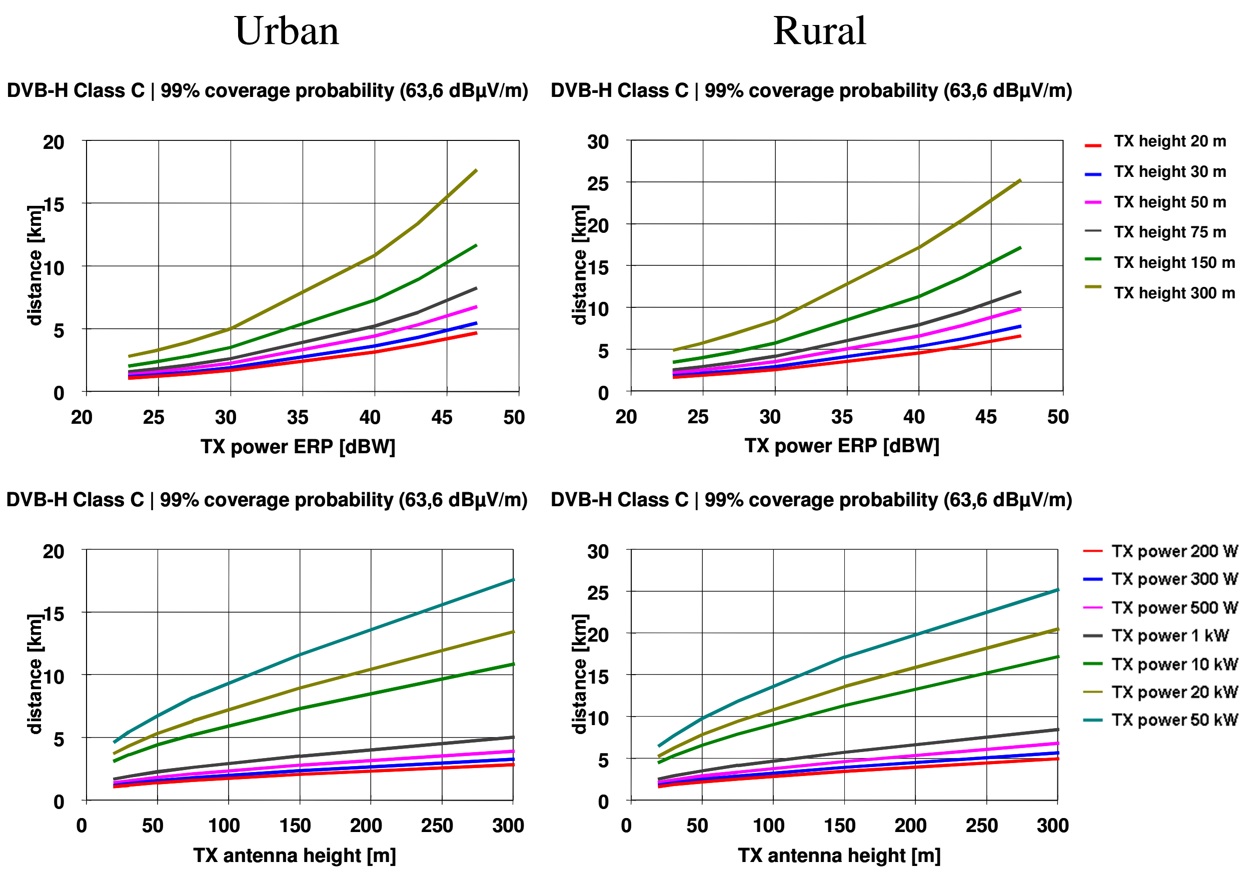


Figure 3.7: The maximum distance between the transmitter and the receiver for DVB-H, class C, reception in an urban (left) and a rural (right) terminal environment for different transmitter powers and heights.

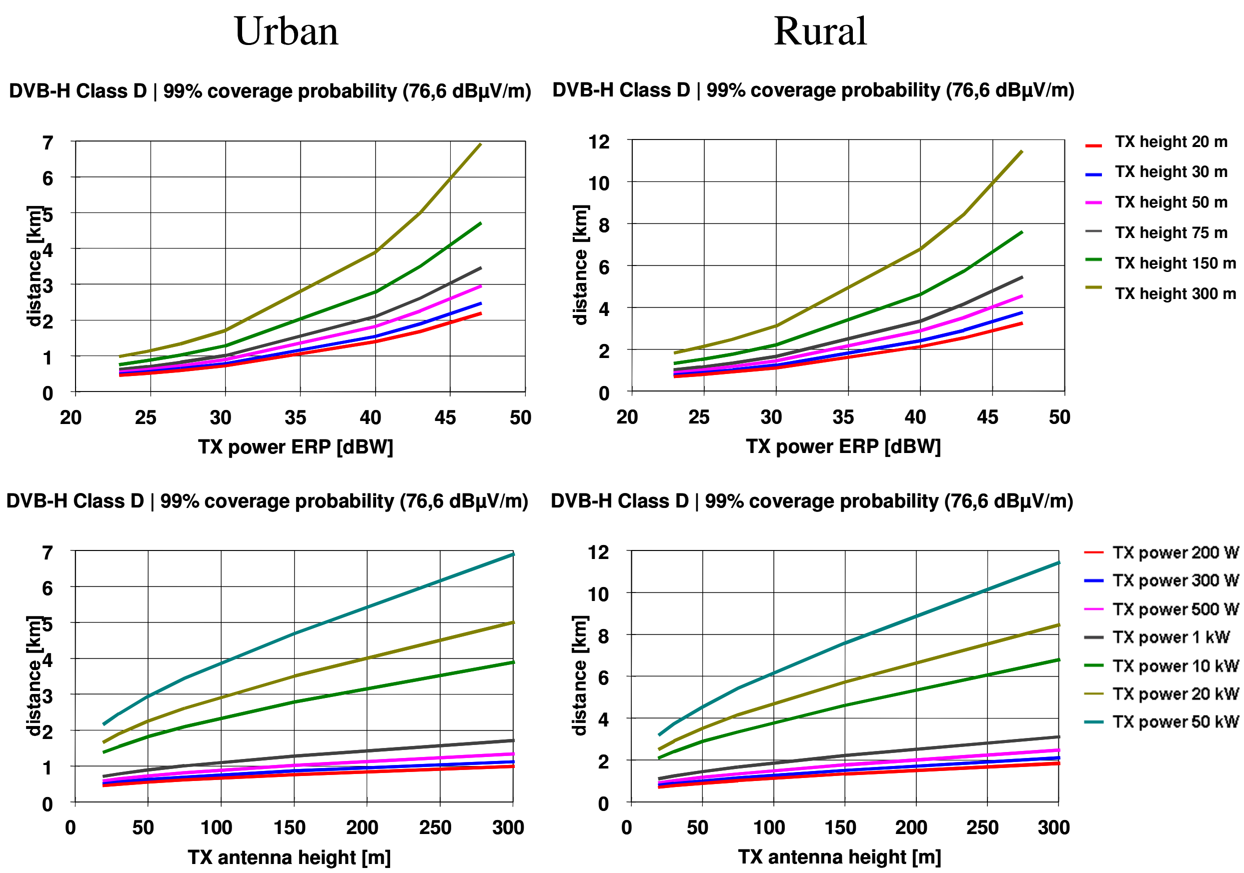


Figure 3.8: The maximum distance between the transmitter and the receiver for DVB-H, class D, reception in an urban (left) and a rural (right) terminal environment for different transmitter powers and heights.

3.3 Coverage planning

To evaluate different transmitter network topologies, area coverage planning has to be performed. As a reference area to be covered the Berlin area was chosen. As an example of what can be reached with a single high power / high antenna transmitter Figure 3.9 shows the coverage areas according the parameters given in Table 3.1.

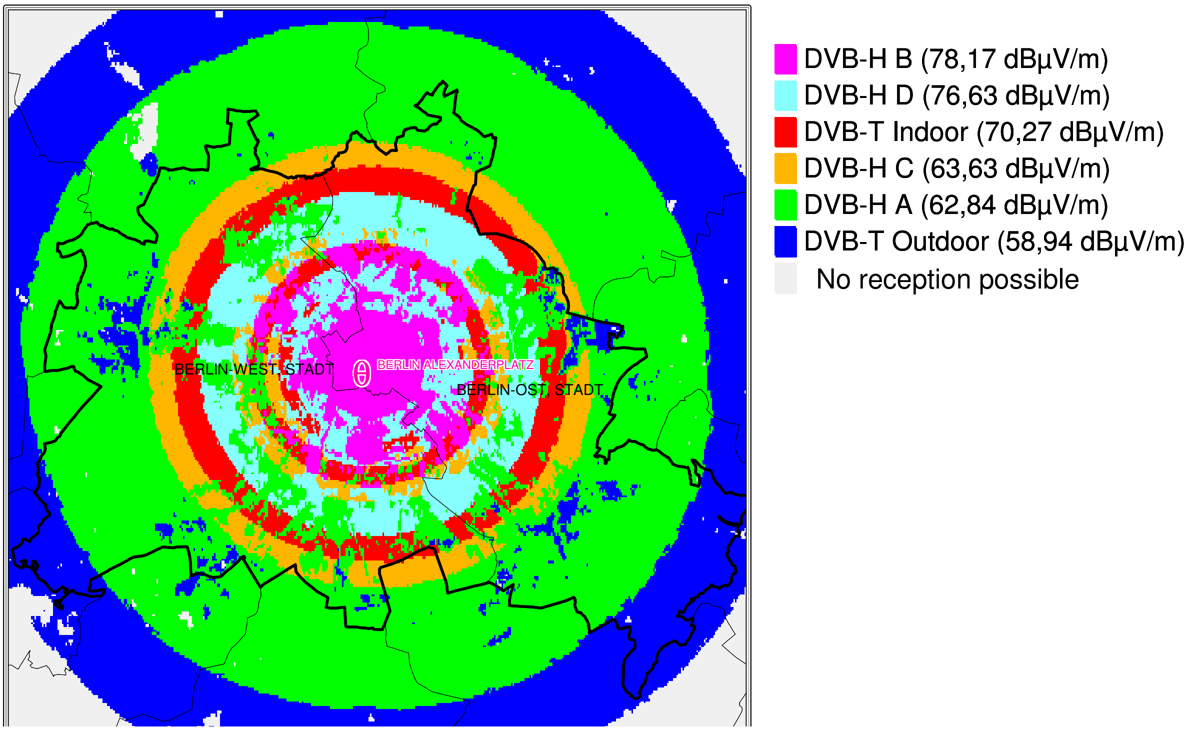


Figure 3.9: Coverage by single transmitter, height: 300 m, power: 20 kW, for different reception modes, for the parameters see Table 3.1.

One major application of DVB-H is expected to be IP datacast delivery technology in conjunction with a mobile telecommunications network like GPRS or UMTS. Therefore, it is of interest to know how the cellular layout of DVB-H cells can be adapted from the typical broadcast cell layout with high antennas, high power transmitters with wide coverage range towards the typical layout of low height, low power sites with small cell ranges of mobile telecommunication networks. Of particular interest is the question of whether or not the cositing of DVB-H transmitters with mobile radio sites is feasible. Within this chapter these questions are only treated from the radio network perspective. It should be mentioned that the necessary feeding of the DVB-H transmitters, which could be far too costly for a high density of transmitters within an area to be covered, is outside of the scope of this chapter.

3.3.1 Single frequency networks (SFN)

For comparison purposes a reference coverage area was defined as a circle of 20 km around Berlin Alexanderplatz corresponding to an area of approx. 1250 km^2. For DVB-H, class A reception, a coverage probability of at least 95 % is reached for nearly all pixels within this area with a single 300 m high transmitter at a power level of 20 kW ERP with respect to the parameters of Table 3.1, column 3. The coverage probability for this single transmitter reference network is given in Figure 3.10.

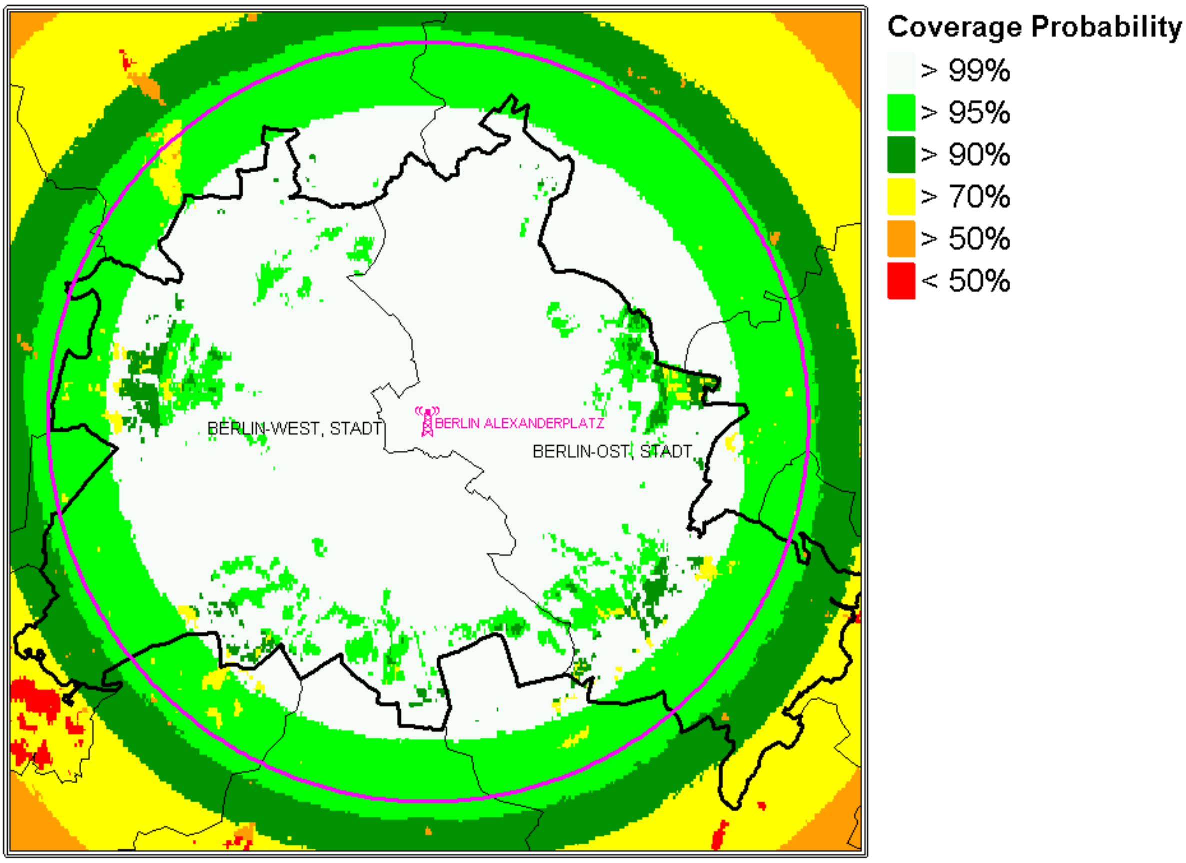


Figure 3.10: Coverage probability of a single DVB-H transmitter (300 m high, 20 kW), in 8k mode, 16-QAM, inner code rate 2/3, for class A reception. The circle is of 20 km radius around transmitter site.

Attempts were made to achieve at least the same coverage area as enclosed by the circle of 20 km radius around Berlin Alexanderplatz at a coverage probability of 95 % as depicted in Figure 3.10 by different regular single frequency network topologies. Different heights of the transmitter antennas as well as different distances between the transmitters were specified in advance. Then the transmitter powers - equal for each transmitter of the SFN – were adjusted to achieve the target coverage within the circular area around Berlin Alexanderplatz comparable to the single transmitter reference. The superposition method for single frequency network coverage calculation used in this study is the log-normal method [1], see also Appendix 3.

Figure 3.11 shows the coverage probability for a SFN consisting of 19 transmitters each with 150 m high antennas with a distance of 10 km between the transmitters. The power necessary at each transmitter is 400 W to achieve approximately the same coverage area as the single transmitter reference. Thus, the power sum of all the transmitters is 19 x 400 W = 7.6 kW. If the antenna height is lowered to 75 m a transmitter power of 1.25 kW is needed to cover the same area. Figure 3.12 shows the coverage probability for a SFN consisting of 19 transmitters with a distance of 10 km between the transmitters and a transmitter power sum of 19 x 1.25 kW = 23.75 kW.

If the network is densified to a distance of 5 km between the transmitters, 61 transmitters fall into a circle of 20 km radius. In Figure 3.13 the coverage probability is shown in this case where each transmitter is at a height of 75 m was and the power at each transmitter is 100 W. The power sum is 61 x 100 W = 6.1 kW for this topology.

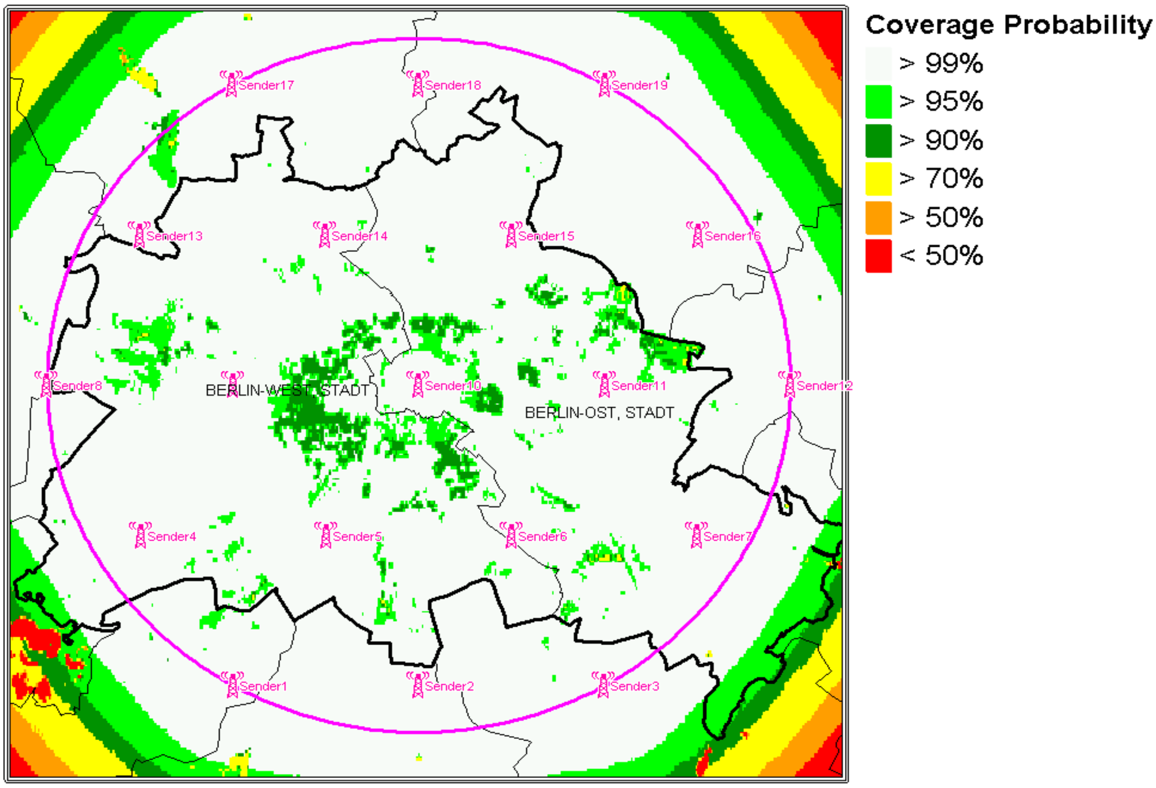


Figure 3.11: SFN for DVB-H, class A reception, 8 k FFT mode, guard interval 1/8, 16-QAM, inner code rate 2/3, TX height 150 m, TX distance 10 km, TX power 400 W.

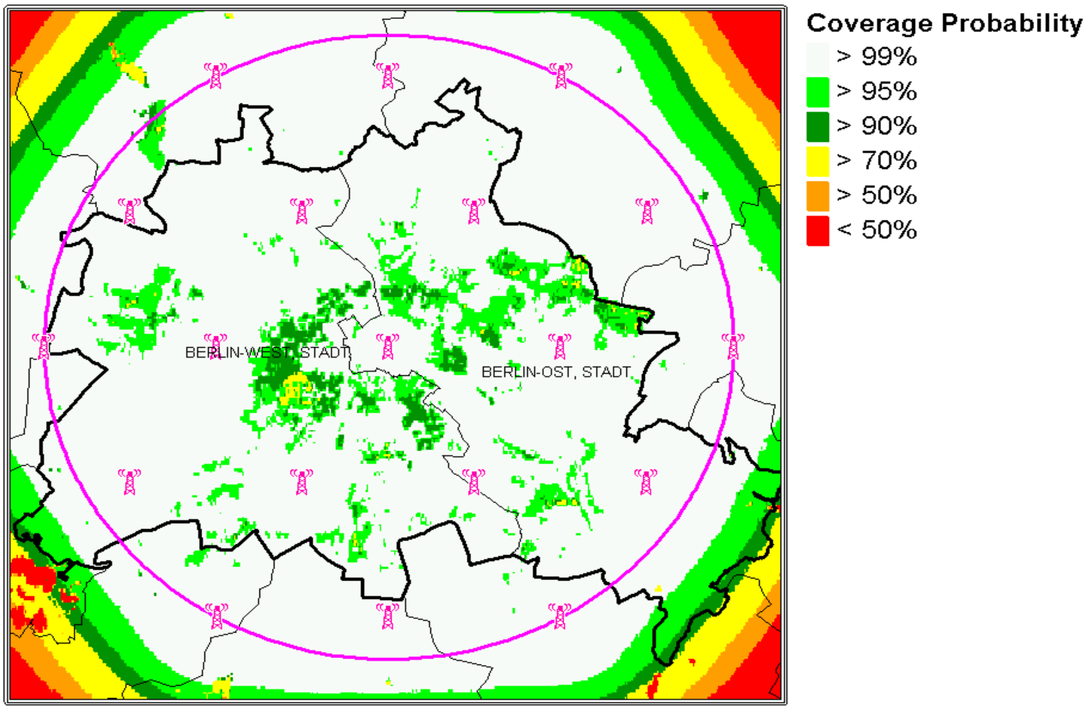


Figure 3.12: SFN for DVB-H, class A reception, 8 k FFT mode, guard interval 1/8, 16-QAM, inner code rate 2/3, TX height 75 m, TX distance 10 km, TX power 1.25 kW.

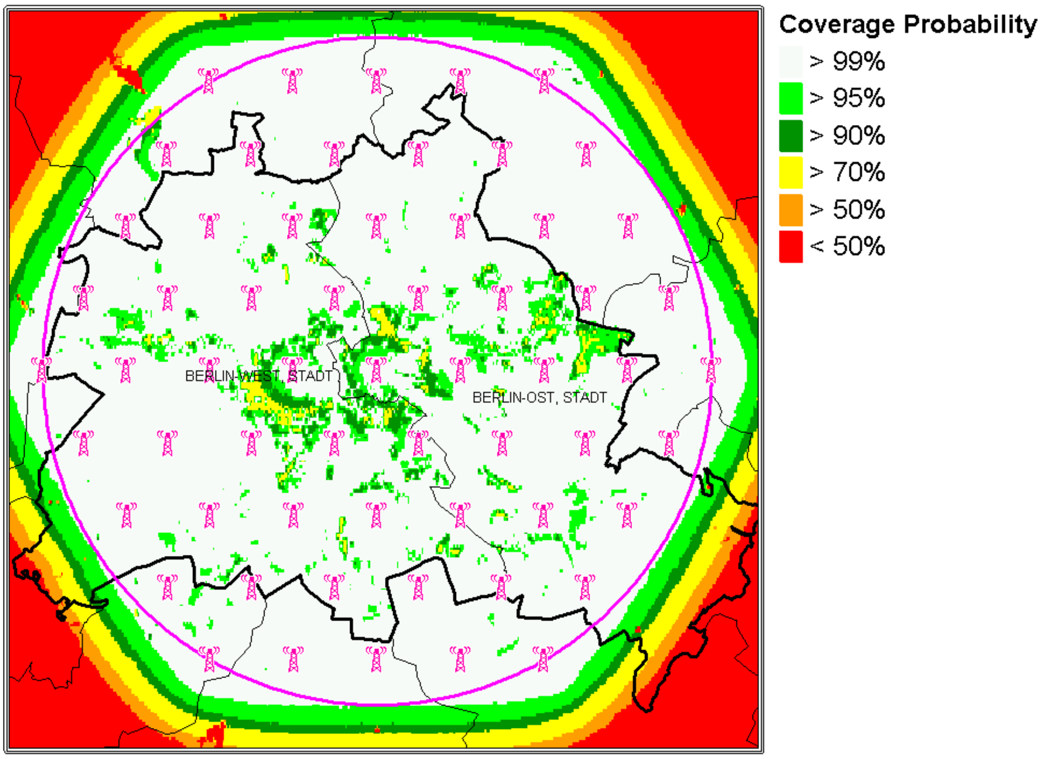


Figure 3.13: SFN for DVB-H, class A reception, 8 k FFT mode, guard interval 1/8, 16-QAM, inner code rate 2/3, TX height 75 m, TX distance 5 km, TX power 100 W.

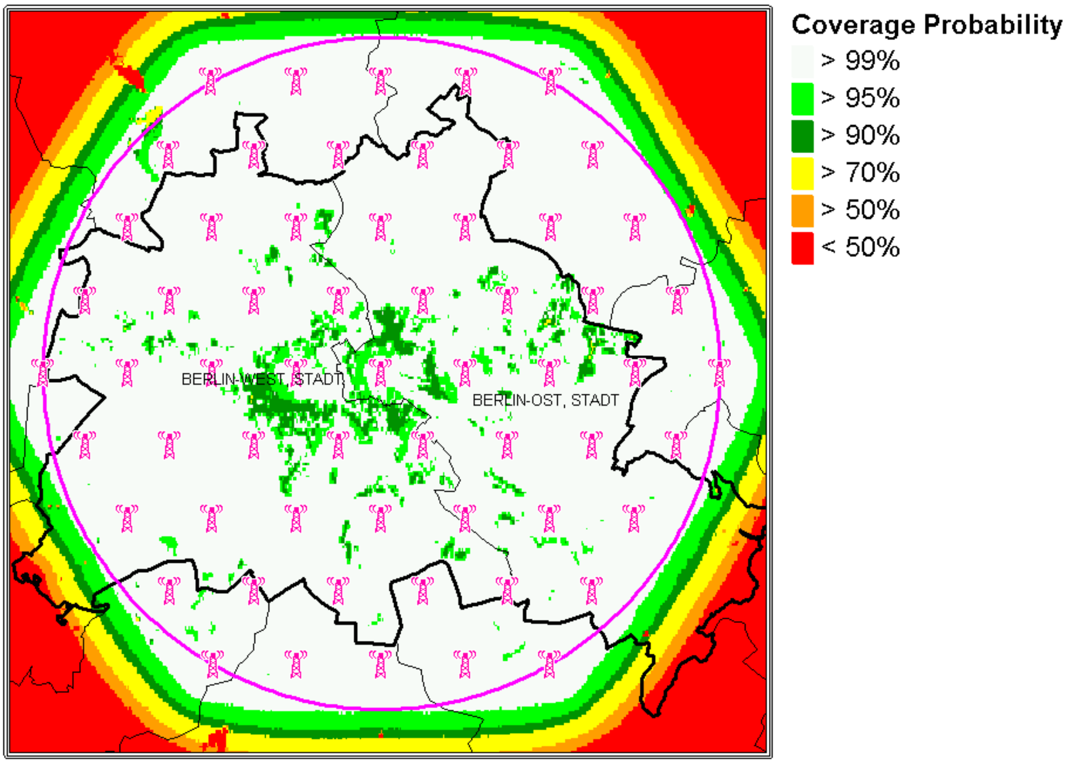


Figure 3.14: SFN for DVB-H, class A reception, 8 k FFT mode, guard interval 1/8, 16-QAM, inner code rate 2/3, TX height 50 m, TX distance 5 km, TX power 200 W.

In Figure 3.14 the coverage area for the SFN with a distance between transmitters of 5 km and the transmitters at a height of 50 m is shown. A transmitter power of 200 W is necessary to achieve the target coverage within the circular area around Berlin Alexanderplatz comparable to the single transmitter reference. Therefore, the overall transmitter power is 61 x 200 W = 12.2 kW.

If the topology is densified further, transmitter heights and distances closer to those of mobile telecommunication networks are possible. Figure 3.15 depicts the coverage probability for a distance of 2.5 km between the transmitters and an antenna height of 20 m. A power of 50 W per transmitter is necessary. The number of transmitters is 241 and thus the power sum is 241 x 50 W = 12 kW.

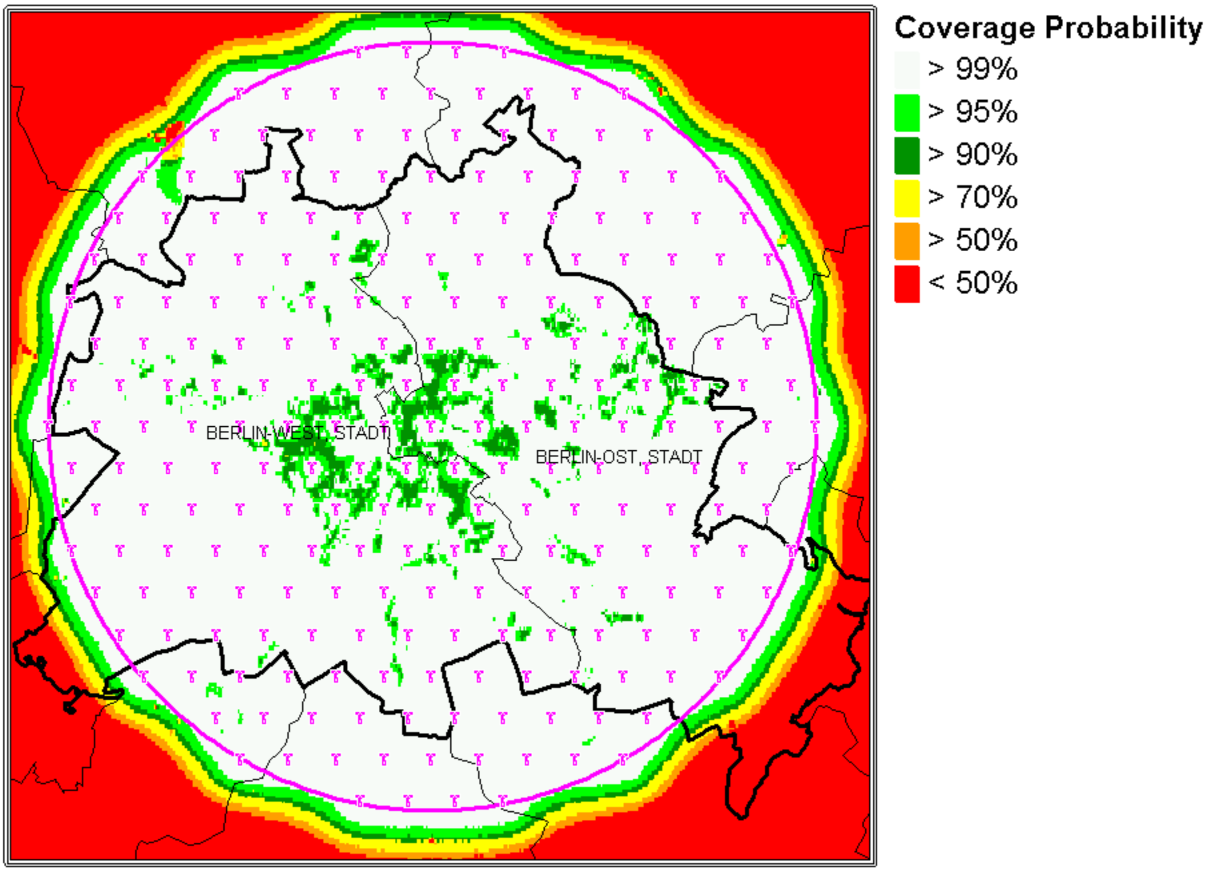


Figure 3.15: SFN for DVB-H, class A reception, 8 k FFT mode, guard interval 1/8, 16-QAM, inner code rate 2/3, TX height 20 m, TX distance 2.5 km, TX power 50 W.

One major issue in SFN topologies is self-interference which is strongly related to the choice of OFDM symbol and guard interval length. Therefore, the guard interval length for different OFDM modes was varied and its impact on coverage was investigated. As a synchronisation strategy in the receiver it is assumed that the received power of the nearest transmitter is set at the beginning of the guard interval.

In comparison to Figure 3.13 the coverage probability plot shown in Figure 3.16 is based on the same parameters except for the guard interval length which was shortened from 1/8 to 1/32 (28 µs). Obviously, self-interference is of no consequence for transmitter distances of 5 km even for this short guard interval.

In Figure 3.17 the coverage probability is shown for the same network topology (distance between transmitters of 5 km, height of antennas 75 m, power 100 W) but for 4k OFDM mode with 1/32 guard interval (14 µs). The coverage probability is slightly reduced due to self-interference in comparison to Figure 3.16 or Figure 3.13, respectively, especially in the central dense urban environment.

Figure 3.18 shows the situation for 2k mode with guard interval 1/32 (7 µs). The impact of self-interference is becoming the limiting factor. Only small areas near the transmitter sites show coverage probabilities over 95%. Thus, this network would be completely unfeasible.

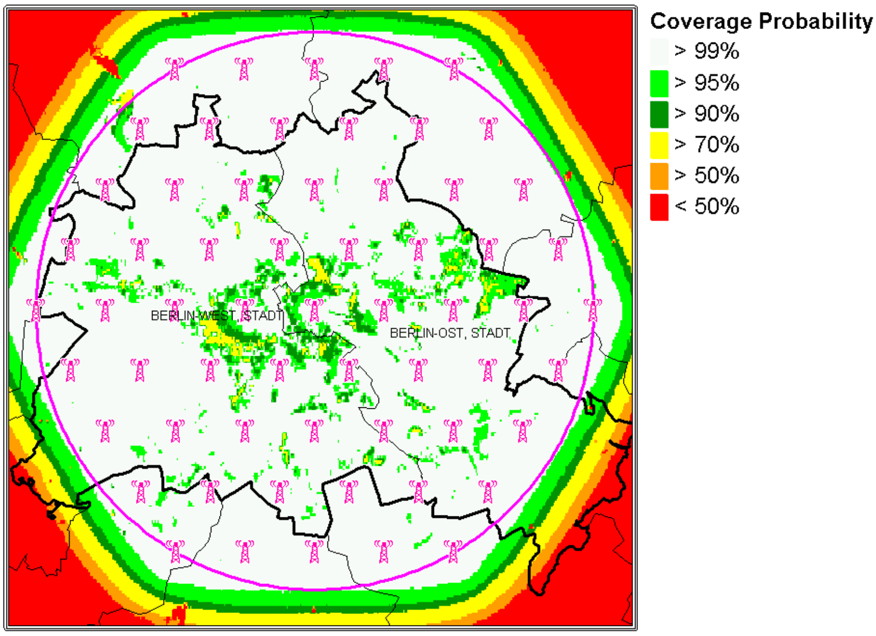


Figure 3.16: SFN for DVB-H, class A reception, 8 k FFT mode, guard interval 1/32 (28 µs), 16-QAM, inner code rate 2/3, TX height 75 m, TX distance 5 km, TX power 100 W.

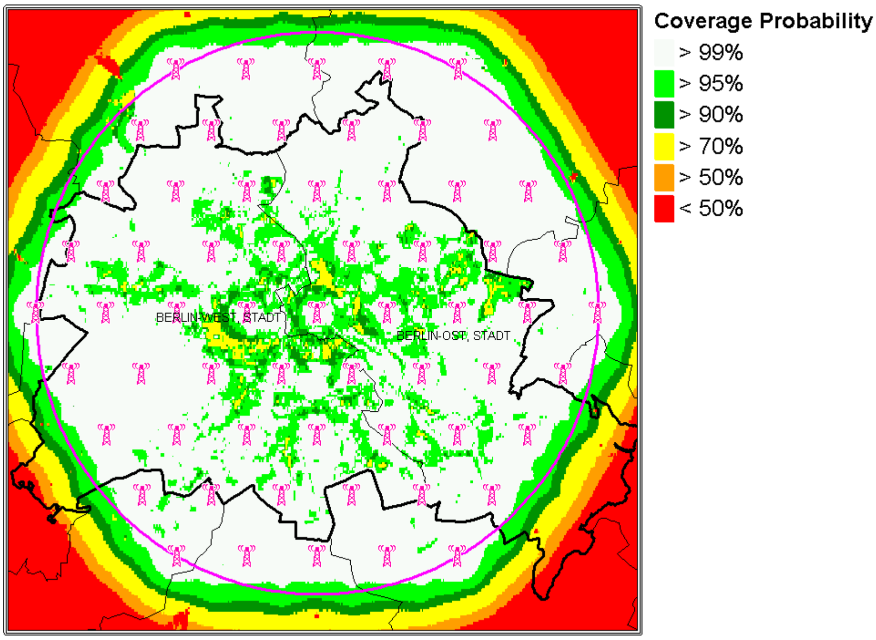


Figure 3.17: SFN for DVB-H, class A reception, 4 k FFT mode, guard interval 1/32 (14 µs), 16-QAM, inner code rate 2/3, TX height 75 m, TX distance 5 km, TX power 100 W.

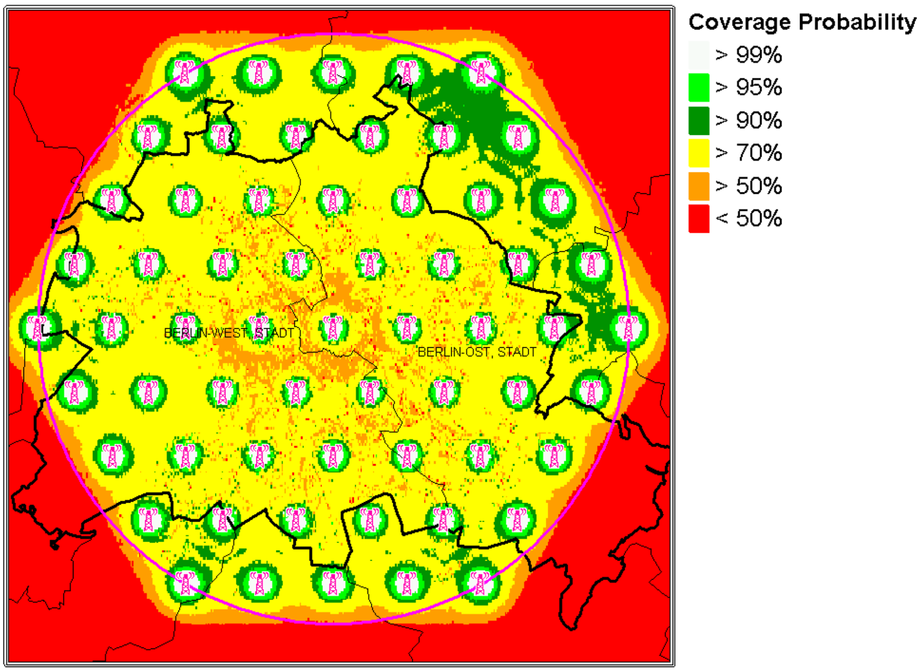


Figure 3.18: SFN for DVB-H, class A reception, 2 k FFT mode, guard interval 1/32 (7 µs), 16-QAM, inner code rate 2/3, TX height 75 m, TX distance 5 km, TX power 100 W.

The main findings in this subsection are:

- "Large" SFNs with low power, low height transmitters are possible. Care has to be taken in choosing the guard interval length in relation to the distance between the transmitters.
- The sum of transmit powers of all transmitters of the SFN in comparison to a single transmitter covering the same area is remarkable lower even for significantly lower antennas within the SFN.
- Further optimization has to be done related to the distribution of the sum power of the SFN, e.g. from Figure 3.13 it can be seen that coverage probability could be enhanced in the central part of the network located in a densely built up urban environment. Thus, one approach could be to increase the transmit power of the central transmitters at the expense of decreasing transmit power for the outer transmitters of the SFN.

3.3.2 Multi frequency networks (MFN)

3.3.2.1 Omni-directional antennas

To evaluate network topologies closer to those of mobile telecommunications networks multi frequency networks with different cluster sizes for omni-directional as well as for sectorized antenna patterns are analyzed in this subsection.

The basis for the investigation is a hexagonal cell layout with cell cluster size N where $N = I^2 + IJ + J^2$, and I, J are integers.

The Euclidian distance between the centres of two co-channel cells is D and the range of each cell is R.

The normalized re-use distance is Q = D/R = sqrt (3 N).

For different cluster sizes it follows that:

N	I	J	Q
1	1	0	1.73
3	1	1	3.00
4	2	0	3.46
7	2	1	4.58
9	3	0	5.20
12	2	2	6.00
13	3	1	6.24
16	4	0	6.93
19	3	2	7.55
21	4	1	7.94
27	3	3	9.00

Table 3.2: Normalized re-use distance Q as function of cluster size N (or integers I, J).

To estimate the inference power different methods were applied to determine the distance from the 6 interferers of the first ring for a location at the border of the central serving cell:

1. "conservative" estimation: distance between every interferer and wanted cell as D-R, see Figure 3.19.

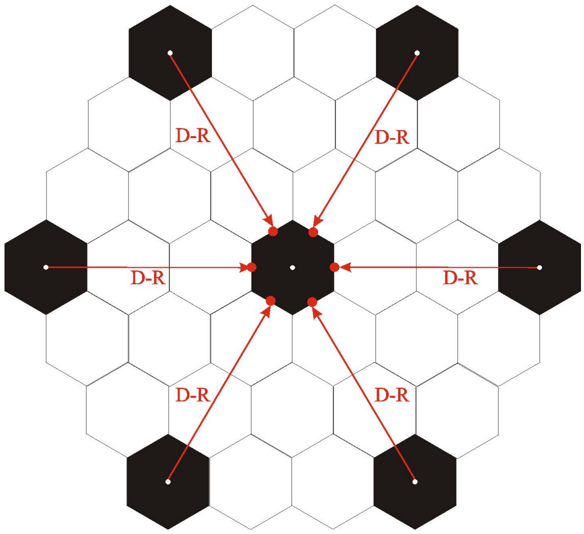


Figure 3.19: Distances for "conservative" interference estimation, cluster N=9.

2. "enhanced" estimation: it is assumed that there pairs of interferers at distances of ~D+R, ~D and ~D-R respectively. For the geometry, see Figure 3.20.

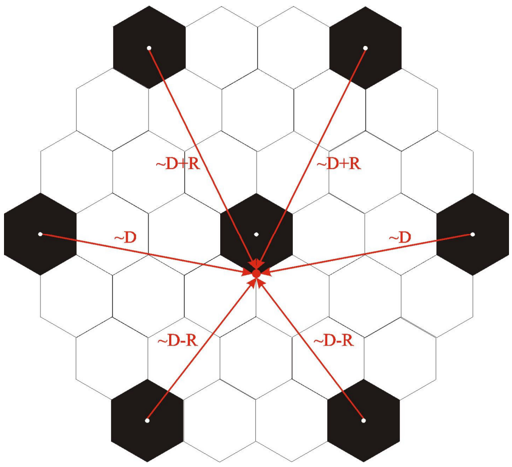


Figure 3.20: Distances for "enhanced" interference estimation, cluster N=9.

3. "regular" estimation: distances as distance D between the centre of the cells, see Figure 3.21.

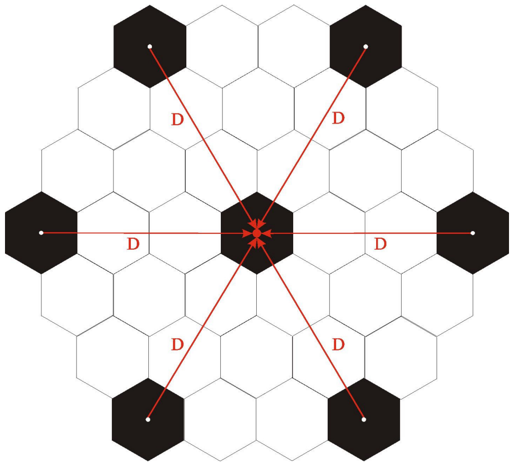


Figure 3.21: Distances for "regular" interference estimation, cluster N=9.

4. "optimistic" estimation: distance for all interference sources D+R, see Figure 3.22.

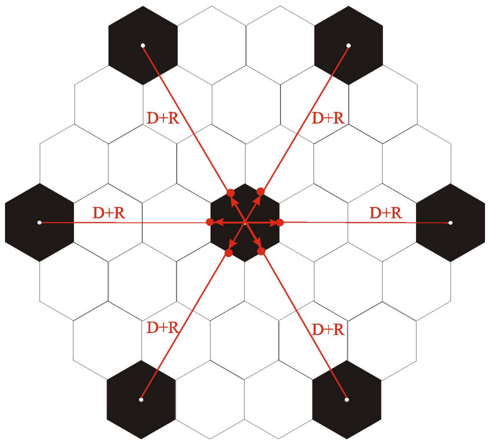


Figure 3.22: Distances for "optimistic" interference estimation, cluster N=9.

Based on the aforementioned estimation methods to take into account the interference power from co-channel cells as a function of distance, C/I values were calculated on the basis of ITU-R P.1546-1 curves for different cluster sizes, transmitter antenna heights and cell ranges R. For a rural environment with cell radii of R = 5 km and R = 2.5 km as well as for an urban environment with cell radii of R = 2.5 km and R = 1.25 km the achieved C/I values were calculated.

In Table 3.3 the achieved C/I values when taking into account the first ring of interferers around a central cell are shown for different cluster sizes N as well as for different transmitter antenna heights for an urban environment where a cell radius of R = 2.5 km is assumed.

"conservative" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	4,34	8,38	15,94	19,23	22,89	23,90	26,46	28,55	29,75
30	3,52	7,27	14,39	17,55	21,12	22,11	24,64	26,72	27,92
50	2,68	6,09	12,62	15,57	18,95	19,89	22,34	24,38	25,56
75	2,14	5,29	11,33	14,07	17,27	18,17	20,52	22,50	23,66
150	1,42	4,28	9,61	12,00	14,79	15,58	17,68	19,46	20,52
300	0,68	3,27	8,03	10,12	12,52	13,20	14,99	16,52	17,43

"enhanced" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	8,41	12,21	19,26	22,30	25,68	26,61	28,97	30,90	32,01
30	7,48	11,00	17,65	20,58	23,89	24,80	27,15	29,08	30,19
50	6,49	9,67	15,76	18,50	21,65	22,53	24,82	26,72	27,83
75	5,81	8,74	14,35	16,92	19,91	20,75	22,96	24,83	25,92
150	4,89	7,49	12,38	14,61	17,23	17,98	19,96	21,66	22,68
300	3,96	6,27	10,55	12,47	14,71	15,35	17,04	18,51	19,39

"regular" estimation

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	12,31	15,25	21,07	23,70	26,72	27,55	29,73	31,52	32,56
30	10,95	13,74	19,34	21,91	24,89	25,73	27,90	29,70	30,75
50	9,45	12,01	17,25	19,70	22,59	23,40	25,53	27,32	28,37
75	8,40	10,76	15,66	17,99	20,76	21,55	23,63	25,40	26,44
150	7,04	9,12	13,38	15,42	17,89	18,60	20,49	22,12	23,10
300	5,75	7,59	11,31	13,07	15,17	15,78	17,41	18,83	19,68

"optimistic" estimation

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	18,23	20,52	25,20	27,39	29,94	30,66	32,53	34,09	35,00
30	16,59	18,80	23,39	25,56	28,11	28,83	30,72	32,31	33,24
50	14,66	16,74	21,13	23,24	25,75	26,46	28,35	29,96	30,91
75	13,22	15,18	19,36	21,40	23,84	24,55	26,42	28,04	28,99
150	11,26	12,97	16,63	18,46	20,69	21,33	23,08	24,64	25,56
300	9,47	10,95	14,10	15,66	17,58	18,14	19,66	21,06	21,88

Table 3.3: Achieved C/I in dB as function of cluster size N and TX antenna height in an urban environment, R = 2.5 km, based on the ITU-R P.1546-1 propagation model.

The yellow fields in Table 3.3 mark where a C/I of at least 26.2 dB is achieved which would be sufficient for a protection ratio of 14.2 dB + 3 dB = 17.2 dB as in case of DVB-T with 16-QAM, code rate 2/3 reception and DVB-T as the interfering signal. An additional location correction of 9 dB for 95 % coverage probability leads to a required C/I of 26.2 dB.

Table 3.4 shows the resultant C/I values for R = 1.25 km under the same conditions as for Table 3.3. Again the yellow fields in Table 3.4 mark where a C/I of at least 26.2 dB is achieved which would be sufficient for a protection ratio of 14.2 dB + 3 dB = 17.2 dB as in case of DVB-T with 16-QAM, code rate 2/3 reception and DVB-T as the interfering signal. An additional location correction of 9 dB for 95 % coverage probability leads to a required C/I of 26.2 dB.

"conservative" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	3,03	6,46	13,11	16,07	19,47	20,42	22,88	24,91	26,09
30	2,59	5,83	12,01	14,75	17,91	18,80	21,10	23,01	24,14
50	2,11	5,16	10,85	13,35	16,23	17,03	19,14	20,89	21,93
75	1,79	4,71	10,09	12,42	15,09	15,83	17,77	19,39	20,35
150	1,21	3,95	8,93	11,07	13,47	14,14	15,86	17,29	18,13
300	0,70	3,22	7,80	9,75	11,93	12,53	14,07	15,35	16,09

"enhanced" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	6,86	10,07	16,26	19,02	22,18	23,06	25,35	27,24	28,34
30	6,31	9,31	15,02	17,57	20,51	21,33	23,48	25,27	26,32
50	5,70	8,48	13,69	16,00	18,67	19,41	21,38	23,03	24,00
75	5,28	7,93	12,80	14,93	17,39	18,08	19,89	21,42	22,32
150	4,58	7,02	11,47	13,40	15,59	16,19	17,79	19,12	19,90
300	3,92	6,14	10,18	11,92	13,88	14,42	15,83	17,00	17,69

"regular" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	9,89	12,48	17,77	20,24	23,12	23,93	26,06	27,83	28,87
30	9,03	11,43	16,32	18,62	21,33	22,09	24,11	25,81	26,80
50	8,12	10,33	14,78	16,88	19,35	20,05	21,91	23,48	24,41
75	7,52	9,60	13,75	15,69	17,97	18,61	20,33	21,79	22,66
150	6,56	8,48	12,27	14,01	16,03	16,60	18,11	19,39	20,14
300	5,63	7,39	10,84	12,41	14,23	14,74	16,07	17,19	17,85

"optimistic" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	15,14	17,26	21,66	23,77	26,27	26,98	28,85	30,42	31,35
30	13,89	15,85	19,95	21,94	24,31	24,99	26,78	28,30	29,20
50	12,57	14,36	18,09	19,91	22,09	22,72	24,38	25,81	26,66
75	11,70	13,36	16,81	18,49	20,50	21,08	22,64	23,97	24,77
150	10,41	11,91	15,01	16,49	18,26	18,77	20,12	21,29	21,98
300	9,15	10,52	13,31	14,64	16,20	16,65	17,84	18,85	19,45

Table 3.4: achieved C/I in dB as function of cluster size N and TX antenna height in an urban environment, R = 1.25 km, based on the ITU-R P.1546-1 propagation model.

Comparison of Table 3.3 with Table 3.4 shows that for lower transmitter antenna heights a lower reuse distance is needed. It can also be seen that for smaller cell sizes a higher reuse distance and thus more frequencies are needed.

Table 3.5 shows the calculated C/I values for different cluster sizes N as well as for different transmitter antenna heights for a rural environment where a cell radius of R = 5 km is assumed. The yellow fields in Table 3.5 mark where a C/I of at least 26.2 dB is achieved which would be sufficient for a protection ratio of 14.2 dB + 3 dB = 17.2 dB as in case of DVB-T with 16-QAM, code rate 2/3 reception and DVB-T as the interfering signal. An additional location correction of 9 dB for 95 % coverage probability leads to a required C/I of 26.2 dB.

In Table 3.6 the calculated C/I values for different cluster sizes N as well as for different transmitter antenna heights for a rural environment where a cell radius of R = 2.5 km is assumed. The yellow fields in Table 3.6 mark where a C/I of at least 26.2 dB is achieved which would be sufficient for a protection ratio of 14.2 dB + 3 dB = 17.2 dB as in case of DVB-T with 16-QAM, code rate 2/3 reception and DVB-T as the interfering signal. An additional location correction of 9 dB for 95 % coverage probability leads to a required C/I of 26.2 dB.

Comparison of Table 3.5 with Table 3.6 shows again that for lower transmitter antenna heights a lower reuse distance is needed. Also again it can be seen that for smaller cell sizes a higher reuse distance and thus more frequencies are needed. Table 3.3 for an urban environment compared to Table 3.6 for a rural environment but for the same radius R shows that there is only a negligible difference in required reuse distance and thus frequencies for the above mentioned example where a C/I of 26.2 dB is required for 95 % coverage probability in different environments are considered.

"conservative" estimation

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	6,12	10,49	18,33	21,61	25,21	26,18	28,66	30,66	31,81
30	5,31	9,55	17,33	20,65	24,34	25,35	27,94	30,06	31,28
50	4,23	8,24	15,82	19,16	22,91	23,96	26,66	28,92	30,23
75	3,36	7,14	14,48	17,80	21,58	22,67	25,44	27,80	29,16
150	2,17	5,49	12,08	15,22	18,87	19,96	22,75	25,19	26,61
300	1,25	4,14	9,83	12,60	15,88	16,91	19,53	21,89	23,28

"enhanced" estimation

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	10,23	14,33	21,58	24,59	27,89	28,78	31,05	32,88	33,93
30	9,38	13,37	20,61	23,68	27,09	28,03	30,43	32,39	33,53
50	8,24	12,03	19,12	22,23	25,74	26,73	29,27	31,39	32,62
75	7,29	10,87	17,78	20,90	24,47	25,49	28,13	30,36	31,66
150	5,90	9,04	15,31	18,28	21,78	22,83	25,51	27,87	29,24
300	4,73	7,43	12,85	15,50	18,69	19,69	22,25	24,57	25,93

"regular" estimation

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	14,62	17,63	23,42	25,99	28,91	29,71	31,78	33,48	34,47
30	13,62	16,62	22,50	25,15	28,19	29,04	31,25	33,09	34,16
50	12,17	15,12	21,04	23,76	26,93	27,84	30,20	32,19	33,36
75	10,91	13,79	19,70	22,45	25,71	26,66	29,13	31,25	32,49
150	8,83	11,45	17,05	19,75	23,03	24,02	26,58	28,84	30,16
300	7,02	9,28	14,25	16,71	19,78	20,75	23,24	25,51	26,84

"optimistic" estimation

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	20,62	22,88	27,45	29,55	31,99	32,67	34,45	35,92	36,79
30	19,64	21,95	26,67	28,88	31,47	32,21	34,14	35,76	36,71
50	18,13	20,48	25,34	27,66	30,43	31,23	33,33	35,13	36,19
75	16,77	19,14	24,08	26,48	29,37	30,23	32,46	34,38	35,52
150	14,22	16,51	21,38	23,82	26,83	27,74	30,13	32,23	33,48
300	11,70	13,76	18,24	20,56	23,49	24,41	26,81	28,99	30,27

Table 3.5: achieved C/I in dB as function of cluster size N and TX antenna height in a rural environment, R = 5 km, based on the ITU-R P.1546-1 propagation model.

"conservative" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	4,36	8,41	15,98	19,27	22,94	23,94	26,51	28,60	29,80
30	3,56	7,32	14,45	17,61	21,19	22,17	24,71	26,79	27,99
50	2,75	6,17	12,72	15,67	19,06	20,00	22,46	24,50	25,68
75	2,25	5,42	11,48	14,24	17,44	18,34	20,71	22,68	23,85
150	1,65	4,55	9,94	12,35	15,16	15,95	18,05	19,84	20,91
300	1,19	3,87	8,75	10,88	13,32	14,00	15,81	17,36	18,28

"enhanced" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	8,37	12,18	19,24	22,28	25,66	26,59	28,96	30,88	31,99
30	7,46	10,99	17,65	20,58	23,89	24,80	27,16	29,08	30,20
50	6,50	9,70	15,80	18,55	21,71	22,59	24,88	26,78	27,89
75	5,86	8,81	14,45	17,02	20,02	20,86	23,08	24,95	26,04
150	5,08	7,71	12,66	14,90	17,54	18,29	20,28	21,99	23,00
300	4,45	6,84	11,23	13,18	15,45	16,09	17,81	19,29	20,18

"regular" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	12,35	15,29	21,11	23,74	26,76	27,60	29,77	31,56	32,60
30	11,01	13,80	19,40	21,98	24,96	25,80	27,97	29,77	30,82
50	9,55	12,11	17,36	19,82	22,70	23,52	25,65	27,44	28,50
75	8,55	10,92	15,83	18,16	20,94	21,73	23,82	25,59	26,63
150	7,34	9,44	13,74	15,79	18,26	18,98	20,88	22,52	23,50
300	6,42	8,31	12,09	13,86	15,99	16,61	18,25	19,68	20,54

"optimistic" estimation

TX height [m] / cluster N	3	4	7	9	12	13	16	19	21
20	18,27	20,56	25,25	27,44	29,99	30,71	32,58	34,13	35,05
30	16,65	18,87	23,46	25,63	28,18	28,90	30,79	32,38	33,32
50	14,76	16,85	21,25	23,36	25,87	26,58	28,47	30,09	31,04
75	13,39	15,35	19,54	21,58	24,03	24,73	26,61	28,23	29,19
150	11,61	13,32	17,01	18,84	21,08	21,73	23,48	25,04	25,96
300	10,22	11,72	14,91	16,49	18,42	18,99	20,52	21,92	22,75

Table 3.6: achieved C/I in dB as function of cluster size N and TX antenna height in a rural environment, R = 2.5 km, based on the ITU-R P.1546-1 propagation model.

3.3.3 Sectorized cell layout

In mobile telecommunication networks sectorizing of cells is applied to increase capacity without additional base station locations. In order to investigate network topologies for DVB-H that are similar to mobile telecommunication network topologies in this subsection sectorization of hexagonal cells into 6 x 60° sector and 3 x 120° is considered.

In Figure 3.23 the interferer's distances for 60° and 120° sectorization are depicted. It should be noted that in case of 120° sectorization only 2 interferers have to be considered and for 60° sectorization only 1 interferer has to be taken into account from the first ring around the serving cell.

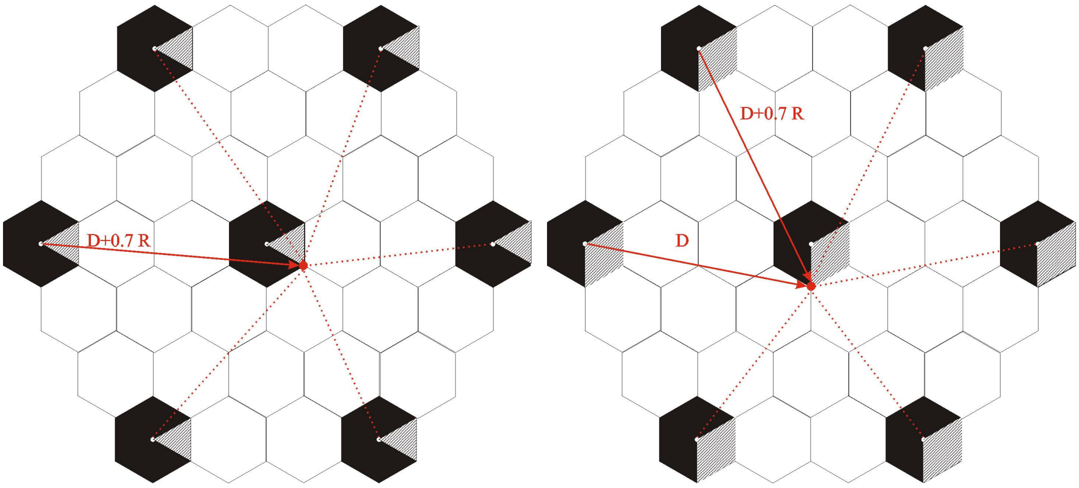


Figure 3.23: Distances for the interference calculation for 60° sectorization (left) and 120° sectorization (right).

Based on the geometry of Figure 3.23, in Table 3.7 the achieved C/I values as a function of cluster size and TX antenna height in an urban environment are given for a cell range of 2.5 km.

The yellow fields in Table 3.7 mark where a C/I of at least 26.2 dB is achieved which would be sufficient for a protection ratio of 14.2 dB + 3 dB = 17.2 dB as in the case of DVB-T with 16-QAM, code rate 2/3 reception and DVB-T as the interfering signal. An additional location correction of 9 dB for 95 % coverage probability leads to a required C/I of 26.2 dB.

120° sectors

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	18,72	21,52	27,08	29,60	32,49	33,30	35,39	37,11	38,11
30	17,30	19,96	25,33	27,80	30,66	31,47	33,56	35,30	36,32
50	15,71	18,16	23,19	25,56	28,34	29,13	31,19	32,93	33,95
75	14,57	16,84	21,55	23,81	26,49	27,26	29,28	31,00	32,03
150	13,07	15,06	19,16	21,14	23,54	24,23	26,08	27,69	28,66
300	11,66	13,41	16,97	18,66	20,71	21,31	22,90	24,31	25,16

60° sectors

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	24,39	26,85	31,83	34,13	36,81	37,56	39,51	41,13	42,08
30	22,82	25,18	30,03	32,31	34,98	35,73	37,69	39,34	40,31
50	21,00	23,20	27,81	30,02	32,62	33,36	35,32	36,98	37,96
75	19,66	21,72	26,08	28,20	30,74	31,47	33,39	35,05	36,04
150	17,87	19,67	23,48	25,36	27,65	28,32	30,11	31,68	32,63
300	16,23	17,80	21,09	22,69	24,66	25,23	26,78	28,17	29,03

Table 3.7: achieved C/I in dB as function of cluster size N and TX antenna height in an urban environment for 60° and 120° sectorized cells, R = 2.5 km, based on the ITU-R P.1546-1 propagation model.

For a decreased cell range of R = 1.25 km Table 3.8 shows C/I values in case of sectorization for an urban environment as a function of TX antenna height and cluster size N.

Again the yellow fields mark where a C/I of at least 26.2 dB is achieved which would be sufficient for a protection ratio of 14.2 dB + 3 dB = 17.2 dB as in case of DVB-T with 16-QAM, code rate 2/3 reception and DVB-T as the interfering signal. An additional location correction of 9 dB for 95 % coverage probability leads to a required C/I of 26.2 dB.

120° sectors

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	16,16	18,64	23,72	26,09	28,87	29,66	31,71	33,43	34,44
30	15,22	17,51	22,20	24,42	27,03	27,77	29,73	31,37	32,34
50	14,21	16,31	20,58	22,60	24,99	25,67	27,47	29,00	29,90
75	13,55	15,52	19,48	21,34	23,55	24,18	25,85	27,27	28,11
150	12,51	14,32	17,92	19,58	21,53	22,08	23,54	24,78	25,51
300	11,50	13,15	16,41	17,91	19,65	20,14	21,43	22,51	23,15

60° sectors

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	21,48	23,70	28,35	30,55	33,15	33,89	35,83	37,46	38,41
30	20,34	22,39	26,71	28,78	31,24	31,94	33,79	35,36	36,29
50	19,14	21,01	24,94	26,82	29,08	29,73	31,45	32,92	33,79
75	18,34	20,09	23,73	25,47	27,55	28,15	29,75	31,12	31,93
150	17,15	18,75	22,02	23,57	25,40	25,93	27,32	28,52	29,23
300	15,98	17,44	20,40	21,79	23,42	23,88	25,11	26,15	26,76

Table 3.8: achieved C/I in dB as function of cluster size N and TX antenna height in an urban environment for 60° and 120° sectorized cells, R = 1.25 km, based on the ITU-R P.1546-1 propagation model.

Inspection of Table 3.7 and Table 3.8 reveals that for a smaller sector and lower TX antenna the cluster size can be smaller for a given C/I that should be achieved. Similar results to those in Table 3.7 and Table 3.8 are obtained in the case of a rural environment.

It should be noted that the cluster sizes given in Table 3.7 and Table 3.8 may be too optimistic, because ideal sector antennas are assumed with infinite front-to-back / front-to-side ratio.

Although the cluster size N can be considerably lowered by sectorizing the hexagonal cells into 120° or even into 60° sectors to achieve a given C/I that does not mean that a lower number of frequencies is needed to provide area coverage. This is due to the fact that the required total number of frequencies is the cluster size times the number of sectors. Therefore e.g. in case of 120° sectoring of cells the number of required frequencies is 3 x N and in case of 60° sectors 6 x N frequencies will be needed. An example should make this clear:

For an urban environment, a cell radius of 2.5 km and a TX antenna height of 20 m, from Table 3.3 it can be seen that in case of a non-sectorized cell layout a cluster size of N = 16 is needed to fulfil the C/I requirement of 26.2 dB. In Table 3.7 a corresponding value for the cluster size in case of 120° sectorization is given as N = 7. In fact this value has to be multiplied by 3 to give the number of frequencies needed which is thus higher than in case of non-sectorized cells. Therefore, for broadcast applications where capacity is of no concern sectorization seems not to be an adequate way to lower the frequency needs for area coverage.

3.3.4 Antenna down-tilting

Taking into account the elevation pattern of a directional antenna leads to the idea of down-tilting the antennas of the radio network's transmitters. This approach is heavily used in mobile telecommunications networks especially in small cells to effectively lower the cell range in areas were high capacity is demanded and to have a sharp transition at the cell border with the neighbouring cells.

In Figure 3.24 the assumed $\cos^2$ shaped elevation antenna diagram and the geometry for C/I calculation is given.

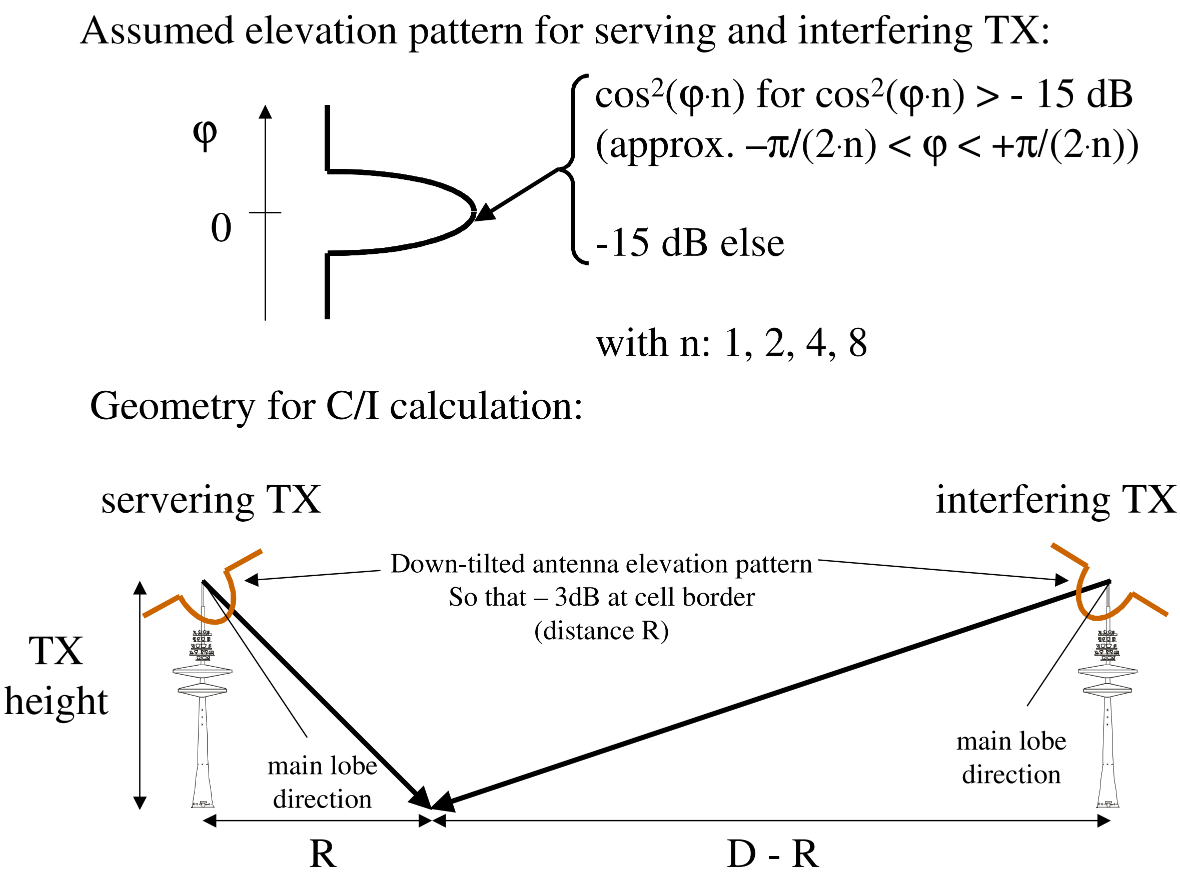


Figure 3.24: Antenna elevation pattern and geometry for C/I calculation.

By increasing the parameter n given in Figure 3.24 the beamwidth of the main lobe can be decreased. For practical n = 4 and 8 it follows that for φ = +/-11.23° and φ = +/-5.62° the –3 dB points with respect to the maximum at 0° are reached.

Based on the elevation antenna pattern and the geometry given in Figure 3.24 the increase of C/I for different cluster sizes, TX antenna heights and cell radii R can be calculated for the hexagonal cell layout with omni-directional antennas for all transmitters based on some simple trigonometry calculations. For n = 4, 8 and R = 2.5 km the resultant C/I increase in dB is given in Table 3.9a/b. In Table 3.10a/b the C/I increase in dB is given in comparison to the uniform elevation antenna pattern in the case of R = 1.25 km for n = 4 and 8.

From the Table 3.9a, 3.9b, 3.10a and 3.10b it can be seen that down-tilting will be more efficient in terms of lowering the needed cluster size especially in the case of:

- high transmitter antennas,
- high re-use factors,
- small cell radii,
- narrow elevation half-power beamwidth antennas.

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	0,14	0,17	0,20	0,22	0,23	0,23	0,24	0,24	0,24
30	0,21	0,25	0,31	0,33	0,35	0,35	0,36	0,37	0,37
50	0,36	0,43	0,53	0,56	0,59	0,60	0,62	0,63	0,64
75	0,55	0,66	0,82	0,87	0,92	0,93	0,96	0,98	0,99
150	1,17	1,43	1,79	1,91	2,03	2,06	2,13	2,18	2,20
300	2,66	3,33	4,36	4,73	5,09	5,18	5,40	5,57	5,66

Table 3.9a: Increase of C/I in [dB] by down-tilting for n = 4 and R = 2.5 km.

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	0,29	0,34	0,42	0,44	0,47	0,47	0,49	0,50	0,50
30	0,44	0,52	0,64	0,68	0,72	0,73	0,75	0,77	0,77
50	0,75	0,91	1,12	1,20	1,26	1,28	1,32	1,35	1,37
75	1,18	1,43	1,79	1,92	2,03	2,06	2,13	2,18	2,21
150	2,68	3,36	4,39	4,76	5,13	5,22	5,44	5,60	5,69
300	7,30	10,20	12,00	12,00	12,00	12,00	12,00	12,00	12,00

Table 3.9b: Increase of C/I in [dB] by down-tilting for n = 8 and R = 2.5 km.

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	0,29	0,34	0,42	0,44	0,47	0,47	0,49	0,50	0,50
30	0,44	0,52	0,64	0,68	0,72	0,73	0,75	0,77	0,77
50	0,75	0,91	1,12	1,20	1,26	1,28	1,32	1,35	1,37
75	1,17	1,43	1,79	1,91	2,03	2,06	2,13	2,18	2,20
150	2,66	3,33	4,36	4,73	5,09	5,18	5,40	5,57	5,66
300	6,99	9,74	12,00	12,00	12,00	12,00	12,00	12,00	12,00

Table 3.10a: Increase of C/I in [dB] by down-tilting for n = 4 and R = 1.25 km.

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	0,59	0,71	0,88	0,93	0,98	1,00	1,03	1,05	1,06
30	0,92	1,11	1,38	1,47	1,56	1,58	1,63	1,67	1,69
50	1,63	2,01	2,55	2,73	2,91	2,96	3,06	3,14	3,18
75	2,68	3,36	4,39	4,76	5,13	5,22	5,44	5,60	5,69
150	7,30	10,20	12,00	12,00	12,00	12,00	12,00	12,00	12,00
300	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00	12,00

Table 3.10b: Increase of C/I in [dB] by down-tilting for n = 8 and R = 1.25 km.

The increase in C/I given in Table 3.9a, 3.9b, 3.10a and 3.10b can be directly added to the absolute C/I values given in the tables of the previous subsections corresponding to the proper radii.

Thus antenna down-tilting is an efficient means to lower the required frequency reuse or cluster size, respectively. But a prerequisite is the realization of a narrow half-power beamwidth antenna pattern in elevation which leads to relatively large antennas due to the low frequencies under consideration for DVB-T/-H in comparison to mobile telecommunications frequencies.

3.3.5 Illumination of MFN cells by SFNs

Combining the benefits of SFNs with the cellular layout of MFNs to distribute more localized content leads to the idea of illuminating the hexagonal cell area by an SFN whose transmitters are located in the corners of the hexagon. In this subsection the analysis is restricted to the case where only 3 transmitters with 120° sector antennas in every second corner of the hexagonal cell are used to illuminate the cell area. This case is the most preferable due to the fact that if only 3 sectorized transmitters are used to form the SFN no more transmitter locations are needed that in the case where omnidirectional antennas in the centre of the cell are used.

In Figure 3.25 the geometry of the cell layout is depicted and the distances for C/I calculation are given.

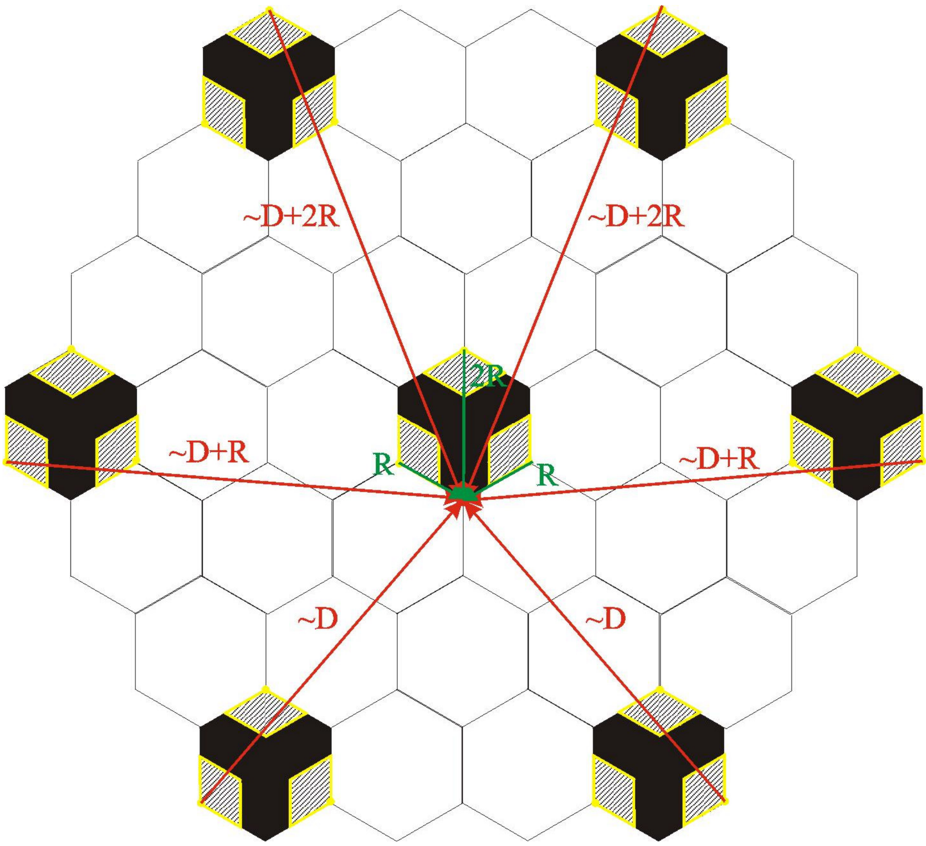


Figure 3.25: Geometry for C/I calculation when illuminating the MFN cells by 3 transmitter SFNs.

For the point on the cell border of the central cell under consideration in Figure 3.25 the serving part of the received power is delivered by two transmitters at a distance of R and one transmitter at a distance of 2R. The interference power comes from the sectorized antennas of the first ring of cells using the same frequency and is given by two transmitters at a distance of ~D+2R, two transmitters at a distance of ~D+R and another two transmitters at distance ~D.

Table 3.11 to Table 3.14 show the achieved C/I with 3 transmitter SFNs for illuminating the MFN cells for different cluster sizes, TX antenna heights, cell radii R and environments based on calculations according to the ITU-R P.1546-1 model. Again the yellow fields in these tables mark where a C/I of at least 26.2 dB is achieved which would be sufficient for a protection ratio of 14.2 dB + 3 dB = 17.2 dB as in case of DVB-T with 16-QAM, code rate 2/3 reception and DVB-T as the interfering signal. An additional location correction of 9 dB for 95 % coverage probability leads to a required C/I of 26.2 dB.

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	22,74	25,51	30,82	33,17	35,84	36,58	38,48	40,04	40,95
30	21,78	24,57	30,01	32,45	35,27	36,06	38,12	39,83	40,83
50	20,37	23,14	28,66	31,20	34,18	35,04	37,26	39,14	40,25
75	19,14	21,86	27,41	30,02	33,11	34,01	36,36	38,37	39,55
150	17,01	19,51	24,85	27,43	30,59	31,54	34,02	36,19	37,48
300	15,04	17,22	21,99	24,39	27,40	28,34	30,79	33,01	34,32

Table 3.11: Achieved C/I for MFN hexagonal layout with SFN illumination of cells by 3 x 120° sectors for R = 5 km and a rural environment based on the ITU-R P.1546-1 propagation model.

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	20,52	23,26	28,63	31,06	33,85	34,62	36,62	38,28	39,24
30	19,15	21,75	26,95	29,33	32,10	32,87	34,88	36,56	37,54
50	17,61	20,00	24,89	27,18	29,87	30,63	32,63	34,31	35,30
75	16,51	18,72	23,31	25,50	28,11	28,85	30,82	32,49	33,48
150	15,12	17,05	21,06	22,99	25,33	26,02	27,83	29,41	30,35
300	14,02	15,73	19,20	20,87	22,88	23,47	25,05	26,44	27,27

Table 3.12: Achieved C/I for MFN hexagonal layout with SFN illumination of cells by 3 x 120° sectors for R = 2.5 km and a rural environment based on the ITU-R P.1546-1 propagation model.

TX height [m] / cluster	3	4	7	9	12	13	16	19	21
20	20,55	23,28	28,66	31,08	33,86	34,64	36,64	38,29	39,26
30	19,16	21,75	26,95	29,33	32,09	32,87	34,88	36,55	37,53
50	17,58	19,96	24,84	27,13	29,82	30,58	32,58	34,25	35,24
75	16,43	18,64	23,21	25,39	28,00	28,74	30,71	32,38	33,36
150	14,89	16,80	20,78	22,71	25,04	25,72	27,53	29,10	30,03
300	13,44	15,11	18,53	20,17	22,17	22,76	24,33	25,70	26,53

Table 3.13: Achieved C/I for MFN hexagonal layout with SFN illumination of cells by 3 x 120° sectors for R = 2.5 km and an urban environment based on the ITU-R P.1546-1 propagation model.

TX height / cluster	3	4	7	9	12	13	16	19	21
20	18,01	20,43	25,34	27,64	30,32	31,07	33,05	34,71	35,68
30	17,03	19,26	23,80	25,94	28,47	29,18	31,07	32,66	33,59
50	15,99	18,02	22,13	24,08	26,39	27,05	28,79	30,27	31,14
75	15,30	17,19	21,00	22,79	24,92	25,52	27,14	28,52	29,34
150	14,24	15,96	19,38	20,97	22,84	23,37	24,78	25,98	26,69
300	13,21	14,77	17,85	19,27	20,92	21,39	22,62	23,67	24,28

Table 3.14: Achieved C/I for MFN hexagonal layout with SFN illumination of cells by 3 x 120° sectors for R = 1.25 km and an urban environment based on the ITU-R P.1546-1 propagation model.

Comparison of tables 3.11-3.14 with tables 3.3-3.6 shows that illuminating the cells of a MFN by a 3 transmitter SFN is a very efficient means of lowering the necessary cluster size and thus the frequency demand without the need for additional transmitter locations.

To demonstrate the feasibility of the derived C/I values for different cluster sizes in tables 3.11 – 3.14 for a transmitter network consisting of hexagonal SFNs with three transmitters and 120° sectors for cluster sizes of N = 7 and N = 9 in the Berlin area the coverage probability was predicted for the case of DVB-H, terminal class A with 8 k FFT mode, 16-QAM, guard interval 1/8 (112 µs) and a inner code rate of 2/3, for further parameters see Table 3.1. The cell radius was 5 km, the transmitter height 75 m and the transmit power 1 kW per 120° sector.

In Figure 3.26 the coverage probability in case of a cluster size of N = 7 is depicted. Due to interference from the outer cells the coverage decreases within the inner cells.

Figure 3.27 shows the coverage probability in the case of cluster size N = 9. Now the distance of the nearest interferers is reduced and the coverage probability increases also for the inner cells.

The results given in Figure 3.26 and Figure 3.27 are in full accordance with the values given in Table 3.13 were a cluster size of 12 is suggested for the assumed parameter set.

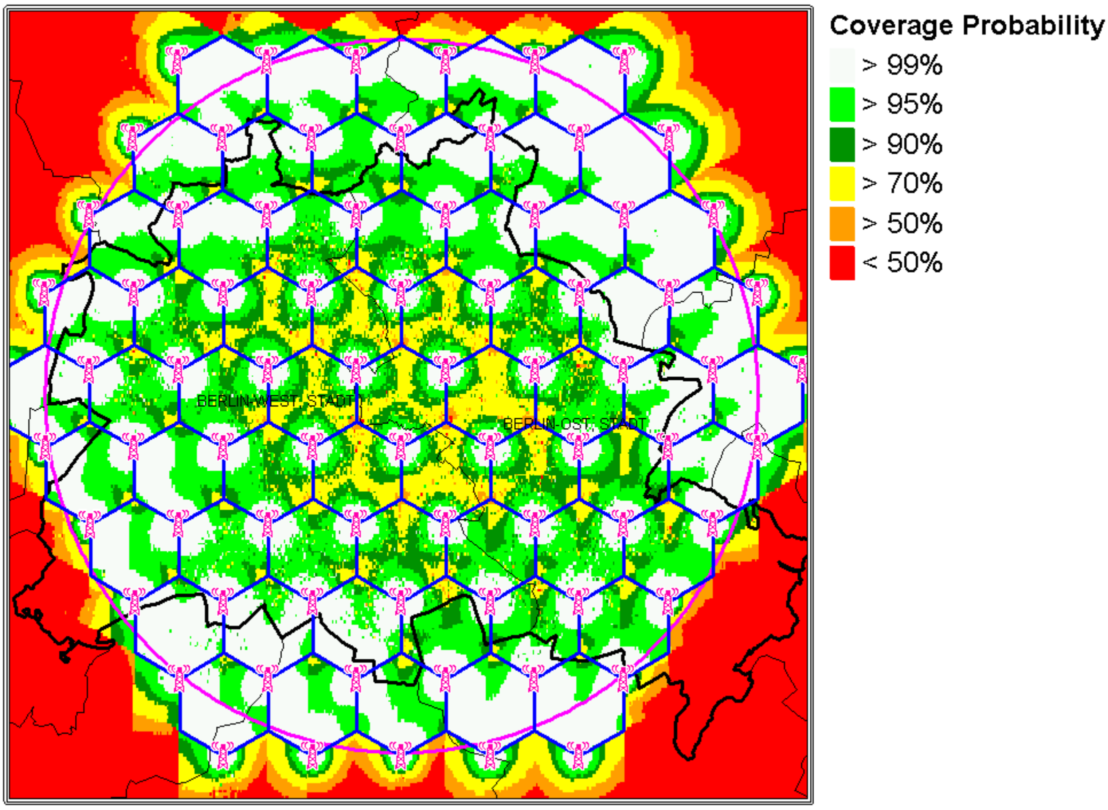


Figure 3.26: Coverage probability for MFN with cluster size N = 7, each cell consisting of 3 x 120° sectorized transmitters.

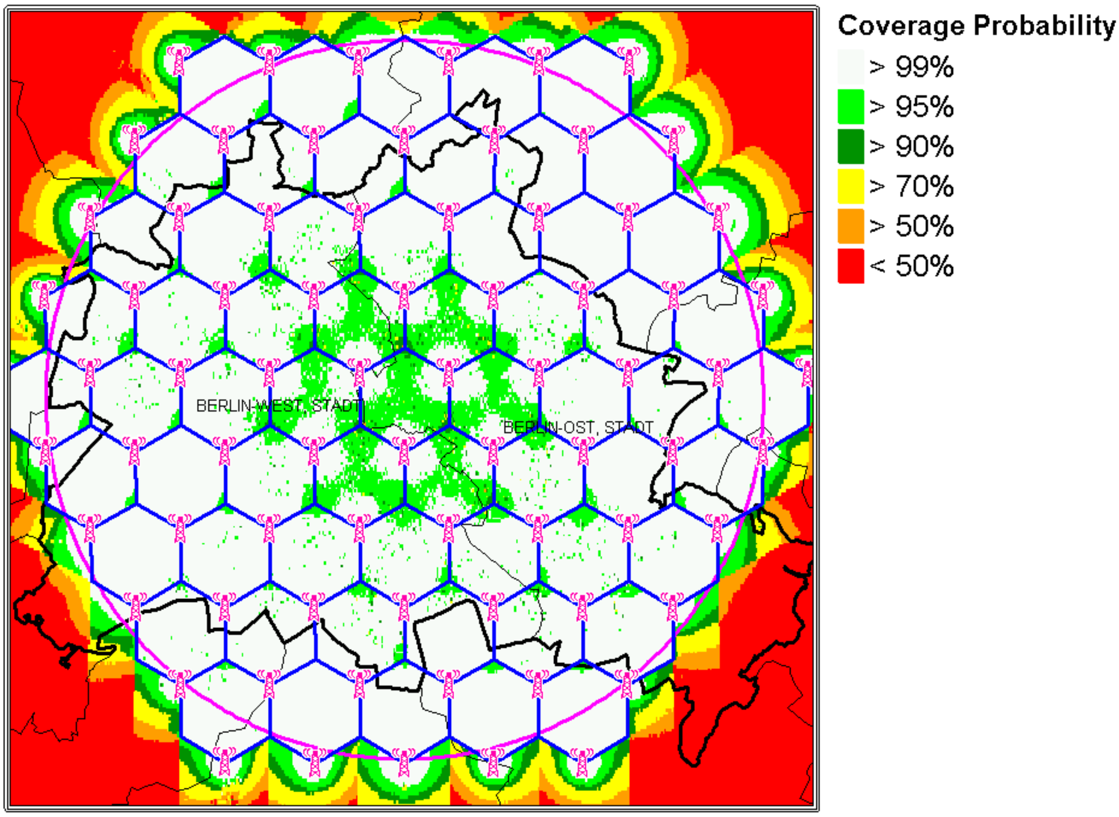


Figure 3.27: Coverage probability for MFN with cluster size N = 9, each cell consisting of 3 x 120° sectorized transmitters.

3.4 References

[1] RRC 04 final document, 2004.
[2] Kittel, L.; Hagenauer, J.: course material on "Digital Mobile Radio". Carl Cranz Gesellschaft, 1991 (in german).
[3] ITU-R Rec. P.1546-1: Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz. 2003.
[4] ETSI TR 102 377 (Draft) Digital Video Broadcasting (DVB); DVB-H Implementation Guidelines, 2005.
[5] Jakes, W.C.: Microwave mobile communications, John Wiley, 1974.

Chapter 4 SFN Network Benefits for DVB-H Networks

For the first deployments of DVB-H networks, it seems that SFN networks will be the favoured option.

This chapter attempts to evaluate the gain in network coverage due to a SFN network to appraise the added coverage area compared to an MFN network.

The study is purely theoretical and should be validated by the practical experience of broadcast operators.

4.1 Elementary analysis

4.1.1 Assumptions

Consider an area that spans such distances that border effects can be neglected but that nevertheless is considered small enough to be able to ignore the interference problems between transmitters in the same SFN network. The guard interval should be selected accordingly (1/4 or 1/8) to meet this latter assumption. These assumptions are not unrealistic for the deployment over a large city where the network will be dense enough.

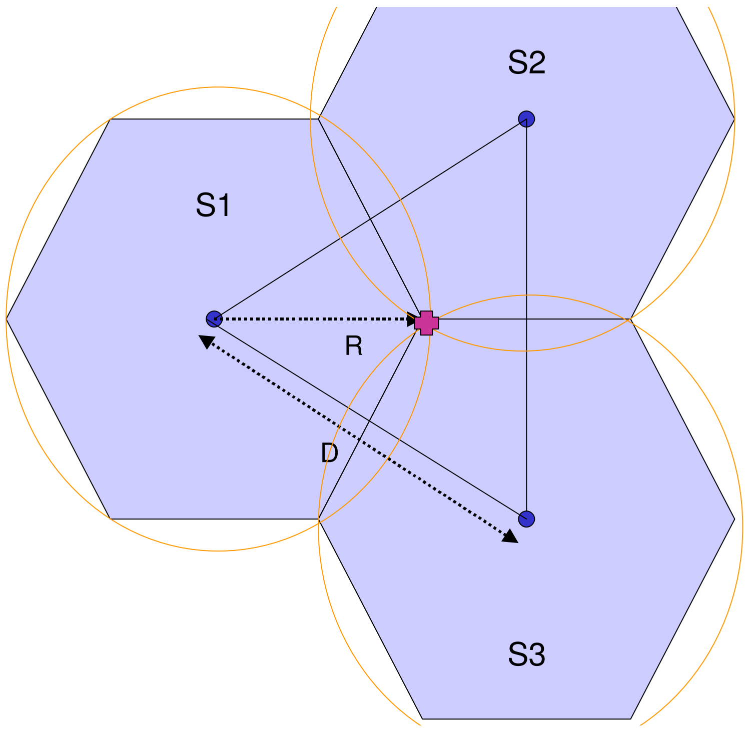


Figure 4.1: SFN sites located along a hexagonal pattern

The SFN sites are supposed to be chosen by the network operator so that they can be located perfectly on a hexagonal pattern.

The Hata propagation model for an urban environment is used. For a transmitter at altitude h(m), power P(kW), frequency F (MHz), and a receiver at 1.5m height, the field strength at distance d(km) from the transmitter is then given by:

E(dBμV/m) = 10*log(P) - (44,9-6,55*log(h))*log(d) +K(F,h)

With K(F, h) = 67,65 –6,16*log(F) + 13,82*log(h)

Finally, all sites are considered to have the same height ho and the same transmission power Po.

4.1.2 Derivation of the optimal distance

Considering the location A, indicated by red cross the on the above figure, the combined field strength is the same as that of a single transmitter with ERP P=Po+10*log(3), at a distance R_{SFN}, since all three transmitters have the same contribution.

In the case of a MFN, only one transmitter would have to create the field strength.

If the MFN transmitter covers an area with radius R_{MFN}, the radius of SFN cells with the same power is R_{SFN} such that:

$$10*\log(Po) - (44.9-6.55*\log(h))*\log(R_{SFN}) = 10*\log(Po) + 10*\log(3) - (44.9-6.55*\log(h))*\log(R_{MFN})$$

or

$$\log(\frac{R_{SFN}}{R_{MFN}}) = \frac{10\log(3)}{44.9 - 6.55\log(h)}$$

The optimal distance between two sites can thus be derived:

$$\boxed{D_{SFN} = 10^{\frac{10\log(3)}{44.9-6.55\log(h)}}\sqrt{3}R_{MFN}}$$

Because the location A is the most difficult location to cover given this hexagonal pattern, when the distance between sites is D_{SFN}, the whole of the hexagon will be covered and the coverage gain in surface area is:

$$SurfaceAreaGain_{SFN} = \frac{\frac{\sqrt{3}}{2}D_{SFN}{}^{2}}{\pi \cdot R_{MFN}{}^{2}} - 1$$

$$\boxed{SurfaceAreaGain_{SFN} = \frac{3\sqrt{3}}{2\pi} \cdot 10^{\frac{20\log(3)}{44.9-6.55\log(h)}} - 1}$$

<u>Examples</u>

Antenna Height	**50m**	**200m**
R_{SFN}	1,38 R_{MFN}	1,45 R_{MFN}

D_{SFN}	2,40 R_{MFN}	2,50 R_{MFN}
SurfaceAreaGain$_{SFN}$	**59%**	**73%**

This means that in theory, the gain in surface area covered when using an SFN can be quite large.

In the above computations, the assumption is made that the field strength of several field strengths is the linear sum of these individual field strengths in µV/m. Because field strength is always a statistical variable, this is not entirely true. However, the use of more accurate formulas will always yield more optimistic results. The gain in surface area computed here is therefore a minimum gain.

Figure 4.2 illustrates the result of a simulation: three transmitters are located at equal distances and would cover the blue area if they were on three different frequencies in a MFN. The yellow area corresponds to the additional area covered by the SFN gain. In Figure 4.2, the symmetry is not complete for the yellow area since the simulation is only performed for transmitters radiating in one quarter of a plane only. Therefore, only the triangle between the three sites is relevant here.

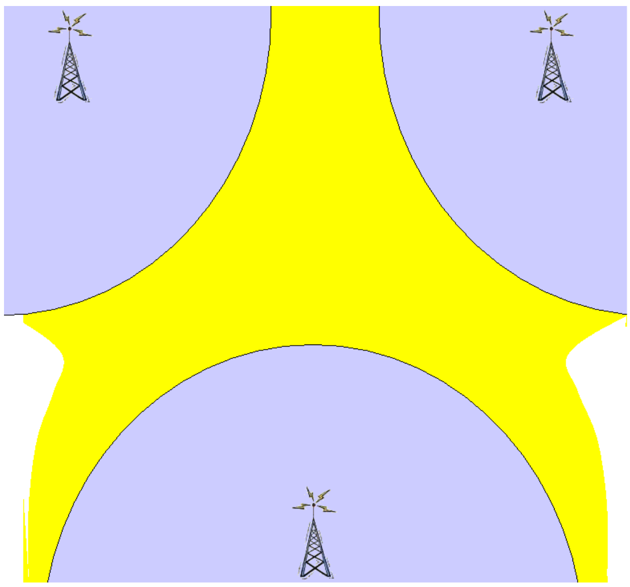


Figure 4.2: Illustration of SFN gain

<u>Limitations</u>

The above computations apply for an optimal site selection with the optimal distance. In a real life situation, the distance will vary between transmitters.

Figure 4.3 shows using again the simulations for a transmitter at 1kW and site heights of 50 m and 200m respectively that the SFN gain will vary quickly depending on the selected distance between sites. Obviously, when SFN sites are located too close to each other there is a loss in efficiency as there is overlap between the covered areas rather than a constructive effect.

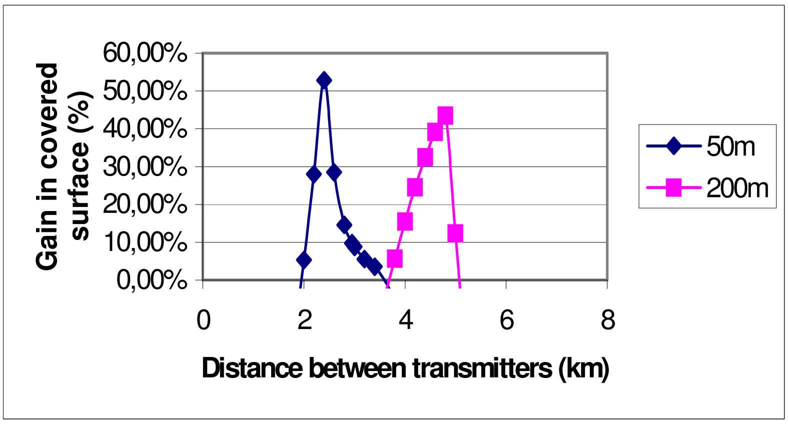


Figure 4.3: Gain area coverage variations depending on distance between transmitters

Figure 4.3 clearly shows that although the gain can be quite impressive (above 50%), it can also be limited (10%).

On the basis of this study only, it can therefore be considered dangerous to rely on the gain in coverage due to the SFN network for real life network planning.

The next section will try to adopt a more rigorous approach as this preliminary study does not enable clear conclusions to be drawn.

4.2 Simulation based analysis

4.2.1 Assumptions

The study is now uniquely based on the comparison between THREE transmission sites in a SFN and the same sites in a MFN. The propagation model is still the Okumura Hata model, at 1.5m, for urban planning.

The gain in surface area is computed as:

$$\mathrm{SurfaceAreaGain}_{\mathrm{SFN}} = \frac{\mathrm{TotalSurface}_{\mathrm{SFN\_3Tx}}/3}{\mathrm{Surface}_{\mathrm{MFN\_1Tx}}} - 1$$

The gain is estimated as the surface area covered by one site of a SFN using the SFN contributions of other sites, divided by the surface are covered by one single site of a MFN.

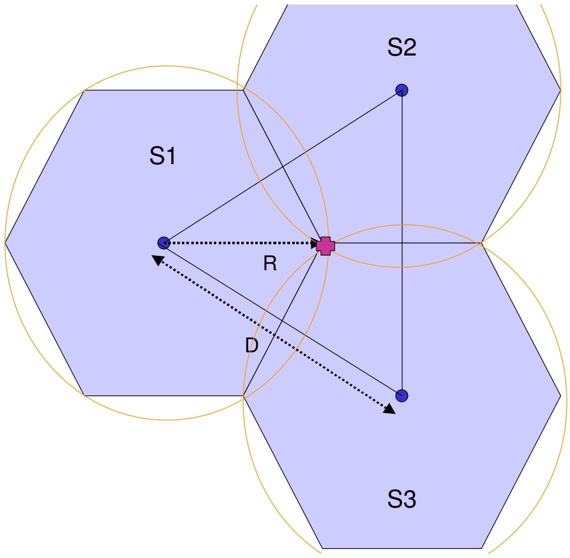


Figure 4.4: Model with 3 transmitters

The simulation is run with a 100m computing step.

For every 100m x 100m square, the following algorithm is applied:

- compute the field strength created by each transmitter using the Okumura Hata model
- compute the mean (*resultingMeanFieldStrength*) and standard deviation (*resultingStdFieldStrength*) of the resulting field strengths using the tLNM method, assuming that all field strengths have the same standard deviation *inputStdFieldStrength*
- decide that the square is covered

in a SFN, when

resultingMeanFieldStrength >= *RequiredMeanFieldStrength* + *corFactor*resultingStdFieldStrength*

in a MFN, when

resultingMeanFieldStrength >= *RequiredMeanFieldStrength* + *corFactor*inputStdFieldStrength*

corFactor is the correction factor to cover 50% (0), 70% (0.55), 95% (1.65) or 99% (2.33) of the locations. It simply assumes a lognormal distribution of the field strengths.

RequireMeanFieldStrength is the average field strength required to cover 50% of the locations for a given transmission mode.

4.2.2 Results

The simulation was run for two different configurations:

- 3 transmitters at 200m, 1kW ERP, for reception in mobility.
- 3 transmitters at 50m, 1kW ERP, for reception in mobility.

In both cases, the required mean field strength is 60dBµV/m, the standard deviation is 6dB.

The correction factor is 2.33 for 99% location coverage.

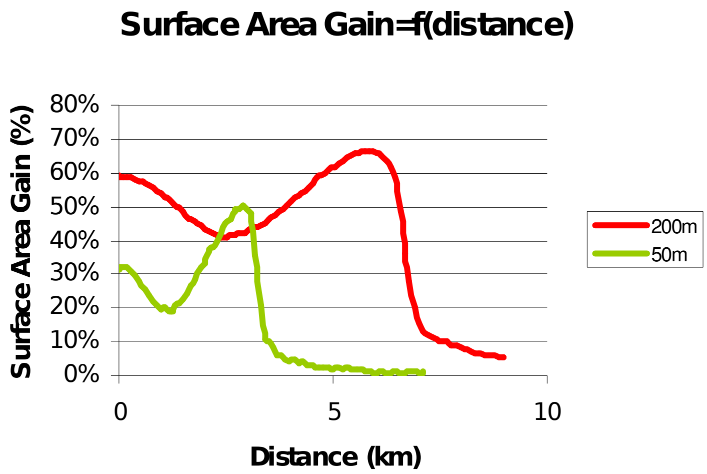


Figure 4.5: Surface Area gain, antenna height influence, 1kW ERP

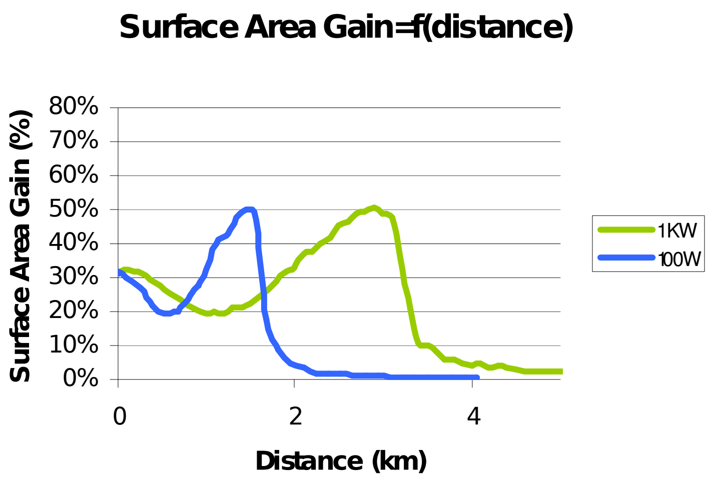


Figure 4.6: Surface area gain, transmitter power influence, 50m height

The simulation was then run for two distances between sites: 1km and 3km, with 200m high transmitters.

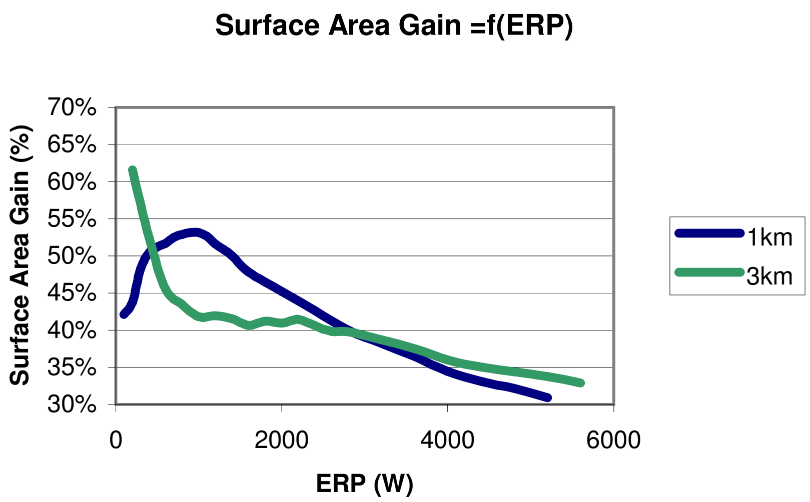


Figure 4.7: Surface area gain, ERP influence for a given spacing of transmitters

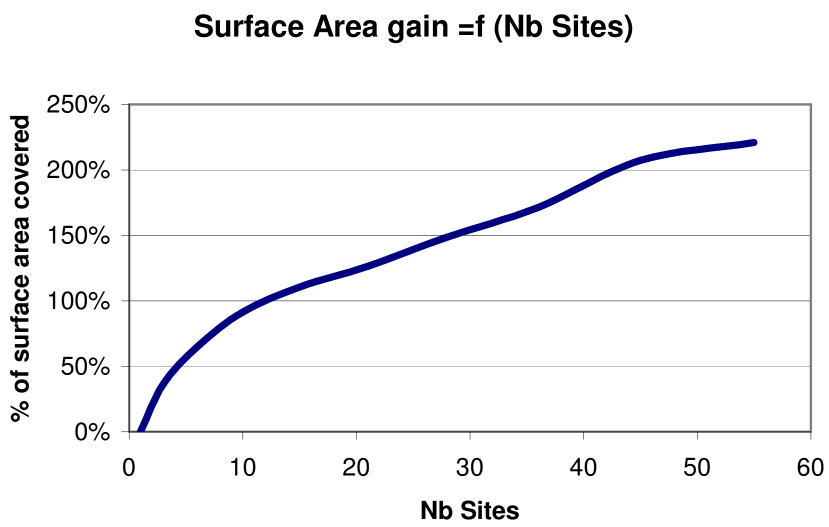


Figure 4.8: Surface area gain, influence of number of sites

In Figure 4.9, the transmitters are spaced at a quasi-optimal distance, for the 200m height case. The area in green corresponds to the coverage of the MFN, the area in blue is the additional area covered by the SFN.

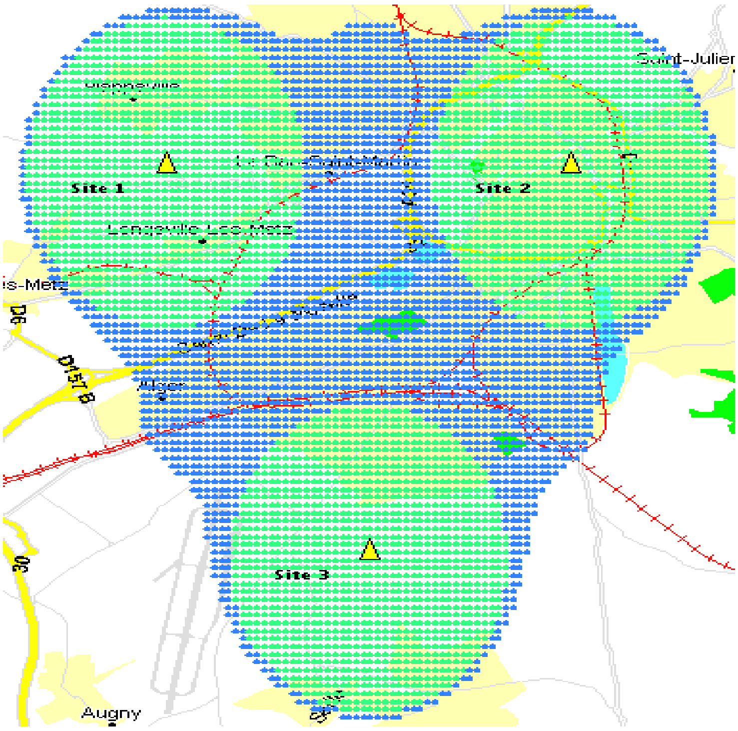


Figure 4.9: SFN coverage vs MFN coverage

4.2.3 Analysis

For a typical mobile configuration, with two kinds of transmitters (50 meters height, 200 meters height), there is **a real benefit of planning the network as a SFN (20% to 60%).**

This benefit seems to be even more impressive when **large transmitters** (high) are used. Conversely, the choice of the transmission power has no influence on the maximum achievable SFN gain. Only the optimal distance is impacted.

Up to the optimal distance *dMax* between transmitters, there is a stable gain in coverage. Then, the gain drops significantly. For real life planning, it will be important to ensure that the distances are kept below this *dMax* value. *dMax* actually corresponds to the distance that maximises the gain in coverage and that is the maximum distance allowed before the gain drops.

When distances between transmitters are fixed, lower ERPs seem to yield increased SFN gain.

4.3 Case of Metz city

A real coverage prediction exercise was performed for the city of Metz. The assumptions are somewhat different from those of the previous section as a real case is studied, where not all transmitters have the same heights and altitudes, and where antennas are not omni-directional.

4.3.1 Site configurations: Scy-Chazelles ; Metz-C2R ; Metz- St-Julien

The city of Metz has a minimum altitude of 162m and a maximum altitude of 256m.

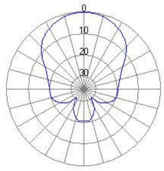
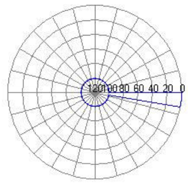
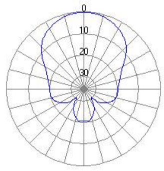
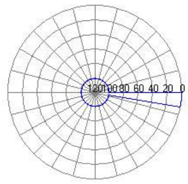
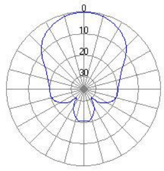
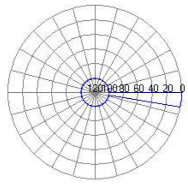
Transmitters	Transmission height	Polarisation	Frequency	ERP	Azimut	Radiation pattern (horizontal and vertical)
Scy-Chazelles	30 m	Vertical	706 MHz (C50)	600/1200 W	110 °	 
Metz-C2R	45 m	Vertical	706 MHz (C50)	600/ 1200 W	290 °	 
Metz- St-Julien	60 m	Vertical	706 MHz (C50)	600/ 1200 W	230 °	 

Table 4.1: Site transmission specifications

Site	Code IG	Latitude	Longitude	Altitude	Estimated effective height	Distance to C2R
Scy-Chazelles - Fort Diou	5764203	49°07’17’’N	06°07’48’’E	353 m	221 m	6.4km
Metz-C2R	5746301	49°06’12’’N	06°12’53’’E	200 m	83 m	0km
Metz- St-Julien	5761601	49°08’30’’N	06°13’00’’E	262 m	160 m	4.26km

Table 4.2: Site coordinates and effective heights

4.3.2 Required Field strength

Two cases are studied: QPSK ½ for which it is estimated that 79dBuV/m is necessary, and 16QAM ½ for which it is estimated that 85 dBuV/m is required.

4.3.3 Results

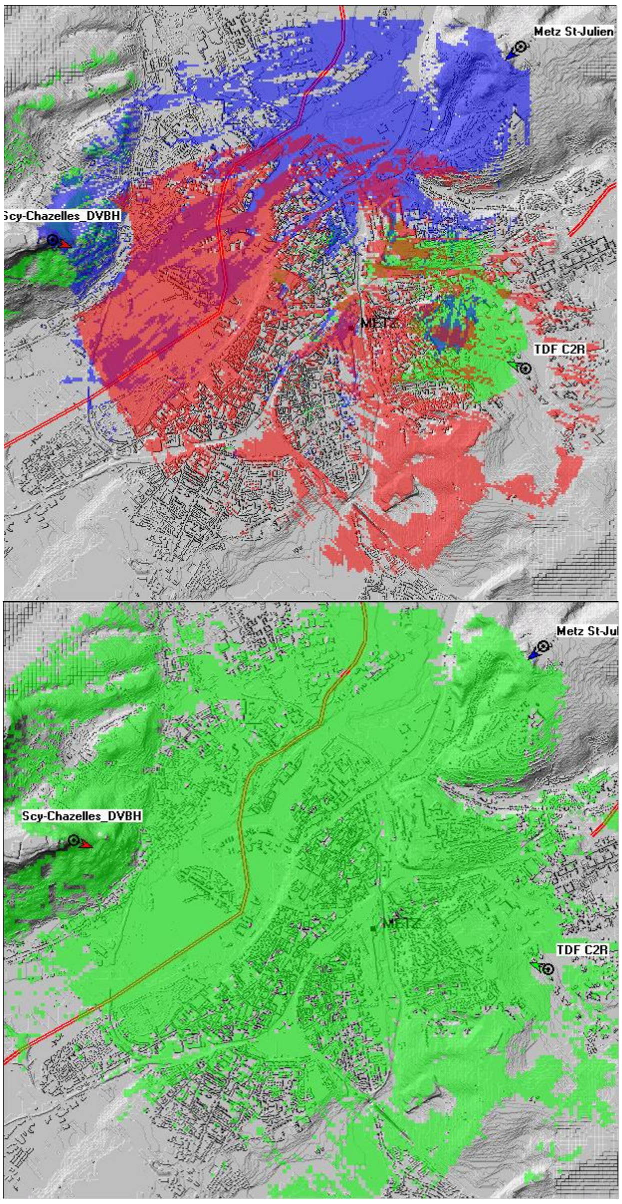


Figure 4.10: Comparison of MFN and SFN coverage, QPSK 1/2, 1200W ERP

	Covered area (km²)			
	QPSK 1/2		**16QAM ½**	
Transmitter	**600 W**	**1200 W**	**600 W**	**1200 W**
Scy-Chazelles	6.06	11.91	1.57	4.04
Metz-C2R	1.98	4.03	0.76	1.21
Metz-St-Julien	7.20	14.71	1.53	3.69
Three sites	14.30	25.84	3.85	8.94
Service zones	24.38	41.90	6.91	13.38
SFN gain	**60%**	**37%**	**79%**	**50%**

Table 4.3: Covered areas in each configuration, SFN gain

The SFN gain is computed as the ratio of the service zone divided by the sum of all three individual surface areas (Scy-Chazelles, Metz-C2R, Metz-St-Julien), according to the definition used in section 2.

The results are similar or even better than those presented in section 3: the SFN gain is quite noticeable, with values of 60% gain easily reached.

It is also interesting to notice the same trend seen in section 3: for a given distance between transmitters, **the SFN gain increases when the ERP of the transmitters decreases.**

4.4 Conclusions

SFN gain can be substantial: from 20% in a worst case scenario, to 70% in the case of optimised site location, ERP and heights, for three transmitters.

SFN gain is even larger when small sites are deployed: little ERP on a large number of sites will increase the SFN gain.

Although **the SFN gain can be quite impressive in the case of a large number of sites**, with values over 100% in the case of 10+ sites, the cost of deployment must be taken into account, and it is anticipated that **the cost of the site multiplication will not be compensated for by the SFN gain**.

Chapter 5 Study of SFN for DVB-H networks

The objective of this chapter is to determine, at a broadcast operator investment cost level, what is the best configuration for a DVB-H SFN network deployment. Would it be more interesting to use large or small sites? Results of simulations (made with the TDF proprietary radio planning tool), for several configurations, and with working assumptions close to future deployments, are presented.

5.1 Assumptions

5.1.1 DVB specifications

Modulation	QPSK
Code rate	½
Guard interval	1/8
Mode	8 k
Net bit rate (Mbits/s)	5,53

Table 5.1: DVB specifications

5.1.2 Transmission

- The transmission will be achieved on channel 50 (706 MHz)

5.1.3 Reception

Some assumptions are made concerning the specifications of DVB-H receivers:

- Handheld portable convergence terminals are considered
- The terminals are used according to the four user classes defined in the ETSI guidelines:

Class A	Portable outdoor
Class B	Portable indoor
Class C	Mobile outdoor
Class D	Inside mobile

Table 5.2: Classes

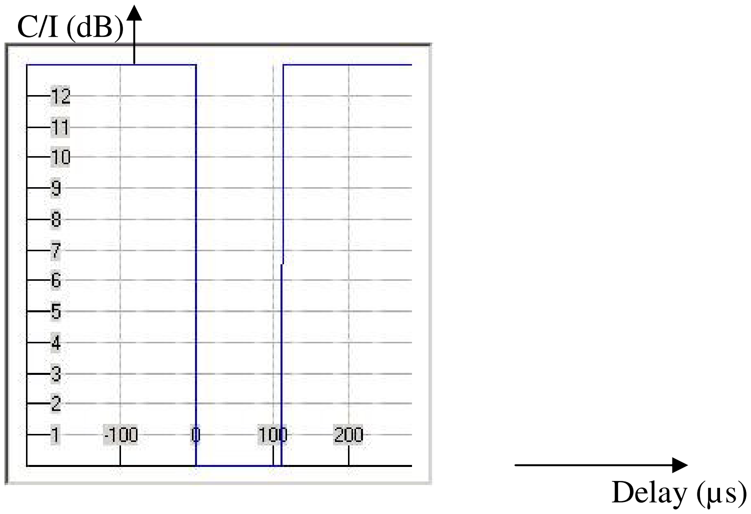
- Only the worst reception case, class D, will be considered

Note: In the "inside mobile" reception situation, no external antennas are used.

- Receiver antenna: patch antenna (Nokia 7700)
- Reception height is 1.50 m
- Vertical polarisation
- Noise factor = 6 dB
- Penetration margin (in car) = 8 dB
- Dense urban environment (DU)

- The standard deviation of the signal inside the vehicle is taken equal to 6 dB, in spite of the recommendations advocating a standard deviation of 5.5 dB, for reception with a rooftop antenna. For indoor portability, the advised standard deviation is 8.1 dB. In a configuration of a terminal with an integrated antenna, inside a vehicle, the environment is a priori less restrictive than indoor portability, but more restrictive than rooftop reception, therefore 6 dB is chosen.
- MPE-FEC is not taken into account

The synchronisation strategy is the one of the Nokia 7700 receiver (cf. graph below).



5.1.4 Field strength

The formula used, comes from the Chester agreement:

$E = F + 10\log(KTB) + C/N - Gr - 10\log(1.64 * (c/f)^2 / (4*\pi)) + p + 145.8 + \sigma *$ correction + penetration

The propagation model is the TDF "digital TV portability" model version 2.0, calibrated for a reception height of 2 meters, in an urban area, UHF band, and for distances lower than 20 km.

	QPSK ½ Class D
Boltzmann constant K	$1.38.10^{-23}$
Temperature T (K)	290
Bandwidth B (Hz)	$7.61.10^{6}$
Noise factor F (dB)	6
C/N (dB)	**9.5**
Reception antenna gain Gr (dBd)	-15
Frequency f (MHz)	706 (C50)
Losses p (dB)	0
Minimum median equivalent field strength at 1.5 m, 50 % of locations (dBµV/m)	*57.41*
Standard deviation σ (dB)	**6**
Percentage of locations (%)	**99** (correction coefficient = 2.33)
Penetration losses (dB)	**8**
Minimum median equivalent field strength at 1.5 m, x% of locations (dBµV/m)	**79.39**

Table 5.3: Minimum median equivalent field strength at 1.5 m for class D – QPSK modulation

Consequently, the tested field level will be **80 dBµV/m**, for the QPSK modulation.

5.1.5 Configurations

Thanks to a TDF cost function, based on CAPEX, a calculation has enabled it to be determined that the following configurations lead to similar investment costs:

- H_{Tx} = 150 m, ERP = 5 kW, 3 sites,
- H_{Tx} = 75 m, ERP = 400 W, 10 sites,
- H_{Tx} = 50 m, ERP = 100 W, 15 sites.

Consequently, simulations will be made of these three configurations, to determine the best configuration in a dense urban environment.

5.2 Prediction coverages

5.2.1 Site configurations

5.2.1.1 Specifications

The geographical coordinates of the sites (coordinates, altitude), in each configuration, are given in Appendix 5.

5.2.1.2 Transmission specifications

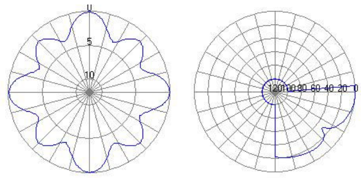
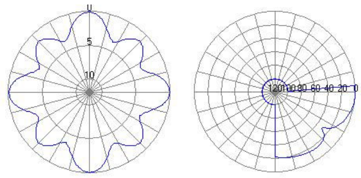
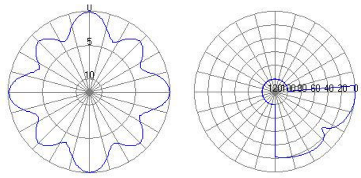
Transmitters	Transmission height	Polarisation	Frequency	ERP	Radiation pattern (horizontal and vertical)
Site C1	150 m	Vertical	706 MHz (C50)	5 000 W	
Site C2	75 m	Vertical	706 MHz (C50)	400 W	
Site C3	50 m	Vertical	706 MHz (C50)	100 W	

Table 5.4: Site transmission specifications in each configuration (C1, C2, C3)

5.2.2 Simulation parameters

- Atoll version 2.1.0 is the radio network planning tool, associated with Ivoire 1.7.1 (TDF).
- The propagation model is the TDF "digital TV portability" model version 2.0, calibrated for a 2-meter high reception, in an urban area, UHF band, and for distances lower than 20 km.
- The terrain database is the DEM (Digital Elevation Model) of Paris, with a 4m resolution,
- The calculation step is 25 meters for prediction coverage, and 50 m for service zones (a trade-off between accuracy and processing time),

Note:

1. The portability model is a semi statistical model calibrated for a height of 2 meters (real reception height is 1.5 m, so the attenuation due to the height difference (0.5 m) is considered negligible). It is valid only in the vertical plan (diffracting edge profile), and hence, does not take into account the multiple reflections in the horizontal plan, that is characteristic of propagation in an urban area. Only terrain measurements can corroborate the predictions presented here.

2. The predicted coverages presented take into account the potential interferences caused by the other transmitters.

5.2.3 Configuration 1: HTx = 150 m, ERP = 5 kW, 3 sites

The distance between two sites is 6 kms.

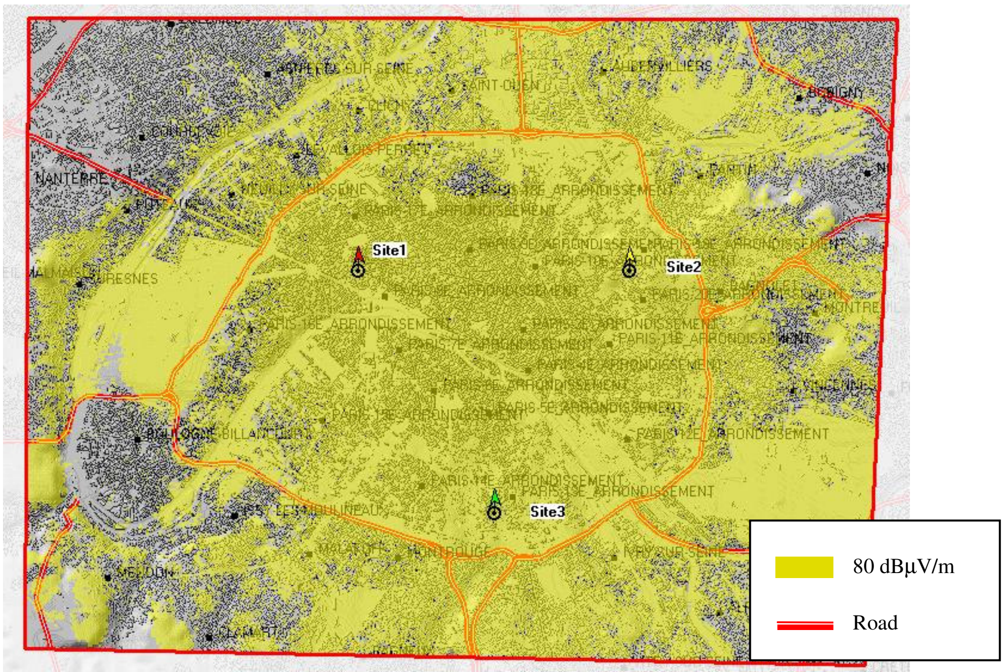


Figure 5.1: Service zone for configuration 1
Scale: 1 cm ↔ 1.72 km

Note:

1. The red frame represents the working zone.
2. The coordinates (NTF France II extended) of the reference point (Louvre Pyramid), on the map zoomed in, are the following:

$$\begin{cases} x = 599952 \\ y = 2429184 \end{cases}$$

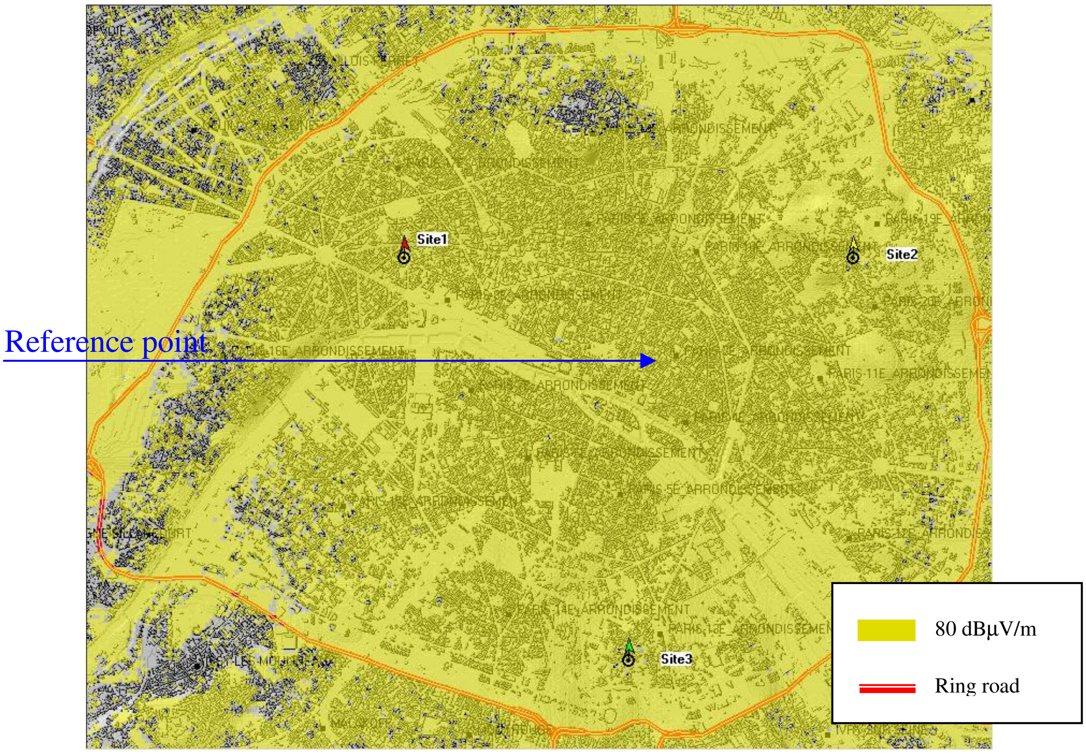


Figure 5.2: Zoom on the service zone obtained for configuration
Scale: 1 cm ↔ 1.07 km

The Paris city centre (CC), limited by the ring road, is rather well covered for the field level 80 dBµV/m. Significant holes of coverage (several hundreds of meters) are visible in the north, and in the west. The coverage of the ring road is nearly continuous.

5.2.4 Configuration 2: H_{Tx} = 75 m, ERP = 400 W, 10 sites

The distance between two sites is 1 km.

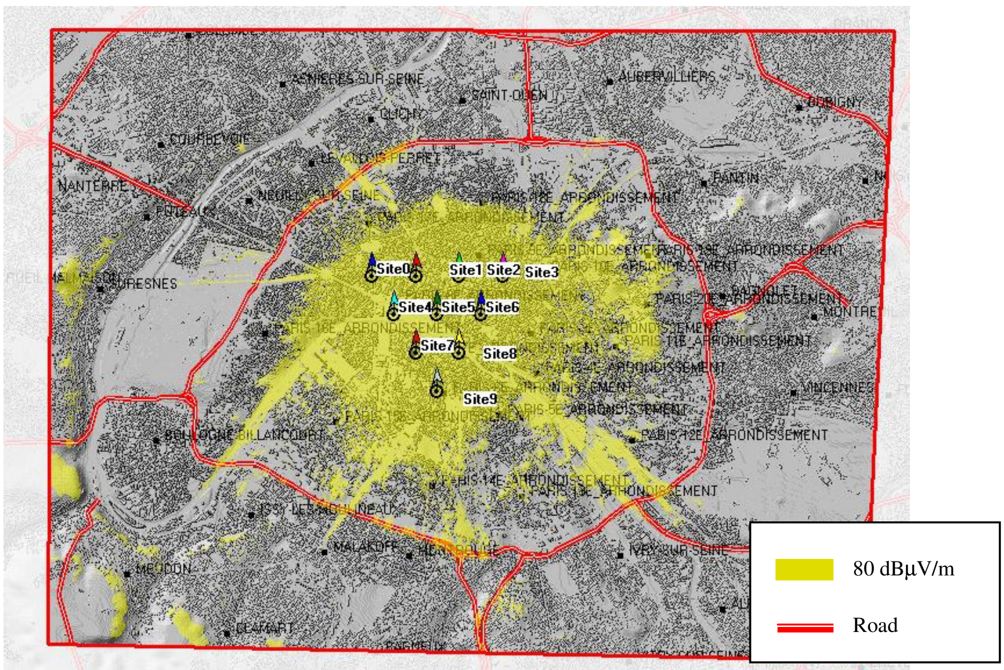


Figure 5.3: Service zone for configuration 2
Scale: 1 cm ↔ 1.72 km

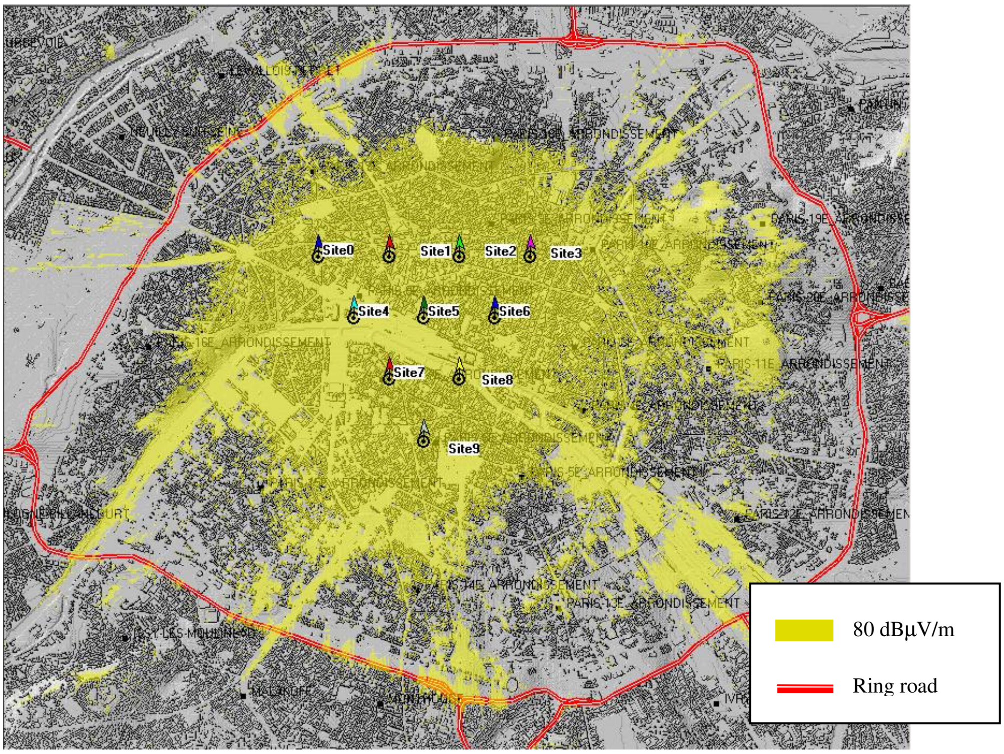


Figure 5.4: Zoom on the service zone obtained for configuration 2
Scale: 1 cm ↔ 1.07 km

The coverage of the CC is distinctly reduced (46 km²), in comparison with the first configuration. A big part of the city centre is no longer covered, and the ring road does not have any coverage.

5.2.5 Configuration 3: H_{Tx} = 50 m, ERP = 100 W, 15 sites
The distance between two sites is 400 m.

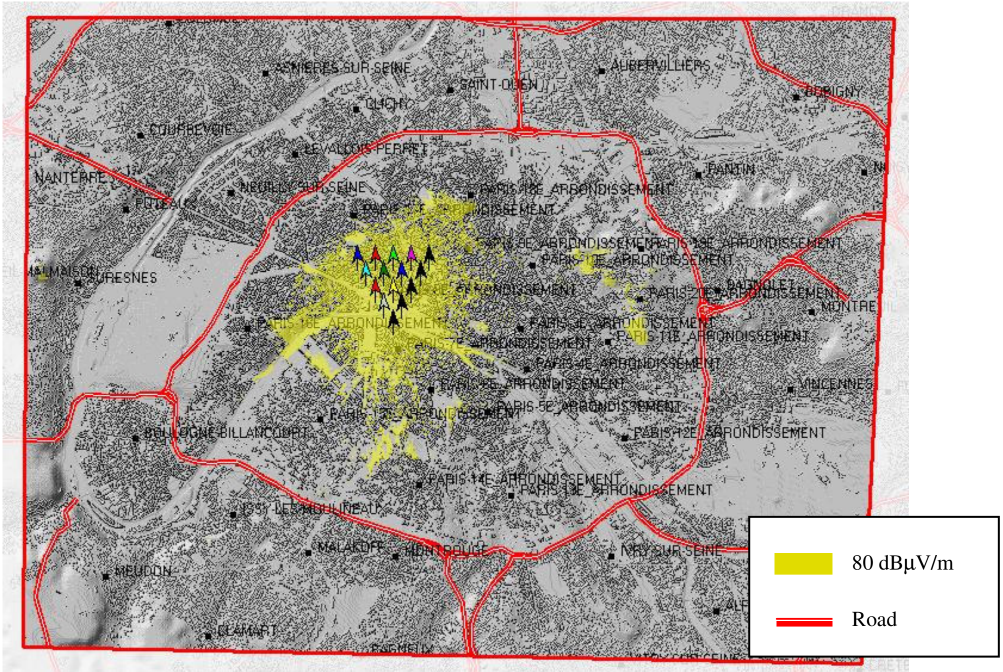


Figure 5.5: Service zone for configuration 3
Scale: 1 cm ↔ 1.72 km

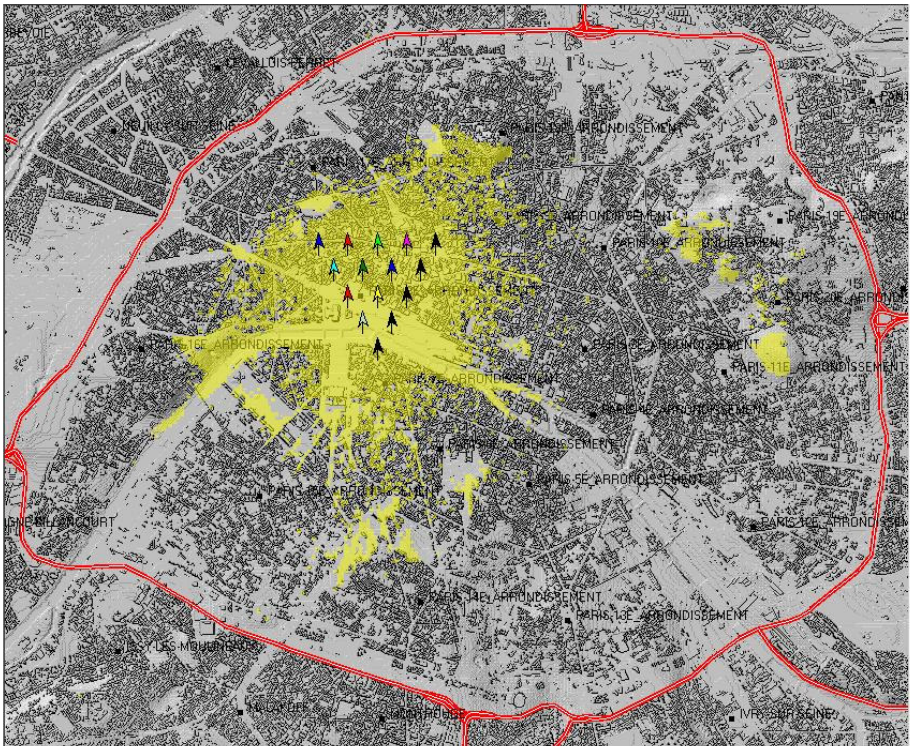


Figure 5.6: Zoom on the service zone obtained for configuration 2
Scale: 1 cm ↔ 1.07 km

The coverage is much smaller (12 km²) than the two previous ones.

5.3 Synthesis

5.3.1 Covered areas

Table 5.5 lists the covered areas obtained for each configuration. The coverage predictions are limited by the working zone defined under Atoll (surface = 266 km²)

Modulation	Signal level (dBµV/m)	Transmitter	Covered area (km²)
QPSK	**80**	Configuration 1	195
		Configuration 2	46
		Configuration 3	12

Table 5.5: Covered areas in each configuration

Red	Bad coverage in the CC
Yellow	Medium coverage in the CC
Green	Good coverage in the CC

CC: City centre

5.4 Conclusions

First, it is important to emphasise that the reception case considered in this chapter is the worst one: the class D (inside mobility), and the terminal used for the simulations is the mobile Nokia 7700. It must be noted that the propagation model used, does not take into account the propagation into the horizontal plane.

The city centre of Paris is well covered within the first configuration: 150 m high, 5 kW ERP, and three sites. In the second configuration the global coverage decreases distinctly, and finally, for the third configuration the coverage is drastically reduced. **The simulations presented in this chapter clearly show that large sites give the best coverage, for a SFN DVB-H QPSK ½ 8k 1/8 class D case, in a dense urban environment (centre of Paris).**

The SFN gain can be quite important in the case of a large number of sites. However, **it is shown here, that the cost of the site multiplication is not compensated for by the SFN gain**.

Chapter 6 DVB-H, GSM900, GSM1800 and UMTS cositing analysis

6.1 Introduction

This chapter presents cositing issues between the DVB-H system and radiocom services (GSM900, GSM1800, and UMTS). The main topic is Electro-Magnetic Compatibility (EMC) between radio systems. In the first part of this chapter the isolation required between systems, to maintain an acceptable Quality of Service (QoS), is derived from radio equipment specifications, and in the second part of the chapter possible cositing architectures are proposed in terms of antenna spacing.

For the EMC analysis three types of interferers are taken into account:

- Spurious emissions from one transmitter falling into the receive band of a cosited receiver
- The blocking effect, that may occur when a strong interferer is located nearby a receiver
- The intermodulation products that are generated when several transmitters are cosited

6.1.1 Frequency bands of studied systems

	Uplink (UL) Mobile → Basestation	Downlink (DL) Basestation → Mobile
GSM900	**880 – 915 MHz**	**925 – 960 MHz**
GSM1800	**1710 – 1785 MHz**	**1805 – 1880 MHz**
WCDMA - FDD	**1920 – 1980 MHz**	**2110 – 2170 MHz**
DVB-H	**Not applicable**	**470 – 860 MHz**

Table 6.1: Frequency bands of studied systems

6.1.2 Decoupling between antennas

The decoupling values between antennas will be evaluated thanks to the software tool named *Lorraine* (TDF internal tool). The decoupling between antennas is considered from antenna port to antenna port whereas the required isolation between systems is considered from base-station connector to base-station connector.

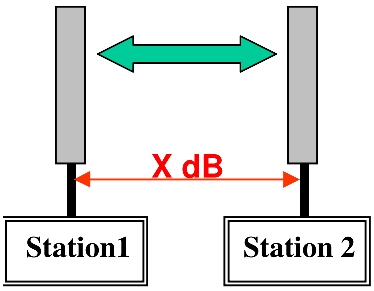
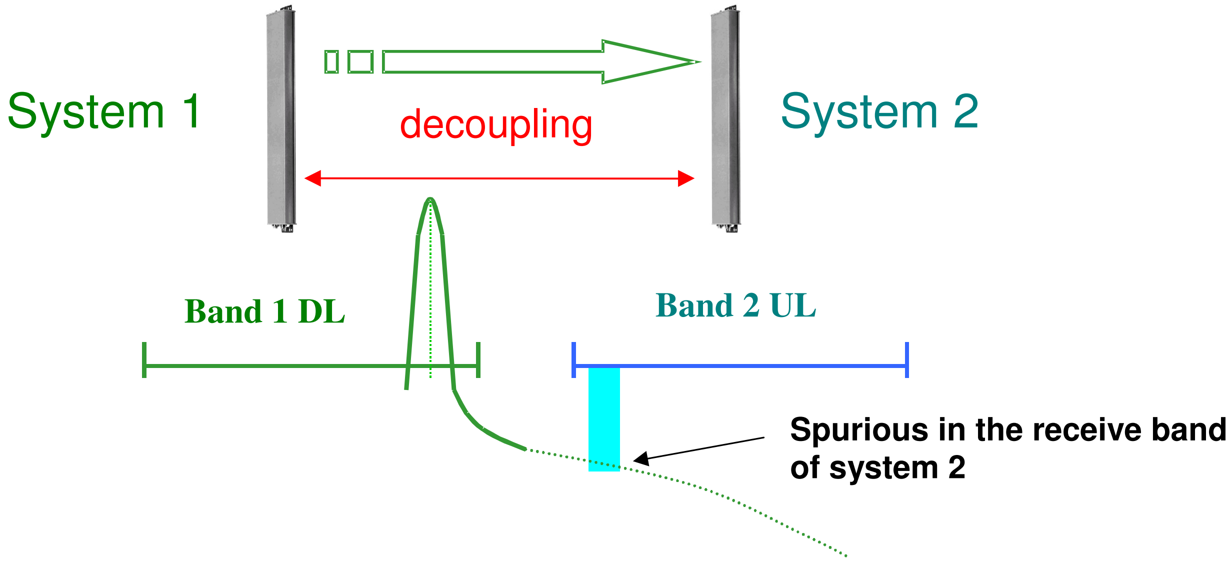


Figure 6.11: Decoupling between antennas

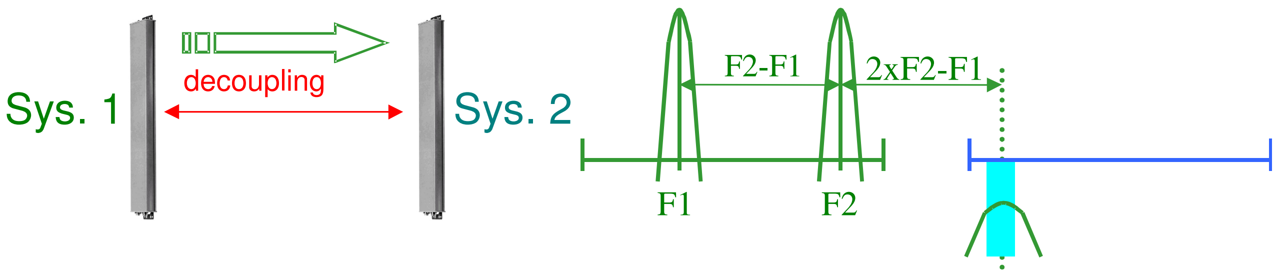
6.1.3 Spurious emissions

Spurious emissions from a transmitter are emissions outside the frequency band of the useful signal. Spurious emissions falling into the receive frequency band of another system may degrade its sensitivity. The specifications [1], [2], and [3] define the maximum authorised level of spurious emissions for each system.



6.1.4 Inter-modulation products

When two or more transmitters coexist on a site interfering frequencies may occur resulting from the mixing of several useful signals. If these intermodulation products fall into the receive band of a receiver, they may degrade its sensitivity.



The level of intermodulation products shall not be higher than the maximum level of spurious emission as indicated in the specifications [1], [2], and [3].

6.1.5 Sensitivity degradation

This subsection describes the computation of the sensitivity degradation of a receiver in the presence of interferer.

The expressions for the sensitivity of GSM900, GSM1800, UMTS and DVB-H systems are:

GSM900 Sensitivity [dBm] = GSM900 Noise Floor [dBm] + C/I [dB]

GSM1800 Sensitivity [dBm] = GSM1800 Noise Floor [dBm] + C/I [dB]

WCDMA Sensitivity [dBm] = WCDMA Noise Floor [dBm] + C/I [dB]

DVB-H Sensitivity [dBm] = DVB-H Noise Floor [dBm]+ C/I [dB]

Where:

C/I depends on the considered service

GSM900 Noise Floor [dBm] = -174 [dBm/Hz] + 10.log(200KHz) + F

GSM1800 Noise Floor [dBm] = -174 [dBm/Hz] + 10.log(200KHz) + F

WCDMA Noise Floor [dBm]= -174 [dBm/Hz] + 10.log(3.84MHz) + F

DVB-H Noise Floor [dBm] = -174 [dBm/Hz] + 10.log(7.61MHz) + F

F is the noise factor of the considered receiver. This study will take F=4dB for GSM900, GSM1800 and UMTS, and F=5dB for DVB-H.

Computation of the sensitivity degradation:

$$(C0)dBm = (NF\_WCDMA)dBm + (\frac{C}{I})dB$$

Where: $NF\_WCDMA = -174 + 10 \times LOG(3.84MHz) + F$

$$(C0)dBm = 10 \times LOG[10^{\frac{(NF\_WCDMA)dBm}{10}}] + (\frac{C}{I})dB$$

The interferer (Power=Pint) is considered as an additional noise:

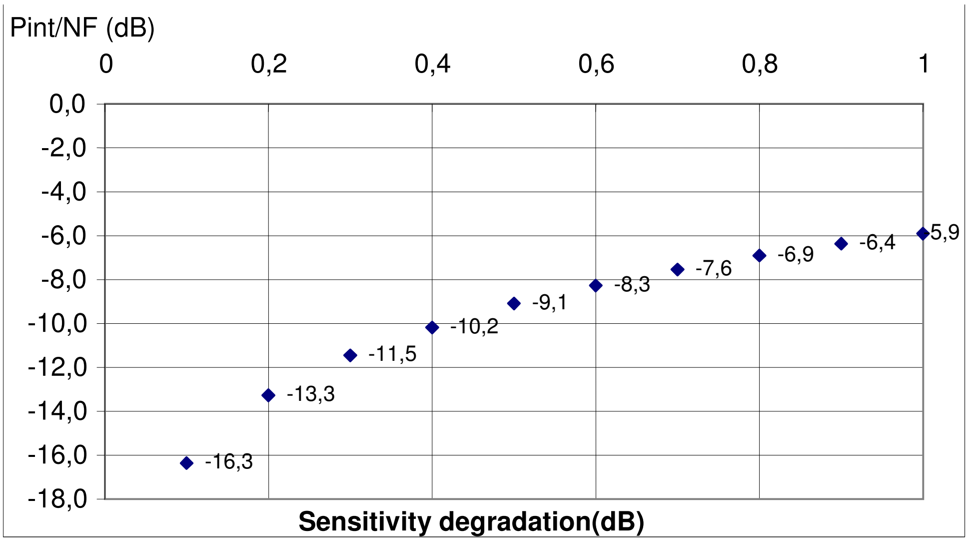
$$(C1)dBm = 10 \times LOG[10^{\frac{(NF\_WCDMA)dBm}{10}} + 10^{\frac{(Pint)dBm}{10}}] + (\frac{C}{I})dB$$

The sensitivity degradation can be expressed as:

$$\boxed{(Degradation)dB = (C1)dBm - (C0)dBm = 10 \times LOG[1 + 10^{\frac{(Pint)dBm - (NF\_WCDMA)dBm}{10}}]}$$

In the following part of this chapter the isolation required to be maintained between systems for **a maximum sensitivity degradation of 1dB** (so a maximum interferer power equal to the noise floor + 6dB) is evaluated.

Graph 6.1 describes the relation between the interferer power level and the sensitivity degradation.

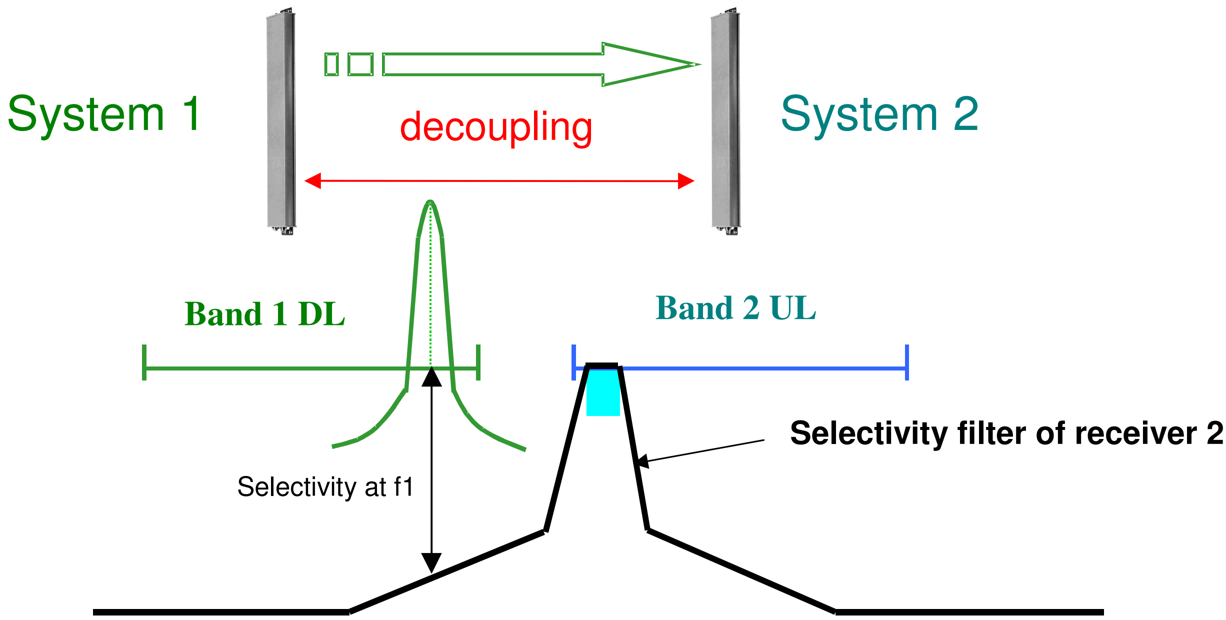


Graph 6.1: Sensitivity degradation versus interferer power

6.1.6 Blocking

The blocking risk that may occur when a strong signal is located nearby a receiver will be taken into account.

A maximum sensitivity degradation of 1dB due to the blocking effect will be considered.



6.2 Required isolation between systems

The following table describes the radio characteristics of the studied systems ([1], [2], [3], and [4]).

System	Frequency band (MHz)	Spurious (from specification)	Spurious (In receive band)	Blocking Level
GSM900 Ptx=43dBm	*UL: 880 - 915* *DL: 925 - 960*	-36dBm/100kHz	-17dBm/7.61MHz (DVB-H Rx)	8dBm for 3dB sensitivity degradation
GSM1800 Ptx=43dBm	*UL:1710- 1785* *DL: 1805 - 1880*	-36dBm/100kHz	-17dBm/7.61MHz (DVB-H Rx)	0dBm for 3dB sensitivity degradation
UMTS Ptx=43dBm	*UL: 1920 - 1980* *DL: 2110 - 2170*	-36dBm/100kHz	-17dBm/7.61MHz (DVB-H Rx)	-15dBm for 6dB sensitivity degradation
DVB-H Ptx=50dBm	*470 - 860*	-25dBm/100kHz (GSM900 Rx)	-22dBm/200kHz (GSM900 Rx)	-28dBm for 3dB sensitivity degradation
		-25dBm/1MHz (GSM1800 Rx)	-32dBm/200kHz (GSM1800 Rx)	
		-25dBm/1MHz (UMTS Rx)	-19dBm/3.84MHz (UMTS Rx)	
DVB-H Ptx=57dBm	*470 - 860*	-18dBm/100kHz (GSM900 Rx)	-15dBm/200kHz (GSM900 Rx)	-28dBm for 3dB sensitivity degradation
		-18dBm/1MHz (GSM1800 Rx)	-25dBm/200kHz (GSM1800 Rx)	
		-18dBm/1MHz (UMTS Rx)	-12dBm/3.84MHz (UMTS Rx)	
DVB-H Ptx=60dBm	*470 - 860*	-16dBm/100kHz (GSM900 Rx)	-13dBm/200kHz (GSM900 Rx)	-28dBm for 3dB sensitivity degradation
		-16dBm/1MHz (GSM1800 Rx)	-23dBm/200kHz (GSM1800 Rx)	

		-16dBm/1MHz (UMTS Rx)	-10dBm/3.84MHz (UMTS Rx)	

Table 6.2: Radio characteristics

Table 6.3 gives the required isolation values to ensure a maximum sensitivity degradation of 1dB for the DVB-H receiver.

Victim / Aggressor		1
		DVB-H
A	**GSM 900** Pem = +43dBm	Spurious : 89dB(*Case n° 1:*) Blocking : 77dB(*Case n° 5*)
B	**GSM 1800** Pem = +43dBm	Spurious : 89dB(*Case n° 1:*) Blocking : 77dB(*Case n° 5*)
C	**UMTS** Pem = +43dBm	Spurious : 89dB(*Case n° 1:*) Blocking : 77dB(*Case n° 5*)

Table 6.3: Required isolation to protect the DVB-H receiver

Table 6.4 gives the required isolation values to ensure a maximum sensitivity degradation of 1dB for the radiocom receivers.

Victim / Aggressor		1	2	3
		GSM 900	**GSM 1800**	**UMTS**
D	**DVB-H** Pem = +50dBm	Spurious : 101dB(*Case n° 2*) Blocking : 48dB (*Case n° 6*)	Spurious : 91dB(*Case n° 3:*) Blocking : 56dB (*Case n°7*)	Spurious : 91dB(*Case n° 4:*) Blocking : 76dB (*Case n° 8*)
E	**DVB-H** Pem = +57dBm	Spurious : 108dB(*Case n°9:*) Blocking : 55dB (*Case n°15*)	Spurious : 98dB(*Case n°10*) Blocking : 63dB (*Case n°16*)	Spurious : 98dB(*Case n°11*) Blocking : 83dB (*Case n°17*)
F	**DVB-H** Pem = +60dBm	Spurious : 110dB(*Case n°12*) Blocking : 58dB (*Case n°18*)	Spurious : 100dB(*Case n°13*) Blocking : 66dB (*Case n°19*)	Spurious : 100dB(*Case n°14*) Blocking : 86dB (*Case n°20*)

Table 6.4: Required isolation to protect the radiocom receivers

Case n° 1:

Item		Power / 7.6MHz	Comment
Max spurious level for GSM900, 1800 or UMTS	**a**	**-17 dBm**	-36 dBm / 100kHz
Noise Figure for DVB-H receiver	**b**	5 dB	Hypothesis
DVB-H noise floor	**c**	-100 dBm	= -174 + 10.log(7.61MHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-106 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**89 dB**	**= a – e**

Case n° 2:

Item		Power / 200kHz	Comment
Max spurious level for DVB-H	**a**	**-22 dBm**	-25 dBm / 100kHz
Noise Figure for GSM900	**b**	4 dB	Hypothesis
GSM900 Noise Floor	**c**	-117 dBm	= -174 + 10.log(200kHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-123 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**101 dB**	**= a – e**

Case n° 3:

Item		Power / 200kHz	Comment
Max spurious level for DVB-H	**a**	**-32 dBm**	-25 dBm / 1MHz
Noise Figure for GSM1800	**b**	4 dB	Hypothesis
GSM1800 Noise Floor	**c**	-117 dBm	= -174 + 10.log(200kHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-123 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**91 dB**	**= a – e**

Case n° 4:

Item		Power / 3.84MHz	Comment
Max spurious level for DVB-H	**a**	**-19 dBm**	-25 dBm / 1MHz
Noise Figure for UMTS	**b**	4 dB	Hypothesis
UMTS Noise Floor	**c**	-104 dBm	= -174 + 10.log(3.84MHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-110 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**91 dB**	**= a – e**

Case n° 5:

Item		Power	Comment
Radiated power (GSM 900/1800 and UMTS)	**a**	+43 dBm	Hypothesis
DVB-H blocking level corresponding to a 3dB degradation of sensitivity	**b**	**-28 dBm**	
DVB-H Noise Floor (F=5dB)	**c**	-100 dBm	= -174 + 10.log(7.6MHz)+7dB
Selectivity of DVB-H receiver	**d**	-72 dB	$= 10.\log \{ 10^{(c+3dB) / 10} - 10^{c / 10} \}$ - b
DVB-H blocking level corresponding to a **1dB** degradation of sensitivity	**e**	**-34 dBm**	$= 10.\log \{ 10^{(c+1dB) / 10} - 10^{c / 10} \}$ - d
Required isolation	**f**	**77 dB**	**= a – e**

Case n° 6:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+50 dBm	Hypothesis
GSM900 blocking level corresponding to a 3dB degradation of sensitivity	**b**	**8 dBm**	GSM 05.05 specification
GSM900 Noise Floor (F=4dB)	**c**	-117 dBm	= -174 + 10.log(200KHz)+4dB
Selectivity of GSM900 receiver	**d**	-125 dB	$= 10.\log \{ 10^{(c+3dB)/10} - 10^{c/10} \} - b$
GSM900 blocking level corresponding to a 1dB degradation of sensitivity	**e**	**+2 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**48 dB**	**= a – e**

Case n°7:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+50 dBm	Hypothesis
GSM1800 blocking level corresponding to a 3dB degradation of sensitivity	**b**	**0 dBm**	GSM 05.05 specification
GSM1800 Noise Floor (F=4dB)	**c**	-117 dBm	= -174 + 10.log(200KHz)+4dB
Selectivity of GSM1800 receiver	**d**	-117 dB	$= 10.\log \{ 10^{(c+3dB)/10} - 10^{c/10} \} - b$
GSM1800 blocking level corresponding to a 1dB degradation of sensitivity	**e**	**-6 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**56 dB**	**= a – e**

Case n° 8:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+50 dBm	Hypothesis
UMTS blocking level corresponding to a 6dB degradation of sensitivity	**b**	**-15 dBm**	
UMTS Noise Floor (F=4dB)	**c**	-104 dBm	= -174 + 10.log(3.84MHz)+4dB
Selectivity of UMTS receiver	**d**	-84 dB	$= 10.\log \{ 10^{(c+6dB)/10} - 10^{c/10} \} - b$
UMTS blocking level corresponding to a 1dB degradation of sensitivity	**e**	**-26 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**76 dB**	**= a – e**

Case n°9:

Item		Power / 200kHz	Comment
Max spurious level for DVB-H	**a**	**-15 dBm**	-18 dBm / 100kHz
Noise Figure for GSM900	**b**	4 dB	Hypothesis
GSM900 Noise Floor	**c**	-117 dBm	= -174 + 10.log(200kHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-123 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**108 dB**	**= a – e**

Case n°10:

Item		Power / 200kHz	Comment
Max spurious level for DVB-H	**a**	**-25 dBm**	-18 dBm / 1MHz
Noise Figure for GSM1800	**b**	4 dB	Hypothesis
GSM1800 Noise Floor	**c**	-117 dBm	= -174 + 10.log(200kHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-123 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**98 dB**	**= a – e**

Case n°11:

Item		Power / 3.84MHz	Comment
Max spurious level for DVB-H	**a**	**-12 dBm**	-18 dBm / 1MHz
Noise Figure for UMTS	**b**	4 dB	Hypothesis
UMTS Noise Floor	**c**	-104 dBm	= -174 + 10.log(3.84MHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-110 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**98 dB**	**= a – e**

Case n°12:

Item		Power / 200kHz	Comment
Max spurious level for DVB-H	**a**	**-13 dBm**	-16 dBm / 100kHz
Noise Figure for GSM900	**b**	4 dB	Hypothesis
GSM900 Noise Floor	**c**	-117 dBm	= -174 + 10.log(200kHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-123 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**110 dB**	**= a – e**

Case n°13:

Item		Power / 200kHz	Comment
Max spurious level for DVB-H	**a**	**-23 dBm**	-16 dBm / 1MHz
Noise Figure for GSM1800	**b**	4 dB	Hypothesis
GSM1800 Noise Floor	**c**	-117 dBm	= -174 + 10.log(200kHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-123 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**100 dB**	**= a – e**

Case n°14:

Item		Power / 3.84MHz	Comment
Max spurious level for DVB-H	**a**	**-10 dBm**	-16 dBm / 1MHz
Noise Figure for UMTS	**b**	4 dB	Hypothesis
UMTS Noise Floor	**c**	-104 dBm	= -174 + 10.log(3.84MHz)+b
Maximum sensitivity degradation	**d**	1 dB	Hypothesis
Corresponding power level of interferer (Pint)	**e**	-110 dBm	$= 10.\log \{ 10^{(c+d)/10} - 10^{c/10} \}$
Required isolation	**f**	**100 dB**	**= a – e**

Case n°15:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+57 dBm	Hypothesis
GSM900 blocking level corresponding to a 3dB degradation of sensitivity	**b**	**8 dBm**	GSM 05.05 specification
GSM900 Noise Floor (F=4dB)	**c**	-117 dBm	= -174 + 10.log(200KHz)+4dB
Selectivity of GSM900 receiver	**d**	-125 dB	$= 10.\log \{ 10^{(c+3dB)/10} - 10^{c/10} \} - b$
GSM900 blocking level corresponding to a 1dB degradation of sensitivity	**e**	**+2 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**55 dB**	**= a – e**

Case n°16:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+57 dBm	Hypothesis
GSM1800 blocking level corresponding to a 3dB degradation of sensitivity	**b**	**0 dBm**	GSM 05.05 specification
GSM1800 Noise Floor (F=4dB)	**c**	-117 dBm	= -174 + 10.log(200KHz)+4dB
Selectivity of GSM1800 receiver	**d**	-117 dB	$= 10.\log \{ 10^{(c+3dB)/10} - 10^{c/10} \} - b$
GSM1800 blocking level corresponding to a 1dB degradation of sensitivity	**e**	**-6 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**63 dB**	**= a – e**

Case n°17:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+57 dBm	Hypothesis
UMTS blocking level corresponding to a 6dB degradation of sensitivity	**b**	**-15 dBm**	
UMTS Noise Floor (F=4dB)	**c**	-104 dBm	= -174 + 10.log(3.84MHz)+4dB
Selectivity of UMTS receiver	**d**	-84 dB	$= 10.\log \{ 10^{(c+6dB)/10} - 10^{c/10} \} - b$
UMTS blocking level corresponding to a 1dB degradation of sensitivity	**e**	**-26 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**83 dB**	**= a – e**

Case n°18:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+60 dBm	Hypothesis
GSM900 blocking level corresponding to a 3dB degradation of sensitivity	**b**	**8 dBm**	GSM 05.05 specification
GSM900 Noise Floor (F=4dB)	**c**	-117 dBm	= -174 + 10.log(200KHz)+4dB
Selectivity of GSM900 receiver	**d**	-125 dB	$= 10.\log \{ 10^{(c+3dB)/10} - 10^{c/10} \} - b$
GSM900 blocking level corresponding to a 1dB degradation of sensitivity	**e**	**+2 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**58 dB**	**= a – e**

Case n°19:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+60 dBm	Hypothesis
GSM1800 blocking level corresponding to a 3dB degradation of sensitivity	**b**	**0 dBm**	GSM 05.05 specification
GSM1800 Noise Floor (F=4dB)	**c**	-117 dBm	= -174 + 10.log(200KHz)+4dB
Selectivity of GSM1800 receiver	**d**	-117 dB	$= 10.\log \{ 10^{(c+3dB)/10} - 10^{c/10} \} - b$
GSM1800 blocking level corresponding to a 1dB degradation of sensitivity	**e**	**-6 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**66 dB**	**= a – e**

Case n°20:

Item		Power	Comment
Radiated power (DVB-H)	**a**	+60 dBm	Hypothesis
UMTS blocking level corresponding to a 6dB degradation of sensitivity	**b**	**-15 dBm**	
UMTS Noise Floor (F=4dB)	**c**	-104 dBm	= -174 + 10.log(3.84MHz)+4dB

Selectivity of UMTS receiver	**d**	-84 dB	$= 10.\log \{ 10^{(c+6dB)/10} - 10^{c/10} \} - b$
UMTS blocking level corresponding to a 1dB degradation of sensitivity	**e**	**-26 dBm**	$= 10.\log \{ 10^{(c+1dB)/10} - 10^{c/10} \} - d$
Required isolation	**f**	**86 dB**	**= a – e**

6.3 DVB-H and radiocom services cositing architectures

6.3.1 General points

<u>DVB-H sites:</u>

Two kinds of DVB-H sites are considered in this study: the transmitter only site and the repeater site where both receiver and re-transmitter coexist. In the latter case enough isolation must be provided between the receiver and the transmitter for the system to work properly (10-15 dB above the re-transmitter gain).

DVB-H sites are high power sites, compared to radiocom sites. DVB-H transmitter power ranges from 100W to 1kW. Considered transmitting antennas consist of several UHF panel antennas, with an equivalent omni-directional pattern. The considered antenna gain is 10 dBi, and the vertical 3dB aperture is 30°.

In repeater sites, the DVB-H receiver antenna is a log-periodic one, located below the transmitter antennas.

<u>Radiocom sites:</u>

Radiocom sites are mostly tri-sector sites. Base station transmitter power is 20W. Radiocom antennas are directional panel antennas with 65° horizontal aperture, 7° vertical aperture, and 17dBi gain.

<u>DVB-H + Radiocoms cositing architecture:</u>

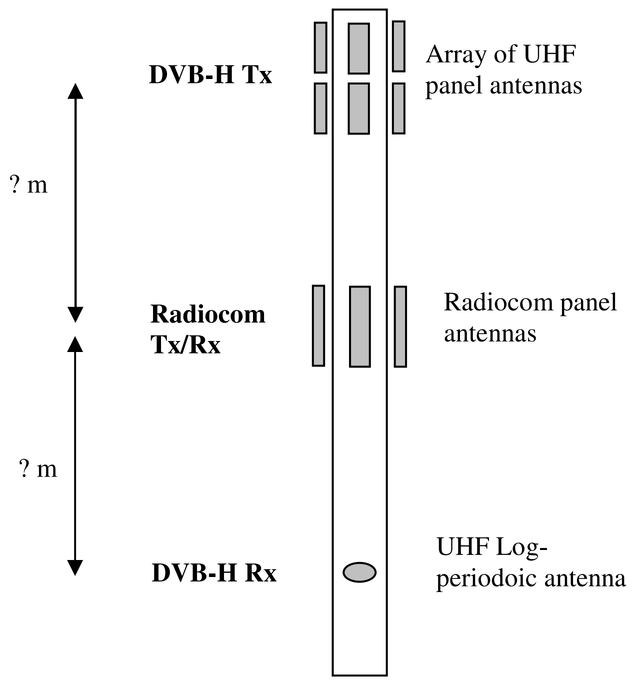


Figure 6.12: DVB-H and radiocom cositing architecture

In the following subsections, decoupling calculations will be performed and minimum separation distances will be proposed for such cositing architectures.

6.3.2 DVB-H and GSM900

6.3.2.1 Input data

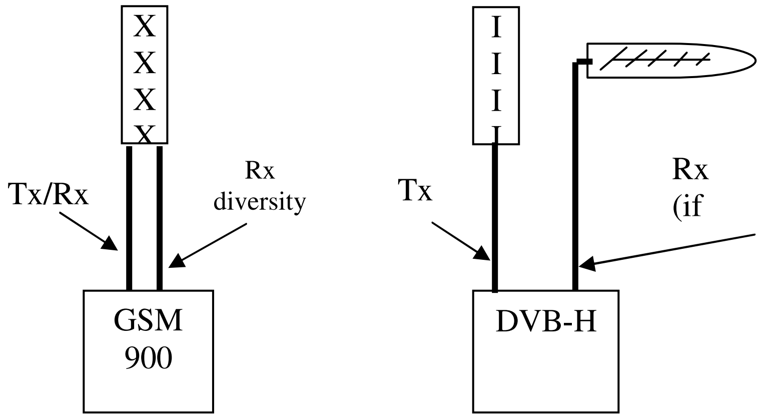


Figure 6.13: Diagram of GSM900-DVBT site

It is assumed that:

- feeders + jumpers losses = 3 dB
- Panel antenna, ±45° dual polarisation, 3dB aperture of 65° (horizontal plane), 3dB aperture of 7° (vertical plane), 17 dBi gain, for GSM
- Array of panel antennas, vertically polarised, 3dB aperture of 30° (vertical plane), 10 dBi gain, for DVB-H Tx
- Log-periodic antenna, horizontally polarised, 3dB aperture of 50° (horizontal plane), 3dB aperture of 60° (vertical plane), 10.5 dBi gain, for DVB-H Rx in case of repeater site.

6.3.2.2 Theoretical decoupling between antennas

The simulations are carried out for the antenna arrangement described in Figure 6.14 and Figure 6.15. Graph 6.2 and Graph 6.3 show the attenuation between the two antennas versus the inter-antenna distance (d) at different frequencies.

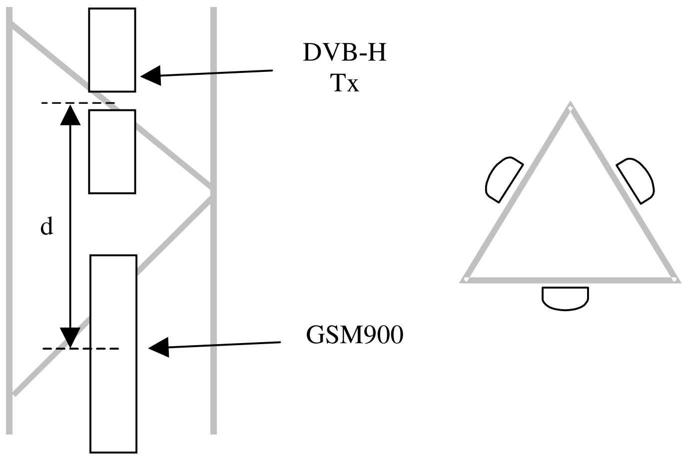
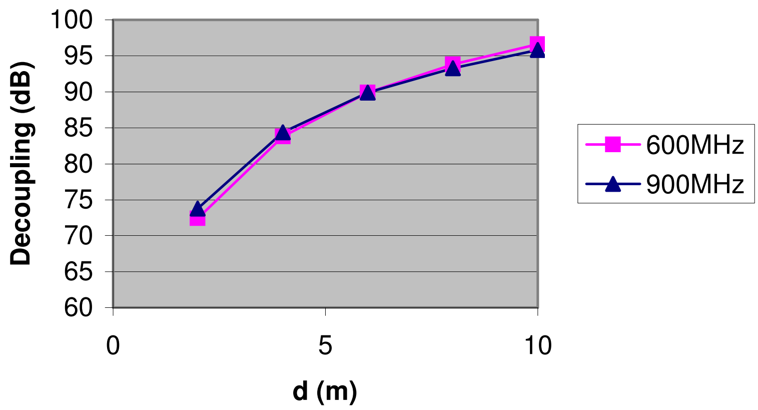


Figure 6.14: GSM900 / DVB-H Tx antenna arrangement



Graph 6.2 : Vertical decoupling between GSM900 and DVB-H Tx antennas

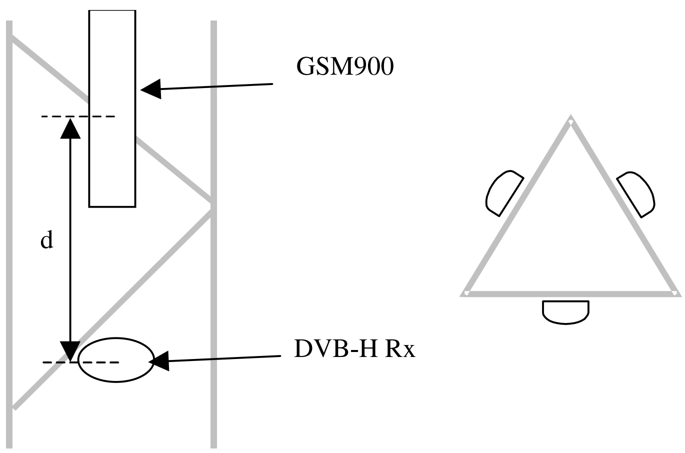
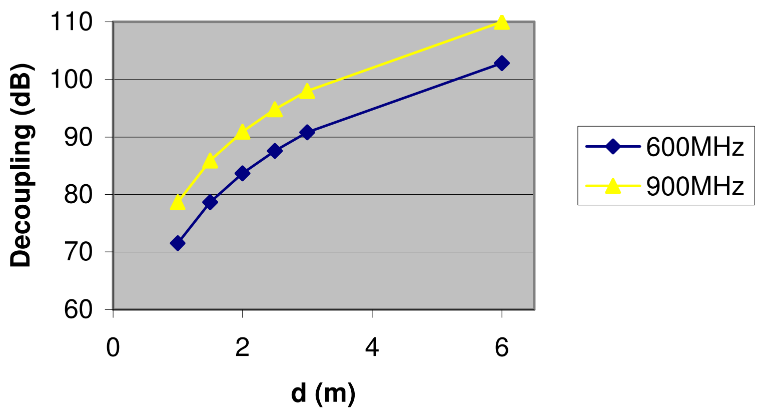


Figure 6.15: GSM900 / DVB-H Rx antenna arrangement



Graph 6.3: Vertical decoupling between GSM900 and DVB-H Rx antennas

6.3.2.3 Required spacing between antennas

DVB-H Tx and GSM900:

DVB-H Tx power	Minimum distance due to DVB-H spurious (Attenuation at 900MHz)	Minimum distance due to GSM900 blocking (Attenuation at 600MHz)
100W	10m + 6dB filter	2m
500W	10m + 13dB filter	2m
1kW	10m + 15dB filter	2m

Table 6.5: Minimum distance between DVB-H Tx and GSM 900 antennas

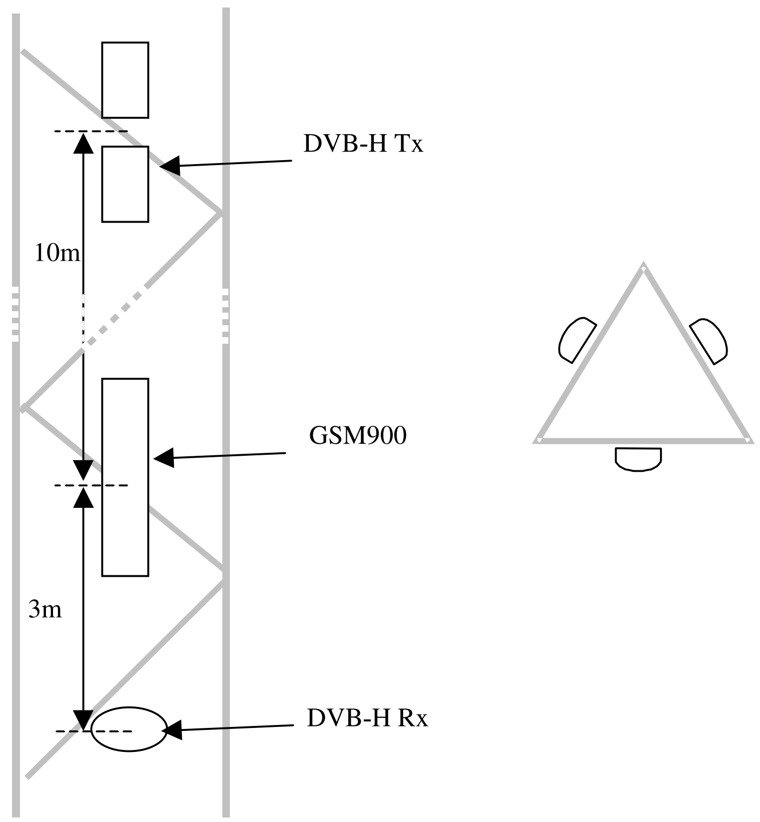
DVB-H Rx and GSM900:

Minimum distance due to GSM900 spurious (Attenuation at 600MHz)	Minimum distance due to DVB-H blocking (Attenuation at 900MHz)
3m	1m

Table 6.6 : Minimum distance between DVB-H Rx and GSM 900 antennas

6.3.2.4 Proposed configuration

With a spacing of 10m between the DVB-H Tx and GSM900 antenna and a spacing of 3m between the DVB-H Rx and GSM900 antenna, an additional bandpass filter is needed on the DVB Tx port.



6.3.3 DVB-H and GSM1800

6.3.3.1 Input data

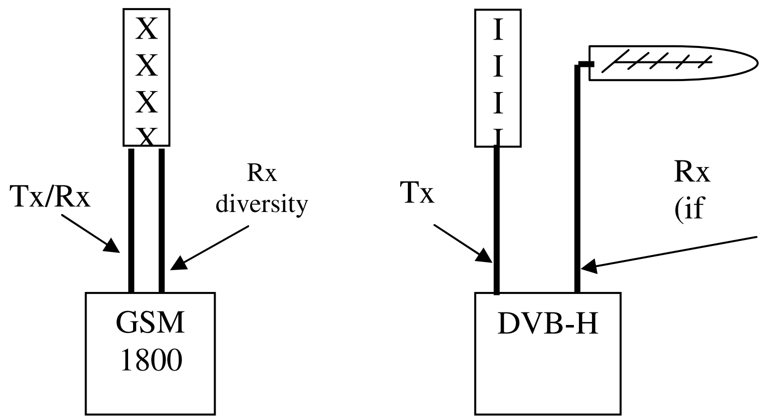


Figure 6.16: Diagram of GSM1800-DVBH site

It is assumed that:

- feeders + jumpers losses = 3 dB
- Panel antenna, ±45° dual polarisation, 3dB aperture of 65° (horizontal plane), 3dB aperture of 7° (vertical plane), 17 dBi gain, for GSM
- Array of panel antennas, vertically polarised, 3dB aperture of 30° (vertical plane), 10 dBi gain, for DVB-H Tx

- Log-periodic antenna, horizontally polarised, 3dB aperture of 50° (horizontal plane), 3dB aperture of 60° (vertical plane), 10.5 dBi gain, for DVB-H Rx in the case of a repeater site.

6.3.3.2 Theoretical decoupling between antennas

Simulations were carried out for the antenna arrangement described in Figure 6.17 and Figure 6.18. Graph 6.4 and Graph 6.5 show the attenuation between the two antennas versus the inter-antenna distance (d) at different frequencies.

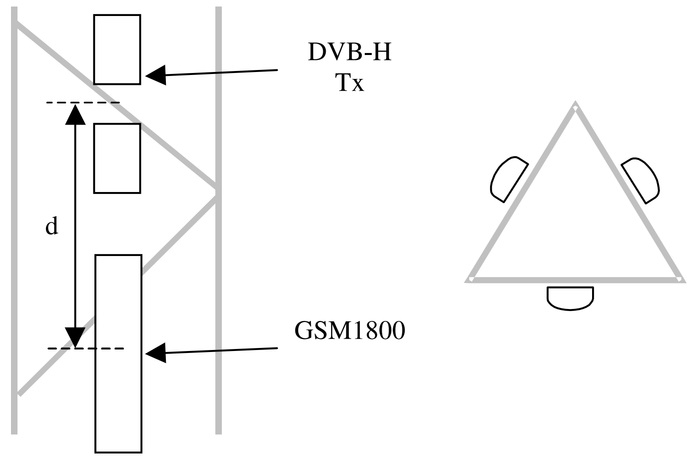
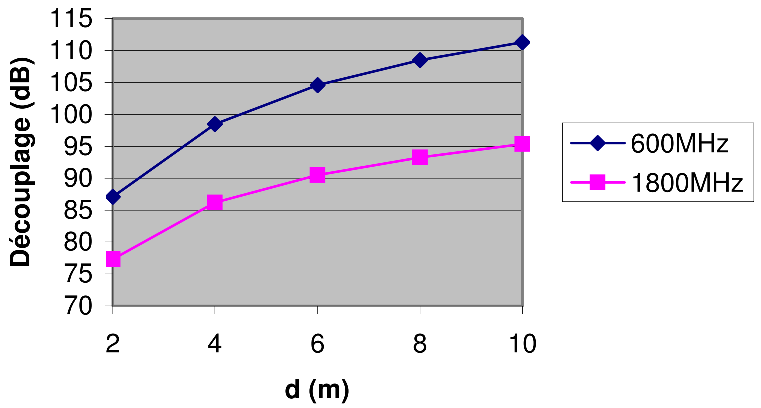


Figure 6.17: GSM1800 / DVB-H Tx antenna arrangement



Graph 6.4: Vertical decoupling between GSM1800 and DVB-H Tx antennas

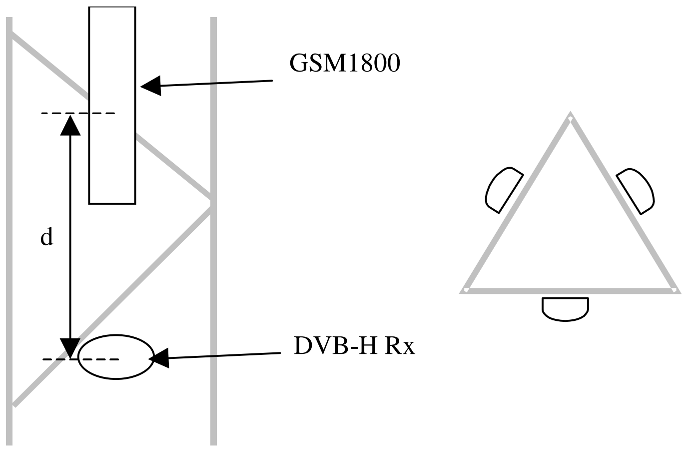
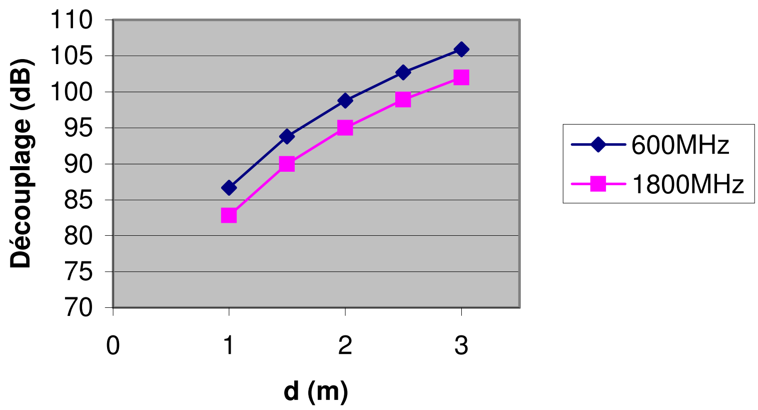


Figure 6.18: GSM1800 / DVB-H Rx antenna arrangement



Graph 6.5: Vertical decoupling between GSM1800 and DVB-H Rx antennas

6.3.3.3 Required spacing between antennas

DVB-H Tx and GSM1800:

DVB-H Tx power	Minimum distance due to DVB-H spurious (Attenuation at 1800MHz)	Minimum distance due to GSM1800 blocking (Attenuation at 600MHz)
100W	6m	2m
500W	6m + 7dB filter	2m
1kW	6m + 9dB filter	2m

Table 6.7: Minimum distance between DVB-H Tx and GSM 1800 antennas

DVB-H Rx and GSM1800:

Minimum distance due to GSM1800 spurious (Attenuation at 600MHz)	Minimum distance due to DVB-H blocking (Attenuation at 1800MHz)
1.2m	1m

Table 6.8 : Minimum distance between DVB-H Rx and GSM 1800 antennas

6.3.3.4 Proposed configuration

With a spacing of 6m between the DVB-H Tx and GSM1800 antenna and a spacing of 1.2m between the DVB-H Rx and GSM1800 antenna, a bandpass filter is needed on the DVB-H Tx port for power greater than 100W.

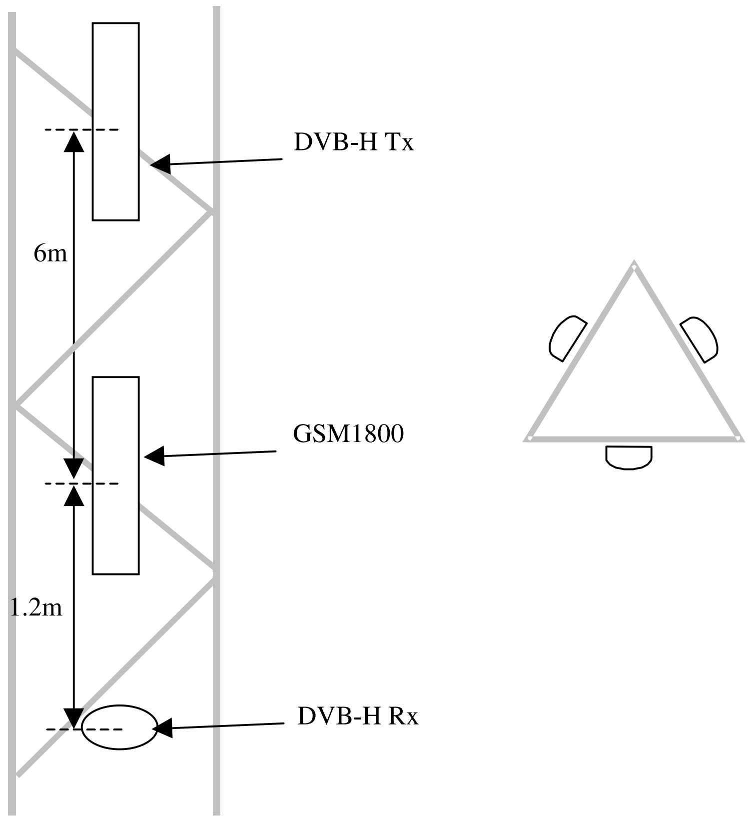


Figure 6.19: Proposed co-siting architecture for GSM1800 / DVB-H

6.3.4 DVB-H and UMTS

6.3.4.1 Input data

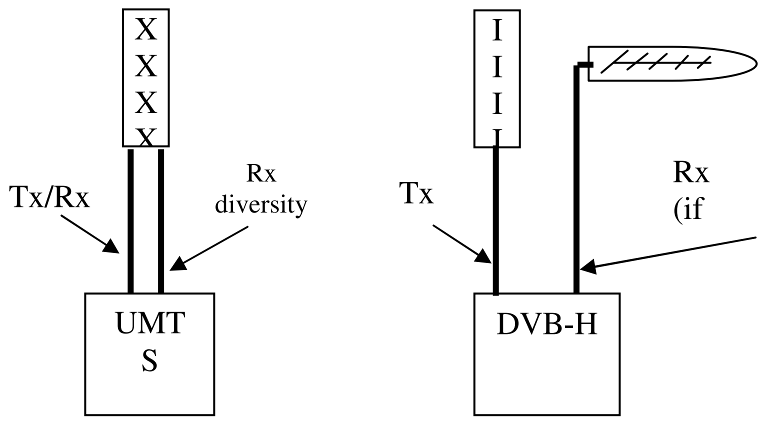


Figure 6.20: Diagram of UMTS/DVB-H site

It is assumed that:

- feeders + jumpers losses = 3 dB
- Panel antenna, ±45° dual polarisation, 3dB aperture of 65° (horizontal plane), 3dB aperture of 7° (vertical plane), 17 dBi gain, for UMTS
- Array of panel antennas, vertically polarised, 3dB aperture of 30° (vertical plane), 10 dBi gain, for DVB-H Tx
- Log-periodic antenna, horizontally polarised, 3dB aperture of 50° (horizontal plane), 3dB aperture of 60° (vertical plane), 10.5 dBi gain, for DVB-H Rx in the case of a repeater site.

6.3.4.2 Theoretical decoupling between antennas

The simulations were carried out for the antenna arrangement described in Figure 6.21 and Figure 6.22. Graph 6.6 and Graph 6.7 show the attenuation between the two antennas versus the inter-antenna distance (d) at different frequencies.

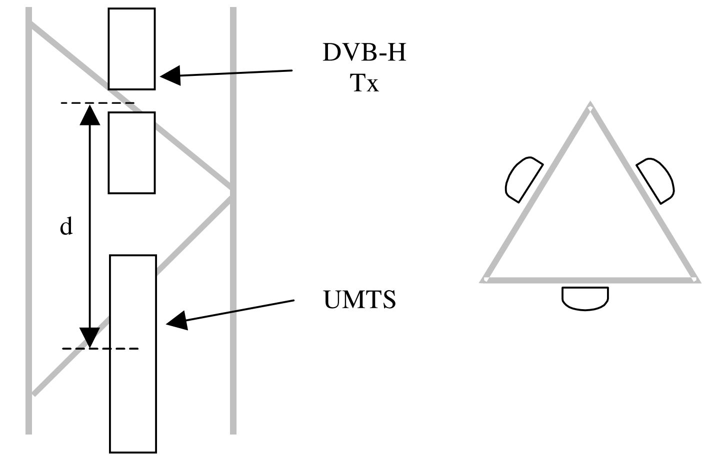
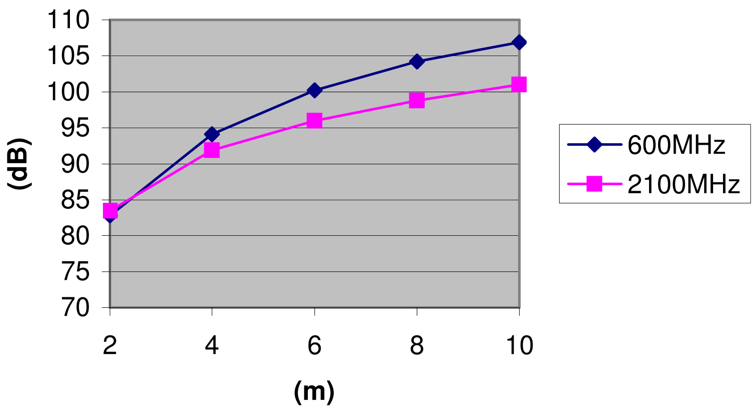


Figure 6.21: UMTS / DVB-H Tx antenna arrangement



Graph 6.6: Vertical decoupling between GSM1800 and DVB-H Tx antennas

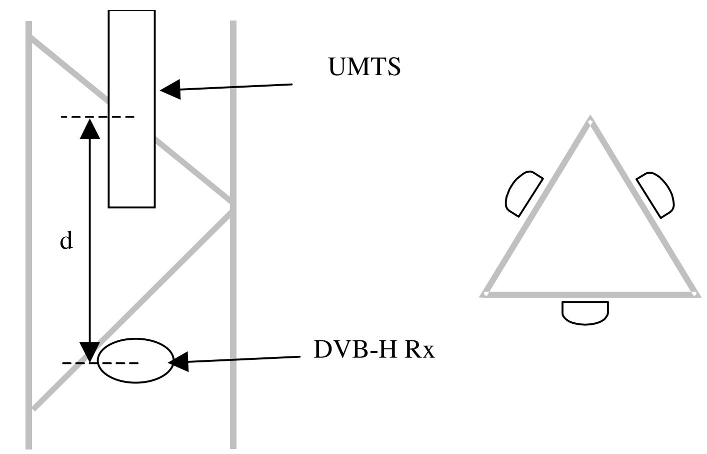
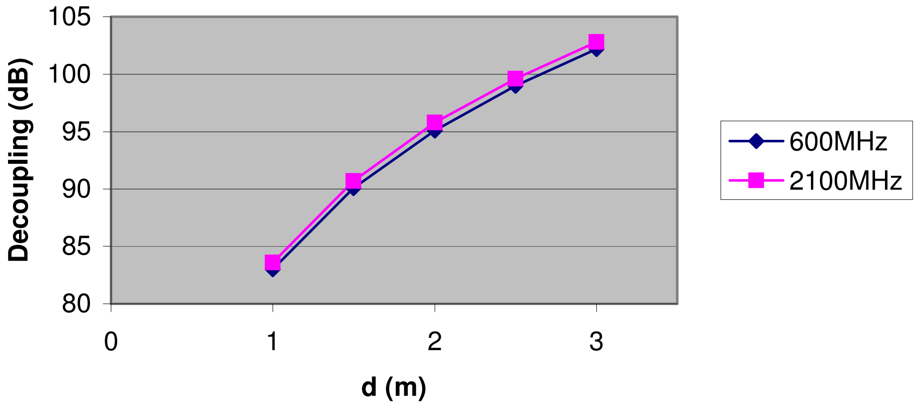


Figure 6.22: UMTS / DVB-H Rx antenna arrangement



Graph 6.7: Vertical decoupling between UMTS and DVB-H Rx antennas

6.3.4.3 Required spacing between antennas

DVB-H Tx and UMTS:

DVB-H Tx power	Minimum distance due to DVB-H spurious (Attenuation at 2100MHz)	Minimum distance due to UMTS blocking (Attenuation at 600MHz)
100W	4m	2m
500W	7m	2m
1kW	9m	2.5m

Table 6.9: Minimum distance between DVB-H Tx and UMTS antennas

DVB-H Rx and UMTS:

Minimum distance due to UMTS spurious (Attenuation at 600MHz)	Minimum distance due to DVB-H blocking (Attenuation at 2100MHz)
1.4m	1m

Table 6.10 : Minimum distance between DVB-H Rx and UMTS antennas

6.3.4.4 Proposed configuration

With a spacing of 9m between the DVBH Tx and UMTS antenna and a spacing of 1.4m between the DVBH Rx and UMTS antenna, no additional filtering is needed.

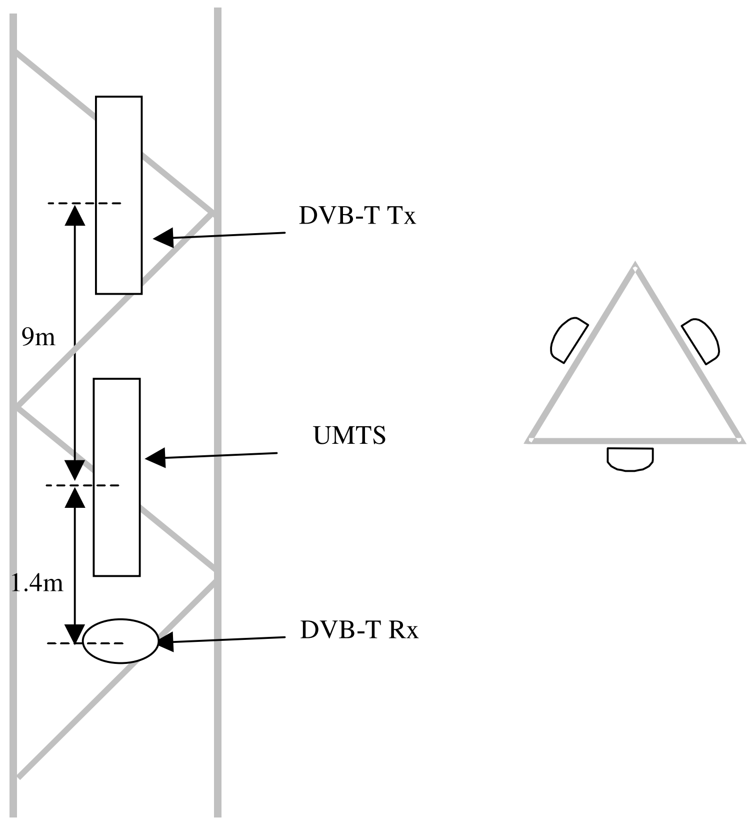


Figure 6.23: Proposed co-siting architecture for UMTS / DVB-H

6.4 References

[1] TS 05.05 V8.18.0 (2005-04)

[2] TS 25.104 V6.8.0 (2004-12)

[3] CEPT Rec 74-01

[4] ETSI guideline DVB-H 159R11

Chapter 7 Coverage Planning and Dimensioning in DVB-T/H

7.1 Introduction

7.1.1 Aim of this chapter

To describe an approach to studying coverage planning and dimensioning in DVB-H.

7.1.2 Objectives of this chapter

The planning of network coverage is currently divided into two steps, the first one is the physical layer simulation which models the receiver sensitivity with different physical layer parameters (See section 7.2) under different kinds of channels and produces a table of SNR values for different parameter combinations; the second step is the coverage planning process using the SNR values produced in step one to simulate the coverage ratio for different network topologies and network level parameters. This chapter mainly addresses the latter step.

Bearing in mind that a MFN is a special case of a SFN, namely, a SFN with a cell size of one, this chapter focuses on coverage planning and dimensioning for SFNs.

This chapter presents a basic approach to modelling DVB-H coverage planning and investigates the dimensioning criteria for a wide area SFN network.

7.2 Parameter definition in coverage planning for DVB-T/H

Digital video broadcasting reception quality experiences abrupt change from a good quality of received picture to no picture at all. See Figure 7.1. The signal strength at one location varies with time because of multi-path fast fading and slow shadowing fading. That the service in one location is covered means the signal to nose ratio (SNR or C/I)) has an expected value higher than the required threshold.

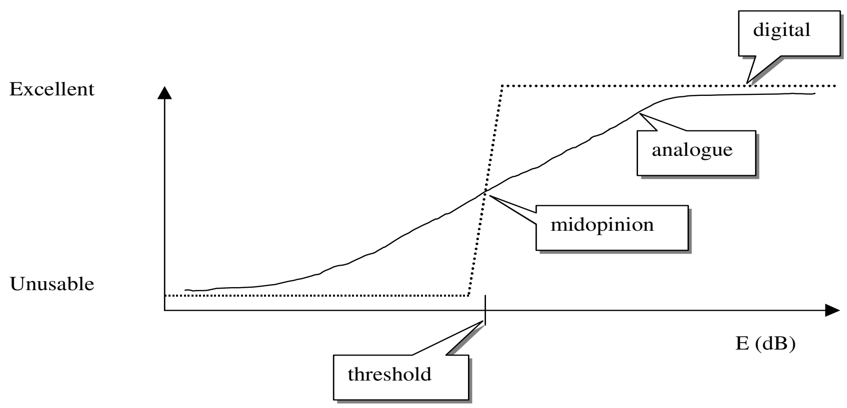


Figure 7.1: Cut-off characteristics of the analogue and digital broadcasting systems [12]

7.2.1 Coverage degree definition

Three levels of coverage are defined in [2].

Level 1: Receiving location

The smallest unit is the receiving location. A transmitter covers the location if the strength of the wanted signal at the location is high enough to overcome the noise and interference present for a given percentage of time. In [2] it is recommended that the percentage used should be 99%. Because according to ITU-1546 the signal strength can be predicted for a maximum of only 50% of the time, 50% of the time is taken in our simulations.

Level 2: Small area coverage (pixel)

A pixel can be taken to be 100m by 100m or 200m by 200m of the studied area depending the type of area studied. The studied area is decomposed into such pixels, and a pixel is defined as "good" if 95% of the area of the pixel is covered and "acceptable" if 70% of the area is covered [2].

Three pixel coverage degrees are defined in terms of the different coverage scenario requirements in this chapter:

Pixel Coverage Grade I (PCGI): If 95% of a pixel area is covered by the signal, then the pixel is a covered pixel with PCGI.

Pixel Coverage Grade II (PCGII): If 90% of a small pixel's area is covered by the signal then the pixel is a covered pixel with PCGII.

Pixel Coverage Grade III (PCGIII): If 70% of a small pixel's area is covered by the signal, then the pixel is a covered pixel with PCGIII.

Level 3: Coverage area

The coverage area of a transmitter or a group of transmitters is made-up of the sum of the small areas (pixels) in which a given percentage (70% or 90%) coverage is achieved.

Three whole area coverage degrees also are defined in this chapter to express the coverage of the whole of the studied area:

Area Coverage Grade I (ACGI): 95% of the pixels in the studied area are covered in terms of one of the predefined pixel coverage grades. This is suitable for densely populated areas like busy urban areas; shopping malls, airports etc.

Area Coverage Grade II (ACGII): 90% of the pixels in the studied area are covered in terms of one of the predefined pixel coverage grades. This is for urban area planning.

Area Coverage Grade III (ACGII): 70% of the pixels in the studied area are covered in terms of one of the predefined pixel coverage grades. This grade can be suitable in rural area planning.

It should be noted that the area coverage grade must be used with the pixel coverage grade. In this chapter, ACGI is used with PCGI, ACGII with PCGII, and ACGIII with PCGIII in the default setting.

7.2.2 Network parameters and ranges used in the simulations

Table 7.2.1: The parameters used in the simulations

Parameters	**Value**	**Provided by the WP6 Partner**
Transmitter frequency (Mhz)	600	Brunel, Agreed by other WP6 partners
Transmitter power (dB)	10~45	T-Systems, IRT, TDF
Transmitter antenna height (m)	20~300	T-Systems, IRT, TDF
Receiver height (m)	1.5	Brunel, Agreed by other WP6 partners
Transmitter antenna pattern	Omni	Brunel, Agreed by other WP6 partners
Symbol time (µs)	448	Brunel, Agreed by other WP6 partners
Guard interval time (µs)	14; 112	Brunel, Agreed by other WP6 partners
Receiver noise level (dB)	-129 (with a receiver noise factor = 6dB)	TDF
Shadowing deviation (dB)	8	Brunel, Agreed by other WP6 partners
C/I threshold (dB)*	5~30	Brunel
Burst on-time duration in a burst cycle	0.5	Brunel

*The C/I threshold is set according to Table 6.1of [14]. In [14], the minimum C/N is 5.4 dB, and the maximum is 27dB, in the simulations the C/I threshold value is rounded to the nearest integer value over the whole range of 5~30 dB.

Time variability and location variability are the parameters determined when computing the path loss using the ITU P-1546.

Time variability: A percentage of 50%, 10%, or 1% of the time period simulated for which a propagation curve representing the field strength exceeded a given value. The propagation curve for any desired time percentage between 1% and 50% can be interpolated between the 50% and 1% curves. Interpolation outside this range is not valid. In the simulations presented in this chapter, the contributed signal uses the 50% of the time curve and the interference uses the 1% of the time curve to represent the worse cases of the interference.

Location variability: A percentage of locations for which a propagation curve representing field-strength exceeded a given value typically within an area 200 m by 200 m. Location variability is related to the spatial statistics of local ground cover variations including multi-path variations. Extensive data analysis suggests that the distribution of median field strength due to ground cover variations over such an area in urban and suburban environments is approximately lognormal [11]. The percentage of 98% of the locations where the signal will exceed the given field strength value is used in simulations presented in this chapter.

The parameters that indirectly participate in the computation of coverage planning are those that effect the C/I threshold used in computing the coverage probability, the different combinations of these physical parameters will lead to different C/I thresholds.

The following parameter values were agreed to be realistic by the INSTINCT WP6 partners.
Sub-carrier number: 2k, 4k, and 8k
Modulation scheme: Hierarchal, non-hierarchal modulation; 16QAM, 64QAM
Code rate; ½; 2/3; ¾; 4/5; 5/6
Radio Channel model: Gaussian channel, Rice channel (F1) and Rayleigh channel (P1), Directional antenna

7.3 SFN inner self-interference and outer-interference

Inner and outer interference are the two main interference sources that constrain the cell size of a DVB-T/H network. The inner interference is the interference generated by the transmitters in the SFN itself when the echo delay of the signal is higher than the guard interval. The outer interference is the interference coming from other SFNs or MFNs that operate at the same frequency.

7.3.1 Inner self-interference in a SFN

For an arbitrary receiving location A, see Figure 3.1, if only one signal path comes from each transmitter and LOS reception is assumed, the first signal the receiver receives is from the nearest transmitter. Then the time delays of the signals from the other two transmitters shown in Figure 3.1 are equal to the distance from location A to each transmitter, say transmitter C and transmitter D, divided by the velocity of light.

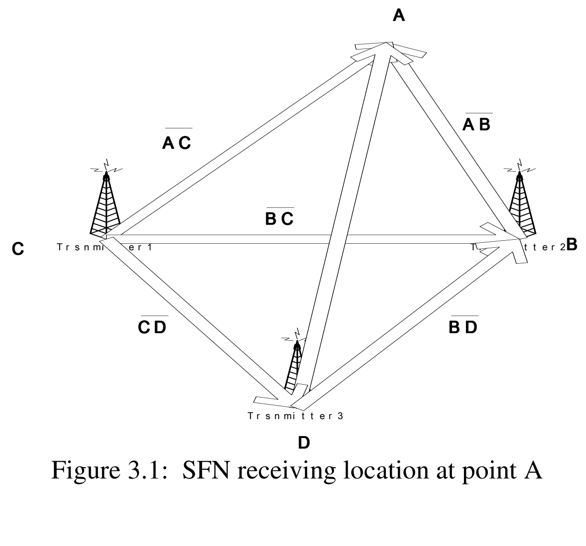


Figure 3.1: SFN receiving location at point A

Let V_L denote the velocity of the light.

Since:

$$\left|\overline{AC} - \overline{AB}\right| < \overline{BC}$$

If the guard interval is T_g, as long as the maximum distance between the transmitters in the SFN is less than:

$$R_{tg} = V_L * T_g \qquad (7\text{-}3\text{-}1)$$

then there is no self-interference in a network with only two transmitters. Otherwise, self-interference will occur. However, this is only true under the assumption that there is only one signal coming from each transmitter in the SFN. In practice multiple path signals will be received simultaneously coming from one transmitter with different delays and amplitudes and self-interference is inevitable.

For different guard interval to the time duration of the useful part of a symbol ratios T_g / T_u, [9], Table 7.3.1 shows the maximum distance (using equation (7-3-1)) among the transmitters in a SFN which would produce minimal inner interference. Here minimal interference means that if the distances between the transmitters were bigger than the ones in Table 7.3.1, given that the other corresponding network parameters remain the same, the network itself will incur more self-interference. However, what is wanted is the largest coverage area for a given network topology and a trade-off between the cell distance and self-interference exits. The bigger the cell distance the higher the percentage of the cell area that will receive interference from other transmitters of the same SFN. Of course, the final cell distance depends on the contributed signal and the interference, the C/I ratio; the above analysis only relates to the self-interference.

Table 7.3.1: R_{tg} in 2k, 4k and 8k DVB-T (Computed using equation (3-1), The time duration of the useful part of a symbol in 2K is 224μs, 4k 448μs and 8k 896μs)

T_g/T_U	Guard interval in 2K(FFT) (μs)	R_{tg} (2K) (km)	Guard interval in 4K(FFT) (μs)	R_{tg} (2K) (km)	Guard interval in 8k(FFT) (μs)	R_{tg} (8K) (km)
1/32	7	2.1	14	4.2	28	8.4
1/16	14	4.2	28	8.4	56	16.8
1/8	28	8.4	56	16.8	112	33.6
¼	56	16.8	112	33.6	224	67.2

7.3.2 Outer interference in a SFN

If different SFNs use different frequencies to compose a wide area network, then the interference coming from the other SFNs that use the same frequency will impair the reception quality in each SFN that uses that frequency. Figure 7.3.2 shows a single SFN of size = 3 and reuse factor = 7 network in a two tier layout. In this chapter for the frequency reuse scenarios this two tier layout is used for testing the coverage of studied SFN which means 18 SFNs other than the concerned SFN are needed to be considered for co-channel outer interference. In [20], the two ring topology is taken as an example to study the outage probability in the central SFN.

The mean signal power received P_r in any location decreases with the power exponent $-n$ where n is the exponent of path loss attenuation. The received mean power P_r at a distance d from the transmitter can be estimated [6] as:

$$P_r = P_0 \cdot (\frac{d}{d_0})^{-n} \tag{7-3-2}$$

where P_0 is the reference-received power at a reference distance d_0. In an urban cellular environment, the attenuation exponent is around 2 ~ 4 [6].

If no self-interference or thermal noise is assumed and all the transmitters transmit at the same power, then the external interference will not depend on the power

$$\frac{C}{I} = \frac{\sum_{j=1}^{N_{SFn}} P_0 \cdot \left(\frac{d_j}{d_0}\right)^{-n}}{\sum_{k=1}^{18 * N_{SFn}} P_0 \cdot \left(\frac{d_k}{d_0}\right)^{-n}} = \frac{\sum_{j=1}^{N_{SFn}} d_j^{-n}}{\sum_{k=1}^{18 * N_{SFn}} d_k^{-n}} \tag{7-3-3}$$

where N_{SFn} is the SFN size, P_0 is the transmitter power and d_j and d_k are the distance from the respective transmitter to the receiving point.

For different SFN sizes, see Figure 7.3.3, the edge points indicated by yellow circles are taken as the test points for testing the interference. These points are at the maximum distance to the centre of the SFN and experience more interference than inner points. The SNR at these points was computed for different reuse factors and SFN size. Taking n = 4, Figure 7.3.4 shows, a larger reuse factor can give a larger SNR which means a bigger coverage area. Increasing the SFN size can also enlarge the coverage area, but this is not the case for reuse factor 9, which is more asymmetric and experiences more interference. When the SFN size equals 1, then the network becomes a MFN.

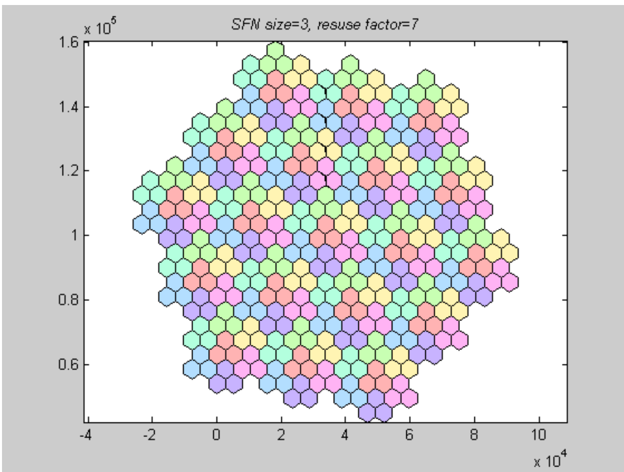


Figure 7.3.2: Two tiers SFN networks SFN size =3 and Reuse factor =7 (different colours represent different frequencies)

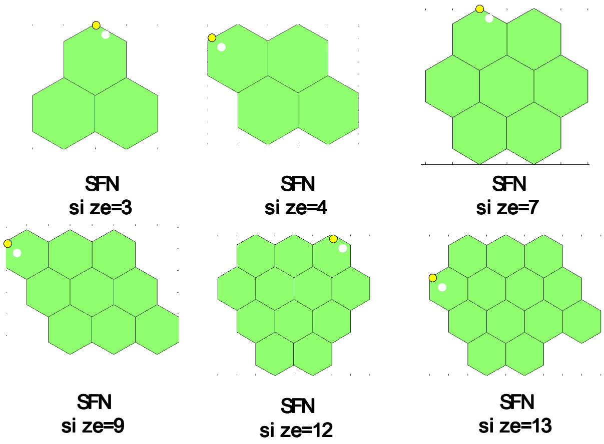


Figure 7.3.3: The different SFN sizes used in the simulations
(The yellow circles represent the test points)

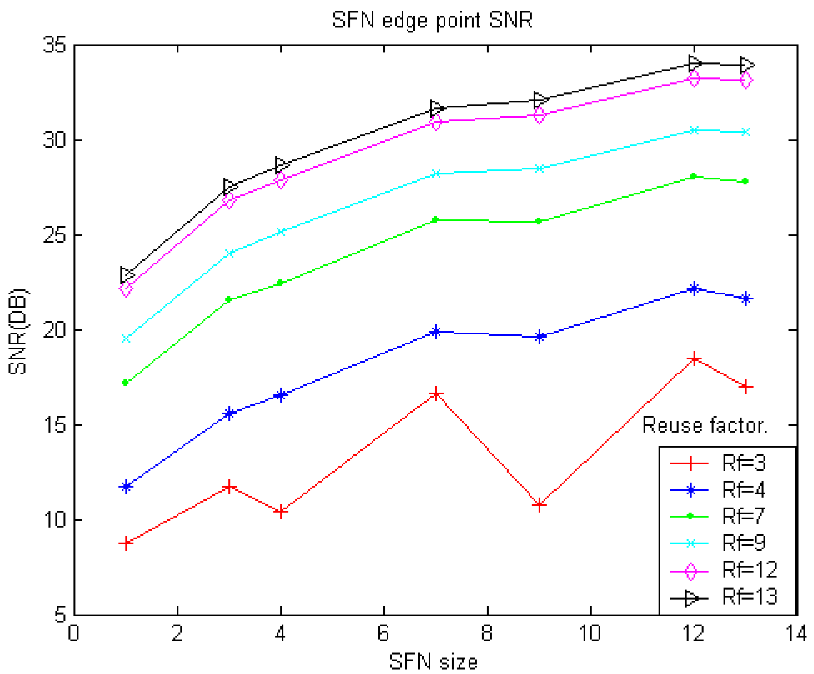


Figure 7.3.4: The test point SNR at the cell edge of one SFN among multiple SFN networks

7.4 Coverage planning simulation

In the coverage planning simulation presented below only one signal coming from each transmitter, with this signal having no correlation with the other signals, is assumed. In practice for one receiving location there are several signals coming by different paths with different delays and amplitudes. If no terrain data is available, the signals can be taken as line of sight (LOS).

7.4.1. Field strength prediction

7.4.1.1 Terrain model

Because of the unavailability of real terrain data, a fictitious terrain model is used to compute the field strength.

The assumptions made in generating the terrain model were:

1. The hills in the map are uniformly distributed.
2. The height of the hills follows a Gaussian distribution according to the distance between a random location and the centre of the hill.
3. The number of the hills Nhill in the defined map is 0.6 times the maximum number of pixels in the map.
4. The deviation of the Gaussian distribution of hill height is 0.04 times the maximum number of pixels in the map.
5. The height factor Height_factor is set according to the maximum height the terrain can have.
   Height_max = Nhill * Height_factor;

Nhill and Height_max are set before generating the terrain

The map is generated according to a random terrain.

The height of a random location (x, y) in the map is given by

$$\text{Height}(x, y) = \text{Height\_factor} * \sum_{k=1}^{Nhill} \exp(-((x - x(k))^2 - (y - y(k)^2)/2/delta)$$

delta is the deviation of the Gaussian distribution, $x(k), y(k)$ is the kth hill location

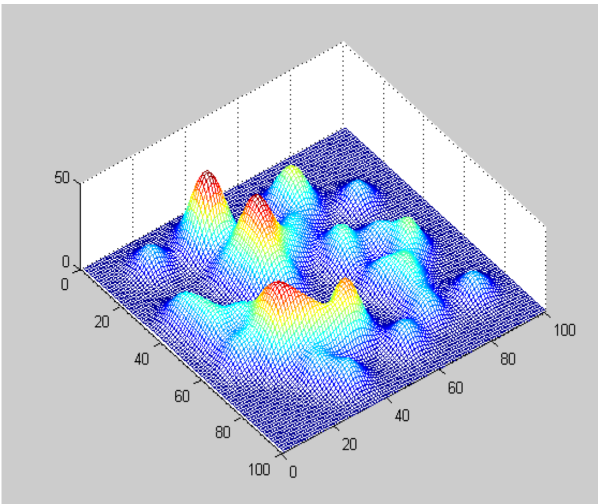


Figure 7.4.1: 100 * 100 pixels terrain map, Maximum Height = 40m

If the maximum number of pixels in the computed map is greater than 100, then this 100 by 100 terrain map pattern is repeated. At the edge of a small 100 by 100 pixel terrain map such as that of Figure 7.4.1, a low height of terrain is preferred for continuity of the terrain map when several such maps are concatenated together.

7.4.1.2 ITU R-P1546-1

ITU R-P1546-1 is a new ITU recommendation for field strength prediction that replaces the old ITU-R 370. The curves in ITU R-P1546-1 represent the field strength in the VHF and UHF bands as a function of different parameters.

The propagation curve for a given value of field strength represents the field strength exceeding that value in 50% of the locations typically within an area of 200m by 200m for 1%, 10% or 50% of time; For other percentage locations and percentage times, the interpolation and correction methods are used; Recommendation ITU R-P1546-1 is not valid for field strengths exceeded for percentage times outside the range from 1% to 50%.

Recommendation ITU R-P1546-1 can be used without taking the actual terrain into account. However, for land paths, improved accuracy of predicted field strengths can be obtained by taking into account terrain near the receiving/mobile antenna by means of the Terrain Clearance Angle [11].

7.4.2 Outage probability computation

In a single frequency network, the receiver combines the different signal components coming from the different transmitters in the SFN network. For the *i*th signal component the received signal power P_i, may contribute to the useful part of the combined signal or the interfering part or to both parts depending on the relative delay. The ratio between the useful contribution, U_i and the interfering contribution, I_i, of the *i*th signal component is modelled by the weighting function $w(\tau_i - \tau_0)$ where τ_i represents the signal delay relative to starting point of the receiver detection window τ_0 [3] [4].

$$U_i = w(\tau_i - \tau_0) \cdot P_i$$

$$I_i = (1 - w(\tau_i - \tau_0)) \cdot P_i$$

For the weighting function $w(\Delta\tau)$, the following quadratic form has been suggested in [5]:

$$w(\Delta\tau) = \begin{cases} 0 & \text{if } \Delta\tau \le 0 \\ 1 & \Delta\tau \le T_g \\ \left(\dfrac{T_u - \Delta t + T_g}{T_u} \right)^2 & \text{if } T_g < \Delta\tau < T_F \\ 0 & \text{if } \Delta\tau \ge T_F \end{cases} \qquad (7\text{-}4\text{-}1)$$

Where T_u and T_g denote the time duration of the useful signal and the guard interval time. T_F is the inverse of the pass-band in Hz of the frequency domain interpolation filter which the constellation equalization and coherent detection is based on in the channel estimation process. This value cannot exceed $T_u/3$ [5]. In [5], it is assumed that $T_F = T_u/3$.

If the index set of the transmitters of the studied SFN is represented by $\Omega = \{1,\ldots,N\}$ and the transmitters of other SFNs operating at the same frequency are denoted by $\Psi=\{1,\ldots,M\}$, P_i is the received signal power coming from *i*th transmitter and usually P_i (dB) can be represented by a lognormal distribution variable with a mean value of m_P and a standard deviation of σ_p , the mean of $w \cdot P_i$ is $m_P + 10 \cdot \log(w)$ and the standard deviation is σ_p . The background noise power is N_0, the C/N ratio can be written as:

$$\Gamma = \frac{U}{I} = \frac{\sum U_i}{\sum I_i} = \frac{\sum_{i \in \Omega} P_i \cdot w(\tau_i - \tau_0)}{\sum_{i \in \Omega} P_i \cdot (1 - w(\tau_i - \tau_0)) + \sum_{i \in \Psi} P_i + N_0} \tag{7-4-2}$$

The total useful signal U and the interference signal I , ignoring N_o in the presence of the inner interference and/or outer interference, can be represented by log-normal distribution variables with parameters, m_u and σ_u , m_I and σ_I , respectively. In this case, the C/N ratio in dB has a normal distribution with mean $m_\Gamma = m_u - m_I$ and standard deviation $\sigma_\Gamma^2 = \sigma_u^2 + \sigma_I^2$, assuming U and I are uncorrelated. The performance of a DVB-T network is usually measured by the coverage probability, P_{cT} , which is defined as the probability that the C/N ratio exceeds a system specific protection ratio γ_0 :

$$P_{cT} = \Pr\{(\Gamma > \gamma_0\} = 1 - P_{oT} \tag{7-4-3}$$

Compared to the DVB-T receiver which receives the video stream all the time, the DVB-H receiver only receives the stream for the specified time slice and the burst duration has a maximum value in one time period which is set in the encapsulator. If in a DVB-T receiver the outage probability for one location is P_{oT} , the ratio of the burst duration to one reception period in the DVB-H receiver is β , the outage probability for DVB-H receiver P_{oH} will be

$$P_{oH} = \beta \cdot P_{oT} \tag{7-4-4}$$

Then the coverage probability P_{cH} in the DVB-H network

$$P_{cH} = \Pr\{(\Gamma > \gamma_0\} = 1 - P_{oH} = 1 - \beta \cdot P_{oT} \tag{7-4-5}$$

and the P_{oT} for which the C/I ratio is less than the threshold is

$$P_{oT} = \Pr\{(\Gamma < \gamma_0\} = 1 - \int_{\gamma_0}^{\infty} \frac{1}{\sqrt{2\pi}\sigma_\Gamma} \cdot \exp(\frac{-(\Gamma - m_\Gamma)^2}{2\sigma_\Gamma{}^2}) d\Gamma \quad (7\text{-}4\text{-}6)$$

7.4.3 The number of pixels and pixel resolution used in the simulations

In the simulation program, the pixel resolution is a critical parameter and deciding how many pixels should be included in the simulation is fundamental decision. For one defined radius, the higher the resolution of the simulation set, the more pixels will be produced and the better the precision of the results obtained. Here the resolution refers to the area in square metres simulated. However, as the number of pixels increases the time the simulation takes increases, because of the assumptions made in developing the simulation program and the receiver model, even the best result the simulation tool can provide will differ from the corresponding practical situation. In some cases, small sacrifices in result precision can lead to significant gains in simulation speed. Table 7.4.1 lists the different resolutions used, their corresponding total pixel number. The pixel numbers given in Table 7.4.1 are taken from Figures 7.4.2 to 7.4.5 and correspond to the absolute error being below the limit error set at 1% for the least number of pixels. Here it is assumed that the simulation results obtained using the resolution of 200m*200m are the "true" results and the other simulation results with different resolutions are compared with the "true" value.

Several resolutions are used to get different numbers of pixels simulated. The highest resolution is 200m*200m to get the "true" results in the sense given above and the lowest resolution is 2000m*2000m. For one resolution, ACG I to III are tested and for C/I threshold values of 5 to 30 dB. The maximum absolute error with respect to the "true" value is computed for every resolution. For the purpose of generating a general rule concerning the resolution for different cell radius ranges, the maximum and minimum values of the transmit power and the antenna height are simulated. A cell radius in the range 5km to 60km is simulated. For a large radius such as 40km or 60km, the 200m*200m resolution will produce so many pixels that the computation load incurred will exhaust the computer's memory in the frequency reuse condition. In such cases the 400m*400m resolution will replace the 200m*200m to represent the "true" results. The simulations show that the absolute error of the result of the 400m*400m resolution with respect to the 200m*200m resolution is below 0.5%.

Notice the pixel coverage threshold ratios in the whole area considered are 95%, 90% and 70% corresponding to ACGI, II and III coverage. If the "true" value is set to 95%, 90% and 70%, respectively, then a 1% absolute error upper limit will give the results for these three cases with less than 1.5% error relative to these "true" values.

For the no frequency reuse scenario, SFN sizes 3 and 7 are simulated using different resolutions. For the frequency reuse scenario, SFN sizes 3 and 7 with reuse factor 3 are tested. Reuse factor 3 is tested because in this condition, the studied area will receive more outer interference than a higher reuse factor. The lower the reuse factor the SFN network uses, the closer the studied area is to the interferer and the result will be more "sensitive" to the resolution variation than the corresponding high reuse factor results.

For computing the optimal cell radius, the radius range of 1km to 80km is the range of search because in the case of the highest transmitter power, 45 dB, and highest antenna height, 300m, the optimal radius will be less than 80km in the testing scenarios in this chapter. Several typical radiuses, 5km, 10km, 20km and 40km, are set in order to find a reasonable resolution for successive intervals of search. These values are chosen from the simulation results shown in Figures 7.4.2 to 7.4.5. Within the intervals marked out by these typical radiuses, a common pixel number can be found for each interval to get a result under the 1% error limit.

Observations:

Figure 7.4.2 to Figure 7.4.5 show the results that different scenarios give. The more pixels used in the simulation, the closer the precision of the results gets to the corresponding results obtained using the "delicate" resolution. It is hard to find a common pixel number (one common resolution) that can guarantee that the absolute error of the results will be below the upper limit of 1%, but a common resolution for each interval of search can easily be selected.

Table 7.4.1 lists the number of pixels needed for each interval of search and their corresponding resolution. The pixel numbers listed in Table 7.4.1 refer to the least number of pixels per cell needed in terms of the set of allowable resolutions simulated. For example, if the observed number of pixels is 2000 for a SFN of size 3, then the pixels needed per cell after dividing by the SFN size will be rounded to 667. Sixteen resolutions were used in the simulations ranging from 200m*200m to 4000m*4000m.

Table 7.4.1: The resolution for different cell radius ranges

Cell radius range (km)	R=1~5	R=5~10	R=10~20	R=20~40	R=40~80
Pixels needed*	-----	667	1000	1333	1333
Corresponding Resolution (m^2)	200*200	400*400	800*800	1200*1200	2000*2000

*Pixels needed means to get the absolute error compared to the 200m*200m resolution results below 1%.

For a cell radius between 1km and 5km, a resolution of 200m*200m is set because only a relatively small number of pixels need be computed.

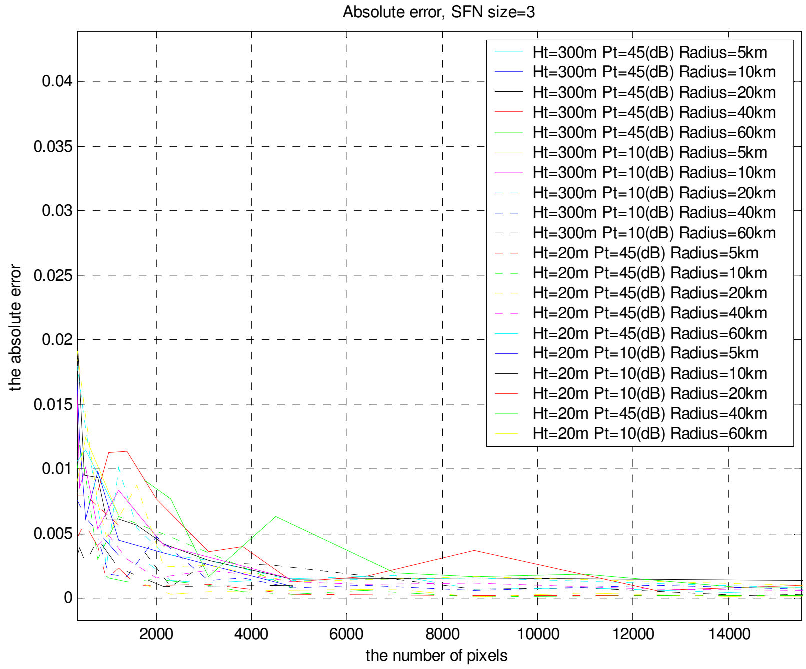


Figure 7.4.2: The absolute error for SFN size=3 (no frequency reuse)

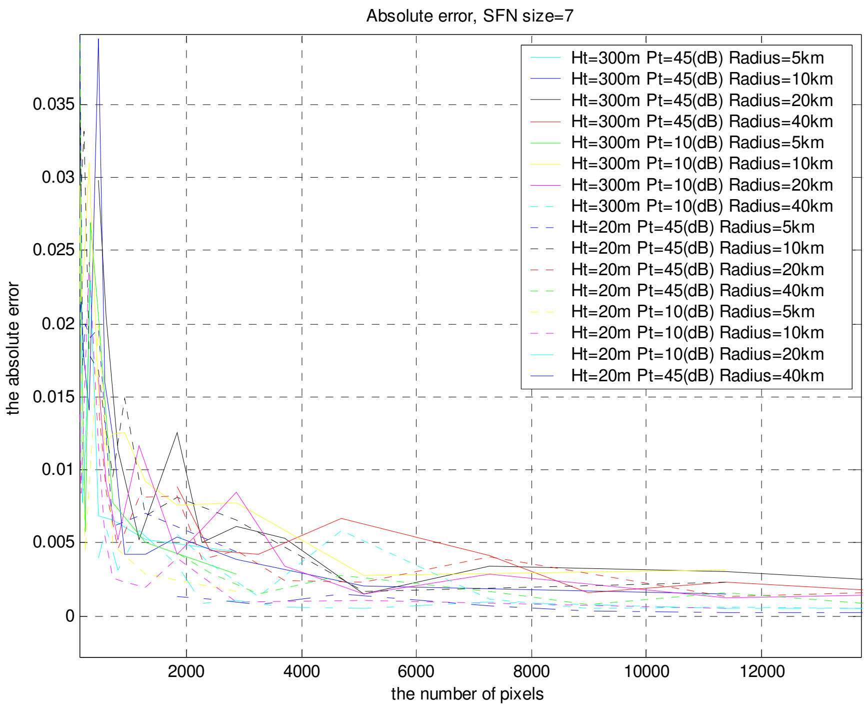


Figure 7.4.3: The absolute error for SFN size=7 (no frequency reuse)

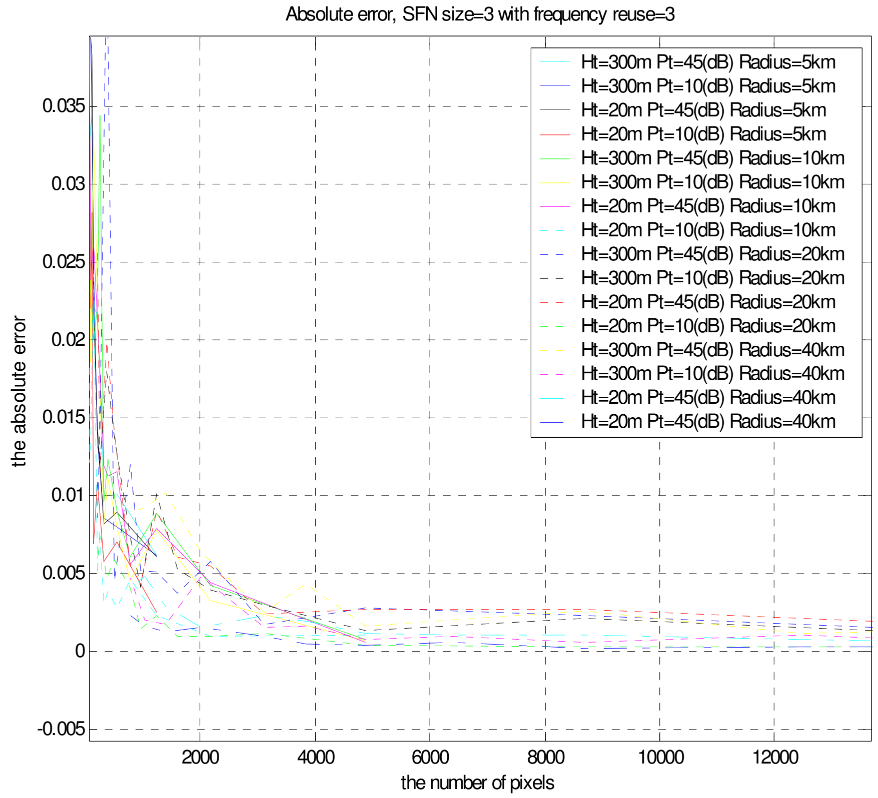


Figure 7.4.4: The absolute error for SFN size=3 and frequency reuse factor=3

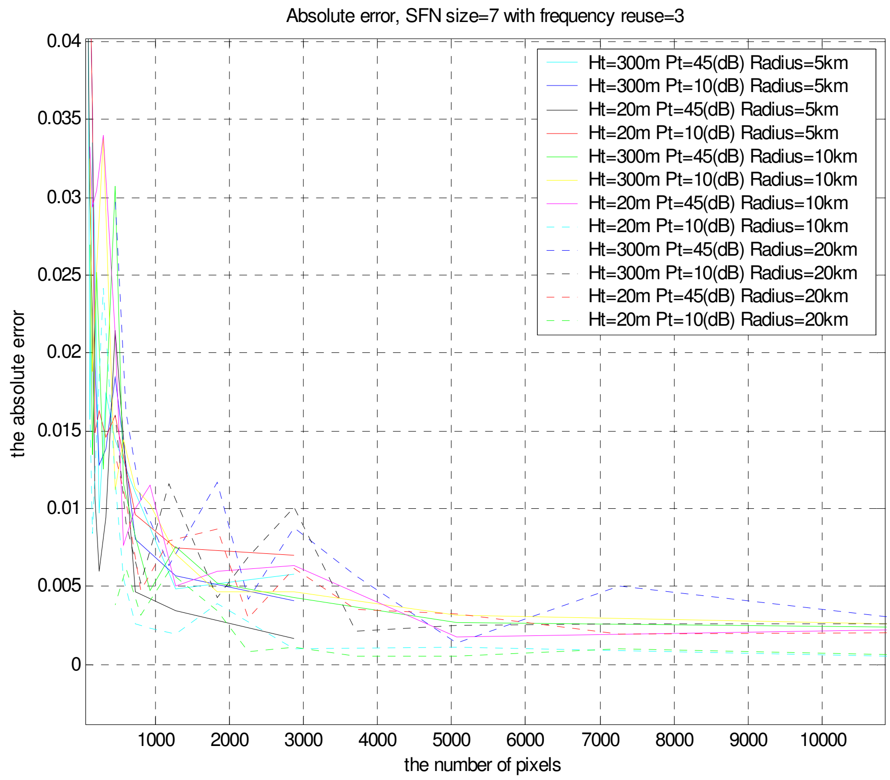


Figure 7.4.5: The absolute error for SFN size=7 and frequency reuse factor=3

7.4.4 Comparison of the sum methods of lognormal distribution variables

In cellular frequency reuse systems, the interference signal power distribution of the sum of several lognormal signals is required to estimate the outage probability of the typical lognormal signal. The Monte-Carlo method is the most accurate way to compute the distribution of the sum of several lognormal variables. However, this method is time consuming and usually an approximation method is used for simulation purposes. Although there is no exact mathematical expression to describe the distribution function of the sum of lognormal variables there are several approximation methods based on the assumption that the sum of lognormal variables is a lognormal variable, e.g., the Fenton-Wilkinson, Schwarts-Yeh [19], Farley [6], t-LNM [5] and CH method [18]. The approximation accuracy usually depends on the number of interference sources and their deviation, etc [6].

Based on the CDF (cumulative distribution function) obtained by simulation, it was found in [7] that the simplest of the above approximation methods, the Fenton-Wilkinson method, may be more accurate than Schwarts-Yeh's method for small to medium dB spreads ($\sigma = 6$ dB) and that Farley's approach is the best method for large dB spreads ($\sigma = 12$ dB). In this chapter, dB spreads of $\sigma = 8$ dB are taken in the simulations to test how closely the different approximation methods approximate the Monte Carlo method in different scenarios.

In the simulation study reported here, the thermal noise is included into the C/I computation assuming that the thermal noise has a lognormal distribution with a variance of zero for computing convenience. When no outer interference occurs or the outer interference is smaller than the thermal noise or the interferer is far away from the receiving point, the thermal noise will be the main interference in the C/I computation.

The sum of lognormal variables of different variance that contribute to the interference needs to be computed using an approximation method. Only the SY, t-LNM and CH methods can be tested for their approximation to the Monte Carlo method because the other methods require that the lognormal variables contributing to the sum have identical variance. The implementation guidelines [8] show that the Monte Carlo simulation method when applied to different testing scenarios agrees quite closely with the assumed Gaussian CDF (based on the calculated mean and variance). In the comparison here, the reference CDF is the Gaussian CDF calculated using the Monte Carlo simulation method for the given scenario.

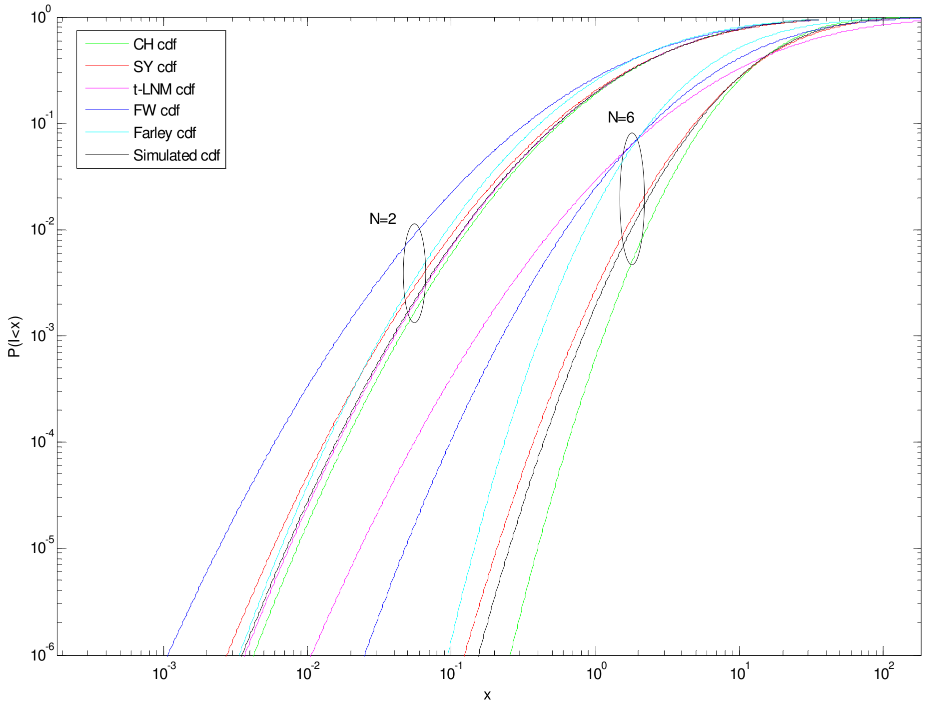


Figure 7.4.6: The CDF obtained using different methods for computing the sum lognormal distribution in the case of different numbers of lognormal variables (of mean = 0 and variance = 8 dB)

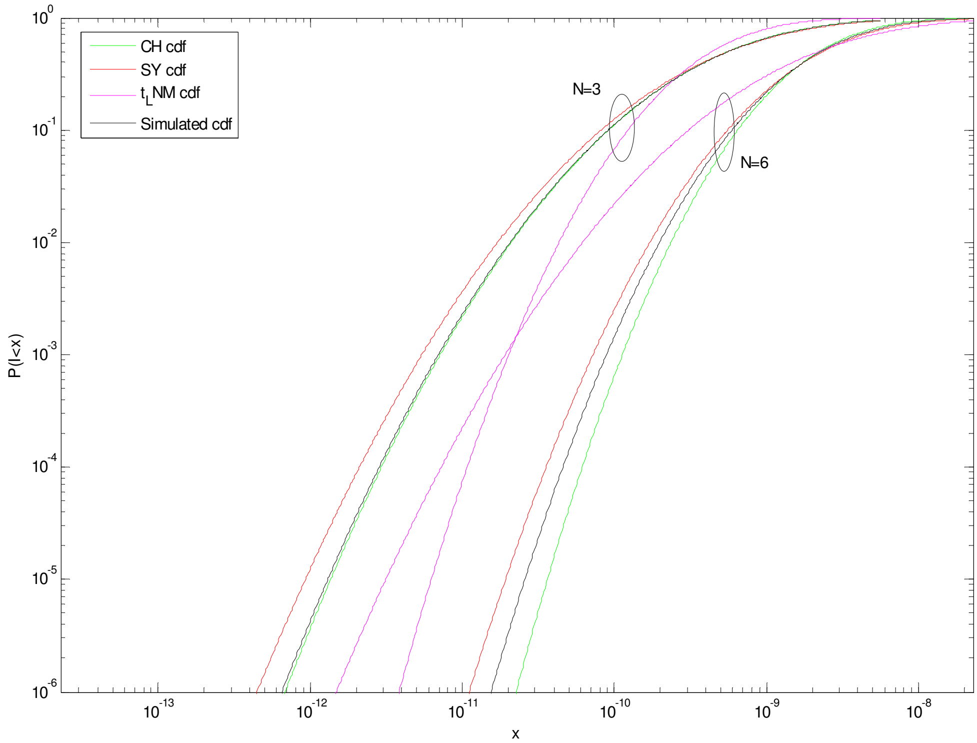


Figure 7.4.7: The CDFs obtained using different methods for computing the sum lognormal distribution in the case of different numbers of lognormal variables with different means and variances (N=3, mean = [-98 -129 –98], variance = [8 0 8]; N=6, mean = [-98 -98 -129 -98 -98 -98], variance = [8 8 0 8 8 8]);

Observations:

Figure 7.4.6 shows the CDF (cumulative distribution function) obtained using different methods for determining the sum lognormal distribution for different numbers of lognormal variables. In the case of only two variables, except for the Fenton-Wilkinson method, all the methods give a good approximation. The better the CDF curve generated by an approximation method fits the CDF curve obtained by simulation using the Monte Carlo method the more accurately the method approximates the Monte Carlo method. For the case of six variables of the same variance contributing to the interference, see Figure 7.4.6, the SY method gives the best approximation though the CH method also performs well. Figure 7.4.7 shows the CDFs of the sum of different numbers of lognormal variables with different variances, in the testing scenarios the mean is chosen according to the typical values. It can easily be seen that the SY and CH methods give the best fit to the Monte Carlo simulated CDF in the N=3 and N=6 cases. In light of the above, in the simulation study reported below the SY method is used to approximate the Monte Carlo simulation method.

7.4.5 Simulation procedure

The simulation chart flow below illustrates how to get the outage probability for one pixel area.

The simulation steps for one pixel area are, see Figure 7.4.8:

1. Set the parameters to be used in the simulation.
2. Load the terrain model.
3. Use ITU 1546 to compute the path loss.
4. Compute the delay times from the other transmitters.
5. If the maximum delay is less than the guard interval time, then set the loop limit = 1, otherwise set the loop limit = N. (N=10 is used for reasonably accurate results for modest computational effort
6. Move the start time of the FFT window from zero to the maximum signal delay according to the loop time.
7. Compute the weight coefficient of the signal component.
8. Use the SY method to compute the mean and the deviation of the C/I value.
9. Compute the outage probability of the pixel.
10. If the loop time is less than the loop limit then go to 6, otherwise go to the next step.
11. Find the minimum outage probability as the pixel outage probability.
12. Graphically display the result.

Usually the computation of the FFT window start reference time is one part of the synchronization algorithm used in the receiver. Because different manufacturers use different algorithms it is impossible to find a universal algorithm to compute the FFT window start time. In the coverage planning simulation discussed in this chapter, the optimal start time is chosen according to the minimum outage probability occurring for some C/I threshold. Because in the SY lognormal distribution combination method, the variance of the sum of the interferences is also a function of the expected value of the total interference, only from the outage probability computation can we know the optimal start time of the FFT window. It is assumed that the receiver can operate so that the outage of the signal occurs with the minimum outage probability.

However, in the simulation scenario where all the transmitters have the same antenna height and transmitter power, the first received signal is also the largest contributed signal. In such a case, the optimal FFT window start time is the first received signal time and N=1.

7.5 Cell dimensioning and optimal cell radius

In the wide area SFN network, after all the network parameters have been specified, the optimal cell radius for one hexagonal cell will be identified. The optimisation criterion for cell radius is that the ratio of the area composed of the locations within the cell which can receive the minimum C/I required by the receiver to achieve a predefined QoS to the total area of the hexagonal cell is the maximised and the cell radius is the largest one that gives this maximum area ratio.

7.5.1 Procedure to compute the optimal cell size

For the purposes of illustration, the flow chart of Figure 7.5.1 is set for ACG I (95% of pixels are covered) with PCG I (95% of the area of the pixel is covered).

Exhaustive search method:
In the search for the optimal cell radius, if there are more than two radiuses for which the coverage ratio is greater than 95%, then the bigger radius is chosen as the optimal radius.

1. Set the cell radius range, transmitter power range, antenna height range and the other related parameters in the simulation tool.
2. Set one antenna height.
3. Set one transmitter power.
4. Set one cell radius.
5. According to the cell radius set in Step 4, choose a suitable resolution.
6. Use the receiver model to compute the contributed and interference signal level for all pixels.
7. Use the S_Y method to get the mean and standard deviation of the sum of the lognormal contributed signals and interference signals.
8. Compute the outage probability Pout for all pixels.
9. If Pout is less than 0.05 for a pixel, the pixel is covered and a variable recording this covered pixel is set to 1, otherwise 0;
10. After the outage probability of every pixel has been computed, compute the coverage pixel ratio for ACG I.
11. If the checking condition is true go to 13, otherwise, go to next step.
12. If the cell radius is less than the maximum radius, return to Step 4 for an increased cell radius; Otherwise go to next step;
13. Interpolate the optimal cell radius for the area coverage ratio ACG I (>95%).
14. If the transmit power is less than the maximum transmit power, return to Step 3 for an increased transmit power; Otherwise go to next step;
15. If the antenna height less than the maximum height, return to Step 2 for an increased antenna height; Otherwise go to next step;
16. End

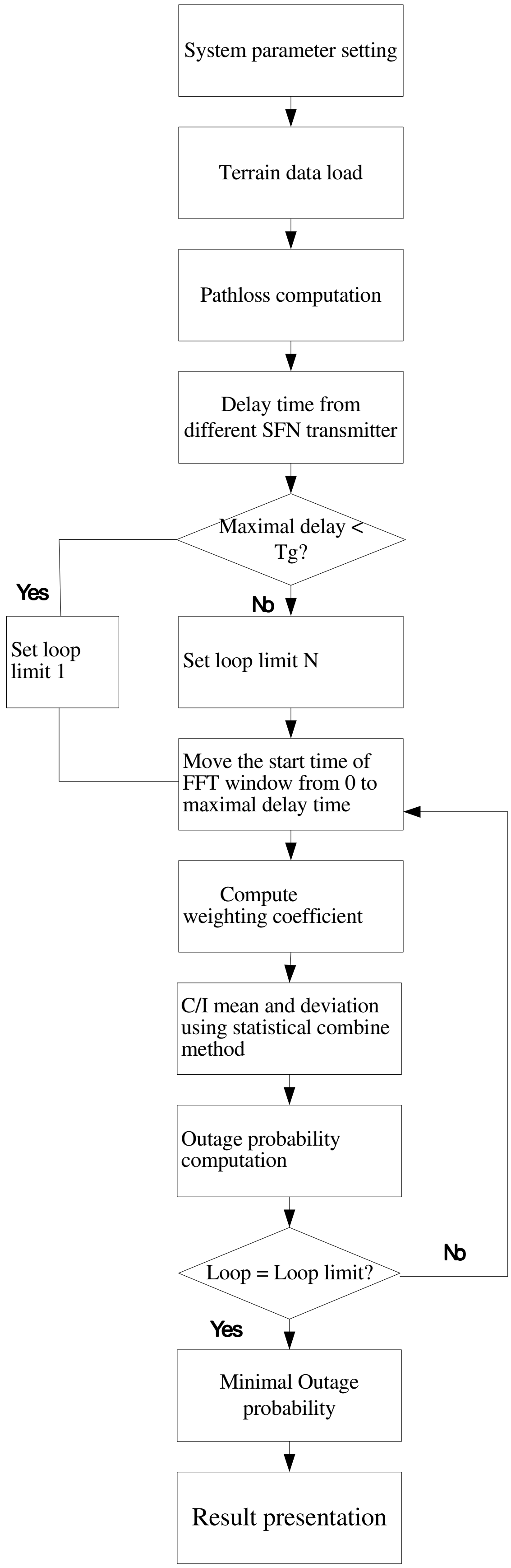


Figure 7.4.8: Flow chart of the coverage simulation for one pixel area

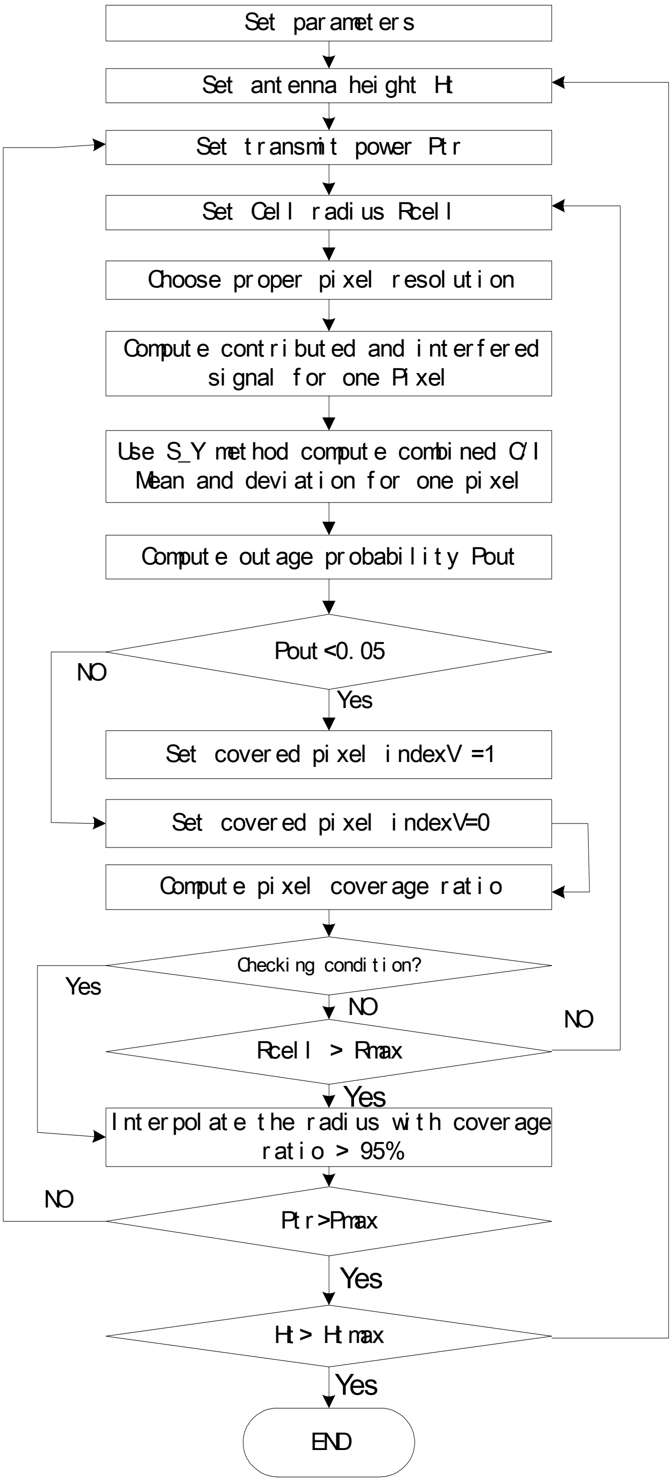


Figure 7.5.1: The flow chart for computing the optimal cell radius for a given parameter set

The checking condition:

If the topology is a SFN without frequency reuse, then the pixel coverage ratio for any C/I threshold will monotonically decrease with increasing cell radius as Figure 7.5.2 shows. Then after Step 10, if a checking condition for a coverage ratio of less than 90% (5% less than the coverage ratio threshold) is used, when this condition is true, the loop for the cell radius (back to Step 4) can break. For a SFN with a frequency reuse topology, the pixel coverage ratio reaches a peak value as the cell radius increases (see Figure 7.5.3), and decreases with further radius increments.

A combination checking condition of ratio decreasing and less than 90% coverage (for ACGI) can be used. This will reduce the simulation time when searching for the optimal cell radius.

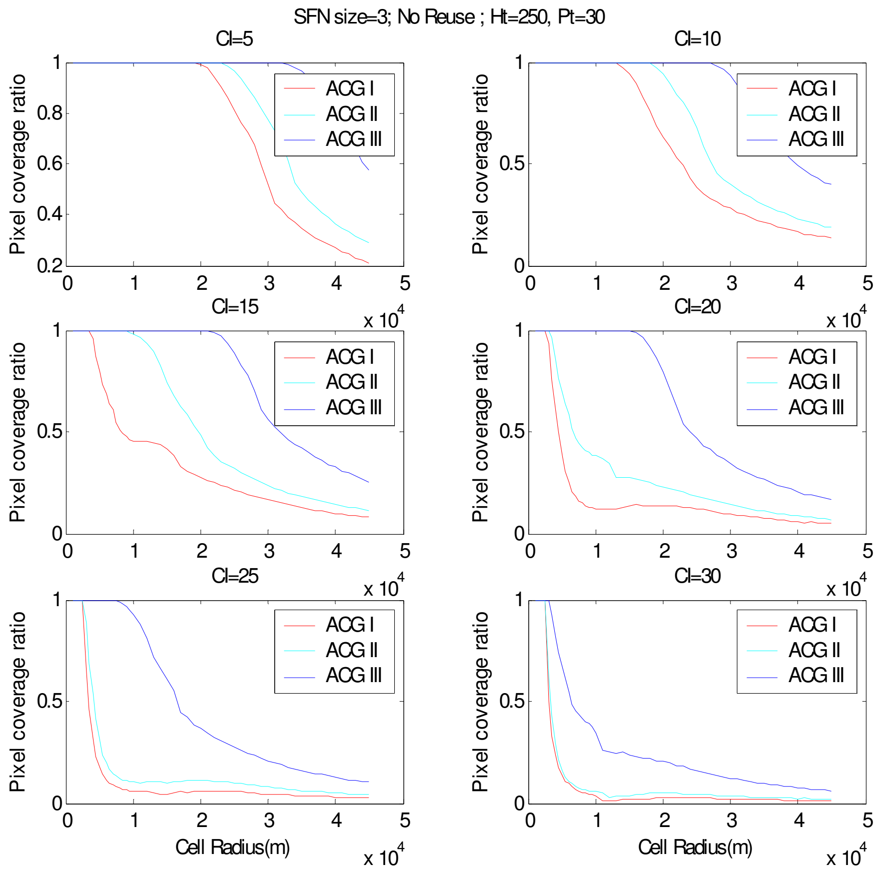


Figure 7.5.2: The pixel coverage ratio for SFN size =3 with no frequency reuse

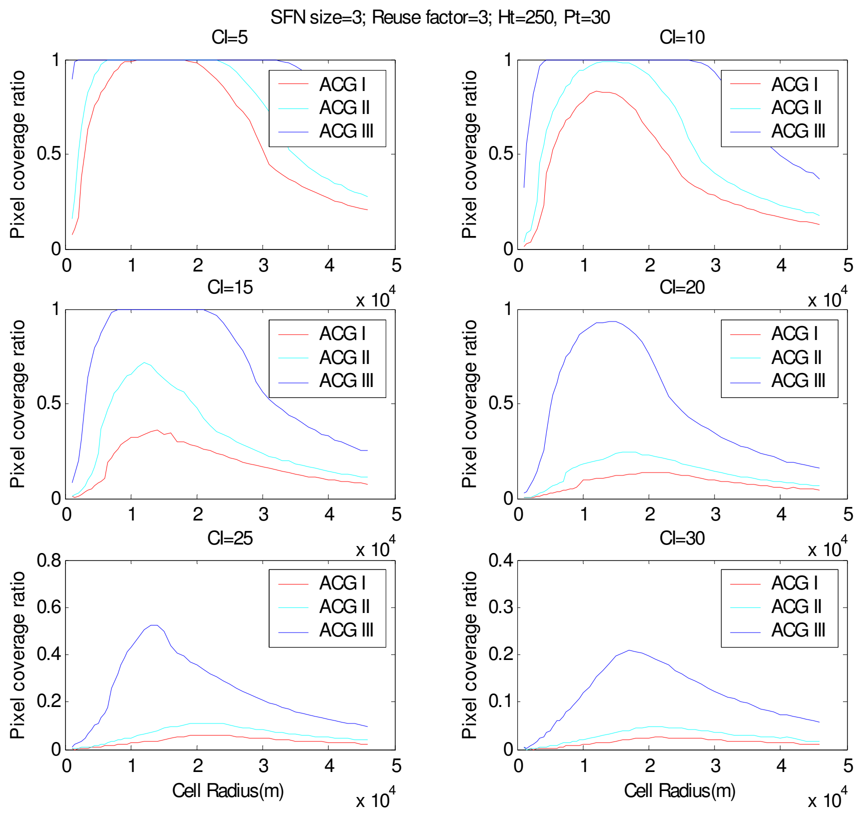


Figure 7.5.3: The pixel coverage ratio for SFN size =3 and Reuse factor=3

Analysis of Figure 7.5.2 and 7.5.3

Figure 7.5.2 shows the pixel coverage ratio monotonically decreasing as the radius increases, ACGI and ACGII have faster decreasing curves than ACG III this is because for a higher pixel coverage ratio, the C/I ratio is more sensitive to the interference and attenuation of the contributed signal. Figure 7.5.3 shows the pixel coverage ratio reaches a peak value as the cell radius increases. This is because in the situation where outer interference exists, the interference is quite strong compared to the contributed signal for a small cell radius, so the C/I ratio in the studied area starts small for small radiuses but as the radius increases the interference attenuates more quickly than the contributed signal thanks to the number of transmitters in the SFN which leads to the C/I ratio in the studied area increasing. As the contributed signals also attenuate as the radius increases further, the C/I ratio will eventually decrease and this leads to the C/I ratio monotonically decreasing. The pixel coverage ratios shown in Figure 7.5.2 and Figure 7.5.3 are approximately directly proportional to the C/I ratios for the studied area.

7.5.2 The optimal cell radius for different network topologies

The optimal cell radius is a function of antenna height and transmitting power after the other parameters have been defined. It assumed that this function is continuous and that at least the first derivatives exit. Based on this assumption, 56 different combinations of antenna height and transmitter power were simulated. The other combinations in the ranges of the antenna height and transmitter power are interpolated.

Figure group A6 to A8 shows the optimal radius for no frequency reuse. Figure A11 and A13 show the optimal radius with frequency reuse.

Figures A6-1 to A6-6 give the optimal cell radiuses for six different single transmitter scenarios. As expected the largest radius happens with the highest antenna height and transmitter power point.

Figures A7-1 to A7-3 give the optimal cell radiuses for different coverage, with the guard interval = 1/32, for a SFN with size = 3 and the Figures A7-4 to A7-6 give the optimal radiuses for different coverage for a SFN of size = 7 and the same guard interval.

Observations on the peak cell radius ranges from the figures of appendix A.7:

1. For a C/I ratio threshold of 5, the optimal cell radius obeys the same rule as for the single transmitter cell for all three ACG coverage requirements and SFN sizes 3 and 7.
2. For a C/I ratio threshold of 10, the ACG I coverage requirement for both sizes 3 and 7 makes the plots of peak cell radius bend to half ellipses. For the ACG II and III coverage requirements, the optimal cell radius obeys the same rule as for the single transmitter cell as with a C/I threshold of 5.
3. For the C/I threshold ratios 15 and 20, the ACG I and II coverage requirements make the plots of peak cell radius bend to approximate half ellipses for SFN sizes 3 and 7, (Figure A7-1, A7-2, A8-4 and A8-5).

Figures A8-1 to A8-6 give the optimal cell radiuses for frequency reuse factors of 3, 7 and 9 with guard interval ¼; It can be easily seen that the optimal cell radius obeys the same rule as for the single transmitter cell.

Figures A11-1 to A11-9 show the optimal cell radiuses with the frequency reuse factors 3, 7 and 9 with the guard interval ¼. Optimal cell radiuses do not exist for some C/I ratio thresholds and ACG coverage requirements because of the outer interference from the other co-channel SFNs. Though the biggest radius is roughly for the highest antenna height and biggest transmitter power, the difference with the single transmitter cell is that there is a range for which this radius exits (Figure 7.5.3, C/I=20).

Figures A13-1 to A13-9 show the optimal cell radiuses with the frequency reuse factors 3, 7 and 9 with the guard interval ¼. Optimal cell radiuses do not exist for some C/I ratio thresholds and ACG coverage requirements for the SFN size 3, they do exit for all C/I thresholds for SFN size 7. Figure A11-3 and A13-3 appear below as Figure 7.5.3 and Figure 7.5.4 for illustration purposes. There is no optimal cell radius for C/I = 30 in Figure 7.5.3 but there is in Figure 7.5.4.

Figures A13-1 to A13-9 show the basic same trend in the largest optimal radius with SFN size 7 that is, a higher antenna height and a bigger transmitter power give a larger optimal radius. However, the SFN size 7 can provide an optimal radius for the higher C/I threshold value with lower transmitter power and antenna height. For example, in Figure 7.5.4, for a C/I = 20, there exits a radius satisfying the coverage requirements, but in Figure 7.5.3, there does not.

The optimal cell radius is more sensitive to the antenna height than to the transmitter power in the high transmitter power range. For example, in Figure 7.5.4, for C/I =15, if Ptr = 30dB, then an increase the antenna height from 20m to 30m increases the optimal cell radius from 6km to

9km. If the antenna height is fixed at 20m, then an increase in the optimal cell radius from 6km to 9km will require that the transmitter power increase from 30dB to 40dB.

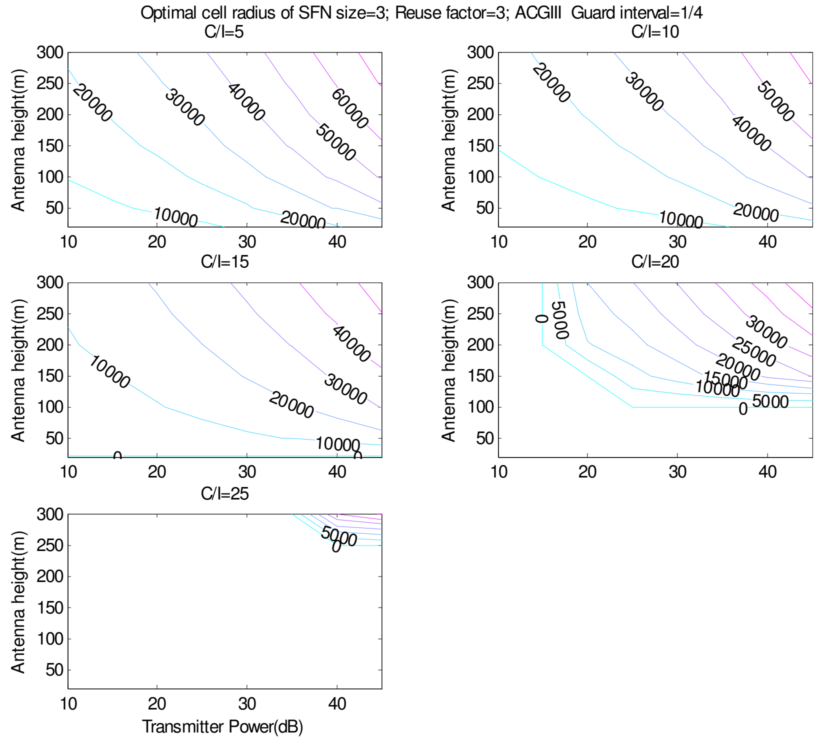


Figure 7.5.3: The optimal cell radius of SFN size=3 and reuse factor=3; ACG III coverage; Guard interval=1/4

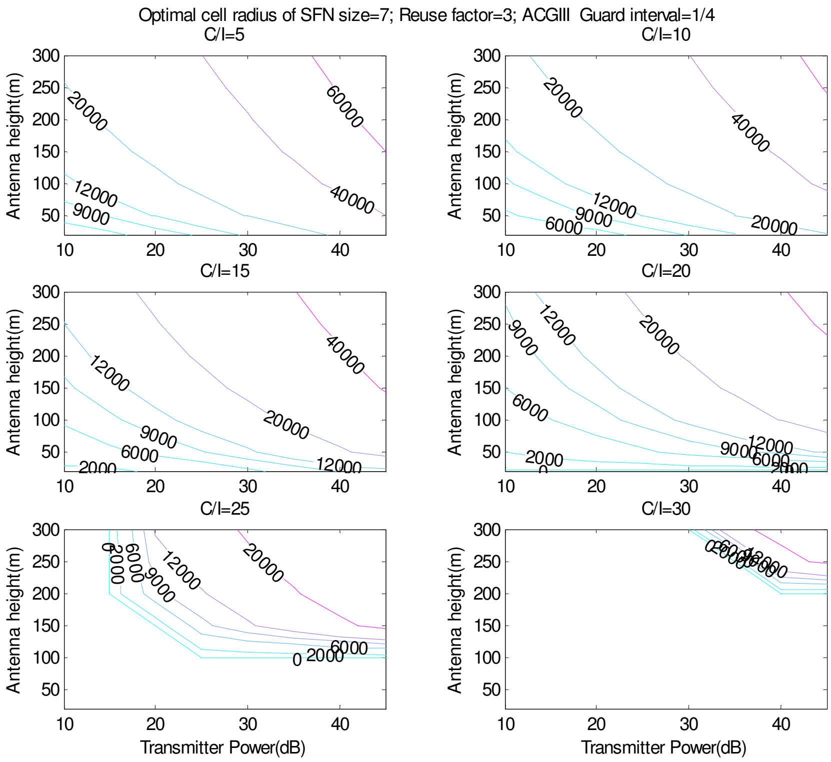


Figure 7.5.4. The optimal cell radius of SFN size=7 and reuse factor=3; ACG III coverage; Guard interval=1/4

7.6. SFN gain

In the single frequency network, whether or not the signals coming from different transmitters can contribute to the useful signal in a C/I ratio computation depends on the signal delays with respect to the strongest signal. If a signal delay is less than the guard interval, this signal can give a positive contribution to the C/I ratio at the receiver; otherwise it will act partly or fully like interference (Equation 7-4-1). In an area where one transmitter signal is strongly attenuated, the contributed signals from other SFN transmitters could improve the received picture quality in this way. In the presence of inner interference or outer co-channel interference, such signals could contribute to the C/I ratio, even when the interference is high. However, this contribution cannot give a C/I ratio improvement as the useful contribution is suppressed by the interference.

In SFN gain analysis, the gain of the SFN is computed from the optimal cell radius.

7.6.1 SFN gain without frequency reuse

After the optimal cell radiuses for different network topologies and the different network parameter configurations have been obtained, a SFN gain comparison can be done based on the following SFN gain definition with different transmitters.

$$\text{Gain}_{\text{SFNn}} = \frac{R_{\text{SFNn}}}{R_{\text{Single}}} - 1 \qquad (7\text{-}6\text{-}1)$$

R_{SFNn} means the optimal cell radius of a SFN network with n transmitters; R_{single} means the corresponding single transmitter optimal cell radius. The SFN gain maps given in the appendices are obtained based on the optimal cell radiuses computed using the parameter ranges in Table 7.2.1.

A positive SFN Gain under same parameter configuration means that the SFN network is effective for such a configuration; it can cover a bigger area compared with using the same number of MFN transmitters with no frequency reuse. It is not recommended to deploy a SFN network for configurations for which the gain is negative.

The group of figures A9-1 to A9-6 and A10-1 to A10-6 give the SFN gain using the contour line representation for different transmitter powers and antenna heights for the guard intervals 1/32 and ¼. These gains are computed under different ACG and different C/I ratio thresholds.

Observations:

1. From Figures A9-1 to A9-6 for guard interval 1/32, the bigger positive gains appear in an area apart from the high antenna and high transmitter power area. For C/I thresholds equal to 5 and 10, low antenna height and middle transmit power can give a higher gain for all three ACG coverages. For C/I thresholds greater than 15, a range of transmitter power from 10 to 30 dB with an antenna height range from 20 to 150 meters can give the highest positive gain.
2. For guard interval 1/32, Figure 7.6.1 shows that:
   - For ACG III coverage the maximum SFN gain increases as the SFN size increases for C/I threshold 5 to 20; For C/I threshold 25 the gain

first increases from size 3 to size 7 then decreases at size 9, increases at size 12 and 19. For C/I threshold 30, the maximum gain first increases from size 3 to size 7, then decreases as the SFN increases from size 9 to 19.

- For ACG II coverage, SFN gain increases with increasing SFN size only for C/I threshold 5. For C/I threshold 10 to 20 the SFN gain first increases at size 7, then decreases at sizes 9 and 12 and increases at size 19. For the C/I threshold 25, the SFN gain increases at size 7 and decreases as the SFN size increases and for C/I threshold 30, the SFN gain decreases as the SFN size increases.
- For ACG I coverage, the maximum SFN gain of C/I thresholds 5 and 10 first increases at size 7 and then decreases at size 9 and increases at sizes 12 and 19; The maximum gain of C/I thresholds 15 and 20 first increases at size 7 and then decreases as the SFN size increases. The maximum SFN gain of C/I thresholds 25 and 30 always decreases as the SFN size increases.

For guard interval ¼, Figure 7.6.2 shows that:

For ACG III coverage, the maximum SFN gain increases as the SFN size increases. For ACG II and I, the maximum SFN gain exhibits the trend of firstly increasing, then decreasing and finally increasing with SFN network size for all C/I thresholds.

3. For the gains for guard interval 1/32, there are negative values for some transmitter power and antenna height ranges for a C/I threshold greater than 10, but for guard interval ¼, all the gains are positive.
4. For the same size SFN, gains for the guard interval ¼ are apparently greater than the gains for the guard interval 1/32.
5. The highest SFN gain happens at the highest antenna height and middle-low transmitting power, or low antenna height, and middle transmit power range.

A higher gain also means a bigger optimal cell radius because in both guard interval 1/32 and ¼ cases, the gains are normalised using the single transmitter cell radius.

The maximum SFN gain decreases at sizes 9 and 12 for ACG I and II coverage because the topology of sizes 9 and 12 is an asymmetric topology compared with that of the sizes 3, 7 and 19 (refer to Figure 7.3.3). This also shows that asymmetric topologies will incur more self-interference than symmetrical ones. For a small guard interval like GI = 1/32, it is not recommended to deploy a SFN with a large number of transmitters for the higher C/I thresholds (C/I thresholds 25 and 30) and high coverage requirement (ACG I) because the gain SFN decreases to zero as the number of transmitters increases.

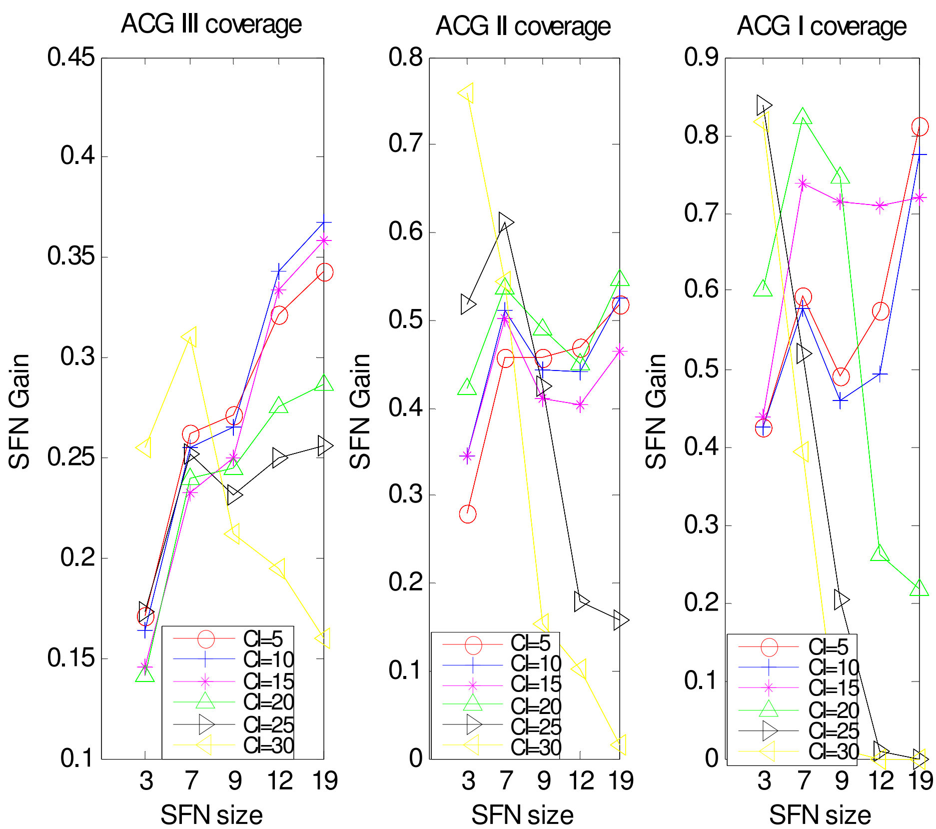


Figure 7.6.1: The maximum SFN gain for ACG coverage without frequency reuse and GI=1/32
(Antenna height range 20m~300m, transmitter power 10dB~45dB)

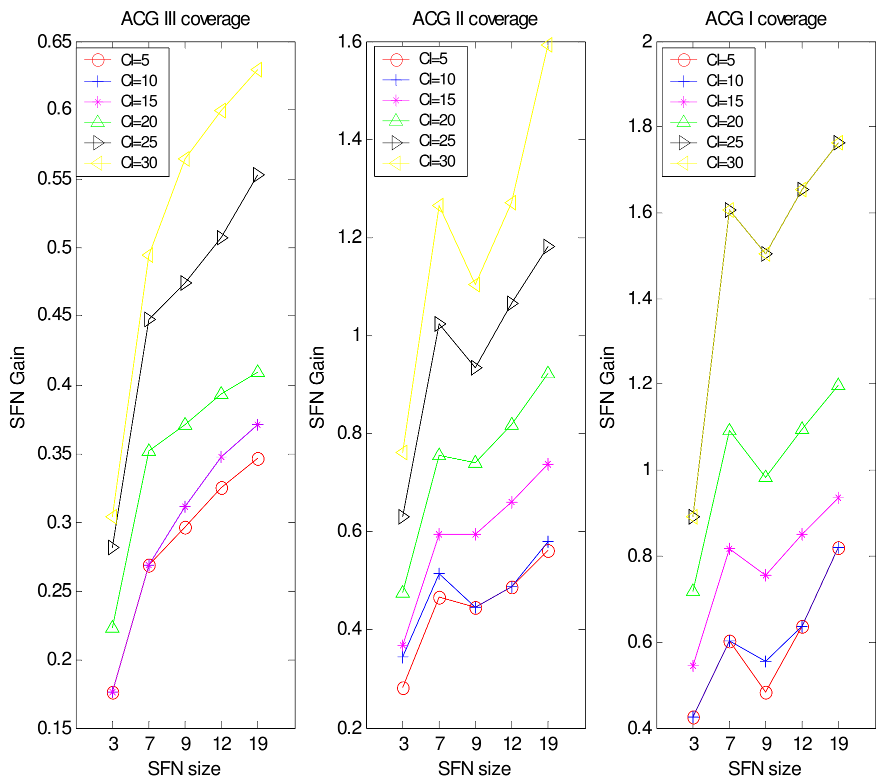


Figure 7.6.2: The maximum SFN gain for ACG coverage without frequency reuse and GI=1/4
(Antenna height range 20m~300m, transmitter power 10dB~45dB)

7.6.2 SFN gain with a frequency reuse:

In the presence of co-channel interference, the equation for SFN gain is:

$$Gain_{SFNn} = \frac{R_{SFNn}}{R_{MFN}} - 1 \qquad (7\text{-}6\text{-}2)$$

R_{SFNn} is the optimal cell radius of a SFN size of n with reuse factor m. R_{MFN} is the optimal cell radius of a MFN with the same reuse factor m.

Due to the high co-channel interference coming from the two SFNs outside, no cell radius for some C/I thresholds can satisfy some ACG coverage requirements. For example, Figure A11-1 shows the optimal cell radius of a SFN of size 3 and reuse factor 3 for ACG I coverage, but for a higher C/I threshold, no radius satisfies this ACG I coverage requirement. Because of this, the SFN gain only can be shown in those cases where optimal cell radius can be derived. For a MFN with the same reuse factor as the SFN the optimal radius does not exist for some ACG coverage requirements and high C/I thresholds in the lower range of the antenna height and transmitter power, and the SFN gain cannot be derived in these cases. So Figure 12-1 to Figure 12-7 only show some SFN gains in the coordinate range.

Observations:

1. The location of highest SFN gain is not fixed in middle or the corner of the coordinate box area.
2. For an area that has SFN gains, the gains are all positive.
3. An optimal cell radius for MFN and SFN size = 3 does not exit for some high coverage requirements and high C/I thresholds, It exits for SFN size = 7; this means the high density of SFN transmitters can improve the cell coverage.
4. Because optimal cell radiuses for the MFN with high C/I thresholds at some reuse factors do not exit for some antenna height and transmitter power combinations, the corresponding SFN gain cannot be computed. Figure 7.6.3 and 7.6.4 shows some SFN gains in terms of the different reuse factors and ACG coverage requirements. The SFN gain can be computed for most of the simulation points. For C/I = 5 and C/I = 10 in Figure 7.6.3, the SFN gain decreases with increasing reuse factor for ACG III coverage. Figure 7.6.4 shows that the SFN gain with C/I = 5 decreases while for C/I=10 it slightly increases with increasing reuse factor.

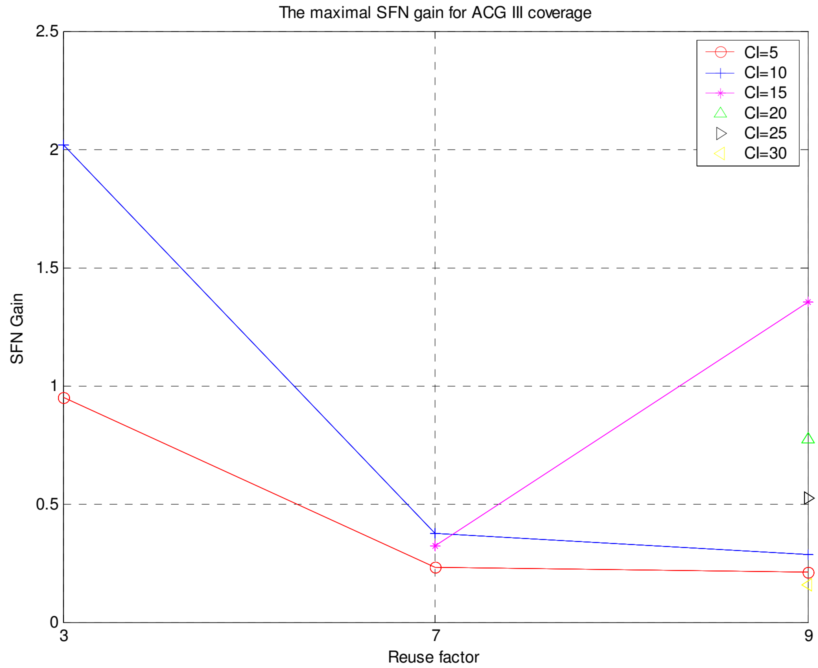


Figure 7.6.3: Comparison of the maximum SFN gain of SFN size=3 for different reuse factors and different CI thresholds

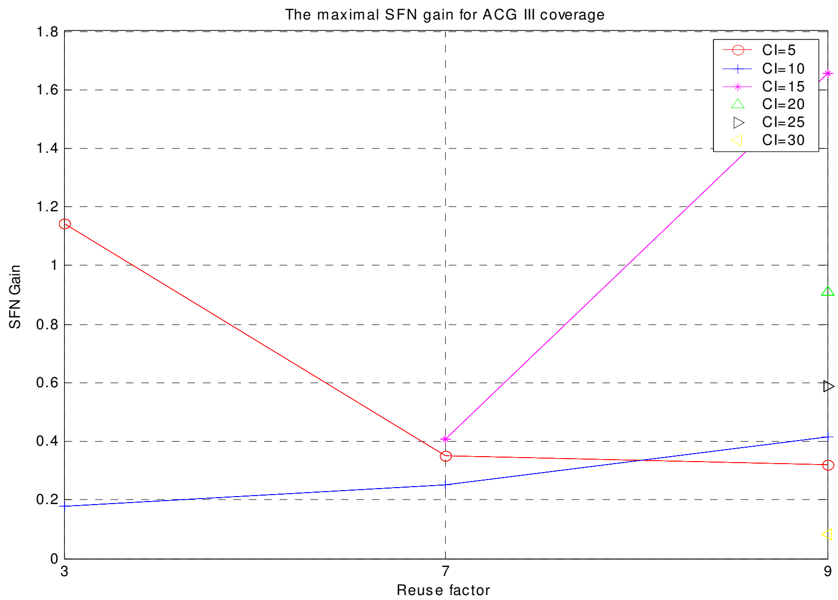


Figure 7.6.4: Comparison of the maximum SFN gain of SFN size=7 for different reuse factors and different CI thresholds

7.6.3 The combination of the use of the optimal cell radius figure and the SFN gain figure

A large SFN gain means that using the same transmitter power and antenna height, the SFN can cover a much larger area than a MFN network with the same reuse factor and the whole network can benefit from the deployment of a single frequency network.

Though there is a range of antenna height and transmitter power combinations that give a predefined cell radius, the best choice is the combination that gives the largest SFN gain at the same time. For example, Figure 7.6.5 shows the optimal point for the 8km radius at the SFN gain = 0.7. The optimal point means that the SFN can get the maximum coverage gain compared with the MFN with the same antenna height and transmit power. In other words, if the MFN is deployed instead of the SFN using the same antenna height and transmitter power and the other network parameters are kept the same, the MFN cell radius will shrink to $R_{SFN}/(1+G)$, here R_{SFN} is the SFN cell radius, and G means the SFN gain.

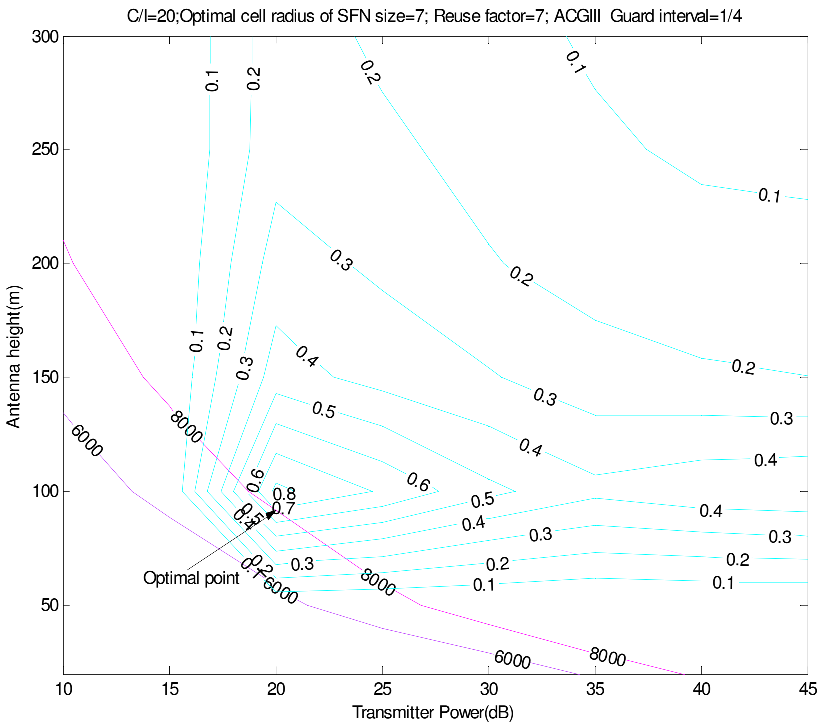


Figure 7.6.5: A combination graph of SFN gain and SFN optimal cell radius for ACG III coverage (the red and purple line represents the contour of the optimal cell radius, the light blue line represents the contour of the SFN gain)

7.7 Conclusions

In this chapter, a coverage planning process for DVB-H SFNs has been presented. Based on simulation results the network performance for different cell sizes and frequency reuse factors was investigated for one DVB-H transmitter configuration leading to the following conclusions:

- External and internal interference play an important role in the coverage planning and dimensioning of DVB-T/H networks.
- DVB-H network planning has an additional burst duration parameter to consider compared with DVB-T network coverage planning.

- For one cell radius, there is a range of transmitter power and antenna height that can achieve the predefined coverage requirement; the optimal choice of the transmitter power and antenna height is that which gives the maximum SFN gain.
- Increasing the number of the transmitters in a SFN can raise the C/I threshold coverage in the case of frequency reuse and ¼ guard interval.
- In the presence of inner interference (1/32 guard interval) and without frequency reuse, the SFN network cannot provide better network performance than a single cell for some transmitter power and antenna height combinations. The network parameters need to be carefully selected based on simulation results and field trials.
- For the no frequency reuse case, a symmetrical topology will give better coverage for the reason of less self–interference incurred than with an asymmetric topology.
- In the small guard interval and no frequency reuse case, for a high C/I threshold like 25 or 30 and a high coverage requirement (ACG I or II), increasing the number of the SFN transmitters will decrease the maximum SFN gain for the reason of increasing self-interference.

7.8 References:

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Chapter 8 DVB-T/-H receiver performance

In order to validate the performance of the RF frontend incorporated in the DVM400 test probe, and to verify some of the conclusions for network planning, a number of tests were carried out in accordance with the test methodology described in the DVB-H Validation Task Force final report [ETSI TR 102 401 v1.1.1 (2005-06)].

8.1 Test set-up

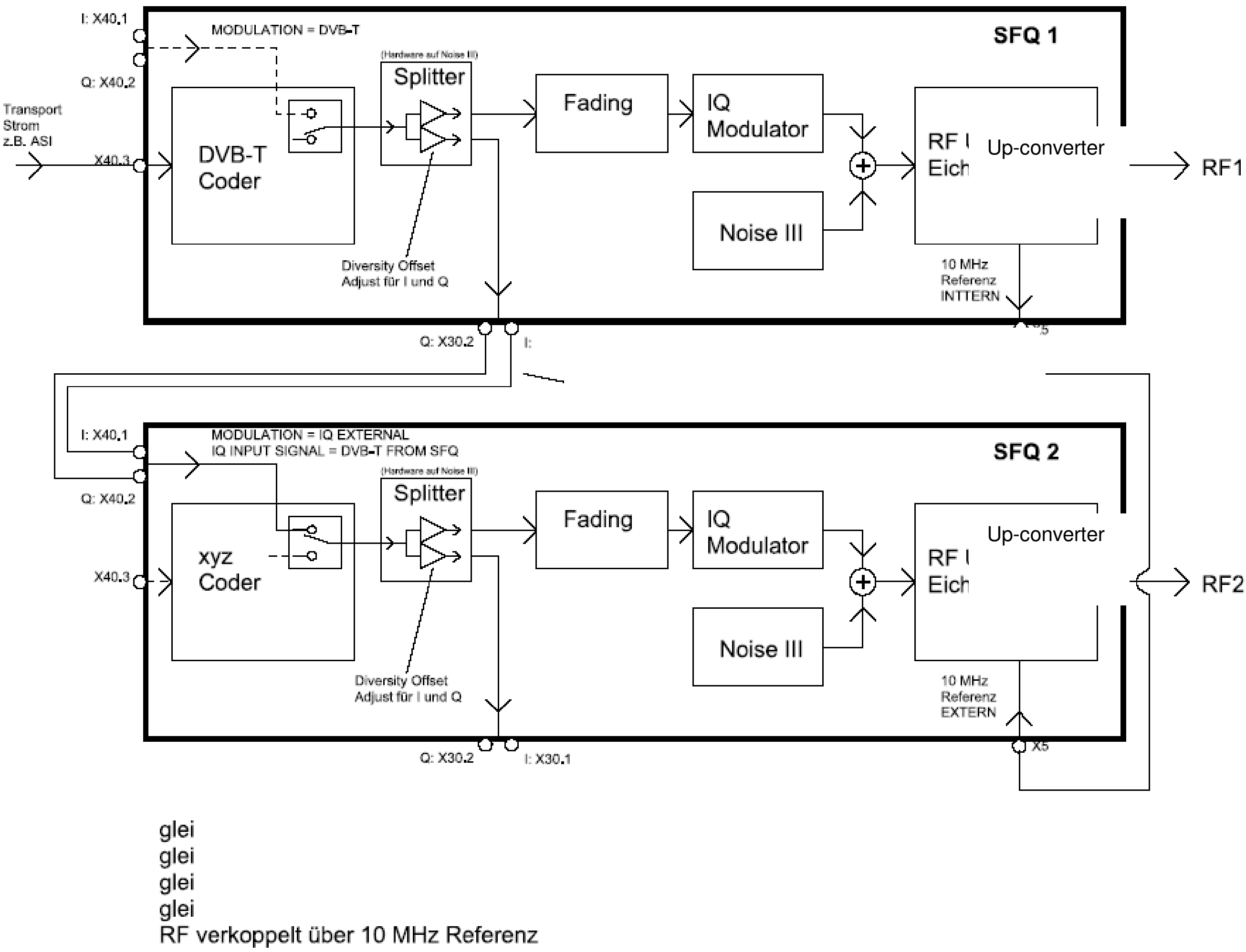


Figure 8.1: Test set-up for diversity measurements

The test set-up includes two test signal generators Type SFQ from R&S which are operated in such a way that the first one provides the channel encoding plus channel simulation (fading) and up-conversion to RF, while for the second only fading and up-conversion are used.

The signals RF1 and RF2 generated by this set-up are synchronised in frequency and are bit synchronous. Since the channel simulators are free-running, there is no correlation between the propagation profiles of the two signals.

8.2 Transmission mode

For the comparison tests a 16QAM CR=2/3 GI=1/4 mode was chosen that had already been used for the DVB-H VTF tests. It is representative since it is already used for DVB-T transmission in several countries. The net bit rate for this mode is 13.27 Mbps. In the table below the minimum C/N requirements are given for static propagation profiles (Gaussian, Rice, Raleigh) which are described in detail in the DVB-T standard (EN 300 744).

For a dynamic channel such as TU6 that was used for the comparison measurements, the minimal C/N requirements are significantly higher.

8 MHz		**FFT**	**ICS**	**Tu**	**Ts 1/4**	**Ts 1/8**	**Ts 1/16**	**Ts 1/32**
		8K	1 116 Hz	896 µs	1120 µs	1008 µs	952 µs	924 µs
		4K	2 232 Hz	448 µs	560 µs	504 µs	476 µs	462 µs
		2K	4 464 Hz	224 µs	280 µs	252 µs	238 µs	231 µs
C/N Gaussian	**C/N Rice**	**C/N Rayleigh**	**Modulation Constellation**	**Modulation CR**	**Bit Rate 1/4**	**Bit Rate 1/8**	**Bit Rate 1/16**	**Bit Rate 1/32**
3,1 dB	**3,6 dB**	**5,4 dB**	**QPSK**	**1/2**	**4,98 Mbps**	5,53 Mbps	5,85 Mbps	6,03 Mbps
4,9 dB	**5,7 dB**	**8,4 dB**	**QPSK**	**2/3**	**6,64 Mbps**	7,37 Mbps	7,81 Mbps	8,04 Mbps
5,9 dB	6,8 dB	10,7 dB	**QPSK**	**3/4**	7,46 Mbps	8,29 Mbps	8,78 Mbps	9,05 Mbps
6,9 dB	8,0 dB	13,1 dB	**QPSK**	**5/6**	8,29 Mbps	9,22 Mbps	9,76 Mbps	10,05 Mbps
7,7 dB	8,7 dB	16,3 dB	**QPSK**	**7/8**	8,71 Mbps	9,68 Mbps	10,25 Mbps	10,56 Mbps
8,8 dB	**9,6 dB**	**11,2 dB**	**16QAM**	**1/2**	**9,95 Mbps**	11,06 Mbps	11,71 Mbps	12,06 Mbps
11,1 dB	**11,6 dB**	**14,2 dB**	**16QAM**	**2/3**	**13,27 Mbps**	14,75 Mbps	15,61 Mbps	16,09 Mbps
12,5 dB	13,0 dB	16,7 dB	**16QAM**	**3/4**	14,93 Mbps	16,59 Mbps	17,56 Mbps	18,10 Mbps
13,5 dB	14,4 dB	19,3 dB	**16QAM**	**5/6**	16,59 Mbps	18,43 Mbps	19,52 Mbps	20,11 Mbps
13,9 dB	15,0 dB	22,8 dB	**16QAM**	**7/8**	17,42 Mbps	19,35 Mbps	20,49 Mbps	21,11 Mbps
14,4 dB	14,7 dB	16,0 dB	**64QAM**	**1/2**	14,93 Mbps	16,59 Mbps	17,56 Mbps	18,10 Mbps
16,5 dB	17,1 dB	19,3 dB	**64QAM**	**2/3**	19,91 Mbps	22,12 Mbps	23,42 Mbps	24,13 Mbps
18,0 dB	18,6 dB	21,7 dB	**64QAM**	**3/4**	22,39 Mbps	24,88 Mbps	26,35 Mbps	27,14 Mbps
19,3 dB	20,0 dB	25,3 dB	**64QAM**	**5/6**	24,88 Mbps	27,65 Mbps	29,27 Mbps	30,16 Mbps
20,1 dB	21,0 dB	27,9 dB	**64QAM**	**7/8**	26,13 Mbps	29,03 Mbps	30,74 Mbps	31,67 Mbps

Figure 8.2: Overview of DVB-T modes

8.3 Test results

For the comparison tests, a failure criterion was defined as in the DVB-H VTF test methodology, i.e. the C/N values were measured for a Frame Error Rate (FER) of 5 % and for a MFER (FER after MPE FEC) of 5 %.

These were the settings:

Output level SFQ	-40dBm
RF frequency	666MHz
FFT-Mode	8K
Code rate	2/3
Guard Interval	1/4
Modulation	16 QAM
Data rate DVB-H Multiplex	4.00MBit/s
Data rate DVB-H Service	512kBit/s
Burst duration	520ms
MPE-FEC Code rate	3/4
MPE-FEC rows	768
Propagation profile	TU 6

The measurement value and the corresponding figures show the dependencies between Doppler shift and required C/N. In the DVB-H VTF report, the following diagram is used to visualise the performance for DVB-T modes (without MPE FEC) and DVB-H modes (including MPE FEC).

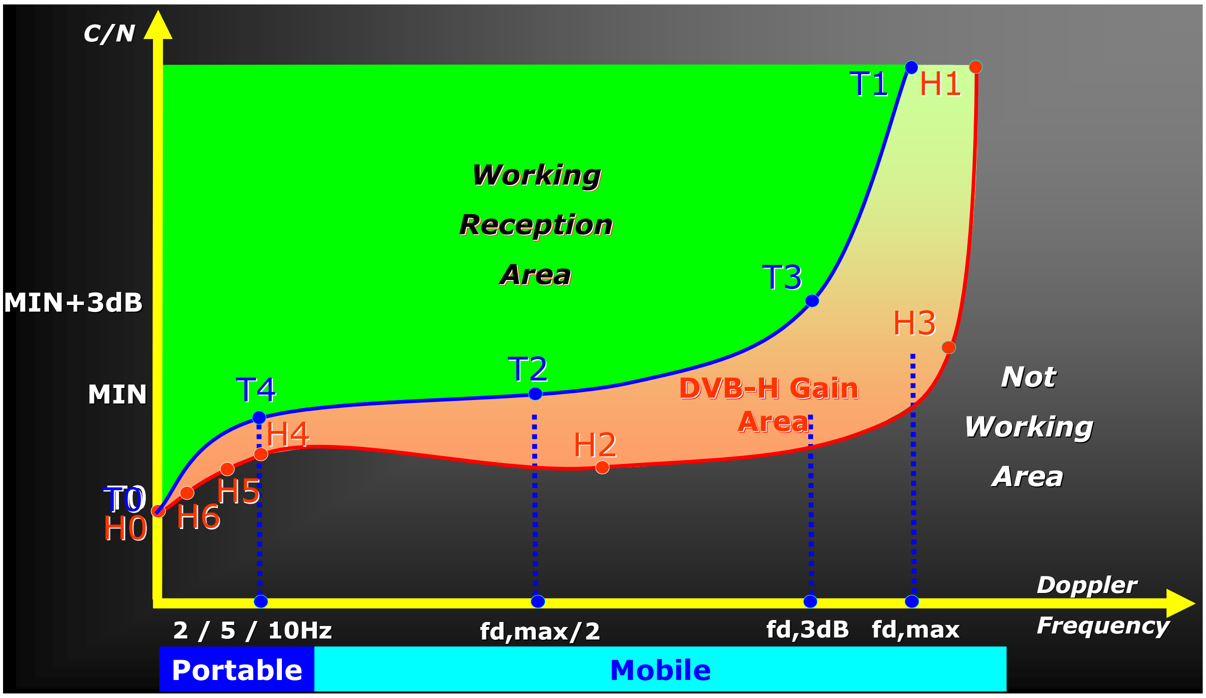


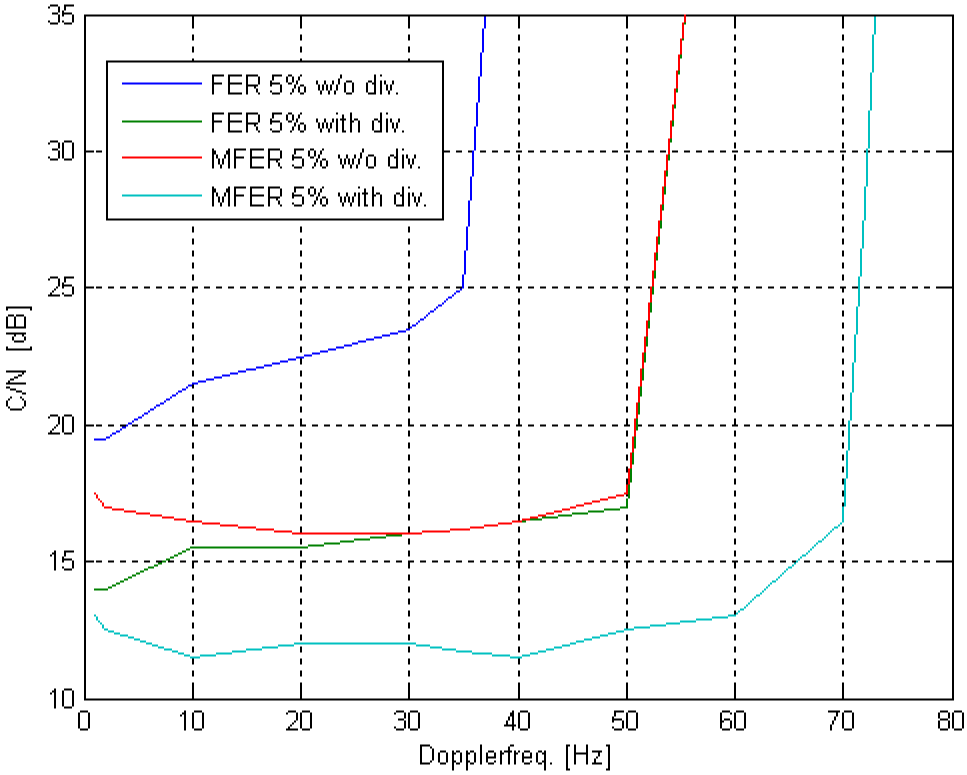
Figure 8.3: Characterisation of a DVB-T/-H receiver in TR 102 401

- FER 5%, Test duration 100 Bursts

Doppler shift	w/o diversity	with diversity
1 Hz	19.5 dB	14.0 dB
2 Hz	19.5 dB	14.0 dB
10 Hz	21.5 dB	15.5 dB
20 Hz	22.5 dB	15.5 dB
fd max (50dB)	40 Hz	60 Hz

- MFER 5%, Test duration 100 Bursts

Doppler shift	w/o diversity	with diversity
1 Hz	17.5 dB	13.0 dB
2 Hz	17.0 dB	12.5 dB
10 Hz	16.5 dB	11.5 dB
20 Hz	16.0 dB	12.0 dB
fd max (50dB)	60 Hz	75 Hz



The tendency in the diagram above can be summarised as follows:

- The usage for MPE FEC increases the tolerable Doppler shift for mobile reception by about 40 %, and reduces the required C/N by about 6 dB.
- The usage of diversity produces an effect in the same order of magnitude: plus 40 % tolerable Doppler shift and minus 6 dB required C/N.
- In the first case the price is paid by a reduction of the usable bit rate, in the second case the effort is paid for in hardware and software.
- The combination of both strategies accumulates both gains.
- For very low Doppler shifts the gain in C/N is reduced. It remains to be investigated if this effect occurs in a similar way when a new profile for outdoor/ indoor reception at pedestrian speed is used. Such a profile is still under development. First results point to the conclusion that TU6 is less applicable in such circumstances.

This is in line with the findings of the DVB-H VTF report. It confirms that the RF front-end represents the state-of-the-art. It also confirms some basic assumptions for the planning of DVB-H networks in comparison with planning for DVB-T networks.

Chapter 9 Conclusions

In this document by means of simulations and measurements, network engineering rules have been defined that will enable a more efficient use of broadcast spectrum by contributing to the definition of protection ratio and frequency allocation management.

Co-working of 2G/3G/4G telecom networks and broadcast networks on the same site has been addressed to cut down on roll out expenses of future services and networks. From the present state-of-the-art planning processes and regulatory aspects, the following have been addressed:

- Description of the spectrum use for analogue TV,
- Description of the theoretical DVB-T network dimensioning
- Description of frequency planning in the real world and during the simulcast period
- Possible scenarios for analogue networks switch off
- Densification of networks that are not dedicated to reception in mobility
- Identification of rules for “cellularized” DVB-T/H planning (ERP, Reuse pattern, etc.)
- Related spectrum demands
- Coverage comparison in defined scenarios

Finally, the potential impact of diversity receivers on spectrum planning is briefly discussed at the end of this chapter.

In overview the main conclusions drawn from this document chapter by chapter are as follows:

In chapter 2 it was shown that it is not clear that spectrum will be available for DVB-H services in all the countries of the European Union after the analogue switch-off. In the context of what follows this means that in the planning of DVB-H networks particular attention must be paid to using spectrum efficiently. On a more positive note, in Brazil an important example of an emerging economy adopting digital TV where there is not anticipated to be any shortage of spectrum for DVB-H.

In chapter 3 the cell ranges for different DVB-T/-H reception modes were given for different transmitter heights / powers and for rural as well as for urban environments. It was shown that large SFNs where the size of the whole network is large in comparison to the guard interval are possible without severe self-interference. For multi-frequency networks (MFN) based on a hexagonal cell layout different C/I (carrier-to-interference) estimates were given for the use of omnidirectional transmit antennas. C/I values for different transmitter heights and cluster sizes were given for different cell radii and propagation environments at the terminal. As the most effective means of lowering the cluster size and thus obtaining the lowest number of frequencies required to deliver full area coverage, the illumination of MFN cells by SFNs consisting of three 120° sectorized transmitters was considered. Compared with the use of omnidirectional antennas in the cell centre there is no need for additional transmitter locations, but the cluster size can be reduced significantly at the expense of two additional transmitters and antennas at each transmitter site.

A positive SFN Gain under same parameter configuration means that the SFN network is effective for such a configuration; it can cover a bigger area compared with using the same number of MFN transmitters with no frequency reuse. In chapter 4 it was shown that SFN gain can be substantial: from 20% in a worst case scenario, to 70% in the case of optimised site location, ERP and heights, for three transmitters. SFN gain is even larger when small sites are deployed: little ERP on a large number of sites will increase the SFN gain. Although the SFN gain can be quite impressive in the case of a large number of sites, with values over 100% in the case of 10+ sites, the cost of deployment must be taken into account, and it was anticipated that the cost of the site multiplication would not be compensated for by the SFN gain. Following on from this in Chapter 5 using the TDF proprietary radio planning tool and a TDF proprietary cost function based on CAPEX it was shown that while the SFN gain can be quite important in the case of a large number of sites, the cost of the site multiplication is not compensated for by the SFN gain.

Chapter 6 presented cositing issues between the DVB-H system and radiocom services (GSM900, GSM1800, and UMTS). The main topic was Electro-Magnetic Compatibility (EMC) between radio systems. The isolation required between systems, to maintain an acceptable Quality of Service (QoS) was derived from radio equipment specifications and possible cositing architectures were proposed in terms of antenna spacing.

Chapter 7 described an approach to studying coverage planning and dimensioning in DVB-H. The planning of network coverage is currently divided into two steps, the first one is the physical layer simulation which models the receiver sensitivity with different physical layer parameters under different kinds of channels and produces a table of SNR values for different parameter combinations; the second step is the coverage planning process using the SNR values produced in step one to simulate the coverage ratio for different network topologies and network level parameters. Chapter 7 mainly addressed the latter step showing that the proposed approach can potentially deliver significant insights into the planning process.

Chapter 8 reported the results of a number of tests carried out in accordance with the test methodology described in the DVB-H Validation Task Force final report [ETSI TR 102 401 v1.1.1 (2005-06)]. The results confirm some basic assumptions for the planning of DVB-H networks in comparison with planning for DVB-T networks.

It has to be emphasised that this deliverable represents only a first step in developing a systematic approach to the planning of DVB-H networks. Not only do many of the results reported need to be developed further new issues will emerge as DVB-H matures. For example, it is probable that diversity will have to be taken into account in the planning of DVB-H networks in the longer term, as diversity has already to be taken into consideration for DVB-T networks. At the moment, the commercial importance of diversity DVB-T receivers for mobile reception is for the scenarios of in the car and indoor portable reception. This aspect of mobile reception was taken into consideration for the network planning in Germany. To allow mobile reception in the car, with diversity, in Germany, an 8k, 16 QAM network was set up. If diversity receivers for DVB-H were widely available DVB-H network planning for indoor portable reception could allow an interesting trade off between coverage (e.g. 90% of people in a given area with one antenna receivers) and additional expenses for diversity receivers (extra costs of about 50 Euro? per receiver) to extend the coverage to e.g. 95% of the people (i.e. only 5% of the people would have to buy the more expensive receiver). However, at the moment, diversity is not a serious option for DVB-H network planning.

Appendices

A1. Frequency allocation in Germany [26]

The following table lists the frequency allocation in the VHF to UHF band in Germany, for details of the frequency allocation in other bands, please refer to [26].

Table A1: Frequency allocation between 40MHz – 900MHz in Germany

FREQUENCY BAND	ALLOCATIONS	APPLICATIONS
39.85 - 41.0 MHz	MOBILE Fixed	Defence systems Point-to-Multipoint Model control (40.66 - 40.7 MHz) Non-specific SRDs (40.66 - 40.7 MHz) On-site paging (40.66 - 40.7 MHz) Short Range Devices (40.66 - 40.7 MHz) Telemetry (civil) (40.66 - 40.7 MHz) Model control (40.71 - 40.74 MHz) Model control (40.76 - 40.79 MHz) Model control (40.81 - 40.84 MHz) Model control (40.86 - 40.89 MHz) Model control (40.91 - 40.94 MHz) Model control (40.96 - 40.99 MHz)
41.0 - 46.0 MHz	MOBILE Fixed	Defence systems (41.0 - 47.0 MHz) Fixed links (41.0 - 47.0 MHz)
46.0 - 47.0 MHz	MOBILE Fixed Radiolocation	Defence systems (41.0 - 47.0 MHz) Fixed links (41.0 - 47.0 MHz) Wind profilers
47.0 - 50.08 MHz	BROADCASTING LAND MOBILE Radiolocation	TV analogue (terrestrial) (47.0 - 68.0 MHz) Tactical mobile (47.0 - 68.0 MHz) Wind profilers (47.0 - 68.0 MHz)
50.08 - 51.0 MHz	BROADCASTING LAND MOBILE Amateur Radiolocation	TV analogue (terrestrial) (47.0 - 68.0 MHz) Tactical mobile (47.0 - 68.0 MHz) Wind profilers (47.0 - 68.0 MHz) Amateur
51.0 - 68.0 MHz	BROADCASTING LAND MOBILE Radiolocation	TV analogue (terrestrial) (47.0 - 68.0 MHz) Tactical mobile (47.0 - 68.0 MHz) Wind profilers (47.0 - 68.0 MHz)
68.0 - 70.0 MHz	LAND MOBILE	PMR/PAMR (68.0 - 68.04 MHz) PMR/PAMR (68.08 - 68.62 MHz) Railway applications (68.62 - 69.56 MHz) PMR/PAMR (69.56 - 69.92 MHz) PMR/PAMR (69.94 - 69.98 MHz)
70.0 - 74.2 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Tactical mobile Railway applications (70.04 - 70.9 MHz) PMR/PAMR (70.2 - 70.22 MHz) PMR/PAMR (70.42 - 70.44 MHz) PMR/PAMR (71.0 - 71.7 MHz) PMR/PAMR (72.34 - 72.76 MHz)
74.2 - 74.8 MHz	LAND MOBILE	Emergency services (74.205 - 74.785 MHz)
74.8 - 75.2 MHz	AERONAUTICAL RADIONAVIGATION	ILS
75.2 - 77.8 MHz	LAND MOBILE	Emergency services (75.205 - 77.465 MHz) SAP/SAB and ENG/OB (77.5 - 77.8 MHz)

77.8 - 84.0 MHz	MOBILE except aeronautical mobile Fixed	PMR/PAMR (77.88 - 78.42 MHz) Railway applications (78.42 - 78.7 MHz) Tactical mobile (78.7 - 84.0 MHz) Railway applications (80.04 - 80.9 MHz) PMR/PAMR (81.0 - 81.7 MHz) PMR/PAMR (82.34 - 82.76 MHz)
84.0 - 87.5 MHz	LAND MOBILE	Emergency services (84.005 - 84.585 MHz) Emergency services (84.585 - 85.005 MHz) Emergency services (85.005 - 85.265 MHz) SAP/SAB and ENG/OB (87.275 - 87.5 MHz)
87.5 - 108.0 MHz	BROADCASTING	FM sound analogue Point-to-Multipoint
108.0 - 117.975 MHz	AERONAUTICAL RADIONAVIGATION	ILS (108.0 - 111.975 MHz) VOR (111.975 - 117.975 MHz)
117.975 - 136.0 MHz	AERONAUTICAL MOBILE (R) Aeronautical Mobile-Satellite (R)	Aeronautical communications (117.975 - 137.0 MHz) Aeronautical satcoms (117.975 - 137.0 MHz) Space Operations (117.975 - 137.0 MHz) Space research (117.975 - 137.0 MHz) EPIRBs (121.45 - 121.55 MHz) SAR (communications) (123.05 - 123.15 MHz)
136.0 - 137.0 MHz	AERONAUTICAL MOBILE (R) Aeronautical Mobile-Satellite (R) Meteorological-Satellite (space-to-Earth)	Aeronautical communications (117.975 - 137.0 MHz) Aeronautical satcoms (117.975 - 137.0 MHz) Space Operations (117.975 - 137.0 MHz) Space research (117.975 - 137.0 MHz) Weather satellites
137.0 - 137.025 MHz	METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) SPACE OPERATION (space-to-Earth) SPACE RESEARCH (space-to-Earth) Mobile except aeronautical mobile (R)	Defence systems S-PCS Space Operations Space research Weather satellites
137.025 - 137.175 MHz	METEOROLOGICAL-SATELLITE (space-to-Earth) SPACE OPERATION (space-to-Earth) SPACE RESEARCH (space-to-Earth) Mobile except aeronautical mobile (R) Mobile-Satellite (space-to-Earth)	Defence systems S-PCS Space Operations Space research Weather satellites
137.175 - 137.825 MHz	METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) SPACE OPERATION (space-to-Earth) SPACE RESEARCH (space-to-Earth) Mobile except aeronautical mobile (R)	Space Operations (137.175 - 137.275 MHz) AGA communications (military) S-PCS Space research Weather satellites
137.825 - 138.0 MHz	METEOROLOGICAL-SATELLITE (space-to-Earth) SPACE OPERATION (space-to-Earth) SPACE RESEARCH (space-to-Earth) Mobile except aeronautical mobile (R) Mobile-Satellite (space-to-Earth)	Defence systems S-PCS Space Operations Space research Weather satellites
138.0 - 144.0 MHz	AERONAUTICAL MOBILE (OR) LAND MOBILE	AGA communications (military) Land mobile Tactical mobile

144.0 - 146.0 MHz	AMATEUR AMATEUR-SATELLITE	Amateur Amateur-satellite
146.0 - 148.0 MHz	LAND MOBILE	PMR/PAMR (146.0 - 146.36 MHz) Railway applications (146.36 - 146.92 MHz) PMR/PAMR (146.92 - 148.0 MHz)
148.0 - 149.9 MHz	MOBILE except aeronautical mobile (R) SPACE OPERATION (Earth-to-space) Mobile-Satellite (Earth-to-space)	PMR/PAMR (148.0 - 148.4 MHz) S-PCS Space Operations PMR/PAMR (148.4 - 149.01 MHz) Telemetry (civil) (149.01875 - 149.03125 MHz) PMR/PAMR (149.01875 - 149.05625 MHz) PMR/PAMR (149.06 - 149.14 MHz) PMR/PAMR (149.14 - 149.88 MHz) On-site paging (149.88 - 149.9 MHz)
149.9 - 150.05 MHz	MOBILE-SATELLITE (Earth-to-space) RADIONAVIGATION-SATELLITE	S-PCS Satellite navigation systems
150.05 - 156.7625 MHz	MOBILE except aeronautical mobile	PMR/PAMR (150.24 - 150.54 MHz) PMR/PAMR (150.56 - 151.06 MHz) Radio Microphones (150.98 - 151.06 MHz) On-site paging (151.06 - 151.08 MHz) Telemetry (civil) (151.08 - 151.1 MHz) Radio Microphones (151.1 - 151.16 MHz) PMR/PAMR (151.1 - 151.72 MHz) PMR/PAMR (151.9 - 152.02 MHz) PMR/PAMR (152.04 - 152.1 MHz) PMR/PAMR (152.28 - 152.76 MHz) PMR/PAMR (152.78 - 153.0 MHz) PMR/PAMR (153.0 - 153.74 MHz) PMR/PAMR (153.74 - 155.96 MHz) GMDSS (156.0 - 156.7625 MHz) Maritime communications (156.0 - 156.7625 MHz) PMR/PAMR (156.015 - 156.035 MHz)
156.7625 - 156.8375 MHz	MARITIME MOBILE (distress and calling)	Maritime communications GMDSS (156.795 - 156.805 MHz)
156.8375 - 174.0 MHz	MOBILE except aeronautical mobile	
174.0 - 223.0 MHz	BROADCASTING	Radio Microphones T-DAB TV analogue (terrestrial)
223.0 - 230.0 MHz	BROADCASTING Fixed Mobile	Radio Microphones T-DAB TV analogue (terrestrial)
230.0 - 235.0 MHz	MOBILE Fixed	AGA communications (military) Tactical radio relay
235.0 - 272.0 MHz	MOBILE Fixed	AGA communications (military) Tactical radio relay EPIRBs (242.95 - 243.05 MHz) Satellite systems (military) (242.95 - 243.05 MHz)
272.0 - 273.0 MHz	MOBILE SPACE OPERATION (space-to-Earth) Fixed	AGA communications (military) Space Operations Tactical radio relay
273.0 - 312.0 MHz	MOBILE Fixed	AGA communications (military) Tactical radio relay
312.0 - 315.0 MHz	MOBILE Fixed Mobile-Satellite (Earth-to-space)	AGA communications (military) Feeder links Tactical radio relay
315.0 - 322.0 MHz	MOBILE Fixed	AGA communications (military) Tactical radio relay
322.0 - 328.6 MHz	MOBILE	AGA communications (military)

	Fixed Radio Astronomy	Radio astronomy Tactical radio relay
328.6 - 335.4 MHz	AERONAUTICAL RADIONAVIGATION	ILS
335.4 - 387.0 MHz	MOBILE Fixed	AGA communications (military) Tactical radio relay Emergency services (380.0 - 383.0 MHz) ISM (380.0 - 387.0 MHz)
387.0 - 390.0 MHz	MOBILE Fixed Mobile-Satellite (space-to-Earth)	AGA communications (military) MSS Earth stations Tactical radio relay
390.0 - 399.9 MHz	MOBILE Fixed	Emergency services (390.0 - 393.0 MHz) AGA communications (military) Tactical radio relay
399.9 - 400.05 MHz	MOBILE-SATELLITE (Earth-to-space) RADIONAVIGATION-SATELLITE	S-PCS Satellite navigation systems
400.05 - 400.15 MHz	STANDARD FREQUENCY AND TIME SIGNAL-SATELLITE	Standard Frequency and Time Signal-Satellite
400.15 - 401.0 MHz	METEOROLOGICAL-SATELLITE (space-to-Earth) METEOROLOGICAL AIDS MOBILE-SATELLITE (space-to-Earth) SPACE RESEARCH (space-to-Earth) Space Operation (space-to-Earth)	Meteorology S-PCS Space Operations Space research Subscriber access excluding MWS
401.0 - 402.0 MHz	METEOROLOGICAL-SATELLITE (Earth-to-space) METEOROLOGICAL AIDS SPACE OPERATION (space-to-Earth)	Meteorology Space Operations Weather satellites Subscriber access excluding MWS (401.1 - 402.0 MHz)
402.0 - 403.0 MHz	METEOROLOGICAL-SATELLITE (Earth-to-space) METEOROLOGICAL AIDS	Medical implants Weather satellites Telemetry (civil) (402.1 - 403.0 MHz) Sondes (402.2 - 403.0 MHz)
403.0 - 406.0 MHz	METEOROLOGICAL AIDS	Medical implants (403.0 - 405.0 MHz) Sondes Subscriber access excluding MWS (405.15 - 406.0 MHz)
406.0 - 406.1 MHz	MOBILE-SATELLITE (Earth-to-space)	GMDSS
406.1 - 410.0 MHz	LAND MOBILE RADIO ASTRONOMY	Subscriber access excluding MWS (406.1 - 407.0 MHz) PMR/PAMR Radio astronomy
410.0 - 420.0 MHz	LAND MOBILE Fixed	Fixed links (410.0 - 410.8 MHz) PMR/PAMR PMR/PAMR (410.00625 - 415.00625 MHz) Fixed links (415.0 - 415.8 MHz) PMR/PAMR (415.80625 - 416.61875 MHz) PMR/PAMR (416.63125 - 417.36875 MHz) PMR/PAMR (417.38125 - 419.71875 MHz) Railway applications (419.72 - 419.8 MHz) PMR/PAMR (419.80625 - 419.99375 MHz) PMR/PAMR (419.99375 - 420.0 MHz)
420.0 - 430.0 MHz	LAND MOBILE Fixed	PMR/PAMR (420.0 - 420.00625 MHz) Fixed links (420.0 - 420.8 MHz) PMR/PAMR PMR/PAMR (420.00625 - 425.00625 MHz) Fixed links (425.0 - 425.8 MHz) PMR/PAMR (425.80625 - 426.61875 MHz)

		PMR/PAMR (426.63125 - 427.36875 MHz) PMR/PAMR (427.38125 - 429.71875 MHz) PMR/PAMR (429.80625 - 429.99375 MHz)
430.0 - 435.0 MHz	AMATEUR	Amateur (430.0 - 440.0 MHz) Radiolocation (military) (430.0 - 440.0 MHz) Short Range Devices (433.05 - 434.79 MHz) Model control (433.0875 - 434.7625 MHz) Telemetry (civil) (433.0875 - 434.7625 MHz) Non-specific SRDs (433.92 - 434.79 MHz)
435.0 - 438.0 MHz	AMATEUR Amateur-Satellite	Amateur (430.0 - 440.0 MHz) Radiolocation (military) (430.0 - 440.0 MHz) Amateur
438.0 - 440.0 MHz	AMATEUR	Amateur (430.0 - 440.0 MHz) Radiolocation (military) (430.0 - 440.0 MHz)
440.0 - 443.6 MHz	LAND MOBILE	
443.6 - 444.9625 MHz	LAND MOBILE Fixed	
444.9625 - 448.6 MHz	LAND MOBILE	
448.6 - 449.75 MHz	LAND MOBILE Fixed	
449.75 - 449.9625 MHz	LAND MOBILE Fixed Space Operation (Earth-to-space) Space Research (Earth-to-space)	
449.9625 - 450.25 MHz	LAND MOBILE Space Operation (Earth-to-space) Space Research (Earth-to-space)	
450.25 - 470.0 MHz	LAND MOBILE	
470.0 - 494.0 MHz	BROADCASTING Land Mobile Radiolocation	Wind profilers Radio Microphones (470.0 - 608.0 MHz) DVB-T (470.0 - 790.0 MHz) TV analogue (terrestrial) (470.0 - 790.0 MHz) PMR/PAMR (477.0 - 790.0 MHz) Radio Microphones (477.0 - 790.0 MHz)
494.0 - 608.0 MHz	BROADCASTING Land Mobile	Radio Microphones (470.0 - 608.0 MHz) DVB-T (470.0 - 790.0 MHz) TV analogue (terrestrial) (470.0 - 790.0 MHz) PMR/PAMR (477.0 - 790.0 MHz) Radio Microphones (477.0 - 790.0 MHz)
608.0 - 614.0 MHz	BROADCASTING Land Mobile Radio Astronomy	DVB-T (470.0 - 790.0 MHz) TV analogue (terrestrial) (470.0 - 790.0 MHz) PMR/PAMR (477.0 - 790.0 MHz) Radio Microphones (477.0 - 790.0 MHz) Radio astronomy
614.0 - 790.0 MHz	BROADCASTING Land Mobile	DVB-T (470.0 - 790.0 MHz) TV analogue (terrestrial) (470.0 - 790.0 MHz) PMR/PAMR (477.0 - 790.0 MHz) Radio Microphones (477.0 - 790.0

		MHz) Radio Microphones
790.0 - 794.0 MHz	FIXED MOBILE except aeronautical mobile	Tactical radio relay (790.0 - 814.0 MHz)
794.0 - 862.0 MHz	FIXED MOBILE except aeronautical mobile	Tactical radio relay (790.0 - 814.0 MHz) Radio Microphones (798.0 - 814.0 MHz) Subscriber access excluding MWS (812.0 - 818.0 MHz) DVB-T (814.0 - 838.0 MHz) Subscriber access excluding MWS (824.0 - 828.0 MHz) Tactical radio relay (830.0 - 862.0 MHz) Subscriber access excluding MWS (857.0 - 862.0 MHz)
862.0 - 890.0 MHz	FIXED MOBILE except aeronautical mobile	Subscriber access excluding MWS (862.0 - 863.0 MHz) Tactical radio relay (862.0 - 868.0 MHz) Radio Microphones (863.0 - 865.0 MHz) Wireless Audio Applications (863.0 - 865.0 MHz) CT2 (864.1 - 868.1 MHz) Alarms (868.0 - 868.6 MHz) Alarms (868.6 - 868.7 MHz) Alarms (868.7 - 869.2 MHz) Subscriber access excluding MWS (869.0 - 873.0 MHz) Alarms (869.2 - 869.25 MHz) Alarms (869.25 - 869.3 MHz) Alarms (869.4 - 869.65 MHz) Alarms (869.65 - 869.7 MHz) Alarms (869.7 - 870.0 MHz) Land mobile (870.0 - 876.0 MHz) GSM-R (876.0 - 880.0 MHz) Tactical radio relay (880.0 - 885.0 MHz) CT1+ (885.0 - 887.0 MHz) Tactical radio relay (887.0 - 890.0 MHz)
890.0 - 960.0 MHz	FIXED MOBILE except aeronautical mobile	GSM (890.1 - 914.9 MHz) Land mobile (915.0 - 921.0 MHz) GSM-R (921.0 - 925.0 MHz) Tactical radio relay (925.0 - 930.0 MHz) CT1+ (930.0 - 932.0 MHz) Tactical radio relay (932.0 - 935.0 MHz) GSM (935.1 - 959.9 MHz)

A2. Frequency allocation in France [26]:

The following table lists the frequency allocation in the VHF to UHF band in France, for details of the frequency allocation in other bands, Please refer to [26].

Table A2: Frequency allocation between 40MHz – 900MHz in France [26]

FREQUENCY BAND	ALLOCATIONS	APPLICATIONS
39.4 - 40.65 MHz	FIXED MOBILE SPACE RESEARCH (active)	Defence systems PMR/PAMR
40.65 - 41.0 MHz	FIXED MOBILE SPACE RESEARCH (active)	Defence systems Short Range Devices
41.0 - 41.5 MHz	FIXED MOBILE	Cordless telephones Fixed links PMR/PAMR
41.5 - 47.0 MHz	FIXED MOBILE	Defence systems
47.0 - 68.0 MHz	BROADCASTING	TV analogue (terrestrial)
68.0 - 68.4625 MHz	FIXED MOBILE except aeronautical mobile	Defence systems PMR/PAMR
68.4625 - 69.25 MHz	FIXED MOBILE except aeronautical mobile	Fixed links PMR/PAMR
69.25 - 70.25 MHz	FIXED MOBILE except aeronautical mobile	Defence systems
70.25 - 70.525 MHz	FIXED MOBILE except aeronautical mobile	Fixed links PMR/PAMR
70.525 - 70.975 MHz	FIXED MOBILE except aeronautical mobile	Defence systems PMR/PAMR
70.975 - 71.95 MHz	FIXED MOBILE except aeronautical mobile	Fixed links PMR/PAMR
71.95 - 72.175 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Fixed links
72.175 - 72.5125 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Model control
72.5125 - 73.3 MHz	FIXED MOBILE except aeronautical mobile	Fixed links PMR/PAMR
73.3 - 74.8 MHz	FIXED MOBILE except aeronautical mobile	Defence systems
74.8 - 75.2 MHz	AERONAUTICAL RADIONAVIGATION	ILS
75.2 - 75.4 MHz	FIXED MOBILE except aeronautical mobile	Fixed links PMR/PAMR
77.475 - 80.0 MHz	FIXED MOBILE except aeronautical mobile	Defence systems
80.0 - 82.475 MHz	FIXED MOBILE except aeronautical mobile	Fixed links PMR/PAMR
82.475 - 83.0 MHz	FIXED MOBILE except aeronautical mobile	Defence systems
83.0 - 87.3 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Fixed links
87.3 - 87.5 MHz	FIXED MOBILE except aeronautical mobile	Fixed links Paging
87.5 - 108.0 MHz	BROADCASTING	FM sound analogue
108.0 - 117.975 MHz	AERONAUTICAL RADIONAVIGATION	VOR
117.975 - 136.0 MHz	AERONAUTICAL MOBILE (R)	Aeronautical communications
136.0 - 137.0 MHz	AERONAUTICAL MOBILE (R) SPACE RESEARCH (space-to-Earth)	Aeronautical communications
137.0 - 138.0 MHz	AERONAUTICAL MOBILE (OR)	Defence systems

	METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE-SATELLITE (space-to-Earth) SPACE OPERATION SPACE RESEARCH (space-to-Earth)	Satellite systems (civil) Space Operations Space research Weather satellites
138.0 - 144.0 MHz	AERONAUTICAL MOBILE (OR) SPACE RESEARCH (space-to-Earth)	Defence systems
144.0 - 146.0 MHz	AMATEUR AMATEUR-SATELLITE	Amateur Amateur-satellite
146.0 - 148.0 MHz	FIXED MOBILE except aeronautical mobile (R)	Defence systems
148.0 - 148.825 MHz	FIXED MOBILE except aeronautical mobile (R) MOBILE-SATELLITE (Earth-to-space) SPACE OPERATION	Defence systems Satellite systems (civil) Space Operations
148.825 - 149.9 MHz	FIXED MOBILE except aeronautical mobile (R) MOBILE-SATELLITE (Earth-to-space) SPACE OPERATION	Fixed links Satellite systems (civil) Space Operations
149.9 - 150.05 MHz	MOBILE-SATELLITE (Earth-to-space) RADIONAVIGATION-SATELLITE SPACE RESEARCH (space-to-Earth)	Defence systems Satellite systems (civil) Space research
150.05 - 150.4 MHz	FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY	Fixed links Land mobile Radio astronomy
150.4 - 151.4 MHz	FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY	Fixed links PMR/PAMR Radio astronomy
151.4 - 153.0 MHz	FIXED MOBILE except aeronautical mobile RADIO ASTRONOMY	Defence systems Maritime military systems Radio astronomy
153.0 - 153.425 MHz	FIXED METEOROLOGICAL AIDS MOBILE except aeronautical mobile (R)	Defence systems
153.425 - 154.0 MHz	FIXED METEOROLOGICAL AIDS MOBILE except aeronautical mobile (R)	Fixed links PMR/PAMR
154.0 - 156.0 MHz	FIXED MOBILE except aeronautical mobile (R)	Defence systems Fixed links Maritime communications PMR/PAMR
156.0 - 156.7625 MHz	FIXED MOBILE except aeronautical mobile (R)	Defence systems EPIRBs
156.7625 - 156.8375 MHz	MARITIME MOBILE	Maritime communications
156.8375 - 157.45 MHz	FIXED MOBILE except aeronautical mobile	Defence systems PMR/PAMR
157.45 - 160.6 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Maritime communications PMR/PAMR
160.6 - 160.975 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Maritime communications PMR/PAMR
160.975 - 161.475 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Maritime communications PMR/PAMR
161.475 - 162.05 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Maritime communications PMR/PAMR
162.05 - 163.0 MHz	FIXED MOBILE except aeronautical mobile	Defence systems Maritime communications PMR/PAMR
163.0 - 168.9 MHz	FIXED MOBILE except aeronautical mobile	Fixed links PMR/PAMR

168.9 - 169.4 MHz	FIXED MOBILE except aeronautical mobile	Defence systems ERMES PMR/PAMR
169.4 - 173.5 MHz	FIXED MOBILE except aeronautical mobile	Defence systems ERMES PMR/PAMR
173.5 - 174.0 MHz	FIXED MOBILE except aeronautical mobile	Defence systems
174.0 - 223.0 MHz	BROADCASTING LAND MOBILE	Broadcasting Land mobile
223.0 - 225.0 MHz	LAND MOBILE	Defence systems Short Range Devices
225.0 - 235.0 MHz	FIXED MOBILE	Defence systems
235.0 - 272.0 MHz	FIXED MOBILE MOBILE-SATELLITE	Defence systems Satellite systems (military)
272.0 - 273.0 MHz	FIXED MOBILE MOBILE-SATELLITE SPACE OPERATION	Defence systems Satellite systems (military)
273.0 - 322.0 MHz	FIXED MOBILE MOBILE-SATELLITE	Defence systems Satellite systems (military)
322.0 - 326.0 MHz	FIXED MOBILE	Defence systems
326.0 - 328.0 MHz	FIXED MOBILE RADIO ASTRONOMY	Defence systems Radio astronomy
328.0 - 328.6 MHz	FIXED MOBILE	Defence systems
328.6 - 335.4 MHz	AERONAUTICAL RADIONAVIGATION MOBILE	ILS
335.4 - 380.0 MHz	FIXED MOBILE MOBILE-SATELLITE	Defence systems Satellite systems (military)
380.0 - 383.5 MHz	MOBILE	Defence systems
383.5 - 390.0 MHz	FIXED MOBILE MOBILE-SATELLITE	Defence systems
390.0 - 393.5 MHz	MOBILE	Defence systems
393.5 - 399.9 MHz	FIXED MOBILE MOBILE-SATELLITE	Defence systems Satellite systems (military)
399.9 - 400.05 MHz	MOBILE-SATELLITE (Earth-to-space) RADIONAVIGATION-SATELLITE	Satellite systems (civil) Satellite systems (military)
400.05 - 400.15 MHz	STANDARD FREQUENCY AND TIME SIGNAL-SATELLITE	Standard Frequency and Time Signal
400.15 - 401.0 MHz	METEOROLOGICAL-SATELLITE (space-to-Earth) METEOROLOGICAL AIDS MOBILE-SATELLITE (space-to-Earth) SPACE OPERATION SPACE RESEARCH (space-to-Earth)	Meteorology Satellite systems (civil) Space research Weather satellites
401.0 - 402.0 MHz	EARTH EXPLORATION-SATELLITE (Earth-to-space) METEOROLOGICAL-SATELLITE (Earth-to-space) METEOROLOGICAL AIDS SPACE OPERATION	Earth exploration-satellite Meteorology Space Operations Weather satellites
402.0 - 403.0 MHz	EARTH EXPLORATION-SATELLITE (Earth-to-space) METEOROLOGICAL-SATELLITE (Earth-to-space)	Earth exploration-satellite Sondes Weather satellites

	METEOROLOGICAL AIDS	
403.0 - 406.0 MHz	METEOROLOGICAL AIDS	Sondes
406.0 - 406.1 MHz	MOBILE-SATELLITE (Earth-to-space)	EPIRBs
406.1 - 408.0 MHz	MOBILE except aeronautical mobile RADIO ASTRONOMY	PMR/PAMR Radio astronomy
408.0 - 410.0 MHz	MOBILE except aeronautical mobile RADIO ASTRONOMY	Defence systems Radio astronomy
410.0 - 414.5 MHz	FIXED MOBILE except aeronautical mobile SPACE RESEARCH (space-to-space)	Defence systems Space research
414.5 - 420.0 MHz	MOBILE except aeronautical mobile SPACE RESEARCH (space-to-space)	Defence systems PMR/PAMR
420.0 - 424.5 MHz	FIXED MOBILE except aeronautical mobile RADIOLOCATION	Defence systems
424.5 - 430.0 MHz	FIXED MOBILE except aeronautical mobile RADIOLOCATION	Fixed links PMR/PAMR
430.0 - 432.0 MHz	AMATEUR FIXED MOBILE except aeronautical mobile RADIOLOCATION	Radiolocation (military)
432.0 - 434.0 MHz	AMATEUR EARTH EXPLORATION-SATELLITE FIXED MOBILE except aeronautical mobile RADIOLOCATION SPACE OPERATION	Radiolocation (military)
434.0 - 435.0 MHz	AMATEUR EARTH EXPLORATION-SATELLITE RADIOLOCATION SPACE OPERATION	Amateur Radiolocation (military)
435.0 - 438.0 MHz	AMATEUR AMATEUR-SATELLITE (Earth-to-space) EARTH EXPLORATION-SATELLITE RADIOLOCATION	Amateur Radiolocation (military)
438.0 - 440.0 MHz	AMATEUR RADIOLOCATION	Amateur Radiolocation (military)
440.0 - 441.5 MHz	FIXED MOBILE except aeronautical mobile RADIOLOCATION	Defence systems
441.5 - 443.55 MHz	MOBILE except aeronautical mobile RADIOLOCATION	Defence systems
443.55 - 444.5 MHz	FIXED MOBILE except aeronautical mobile RADIOLOCATION	Defence systems
444.5 - 447.0 MHz	MOBILE except aeronautical mobile RADIOLOCATION	PMR/PAMR
447.0 - 449.775 MHz	FIXED MOBILE except aeronautical mobile RADIOLOCATION SPACE OPERATION SPACE RESEARCH (Earth-to-space)	Defence systems Satellite systems (military)
449.775 - 450.025 MHz	SPACE OPERATION SPACE RESEARCH (Earth-to-space)	Space Operations Space research
450.025 - 451.5 MHz	FIXED MOBILE SPACE OPERATION SPACE RESEARCH (Earth-to-space)	Defence systems
451.5 - 454.5 MHz	MOBILE	PMR/PAMR
454.5 - 456.0 MHz	FIXED MOBILE	Defence systems
456.0 - 460.0 MHz	MOBILE	PMR/PAMR

460.0 - 463.55 MHz	EARTH EXPLORATION-SATELLITE (space-to-Earth) FIXED METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE	Defence systems
463.55 - 464.5 MHz	FIXED MOBILE	Fixed links PMR/PAMR
464.5 - 466.0 MHz	EARTH EXPLORATION-SATELLITE (space-to-Earth) FIXED METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE	Defence systems Fixed links
466.0 - 470.0 MHz	EARTH EXPLORATION-SATELLITE (space-to-Earth) METEOROLOGICAL-SATELLITE (space-to-Earth) MOBILE	PMR/PAMR
470.0 - 790.0 MHz	BROADCASTING LAND MOBILE	TV analogue (terrestrial)
790.0 - 830.0 MHz	BROADCASTING LAND MOBILE	TV analogue (terrestrial)
830.0 - 854.0 MHz	MOBILE except aeronautical mobile	Defence systems
854.0 - 862.0 MHz	MOBILE except aeronautical mobile	Defence systems
862.0 - 869.2 MHz	MOBILE except aeronautical mobile	Defence systems
869.2 - 869.7 MHz	MOBILE except aeronautical mobile	Alarms
869.7 - 880.0 MHz	MOBILE except aeronautical mobile	Defence systems
880.0 - 890.0 MHz	MOBILE except aeronautical mobile	GSM
890.0 - 915.0 MHz	MOBILE except aeronautical mobile	GSM

A3: k-LNM method from [1]

Mathematical treatment for combining multiple field strengths

A.5.3.1.1 *k*-LNM method

A value of 0.6 is used for k, and this can be expected to provide an accuracy within a few dB over 70% to 99% of location range.

Suppose there are given n logarithmic fields, F_i, with Gaussian distribution (parameters $\overline{F_i}$, $\sigma_i, i=1...n$), i.e. the corresponding powers are log-normally distributed.

The task is to determine the approximate log-normal distribution of the power sum, or, equivalently, to find the parameters of the Gaussian distribution of the corresponding logarithmic sum field:

Step 1: Transform $\overline{F_i}, \sigma_i, i=1...n$, from dB scale to Neper scale:

$$X_{Neper} = \frac{1}{10\log_{10}(\mathrm{e})} \cdot X_{\mathrm{dB}}$$

Step 2: Evaluate the mean values, M_i, and the variances, S_i^2, of the n power distributions:

$$M_i = \mathrm{e}^{\overline{F_i}+\frac{\sigma_i^2}{2}}, \quad S_i^2 = \mathrm{e}^{2\overline{F_i}+\sigma_i^2} \cdot \left(\mathrm{e}^{\sigma_i^2} - 1\right), \quad i=1...n \qquad \text{(Neper scale)}$$

Step 3: Determine mean value, M, and variance, S^2, of the sum power distribution:

$$M = \sum_{i=1}^{n} M_i, \quad S^2 = \sum_{i=1}^{n} S_i^2 \qquad \text{(Neper scale)}$$

Step 4: Determine the distribution parameters $\overline{F_\Sigma}$ and σ_Σ of the approximate log-normal sum distribution:

$$\sigma_\Sigma^2 = \log_\mathrm{e}\left(k\frac{S^2}{M^2} + 1\right), \quad \overline{F}_\Sigma = \log_\mathrm{e}(M) - \frac{\sigma_\Sigma^2}{2} \qquad \text{(Neper scale)}$$

Step 5: Transform $\overline{F_\Sigma}$ and σ_Σ from Neper scale to dB scale:

$$X_{\mathrm{dB}} = 10\log_{10}(\mathrm{e}) \cdot X_{Neper}$$

$\overline{F_\Sigma}$ and σ_Σ are the mean value and the standard deviation, respectively, of the approximate log-normal distribution of the true sum field.

A4. Simulation Model Validation

To enable verification of the validity of the simulation model of chapter 4, below some numerical applications of the formulas implemented in the software used for the simulations are given.

```
 *** Testing models ***
Hokura Hata 1kw/200m/2km/666MHz : 73.07843425806851

Power Sum of field Strength : 70.0dBuV/m +76.02dBuV/m
=76.9892201193662 dBuV/m

Log Normal addition of field Strength :
3x 80.0 dBuV/m, std =8.1 dB,
= 87.02178630125738 dBuV/m std = 6.779442843412486 dBuV/m

Log Normal addition of field Strength :
70.0 dBuV/m +76.02 dBuV/m, std= 8.1 dB,
= 77.78999091176283 dBuV/m std = 7.64951600148
```

A5. Site Configurations

Configuration 1: H_{Tx} = 150 m, ERP = 5 kW, 3 sites

Fictitious site	Latitude	Longitude
Site 0	598 000	2 430 558
Site 1	604 000	2 430 558
Site 2	601 000	2 425 192

Table A4.1: Site coordinates

Configuration 2: H_{Tx} = 75 m, ERP = 400 W, 10 sites

Fictitious site	Latitude	Longitude
Site0	598 000	2 430 558
Site1	599 000	2 430 558
Site2	600 000	2 430 558
Site3	601 000	2 430 558
Site4	598 500	2 429 680
Site5	599 500	2 429 680
Site6	600 500	2 429 680
Site7	599 000	2 428 803
Site8	600 000	2 428 803
Site9	599 500	2 427 925

Table A4.2: Site coordinates

Configuration 3: H_{Tx} = 50 m, ERP = 100 W, 15 sites

Fictitious site	Latitude	Longitude
Site0	598 000	2 430 558
Site1	598 400	2 430 558
Site2	598 800	2 430 558
Site3	599 200	2 430 558
Site4	598 200	2 430 200
Site5	598 600	2 430 200
Site6	599 000	2 430 200
Site7	598 400	2 429 842
Site8	598 800	2 429 842
Site9	598 600	2 429 484
Site10	599 600	2 430 558
Site11	599 400	2 430 200
Site12	599 200	2 429 842
Site13	599 000	2 429 484
Site14	598 800	2 429 126

Table A4.3: Site coordinates

A6. The optimal radius for one single cell

The following figures are drawn using the contour line representation and based on the simulation results.

The figures below give the optimal radius for one single cell that is the basis of the SFN comparison.

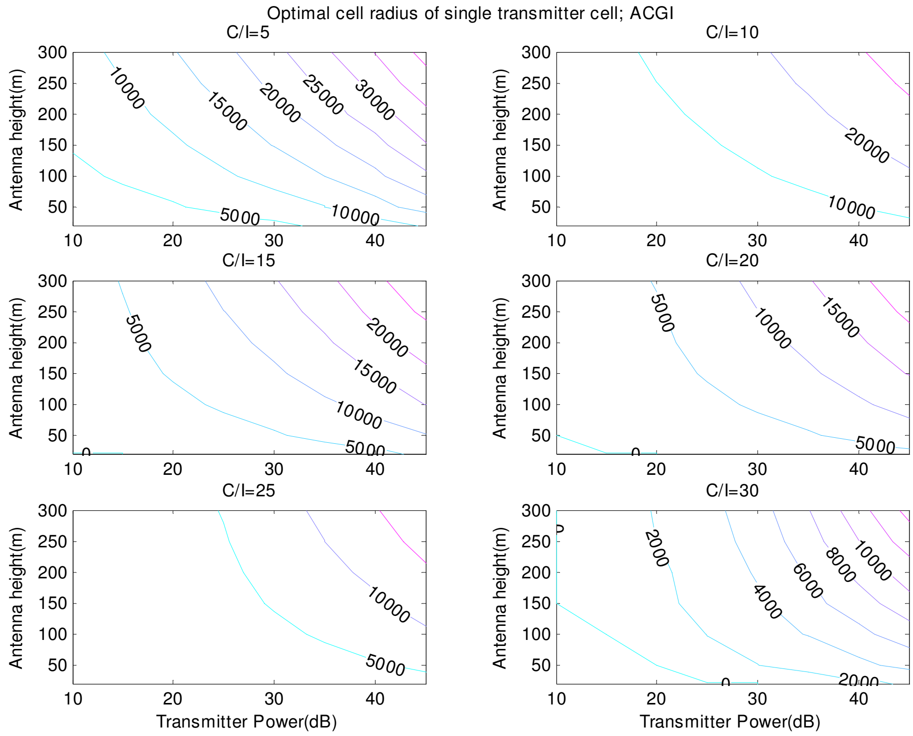


Figure A6-1. The optimal cell radius of a single transmitter cell; ACG I coverage

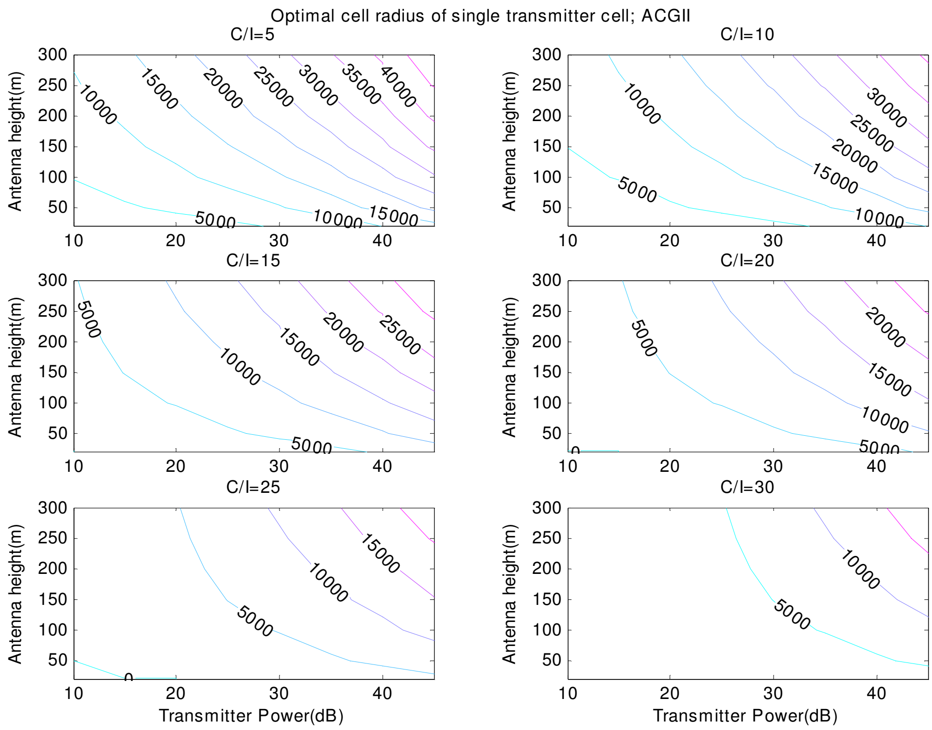


Figure A6-2. The optimal cell radius of a single transmitter cell; ACG II coverage

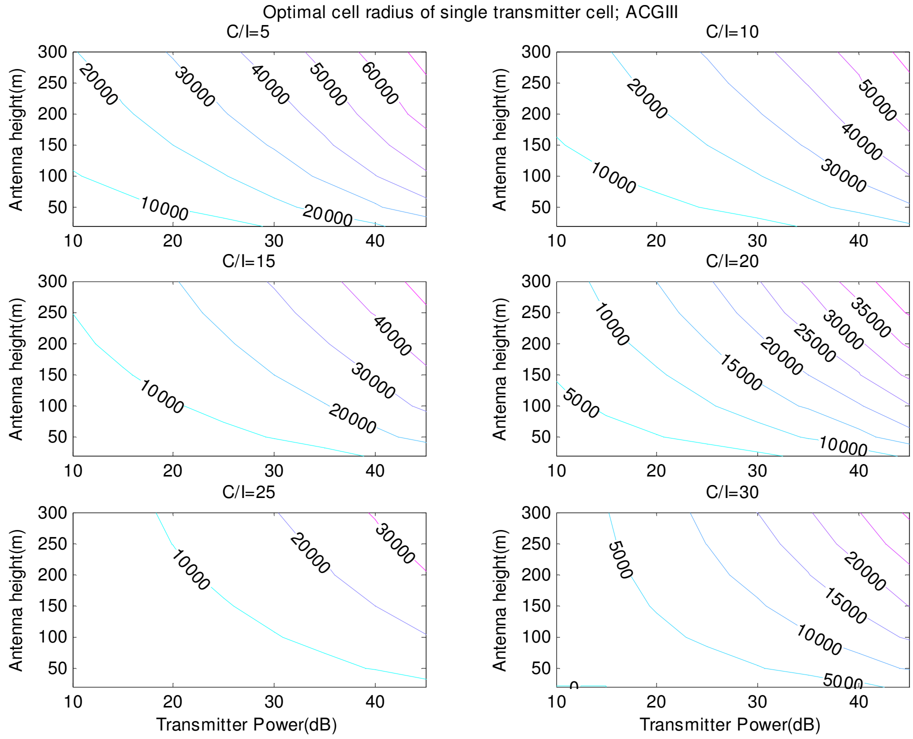


Figure A6-3. The optimal cell radius of a single transmitter cell; ACG III coverage

A7. The SFN optimal cell radius with the guard interval=1/32 and without frequency reuse

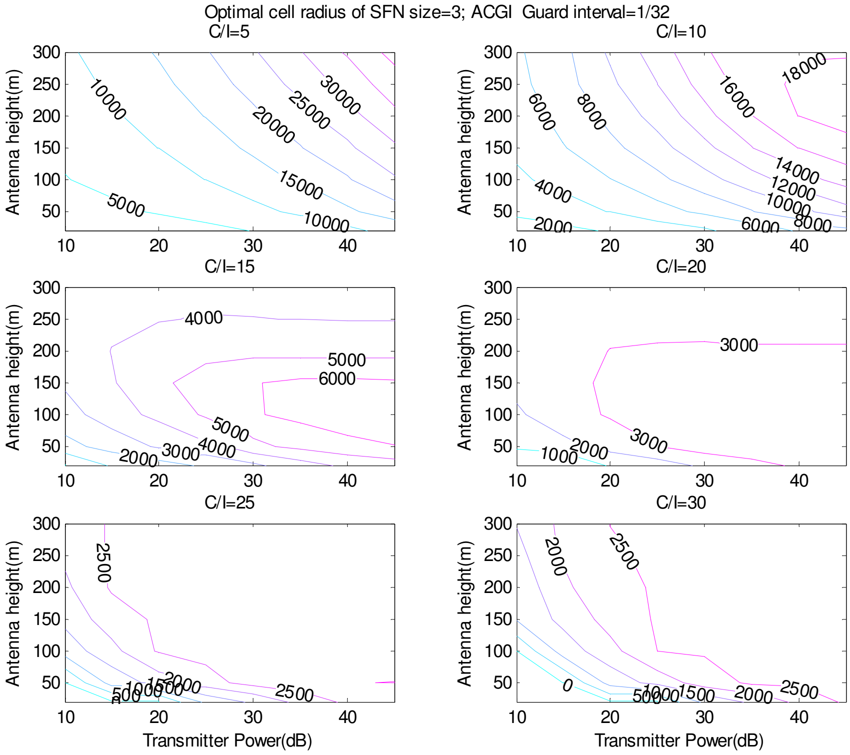


Figure A7-1. The optimal cell radius with the guard interval=1/32 of SFN size=3; ACG I coverage

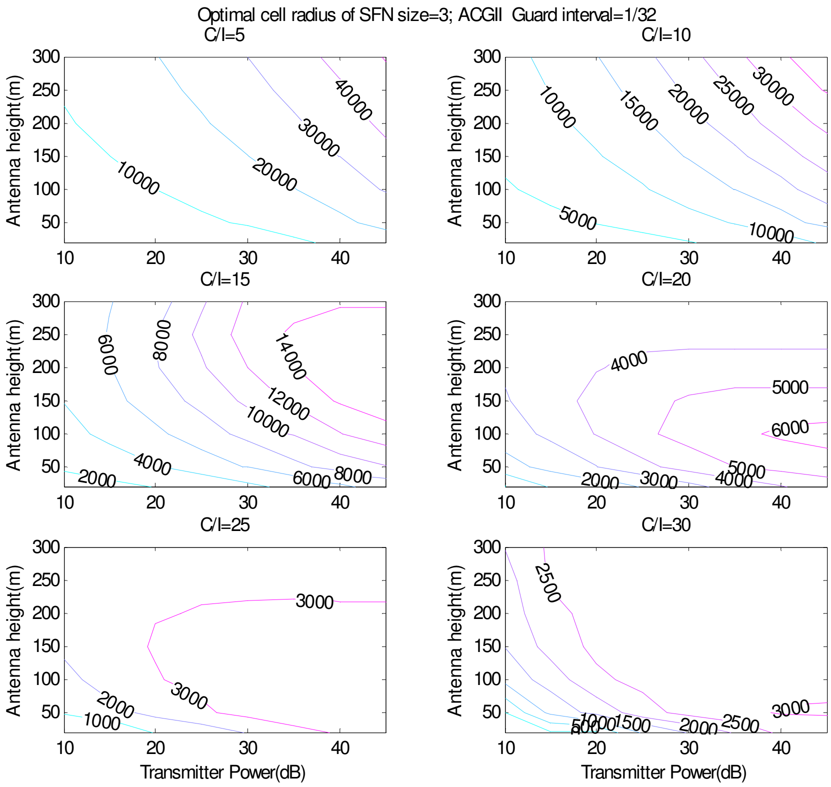


Figure A7-2. The optimal cell radius with the guard interval=1/32 of SFN size=3; ACG II coverage

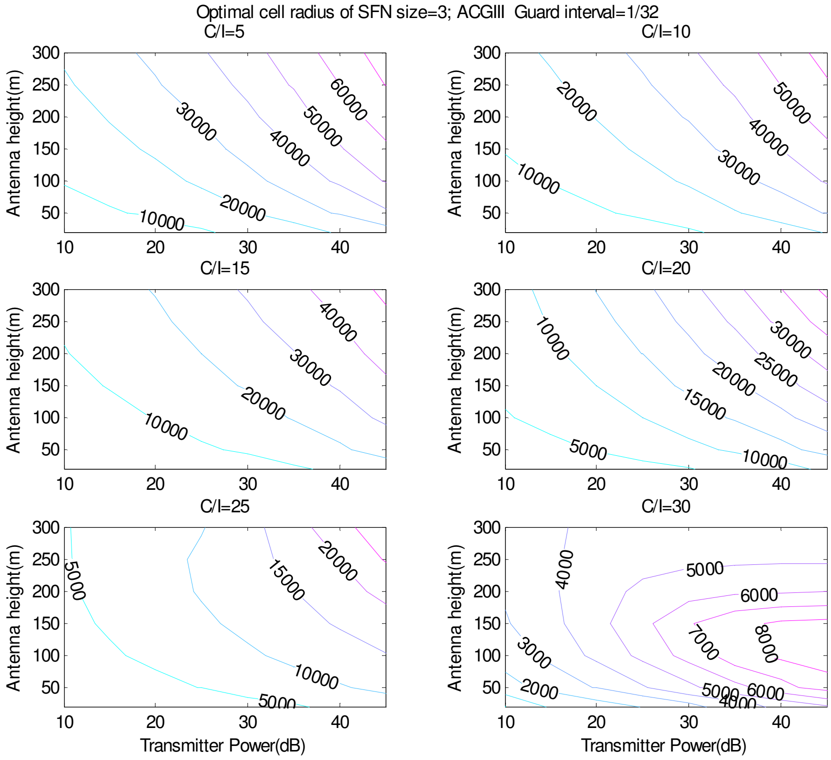


Figure A7-3. The optimal cell radius with the guard interval=1/32 of SFN size=3; ACG III coverage

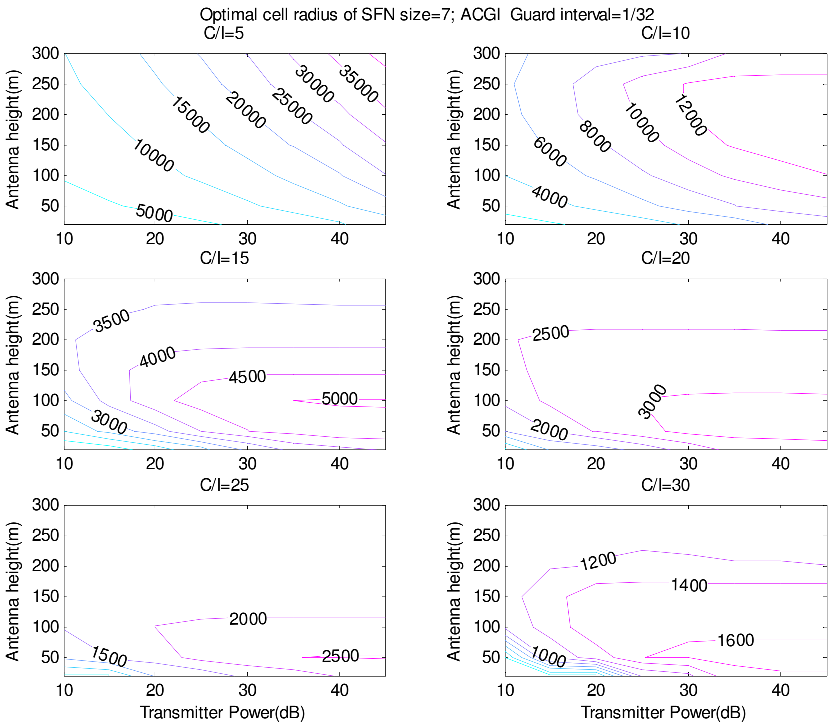


Figure A7-4. The optimal cell radius with the guard interval=1/32 of SFN size=7; ACG I coverage

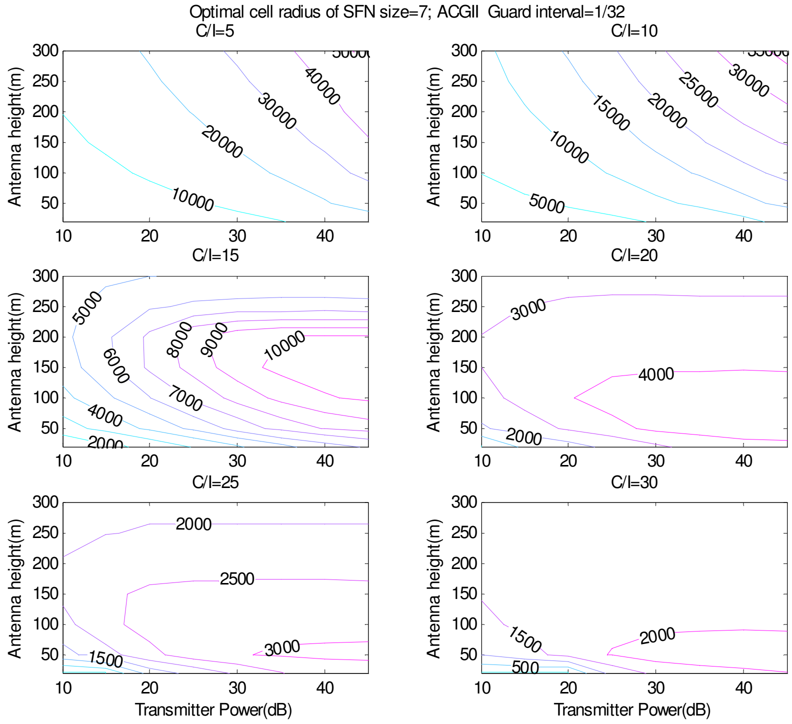


Figure A7-5. The optimal cell radius with the guard interval=1/32 of SFN size=7; ACG II coverage

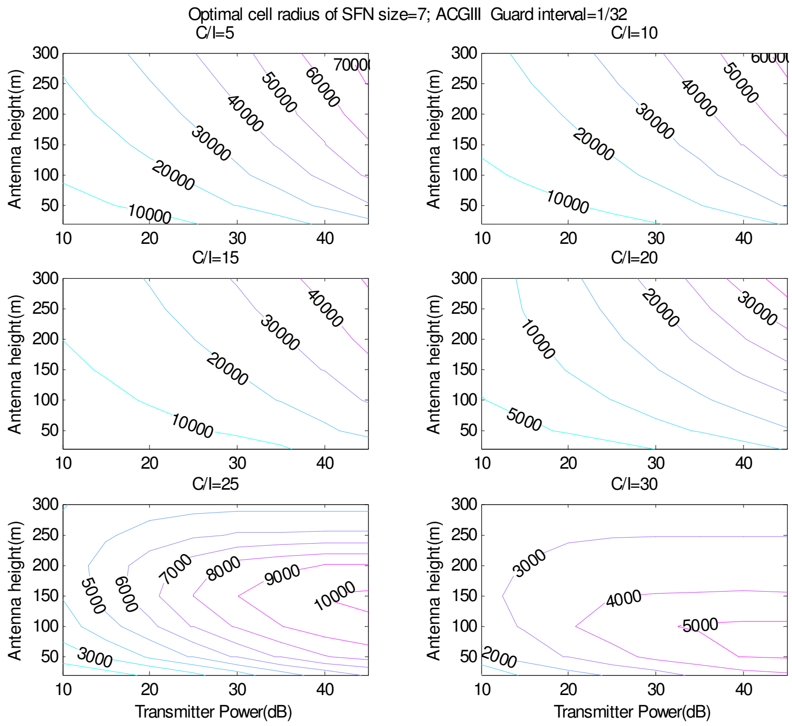


Figure A7-6. The optimal cell radius with the guard interval=1/32 of SFN size=7; ACG III coverage

A8. The SFN optimal cell radius with the guard interval=1/4 and without frequency reuse

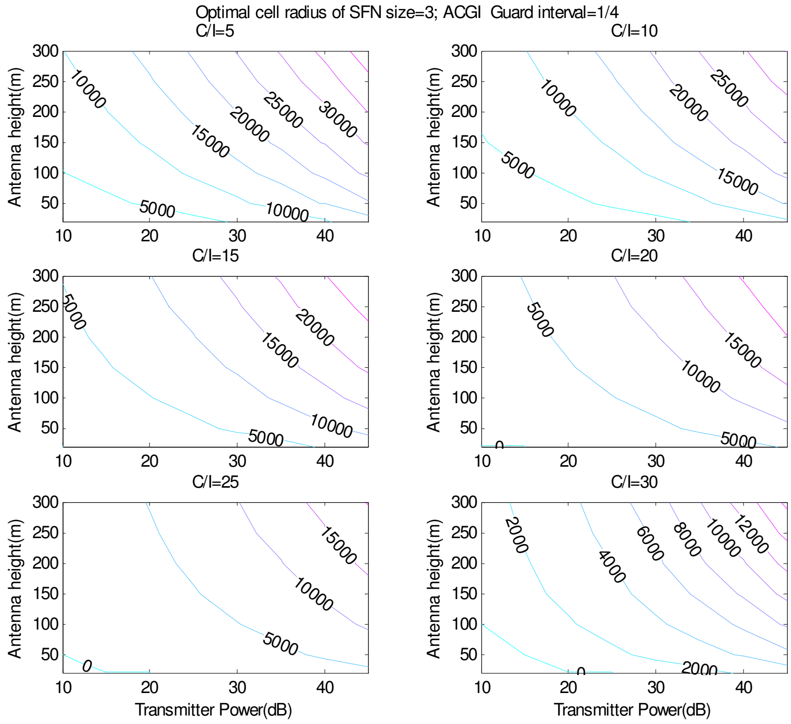


Figure A8-1. The optimal cell radius with the guard interval=1/4 of SFN size=3; ACG I coverage

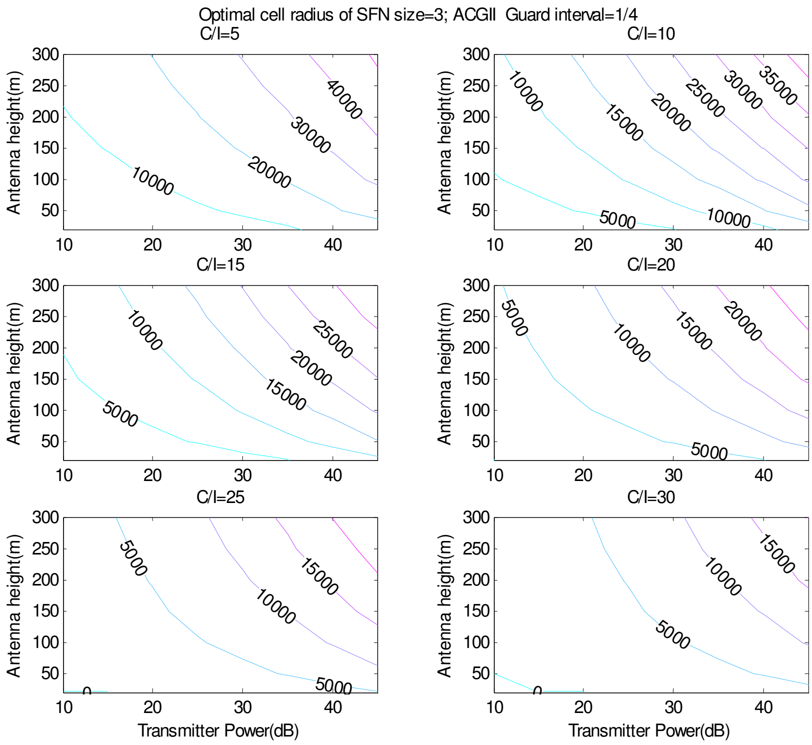


Figure A8-2. The optimal cell radius with the guard interval=1/4 of SFN size=3; ACG II coverage

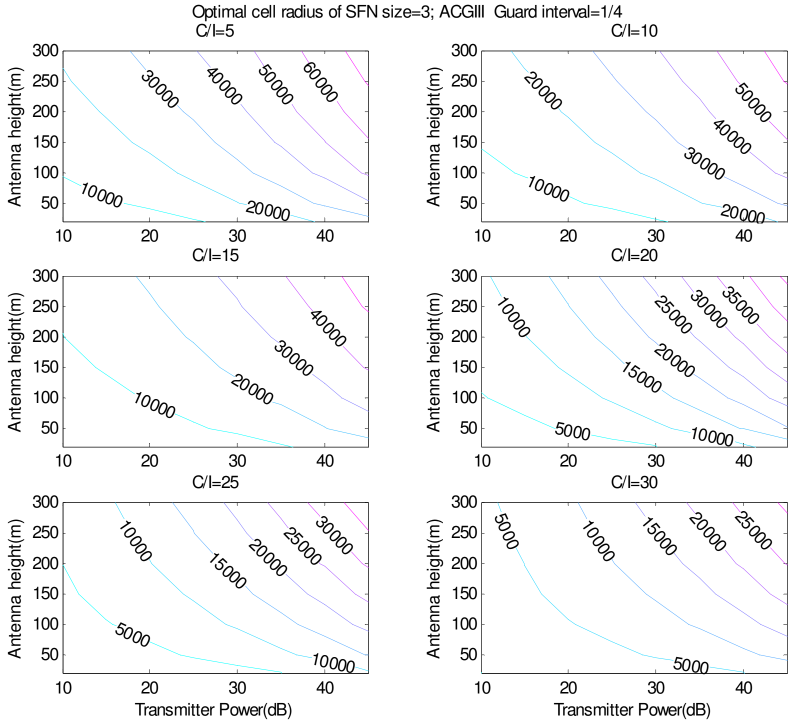


Figure A8-3. The optimal radius with the guard interval=1/4 of SFN size=3; ACG III coverage

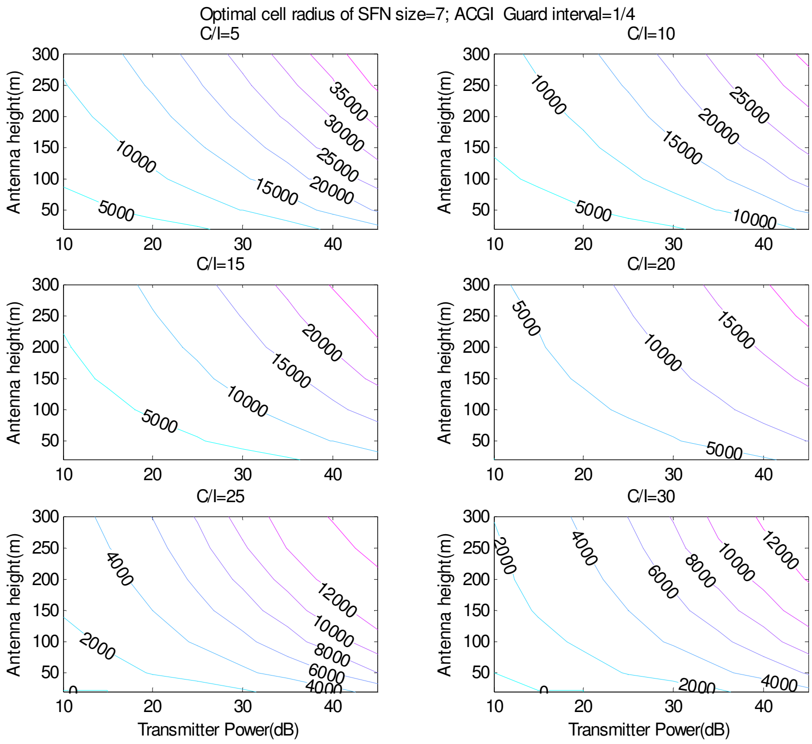


Figure A8-4. The optimal cell radius with the guard interval=1/4 of SFN size=7; ACG I coverage

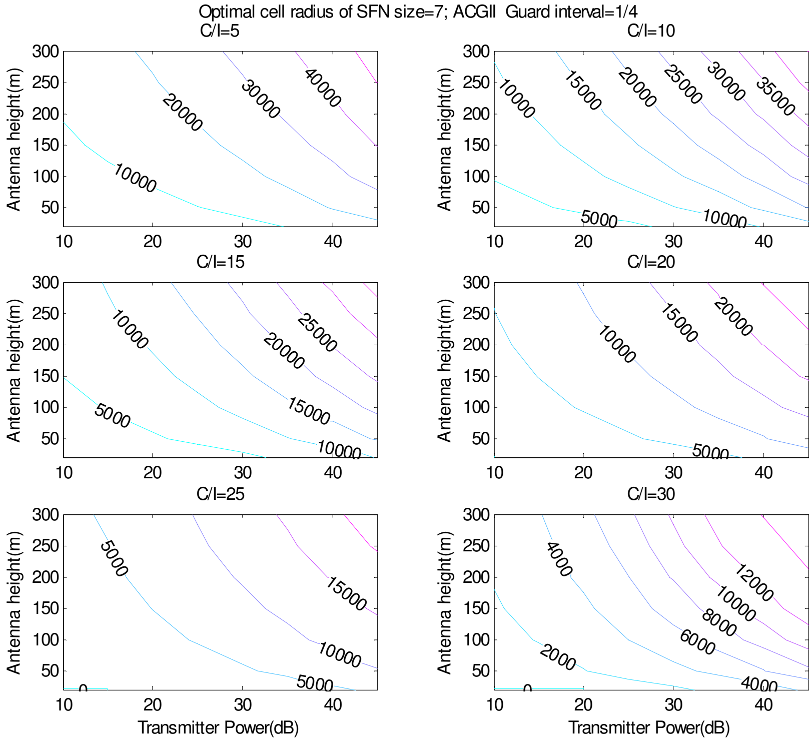


Figure A8-5. The optimal cell radius with the guard interval=1/4 of SFN size=7; ACG II coverage

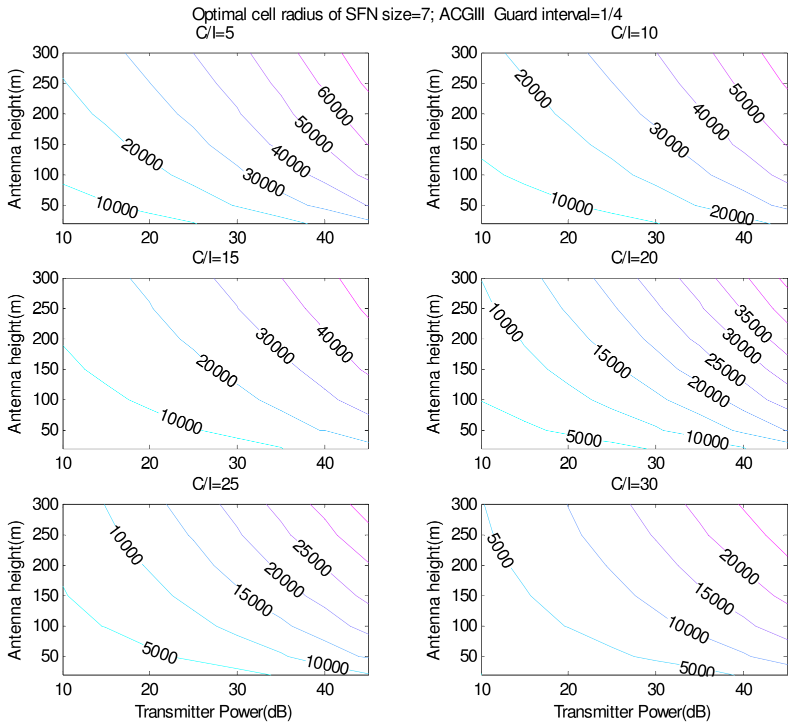


Figure A8-6. The optimal cell radius with the guard interval=1/4 of SFN size=7; ACG III coverage

A9. SFN gain with the guard interval=1/32 without frequency reuse

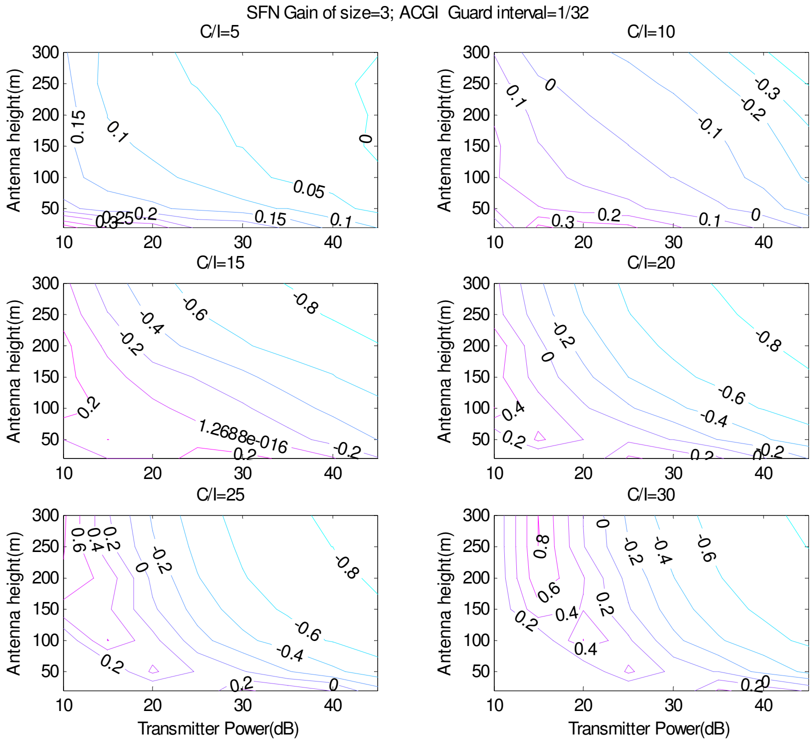


Figure A9-1. The SFN gain with the guard interval=1/32 of SFN size=3; ACG I coverage

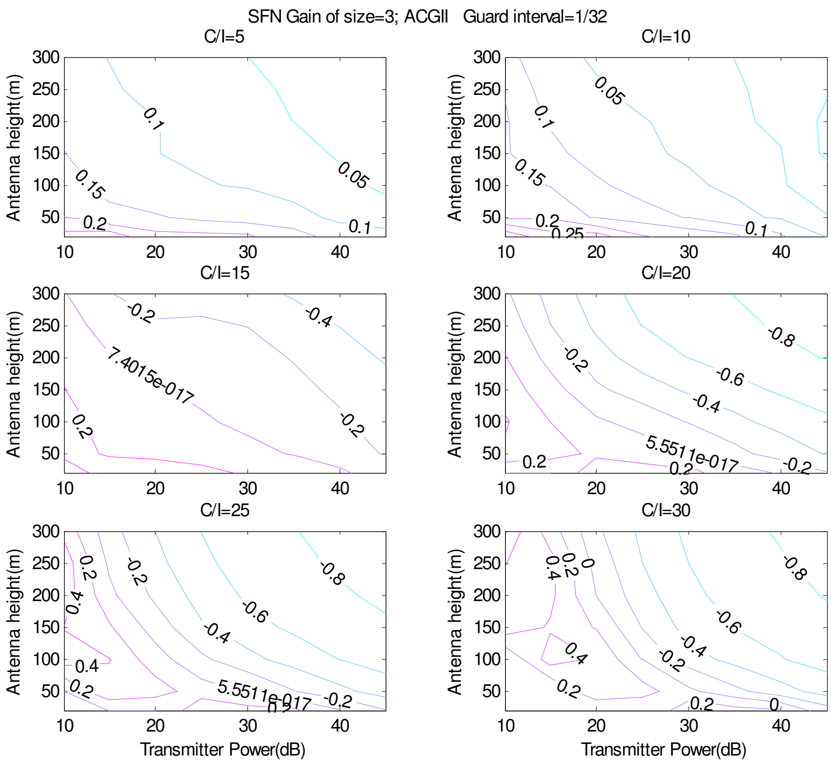


Figure A9-2. The SFN gain with the guard interval=1/32 of SFN size=3; ACG II coverage

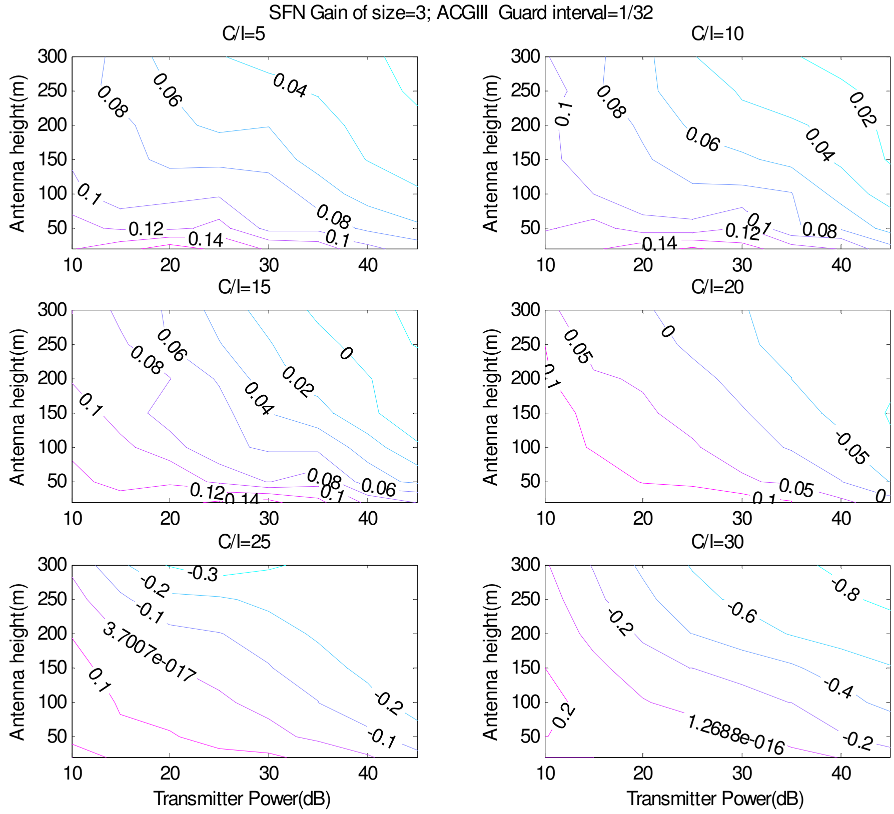


Figure A9-3. The SFN gain with the guard interval=1/32 of SFN size=3; ACG III coverage

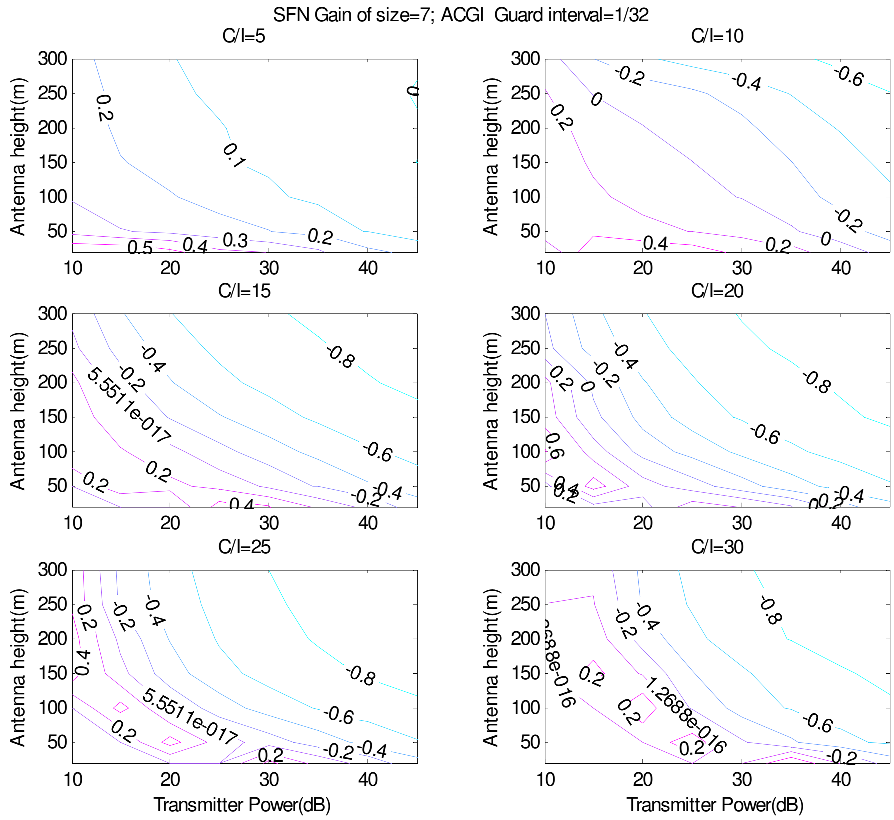


Figure A9-4. The SFN gain with the guard interval=1/32 of SFN size=7; ACG I coverage

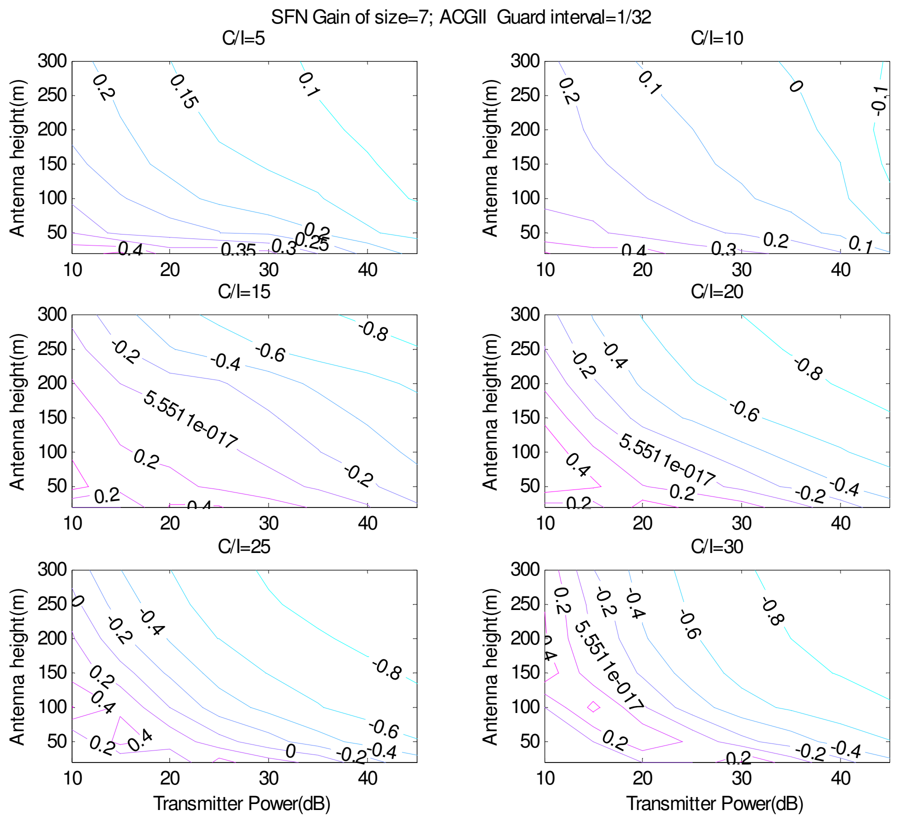


Figure A9-5. The SFN gain with the guard interval=1/32 of SFN size=7; ACG II coverage

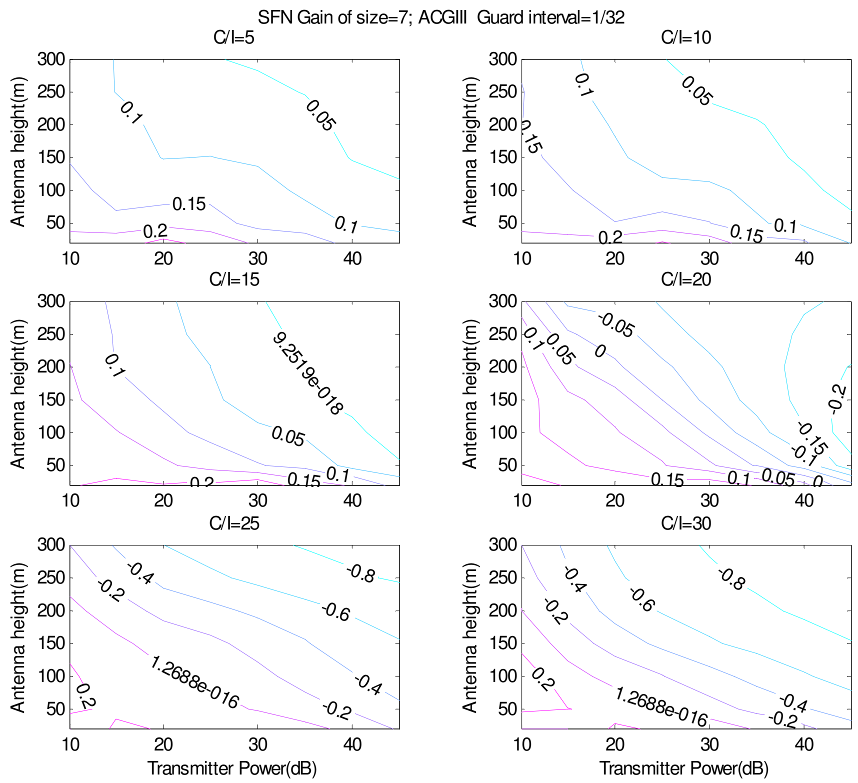


Figure A9-6. The SFN gain with the guard interval=1/32 of SFN size=7; ACG III coverage

A10. The SFN gain with the guard interval=1/4 without frequency reuse

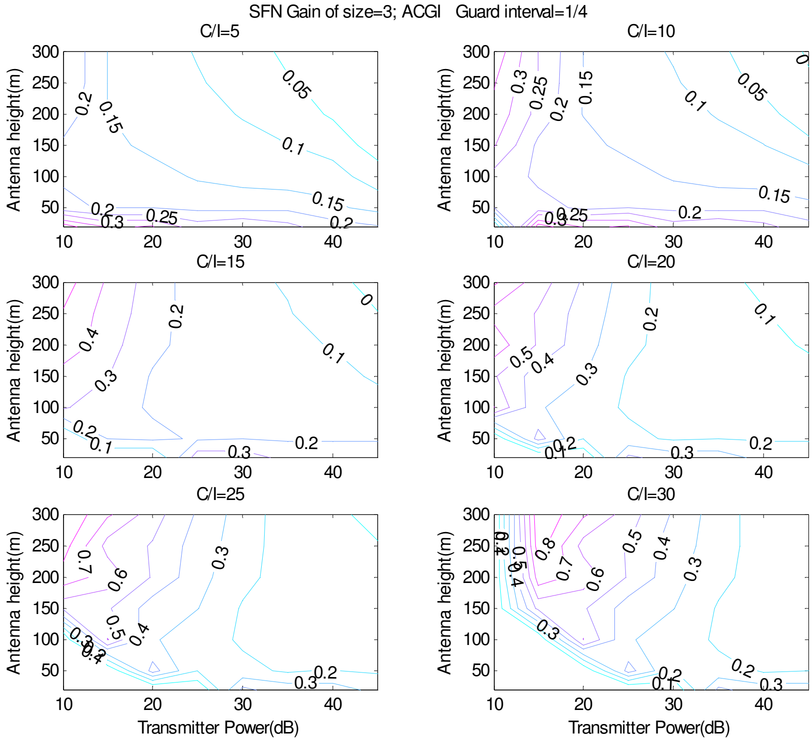


Figure A10-1. The SFN gain with the guard interval=1/4 of SFN size=3; ACG I coverage

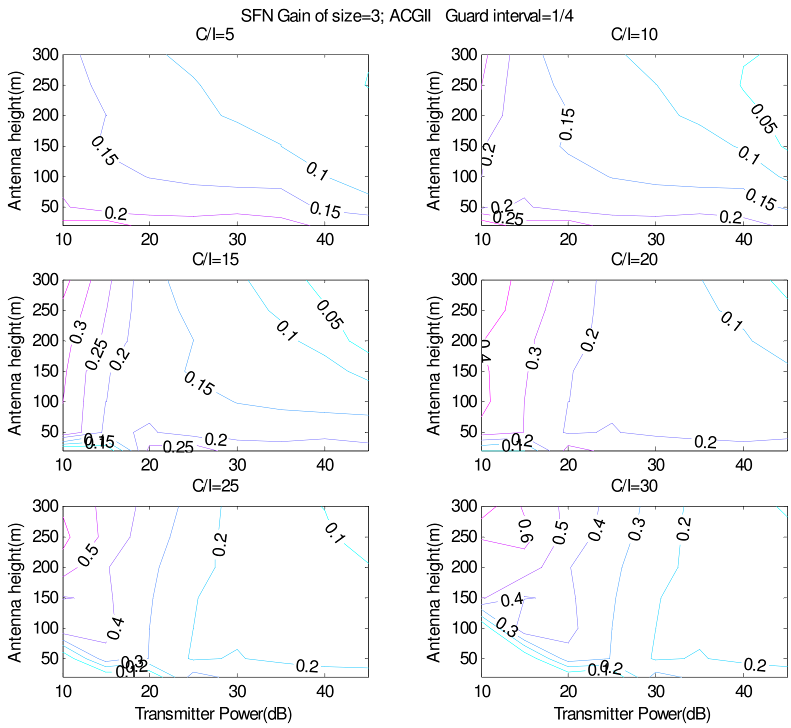


Figure A10-2. The SFN gain with the guard interval=1/4 of SFN size=3; ACG II coverage

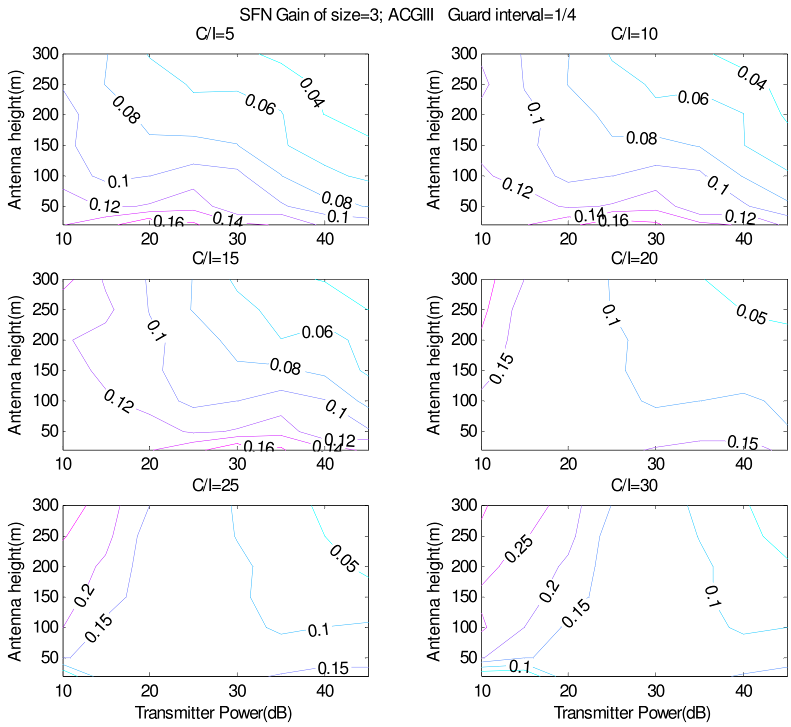


Figure A10-3. The SFN gain with the guard interval=1/4 of SFN size=3; ACG III coverage

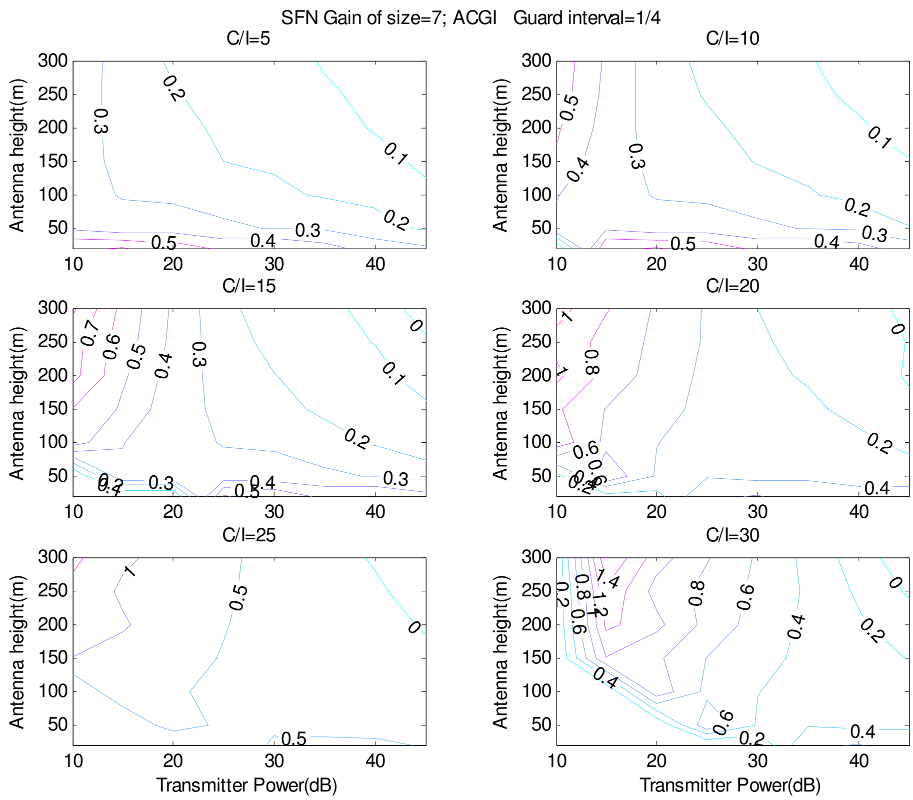


Figure A10-4. The SFN gain with the guard interval=1/4 of SFN size=7; ACG I coverage

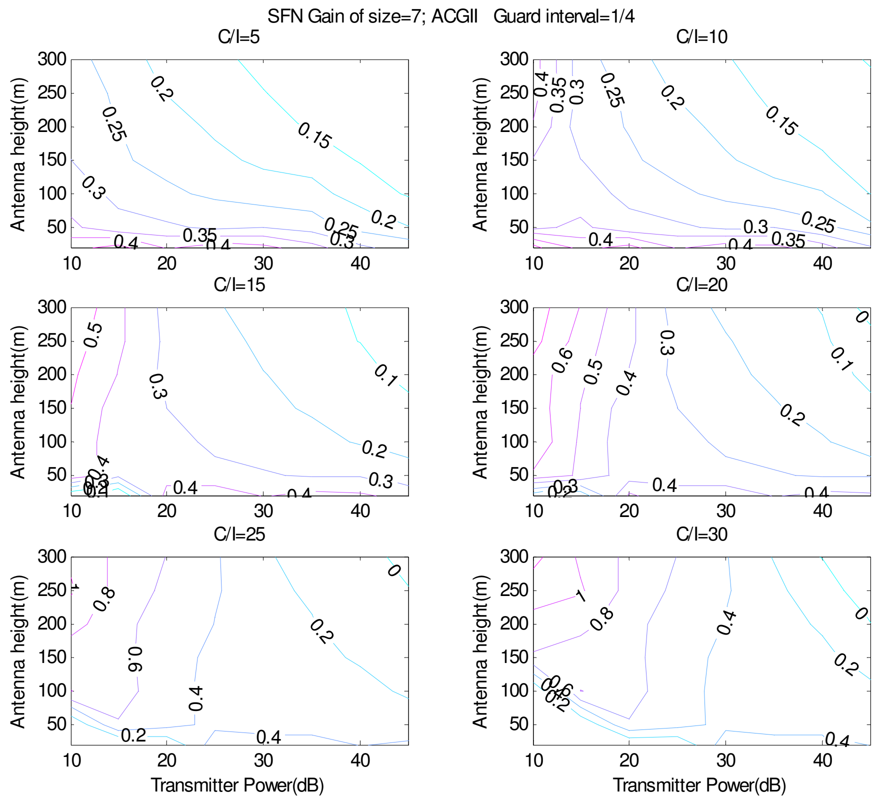


Figure A10-5. The SFN gain with the guard interval=1/4 of SFN size=7; ACG II coverage

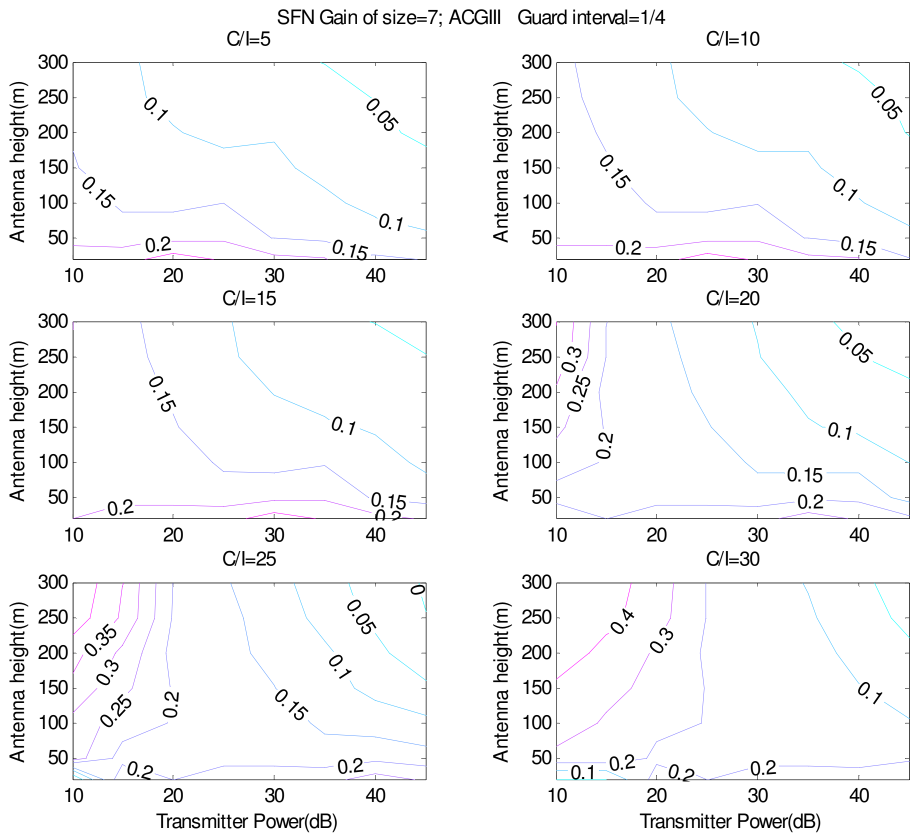


Figure A10-6. The SFN gain with the guard interval=1/4 of SFN size=7; ACG III coverage

A11. The optimal cell radius for SFN size = 3 with a Reuse factor, guard interval = 1/4

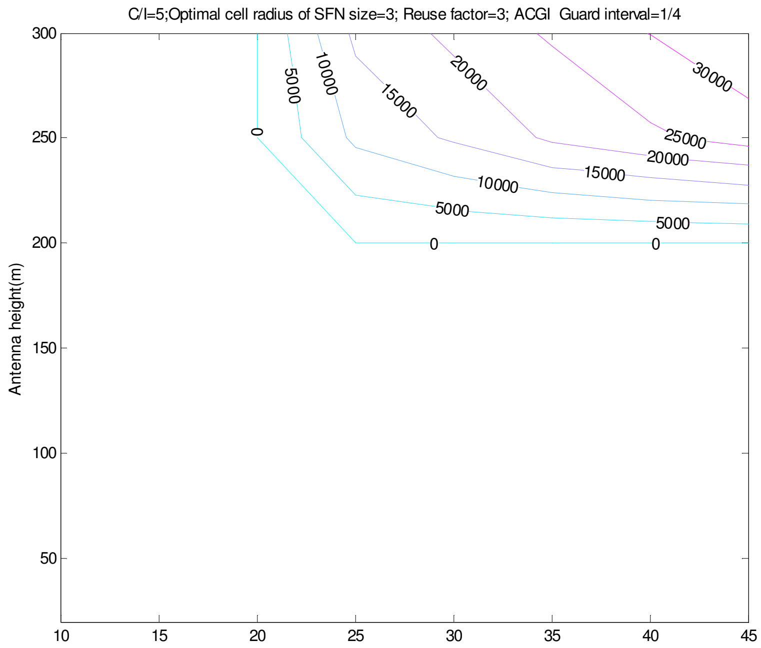


Figure A11-1. The optimal cell radius of SFN size=3 and reuse factor=3; ACG I coverage; Guard interval=1/4

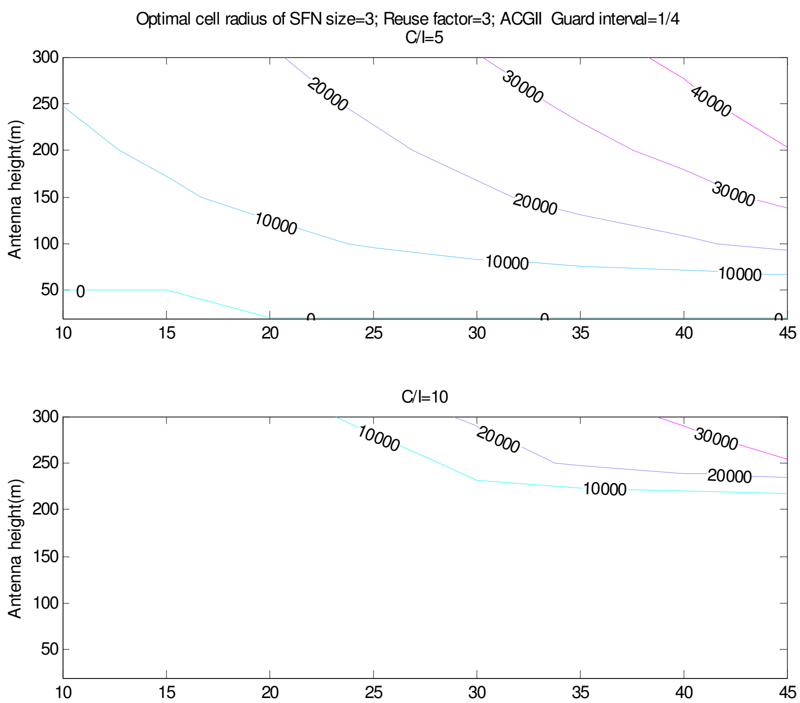


Figure A11-2. The optimal cell radius of SFN size=3 and reuse factor=3; ACG II coverage; Guard interval=1/4

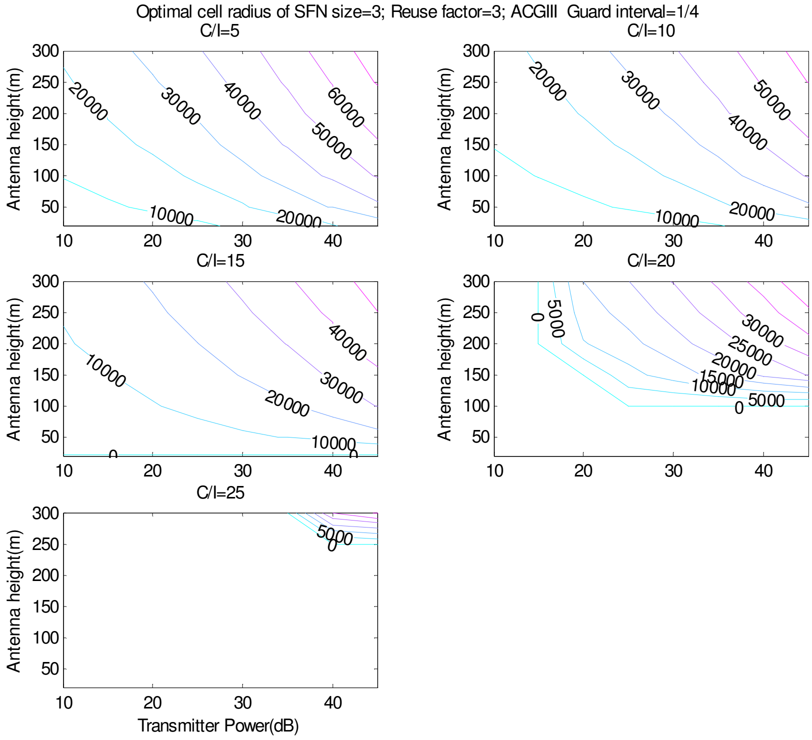


Figure A11-3. The optimal cell radius of SFN size=3 and reuse factor=3; ACG III coverage; Guard interval=1/4

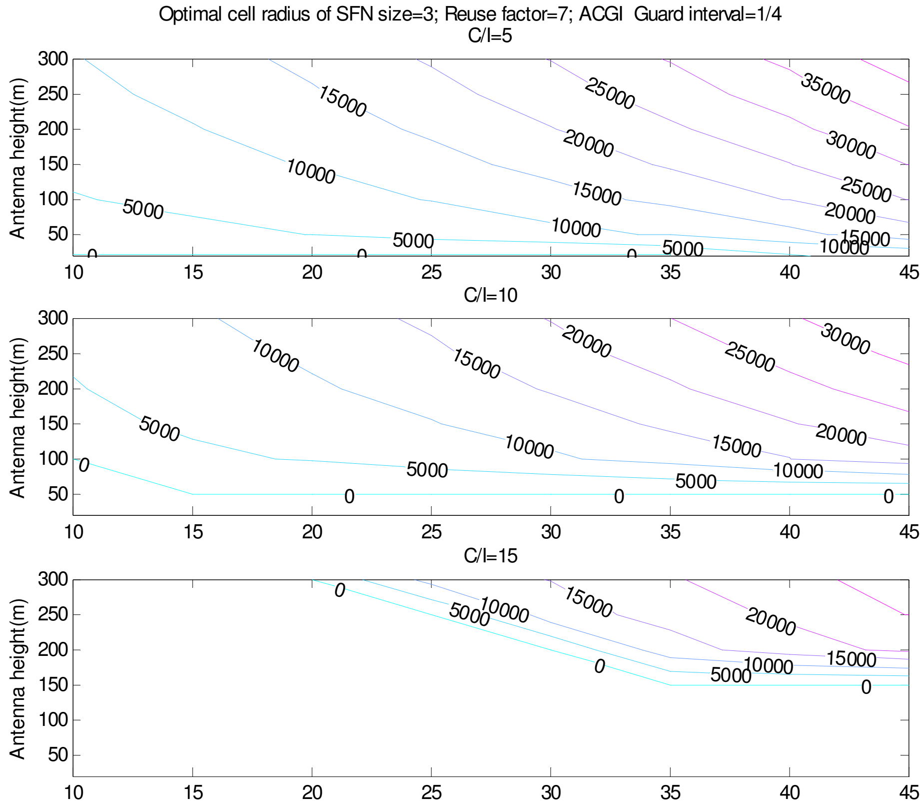


Figure A11-4. The optimal cell radius of SFN size=3 and reuse factor=7; ACG I coverage; Guard interval=1/4

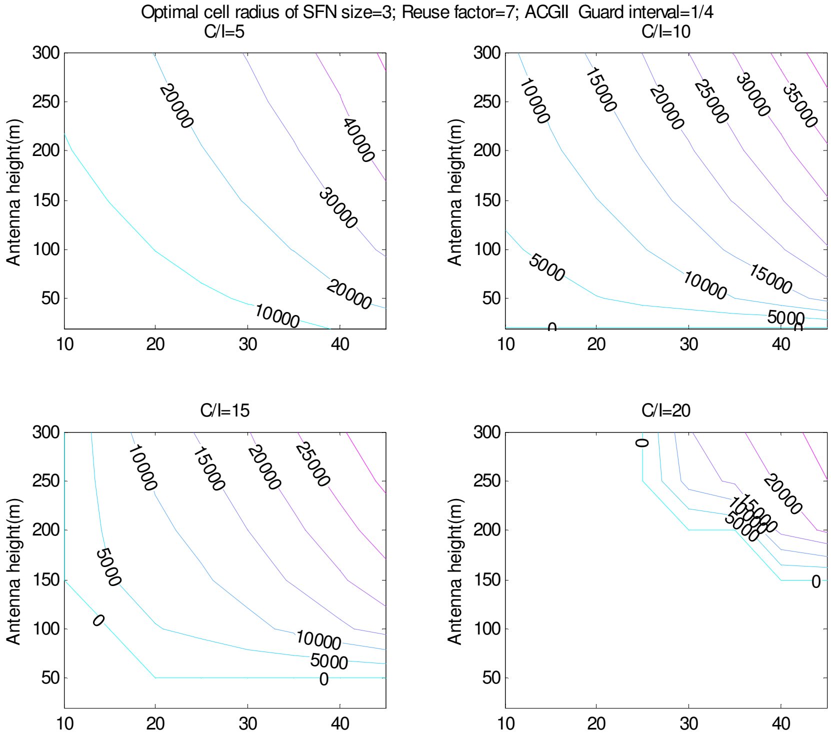


Figure A11-5. The optimal cell radius of SFN size=3 and reuse factor=7; ACG II coverage; Guard interval=1/4

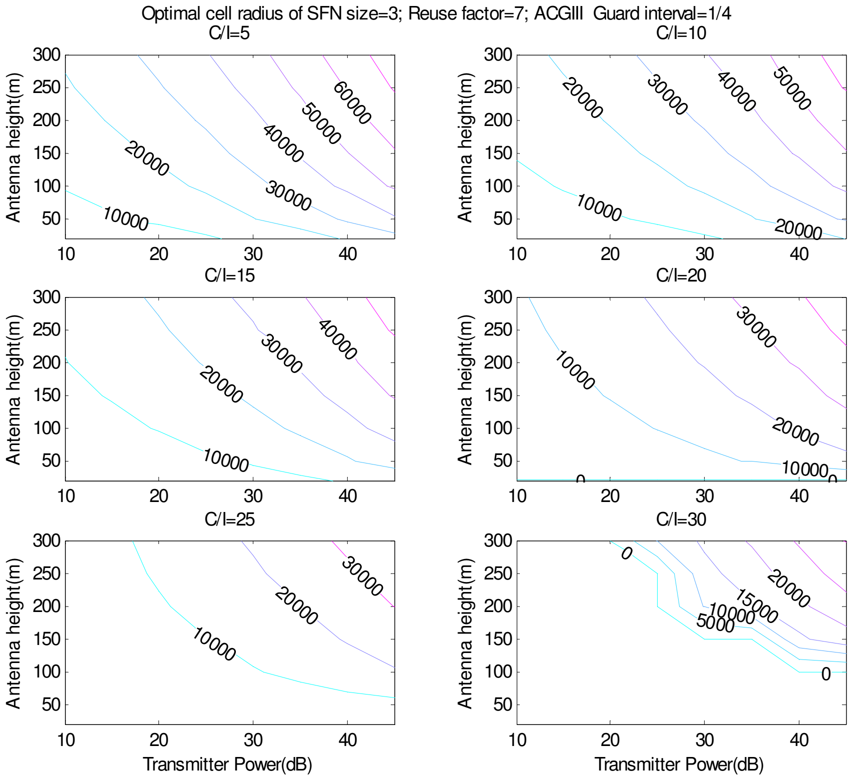


Figure A11-6. The optimal cell radius of SFN size=3 and reuse factor=7; ACG III coverage; Guard interval=1/4

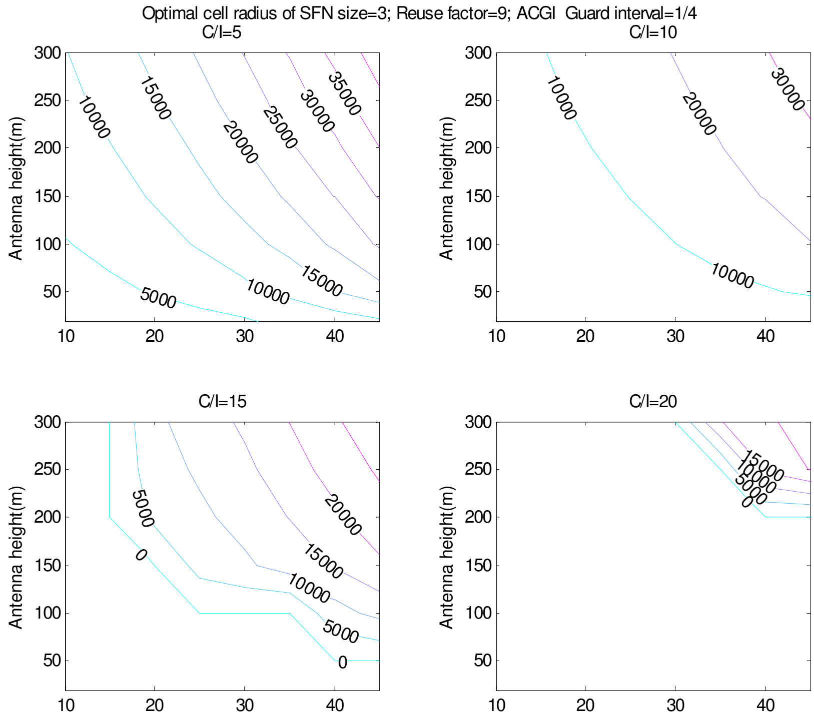


Figure A11-7. The optimal cell radius of SFN size=3 and reuse factor=9; ACG I coverage; Guard interval=1/4

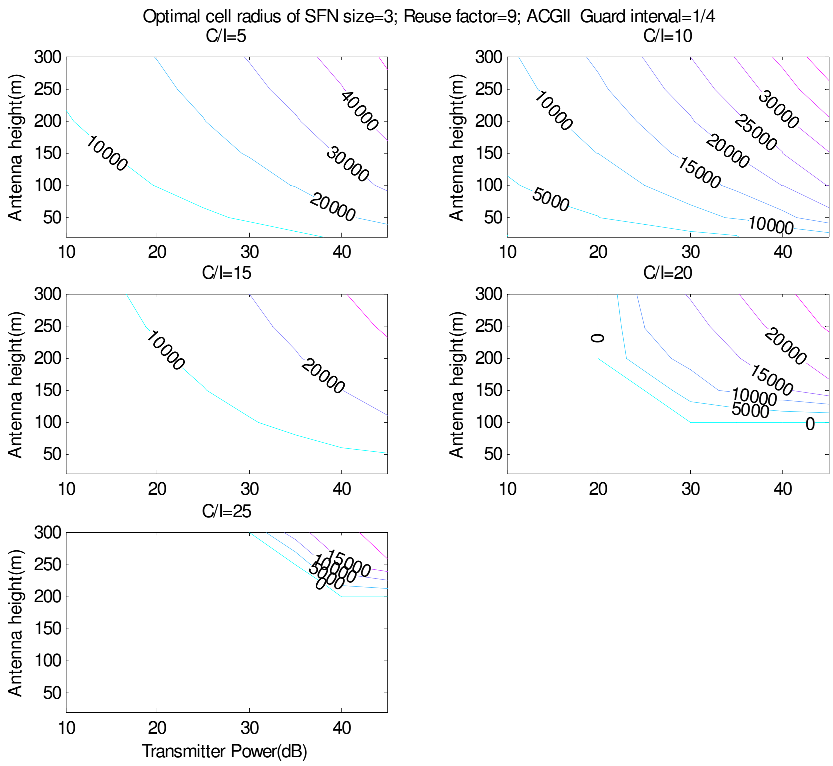


Figure A11-8. The optimal cell radius of SFN size=3 and reuse factor=9; ACG II coverage; Guard interval=1/4

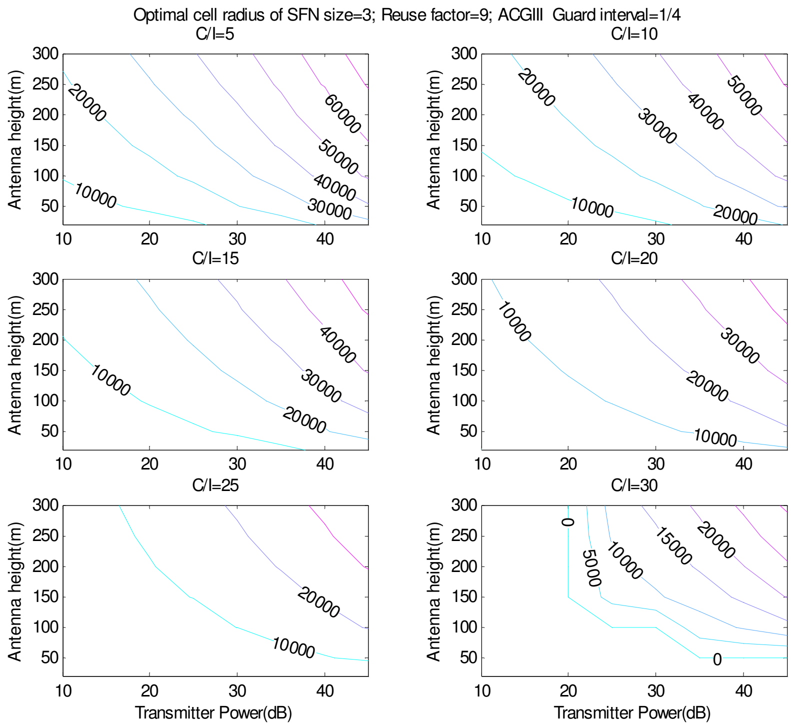


Figure A11-9. The optimal cell radius of SFN size=3 and reuse factor=9; ACG III coverage; Guard interval=1/4

A12. The SFN gain for SFN size = 3 with reuse factor, guard interval=1/4;

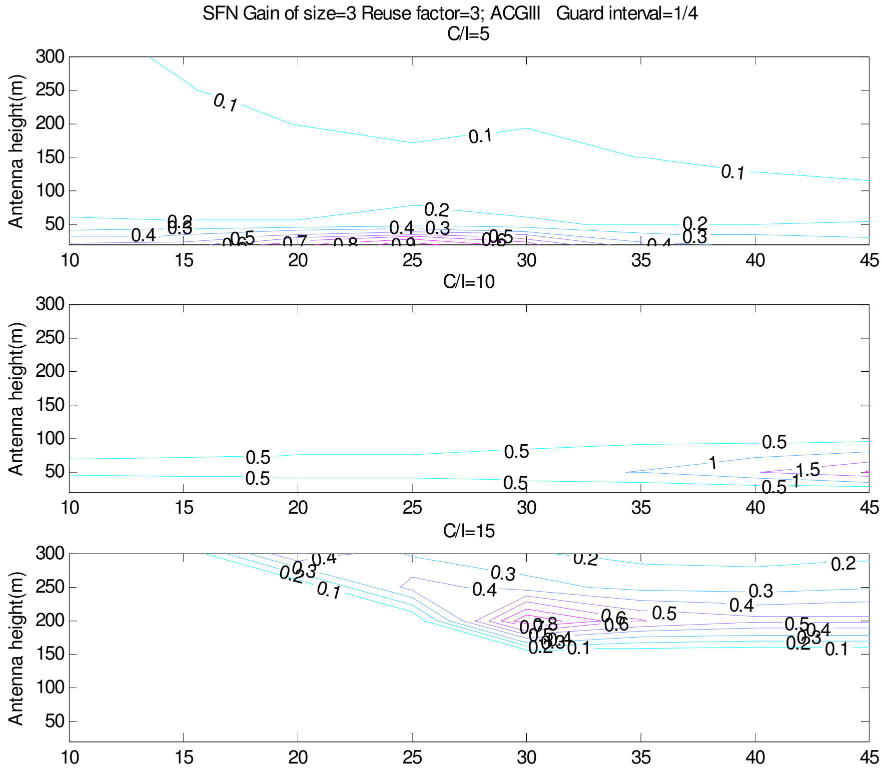


Figure A12-1. The SFN gain of a SFN size=3 and reuse factor=3; ACG III coverage; Guard interval=1/4

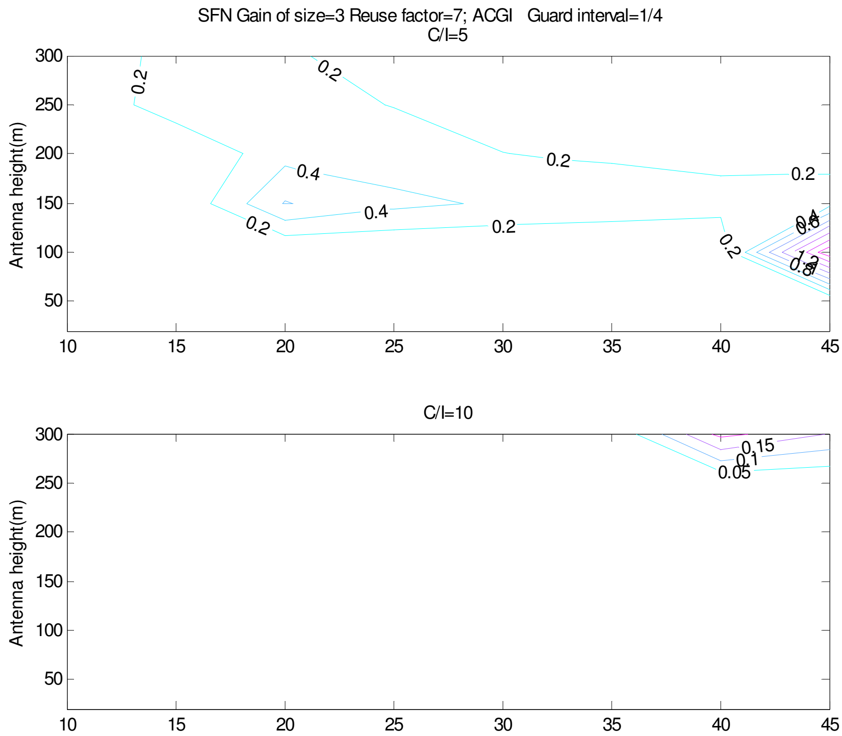


Figure A12-2. The SFN gain of a SFN size=3 and reuse factor=7; ACG I coverage; Guard interval=1/4

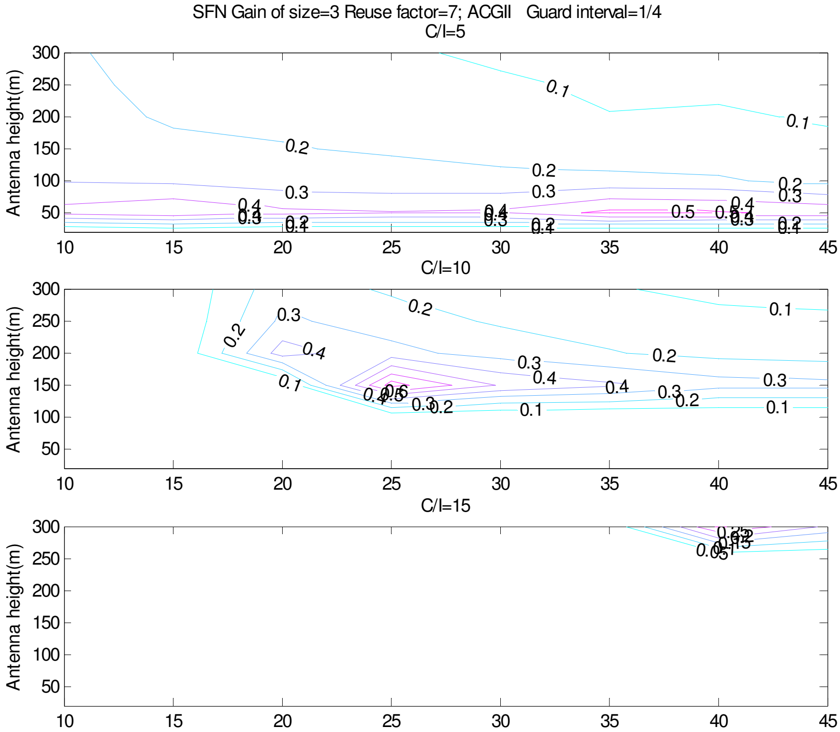


Figure A12-3. The SFN gain of a SFN size=3 and reuse factor=7; ACG II coverage; Guard interval=1/4

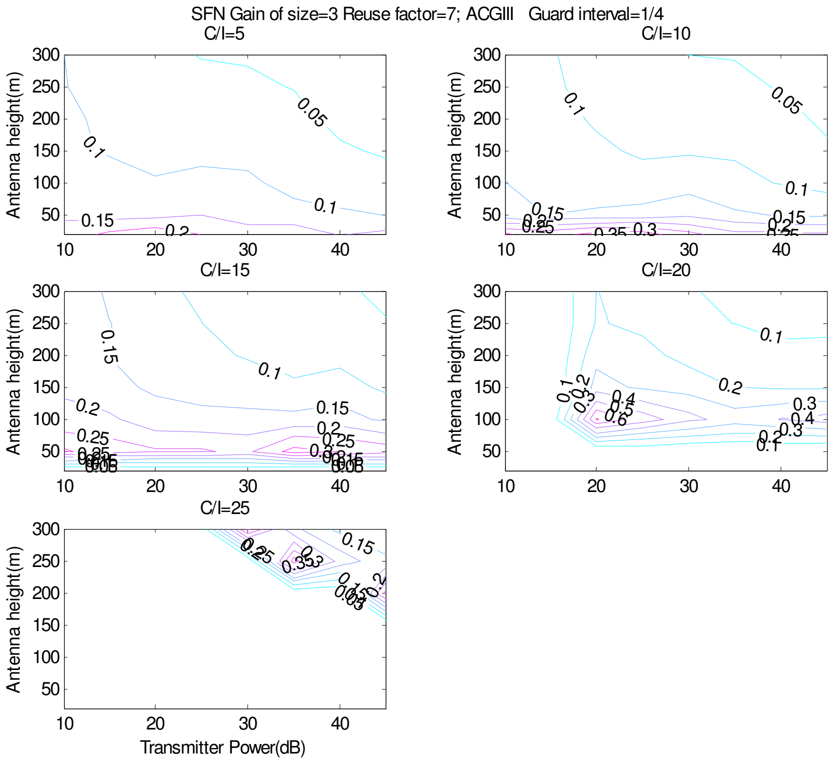


Figure A12-4. The SFN gain of a SFN size=3 and reuse factor=7; ACG III coverage; Guard interval=1/4

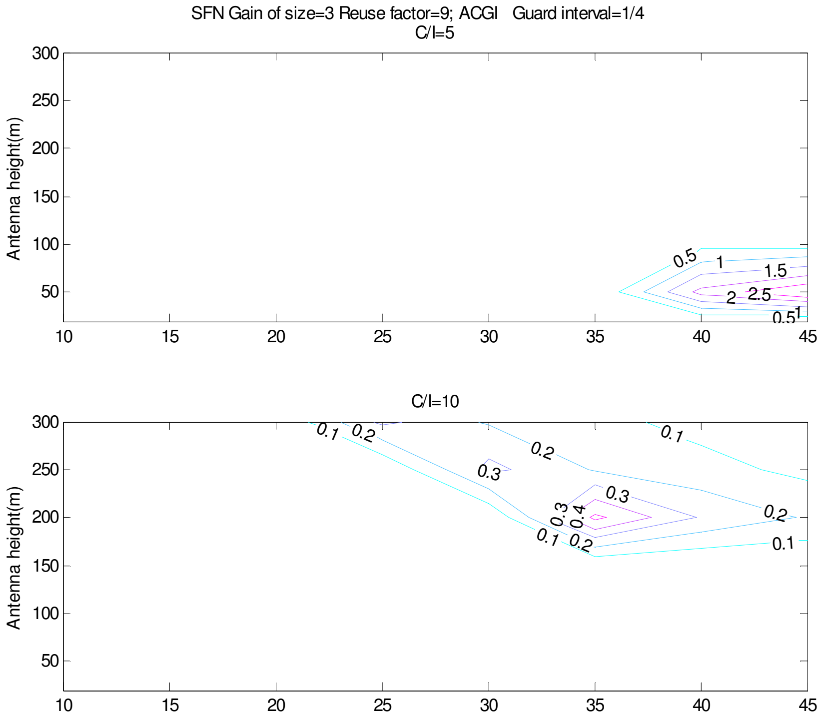


Figure A12-5. The gain of a SFN size=3 and reuse factor=9; ACG I coverage; Guard interval=1/4

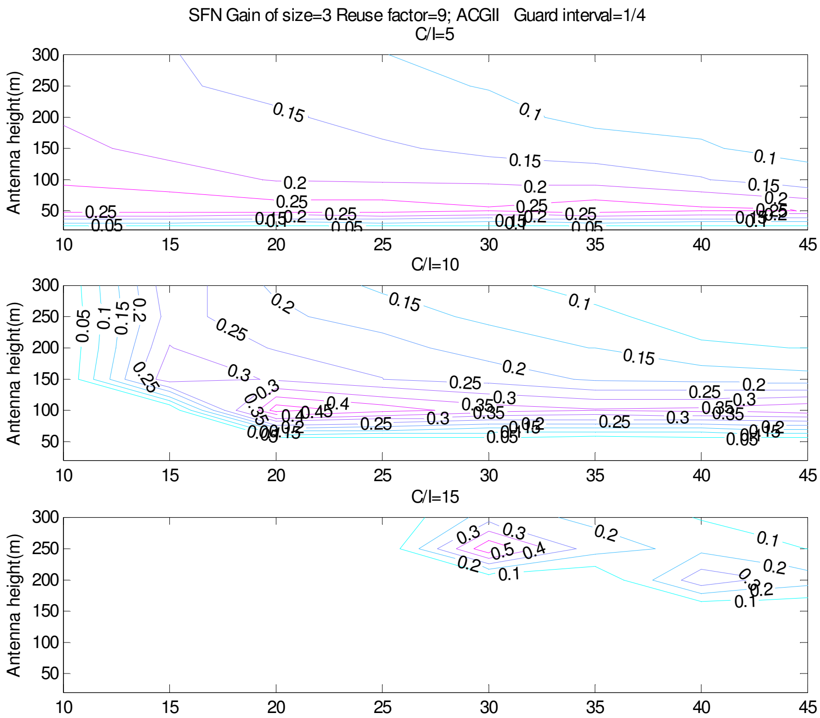


Figure A12-6. The gain of a SFN size=3 and reuse factor=9; ACG II coverage; Guard interval=1/4

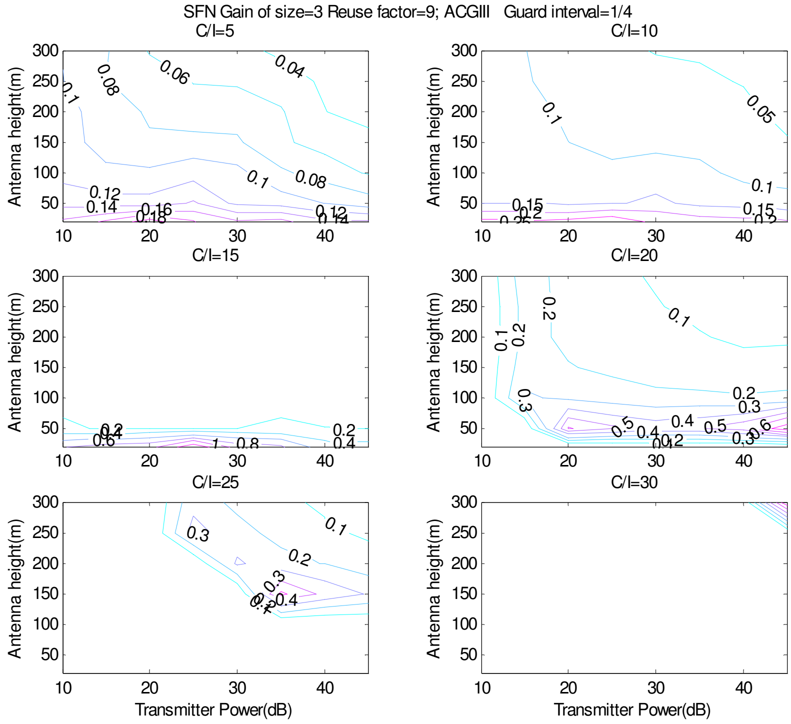


Figure A12-7. The gain of a SFN size=3 and reuse factor=9; ACG III coverage; Guard interval=1/4

A13. The optimal cell radius of SFN size = 7 with a reuse factor, guard interval = 1/4

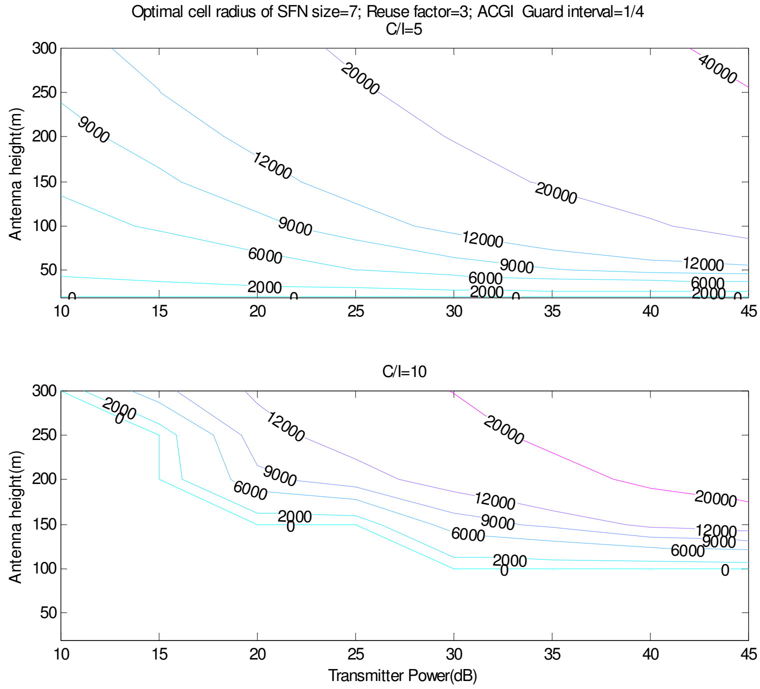


Figure A13-1. The optimal cell radius of SFN size=7 and reuse factor=3; ACG I coverage; Guard interval=1/4

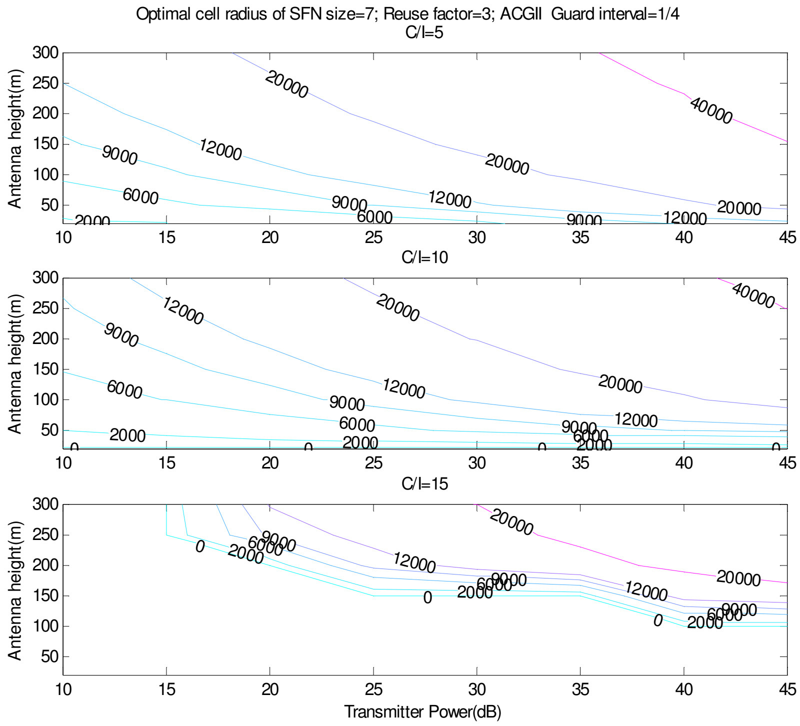


Figure A13-2. The optimal cell radius of SFN size=7 and reuse factor=3; ACG II coverage; Guard interval=1/4

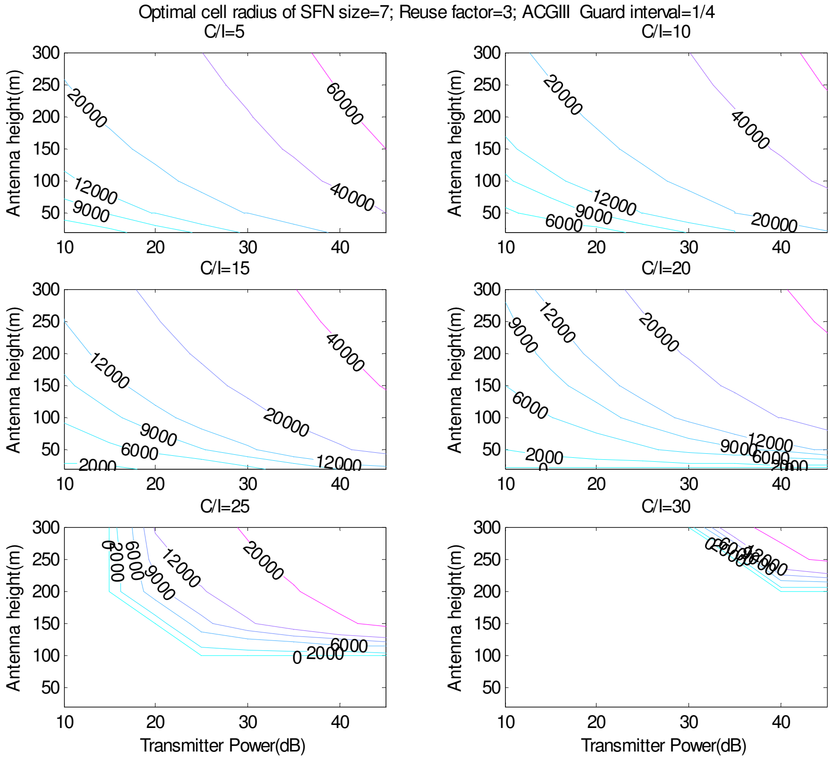


Figure A13-3. The optimal cell radius of SFN size=7 and reuse factor=3; ACG III coverage; Guard interval=1/4

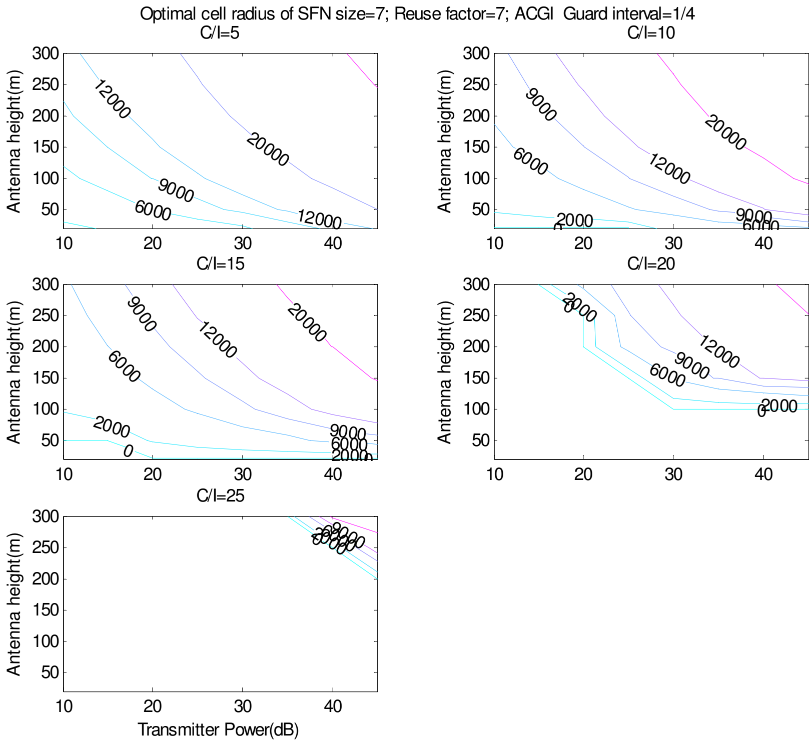


Figure A13-4. The optimal cell radius of SFN size=7 and reuse factor=7; ACG I coverage; Guard interval=1/4

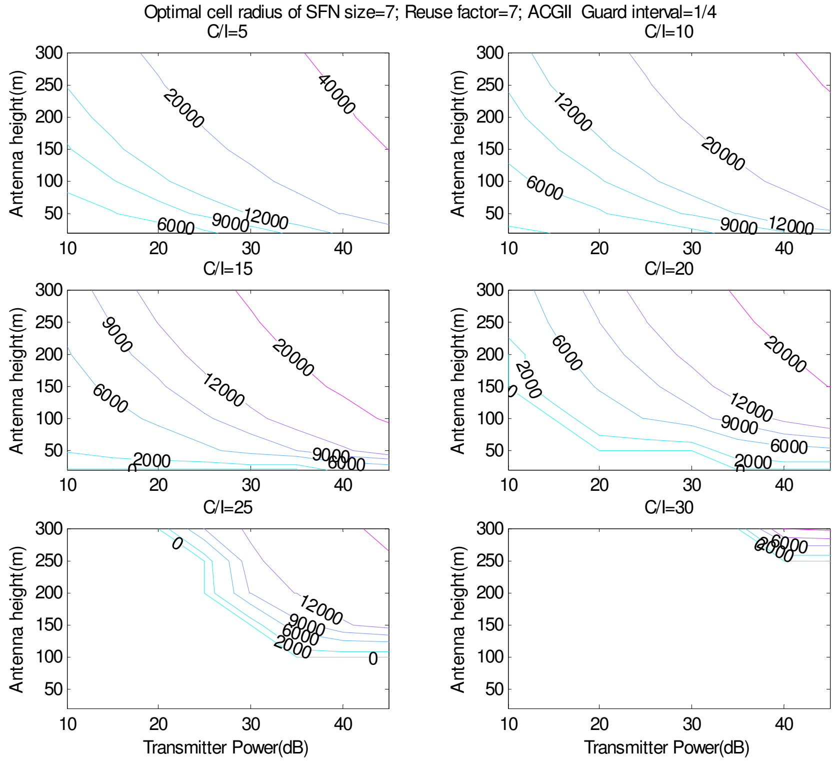


Figure A13-5. The optimal cell radius of SFN size=7 and reuse factor=7; ACG II coverage; Guard interval=1/4

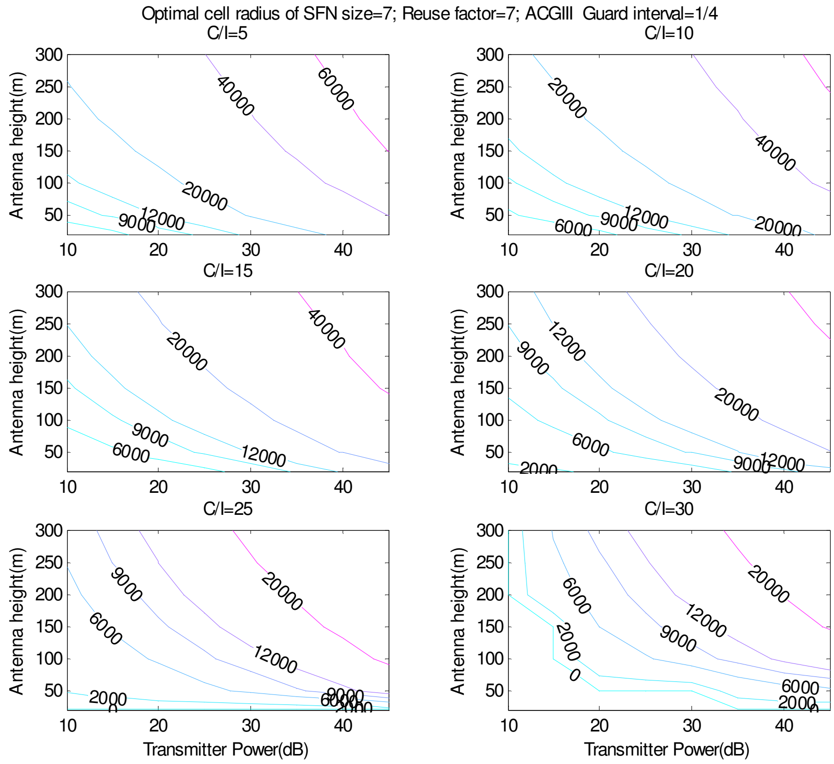


Figure A13-6. The optimal cell radius of SFN size=7 and reuse factor=7; ACG III coverage; Guard interval=1/4

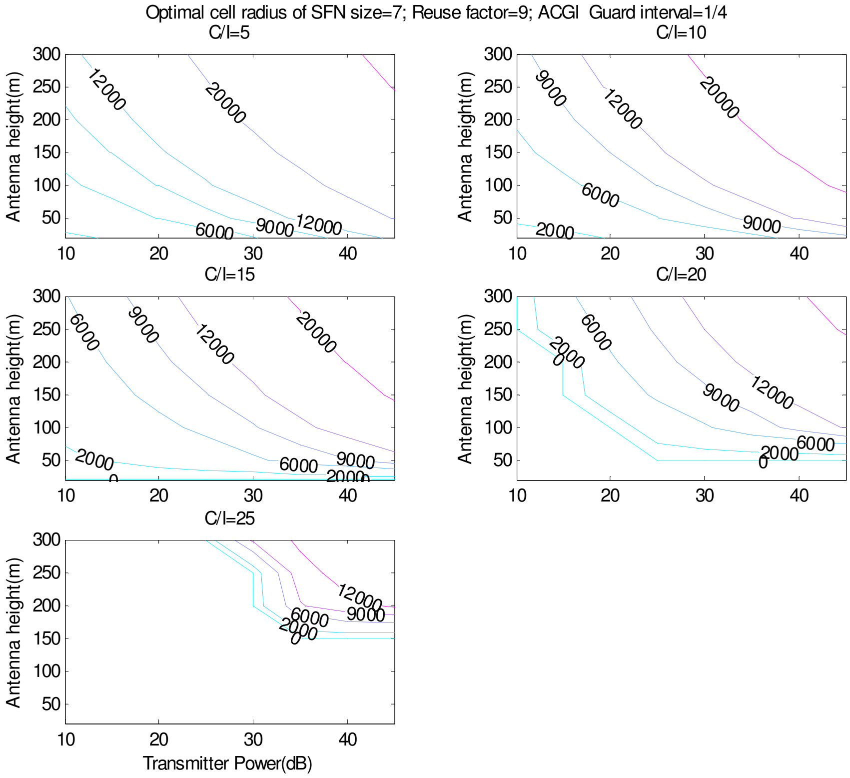


Figure A13-7. The optimal cell radius of SFN size=7 and reuse factor=9; ACG I coverage; Guard interval=1/4

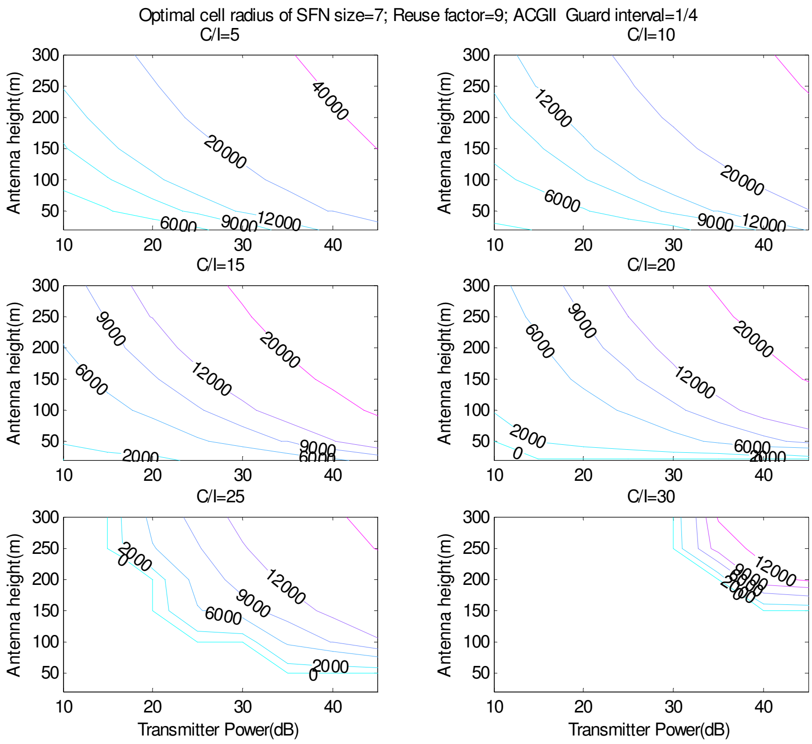


Figure A13-8. The optimal cell radius of SFN size=7 and reuse factor=9; ACG II coverage; Guard interval=1/4

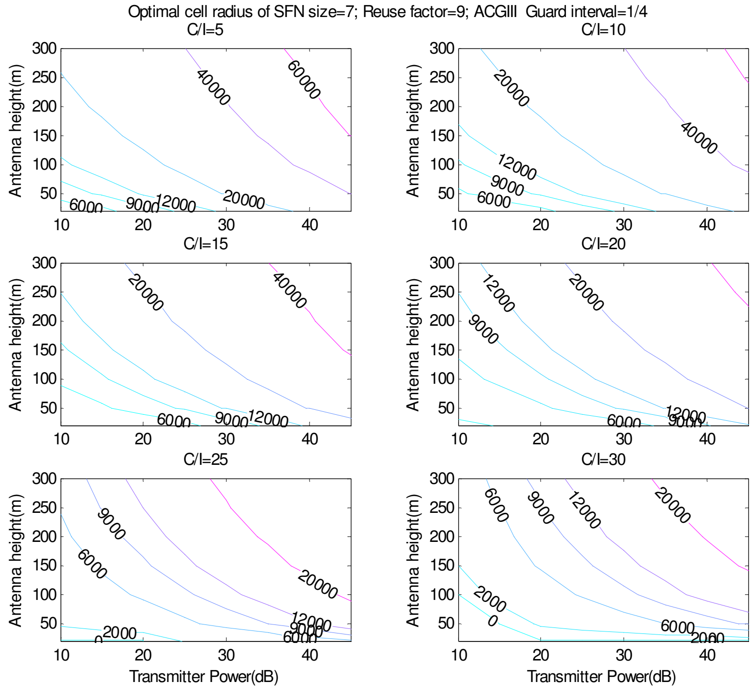


Figure A13-9. The optimal cell radius of SFN size=7 and reuse factor=9; ACG III coverage; Guard interval=1/4

A14. The SFN gain for SFN size = 7 with a reuse factor, guard interval=1/4

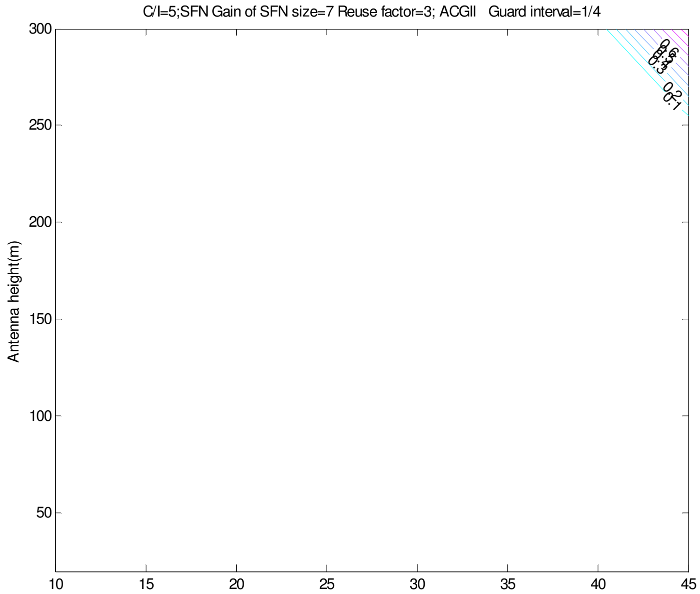


Figure A14-1. The SFN gain of a SFN size=7 and reuse factor=3; ACG II coverage; Guard interval=1/4

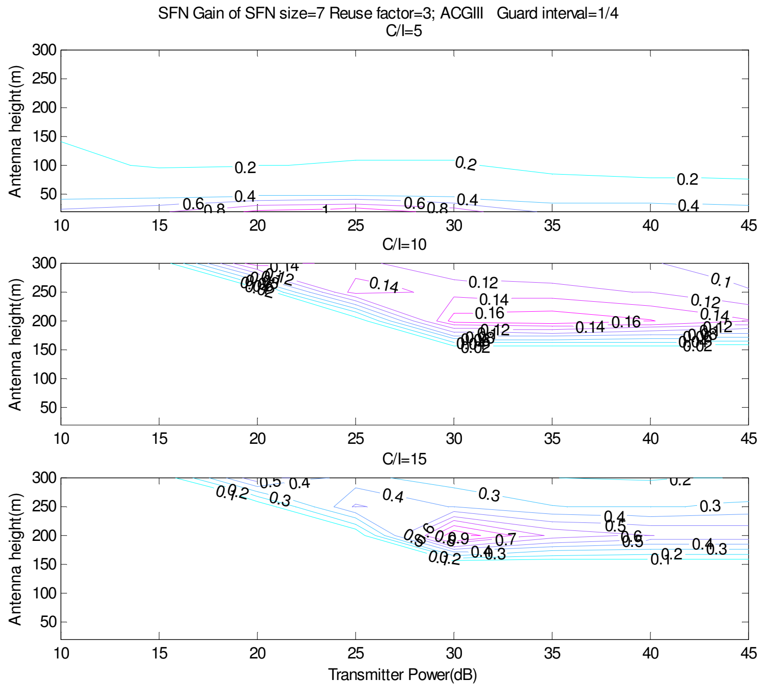


Figure A14-2. The SFN gain of a SFN size=7 and reuse factor=3; ACG III coverage; Guard interval=1/4

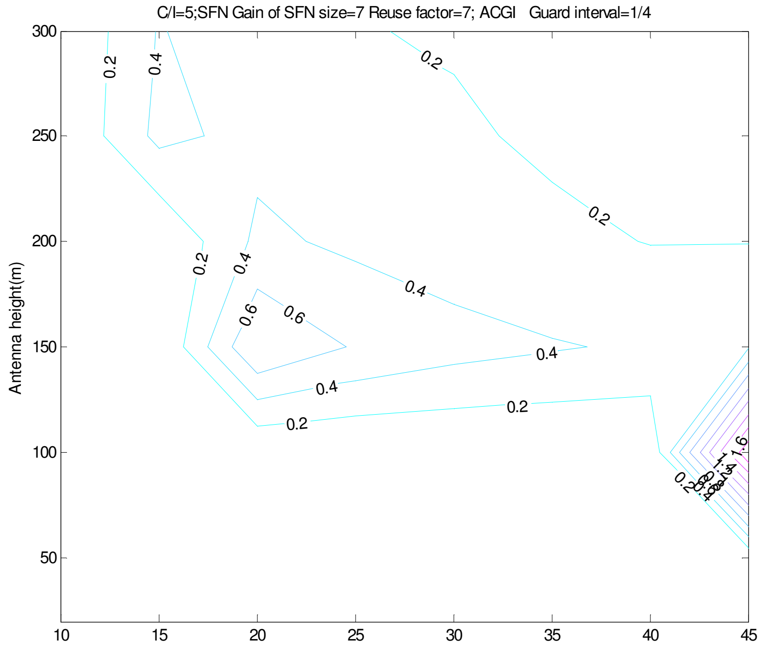


Figure A14-3. The SFN gain of a SFN size=7 and reuse factor=7; ACG I coverage; Guard interval=1/4

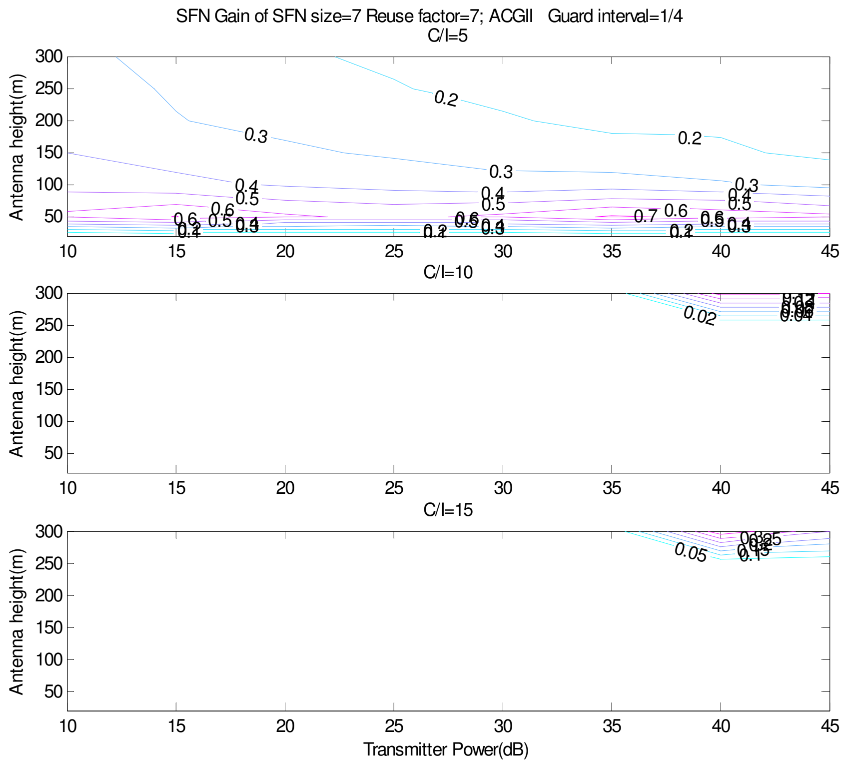


Figure A14-4. The SFN gain of a SFN size=7 and reuse factor=7; ACG II coverage; Guard interval=1/4

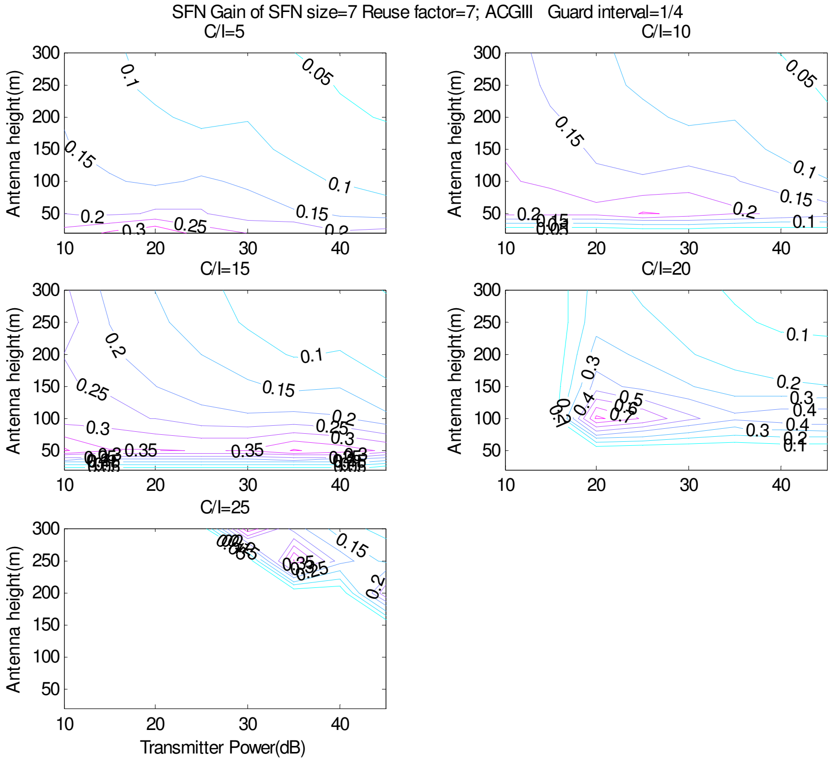


Figure A14-5. The SFN gain of a SFN size=7 and reuse factor=7; ACG III coverage; Guard interval=1/4

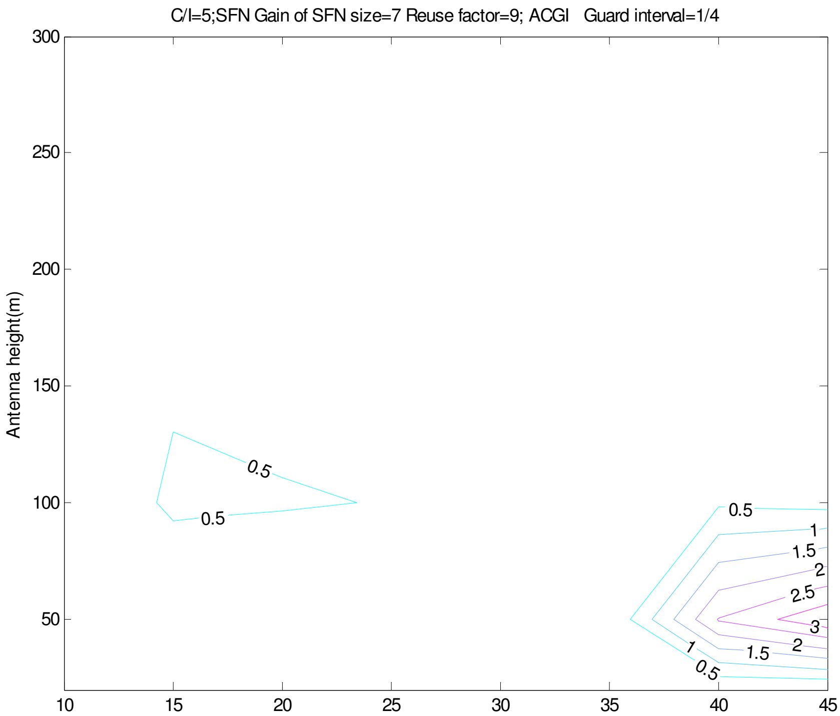


Figure A14-6. The SFN gain of a SFN size=7 and reuse factor=9; ACG I coverage; Guard interval=1/4

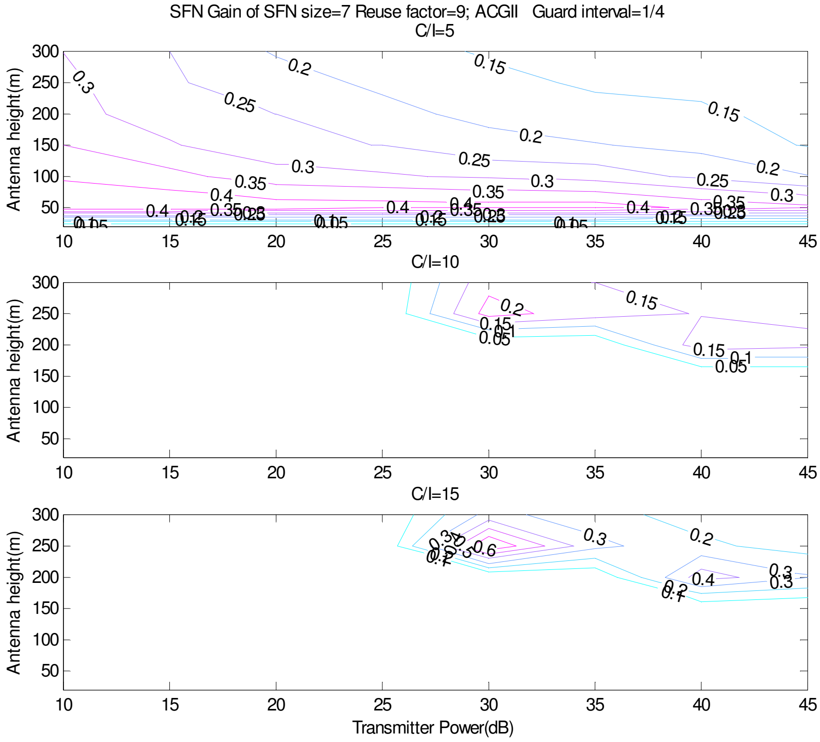


Figure A14-7. The SFN gain of a SFN size=7 and reuse factor=9; ACG II coverage; Guard interval=1/4

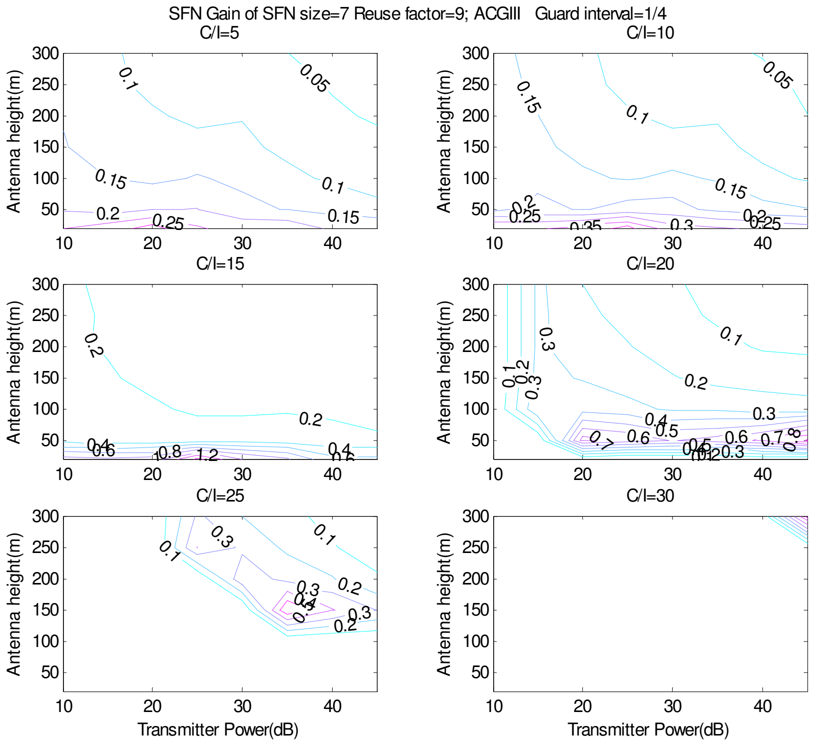


Figure A14-8. The SFN gain of a SFN size=7 and reuse factor=9; ACG III coverage; Guard interval=1/4