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International Telecommunication Union
Radiocommunication Sector

Report ITU-R BT.2549-0

(03/2025)

BT Series: Broadcasting service (television)

Terrestrial multimedia mobile broadcasting System L network planning and evaluation

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2025

REPORT ITU-R BT.2549-0

Terrestrial multimedia mobile broadcasting System L network planning and evaluation

(2025)

Keywords

PSM, broadcast, audiovisual media, LTE-based 5G terrestrial broadcast, 5G Broadcast, hybrid broadcast/unicast, network coverage, network capacity

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List of acronyms and abbreviations

3GPP	3rd Generation Partnership Project
BNO	Broadcast network operator
CAS	Cell acquisition subframe
CDF	Cumulative distribution function
C/*I*	Carrier to interferer ratio
C/*N*	Carrier to noise ratio
CM	Car mounted
COD	Code rate
COFDM	Coded orthogonal frequency division multiplexing
CP	Cyclic prefix (mobile term) – equivalent to Guard Interval (broadcast term)
DAB	Digital audio broadcasting
DTM	Digital terrain model
DTT	Digital terrestrial television
DVB	Digital video broadcasting
DVB-H	Digital video broadcasting – Hand held
DVB-T	Digital video broadcasting – First generation terrestrial
DVB-T2	Digital video broadcasting – Second generation terrestrial
EIRP	Equivalent isotropically radiated power
ERP	Equivalent (or Effective) radiated power
FFT	Fast Fourier Transform
GE06	Geneva Agreement 2006
HHIC	Handheld in car
HHPO	Handheld portable outdoor
HPHT	High-power high-tower
ICI	Inter carrier interference
ISD	Inter-site distance
ISDB-T 1seg	Integrated services digital broadcasting – Terrestrial for handheld mobile reception
LP	Location percentage
LPLT	Low-power low-tower
LTE	Long term evolution
LTE-B / MediaFlo	Qualcomm proprietary broadcast system aimed at handheld reception
MCS	Modulation and coding scheme
MFN	Multi frequency network
MNO	Mobile network operator

MOD	Modulation
MPMT	Medium-power medium-tower
OFDM	Orthogonal frequency-division multiplexing
PMCH	Physical multicast channel
PSM	Public service media
QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
RB	Resource block
SFN	Single frequency network
SINR	Signal to interference plus noise ratio
SNR	Signal to noise ratio

Introduction

The way in which the content and services of Public Service Media (PSM) organizations are delivered is evolving, particularly driven by the popularity of personal devices (smartphones, tablets) for accessing audiovisual media.

Whilst PSM content and services can be accessed on smartphones and tablets, this is only under conditions that do not comply with the fundamental requirements of PSM organizations. These requirements include, in particular, the need to deliver linear services free to air to all audiences, everywhere and at any time. This so-called universality principle lies at the core of the PSM remit.

Since the early 2000s, therefore, PSM organisations have tried to establish full access of such devices to free to air content by including a broadcast receiver within them. All these attempts, which used different broadcast technologies (Digital Video Broadcasting – Handheld (DVB-H), MediaFlo, Integrated Services Digital Broadcasting – Terrestrial for handheld mobile reception (ISDB-T 1seg), Digital Video Broadcasting – Second Generation Terrestrial (DVB-T2) Lite, etc.), have been unsuccessful.

The new technology called LTE-based 5G Terrestrial Broadcast (abbreviated to "5G Broadcast" in this Report and referred to as System-L in ITU-R publications related to Terrestrial Multimedia Mobile Broadcasting), developed and specified as part of the general mobile communication technology of 3rd Generation Partnership Project (3GPP), is a broadcast mode of operation that seems to be a promising candidate for finally allowing all PSM services, both linear and nonlinear, to reach smartphones and tablets.

Many broadcasting organizations around the world are considering 5G Broadcast. However, before adopting this new technology it is crucial for PSM organisations to understand what the implications of such a decision would be. This refers to the potential and pitfalls of this new audio-visual distribution option in terms of technology, regulatory constraints and business implications. This Report sheds some light on the network planning of 5G Broadcast (System-L). The frequency planning of 5G Broadcast, including sharing and compatibility between 5G Broadcast and Digital terrestrial television (DTT) in the spectrum range 470-694 MHz is dealt with in a separate Report [1].

Extensive studies have been carried out. Networks based on theoretical regular topologies and on real existing sites have been investigated, using different sets of scenarios and related technical parameters (as described in this Report and its Annexes). One aim of these studies is to address whether existing broadcasting infrastructure, including High-Power High-Tower (HPHT) and Medium-Power Medium-Tower (MPMT) could be employed to provide 5G Broadcast (System-L) services to car mounted and handheld portable receivers.

In the remaining parts of this Report, for sake of limiting the size of the text, the name “5G Broadcast” is used. It refers in this Report exclusively to System-L as defined in Recommendation ITU-R BT.1833.

The main findings of the studies carried out in this Report can be summarised as follows: 5G Broadcast can be supported by two modes of operation:

1 Broadcast-only mode, in which the receiver relies only on the broadcast signal received from the 5G Broadcast transmitters.

2 Hybrid broadcast/unicast mode, in which the receiver switches seamlessly between the broadcast signal received from the 5G Broadcast transmitters and the unicast signal received from a 4G/5G mobile cellular network or WiFi, depending on the quality of reception (see [10] and [11]).

In broadcast-only mode, as there is no way to retransmit content in case of loss of broadcast reception, a high level of location percentage (LP), usually in the order of 95% for portable/fixed reception and 99% for mobile reception, must be ensured in all pixels[1] forming the coverage area, including at its edge. Due to this constraint, mixed topology networks, with a site density of around 22 sites per 10 000 km^2 would be needed to ensure the required coverage while providing sufficiently high Signal to Interference plus Noise Ratio (SINR) levels, up to 15 dB, to allow the use of efficient 5G Broadcast modulation and coding schemes. These schemes can offer throughputs of up to 12 Mbit/s in 8 MHz in mobile and handheld portable outdoor (HHPO)reception conditions.

In hybrid broadcast/unicast operation, with a complementary coverage target using unicast set to around 10% of the locations in each pixel on average across the coverage area, a mixed topology broadcast network, with a site density of around 11 sites per 10 000 km^2 would be needed to ensure the required coverage while providing SINR levels up to 15 dB. This offers similar throughputs as above in similar reception conditions.

[1] A pixel is a small area of 100 × 100 m, in which the standard distribution of field strength applies.

The hybrid broadcast/unicast seamless switching offers a flexibility in the deployment of the 5G Broadcast network and an improvement of the quality of service, by making use of both the broadcast and unicast networks where and when needed. It also allows a reduction in the number of 5G Broadcast sites required to cover an area, as it reduces the need to install many additional MPMT and Low-Power Low-Tower (LPLT) 5G Broadcast sites to extend the coverage to high levels. This conclusion is based on the studies of theoretical networks in this Report. However, it is well experienced when planning real terrestrial broadcasting networks, that the bulk, e.g. 80%, of population coverage can be achieved with a relatively low number of HPHT sites, while the remaining 20% of population would require hundreds, sometime thousands, of complementary MPMT and LPLT sites to reach near full population coverage[2].

Three networks based on real transmission sites in Italy, Denmark and Germany, where studied, showing significant differences in terms of coverage targets, terrain morphology and population distribution. The results of these studies show a range of required sites densities for 5G Broadcast networks that can ensure a first bulk of population coverage, while the remaining coverage can be ensured by unicast, provided that seamless switching is implemented in the receivers and on the network side.

This Report also provides guidelines in terms of choice of the cyclic prefix and the frequency planning mode (single frequency network (SFN), multi frequency network (MFN) or mixture) depending on the requirements.

1 5G Broadcast system and planning parameters

1.1 5G Broadcast system parameters

Table 1 describes the valid combinations of system parameters for 5G Broadcast data signals: cell acquisition subframe (CAS) signalling can only use variant 1, while the useful payload (carried by the PMCH – Physical Multicast Channel) may adopt any variant from 2 to 6. Those parameters were derived from 3GPP TS36.211 v16.1.0 (2020-03) "E-UTRA Physical channels and modulation (Release 16)".

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[2] The switch to unicast when the receiver is in mobile or portable outdoor reception modes, requires subscription to a Mobile network. This does not meet the free to air requirement for the user. However, it should be noted that the implementation and use of the hybrid broadcast/unicast operation is optional for:

- the user, who can decide to activate this seamless switching in the Application or otherwise.
- the broadcaster, who needs to send the concerned content simultaneously to the content distribution network (CDN) and to the 5G Broadcast transmitter(s) to make the hybrid mode work.
- the 5G Broadcast network planner/operator, who can decide the level of reliance on unicast versus broadcast in the network. The proposed evaluation method using the proportional count of population, as described in the Report, allows the operator to set the cursor of coverage between the broadcast and unicast based on various technical and non-technical criteria.

Also, in portable indoor reception mode, access to unicast can be done through WiFi, without the need for subscription.

It should also be noted that the hybrid broadcast/unicast operation will impose the higher latency of the unicast distribution over the end-to end transmission, as the broadcast-only transmission will need to be delayed further to ensure the same time of arrival from the two systems. This aspect, and any possible solution to mitigate it, is not assessed in this Report.

TABLE 1

5G Broadcast system parameters

Variant	Carrier spacing Δf (kHz)	Subcarriers / RB	OFDM symbols / subframe	Tu (µs)	#Tu samples	CP (µs)	#CP samples	Ts (µs)	CP ratio	Dx	Dy	Nyquist factor	Nyquist limit (µs)	EI- equalisation interval / Tp [(1)] (µs)
1	15.00	12	14	66.7	2 044	4.7	144	71.40	5/71	3	5	1/3	22.23	19.80
2	15.00	12	12	66.7	2 045	16.7	512	83.40	1/4	1	4	1	66.70	59.40
3	7.50	24	6	133.3	4 099	33.3	1 024	166.60	1/4	2	2	1/2	66.65	59.36
4	1.25	144	1	800	24 576	200	6 144	1 000.00	1/4	3	1	1/3	266.67	237.50
5	2.50	72	2	400	12 288	100	3 072	500.00	1/4	2	1	1/2	200.00	178.13
6	0.37	486	1	2 700	82 944	300	9 216	3 000.00	1/9	3	1	1/3	900.00	801.56

(1) Equalization interval duration is usually taken as 57/64 of the Nyquist limit to reflect real implementation of receivers.

NOTE – In coded Orthogonal Frequency Division Multiplexing (OFDM)-based broadcasting systems with fixed bandwidth, a Fast Fourier Transform (FFT) size is specified. In 5G Broadcast system, as the channel width can vary, no FFT size is specified, but rather a carrier spacing:

– 100 µs CP → 2.5 kHz carrier spacing;

– 200 µs CP →1.25 kHz carrier spacing;

– 300 µs CP →0.37 kHz carrier spacing.

As a comparison, if a 5 MHz channel is considered in 5G Broadcast, with 25 Resource Blocks (RB) (180 kHz / RB), the above figures would correspond to 2K / 4K / 13.5K FFT respectively.

1.2 5G Broadcast reception modes and parameters

Table 2 deals with the reception parameters used in the simulations for each of the agreed scenarios, with the following additional assumptions:

– The receiver and transmitters are assumed to use the same polarization; hence no polarization discrimination is assumed.

– The receiver and the transmitter are considered as being in the same environment; the receiver clutter height depends on the environment as follows:
  - – Clutter height = 10 m for a rural or suburban environment;
  - – Clutter height = 20 m for an urban environment;
  - – Clutter height = 30 m for a dense urban environment (only for reference, not considered in the simulations).

TABLE 2

Reception parameters used in the simulations for each of the agreed scenarios

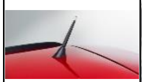
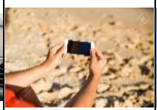
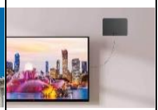
Scenarios	**1**	**2**	**3**	**4**	**5**	**6**
Reception parameters	Car mounted (CM)	Handheld In-Car	Handheld portable outdoor	Fixed rooftop (FRT)	Portable indoor (PI)	Handheld portable indoor (P-H/Internal Antenna)
Type of reception	Mobile	Mobile	Portable	Fixed	Portable	Portable
						
Path type	Land	Land	Land	Land	Land	Land
Receiver antenna gain, including possible body loss and receiver diversity gain (dBi)	3	−5.8	−5.8	13	1.7	−5.8
Entry loss (dB) – Building/vehicle	0	9	0	0	11	11
Standard deviation associated with entry loss (dB)	0	5	0	0	6	6
Receiver height (m) (1)	1.5	1.5	1.5	10	1.5	1.5
Receiver feeder loss (dB)	0	0	0	4	0	0
Other losses (2) (dB)	1	1	1	1	1	1
Receiver strategy for signals from the same SFN	Maximum *C*/*I*					
Location variation standard deviation (dB)	5.5					

TABLE 2 (*end*)

Scenarios	1	2	3	4	5	6
Receiver noise figure (dB)	6	9	9	6	9	9
Percentage of locations to protect on a small area (3)	95%	95%	95%	95%	95%	95%

(1) Received field strength is predicted using the Recommendation ITU-R P.1546-5 model at the specified receiver height, considering the receiver clutter height corresponding to the receiver environment (rural, suburban, urban). At 600 MHz, for rural environment, this corresponds to a height loss of 16.8 dB, for suburban environment to a height loss of 17 dB and for urban environment to a height loss of 23.3 dB for a 1.5 m reception height when compared to the reception at the height of the representative receiver clutter height of the corresponding environment.

(2) Other losses account for implementation losses (front-end performances). There could be other losses related to the performance of the transmitter, like Error Vector Magnitude for LPLT transmitters, but these are not considered in these studies.

(3) For mobile and portable reception, the percentage of locations to protect on a small area can also include 70%, 90% and 99%; for fixed reception, 90% can also be considered.

1.3 Modulation and coding schemes, SINR to capacity mapping

Tables 3, 4 and 5 provide an indicative mapping of the 5G Broadcast system capacity with the corresponding SINR in various reception environments, for a 5 MHz channel. They are based on the recent results relative to link-level simulations of different 5G Broadcast configurations in a paper presented to 2020 IBC [7] for the SINR values.

The 5 MHz channel capacity for the different modulation and coding schemes (MCS) configurations permitted by the 5G Broadcast system were derived from 3GPP TS 36.213 version 16.3.0 Release 16 [8]. As the capacity slightly varies with the number of resource blocks used in the 3GPP system (data mapping varies with the number of resource blocks, see § 11 of the 3GPP TS 36.213 document), the corresponding values differ slightly from the IBC paper, as this latter is based on 10 MHz channels. In addition, only the information regarding SINR values without possible time-interleaving enhancements are presented here, as time-interleaving is not a standardized 3GPP feature for the time being.

TABLE 3

SINR to capacity mapping for 100 µs CP

MCS index	MOD	COD	Raw spectral efficiency (b/s/Hz)	Effective spectral efficiency (b/s/Hz)	Capacity (Mbit/s) in 5 MHz channel	Capacity (Mbit/s) in 8 MHz channel	Fixed SINR (dB)	Portable SINR (dB)	Mobile SINR (dB)
0	QPSK	0.126	0.252	0.133	0.663	1.07			
1	QPSK	0.167	0.335	0.176	0.881	1.38			
2	QPSK	0.203	0.406	0.214	1.069	1.76			
3	QPSK	0.262	0.524	0.276	1.381	2.29			
4	QPSK	0.333	0.667	0.351	1.755	2.78		3.6	3.8
5	QPSK	0.410	0.821	0.432	2.161	3.41		4.6	4.6
6	QPSK	0.481	0.963	0.507	2.535	4.03		5.6	5.8
7	QPSK	0.576	1.153	0.607	3.034	4.84		7	7.2
8	QPSK	0.647	1.295	0.682	3.409	5.41		7.8	8.2
9	QPSK	0.742	1.484	0.782	3.908	6.05		9.2	9.6
10	16-QAM	0.371	1.484	0.782	3.908	6.05		8.2	8.6
11	16-QAM	0.407	1.627	0.856	4.282	6.79		9	9.4
12	16-QAM	0.460	1.840	0.969	4.844	7.79		10	10.4
13	16-QAM	0.531	2.124	1.119	5.593	8.92		11.2	11.4
14	16-QAM	0.598	2.391	1.259	6.295	10.04		12.4	12.8
15	16-QAM	0.669	2.676	1.409	7.043	11.16		13.2	13.8
16	16-QAM	0.716	2.865	1.509	7.543	11.91		14.2	14.8
17	64-QAM	0.478	2.865	1.509	7.543	11.91		14.4	15
18	64-QAM	0.493	2.960	1.558	7.792	12.64		15	15.6
19	64-QAM	0.564	3.387	1.783	8.915	14.32		16.4	17
20	64-QAM	0.612	3.671	1.933	9.664	15.44		17.4	18.6

TABLE 3 (*end*)

MCS index	MOD	COD	Raw spectral efficiency (b/s/Hz)	Effective spectral efficiency (b/s/Hz)	Capacity (Mbit/s) in 5 MHz channel	Capacity (Mbit/s) in 8 MHz channel	Fixed SINR (dB)	Portable SINR (dB)	Mobile SINR (dB)
21	64-QAM	0.659	3.956	2.083	10.413	16.57		18.4	19.8
22	64-QAM	0.707	4.240	2.232	11.162	17.88		19.6	21.2
23	64-QAM	0.776	4.658	2.452	12.262	19.35		21.6	25
24	64-QAM	0.836	5.013	2.640	13.198	20.85		26.4	
25	64-QAM	0.871	5.227	2.752	13.759	22.35		28	
26	64-QAM	0.942	5.653	2.976	14.882				
27	64-QAM	0.978	5.867	3.089	15.444				
28	256-QAM	0.733	5.867	3.089	15.444				
29	256-QAM	0.760	6.080	3.201	16.006				
30	256-QAM	0.813	6.507	3.426	17.129				
31	256-QAM	0.849	6.791	3.576	17.878				
32	256-QAM	0.919	7.351	3.870	19.352				
33	256-QAM	0.954	7.636	4.020	20.101				
34	256-QAM	0.990	7.920	4.170	20.849				

TABLE 4

SINR to capacity mapping for 200 µs CP

MCS index	MOD	COD	Raw spectral efficiency (b/s/Hz)	Effective spectral efficiency (b/s/Hz)	Capacity (Mbit/s) in 5 MHz channel	Capacity (Mbit/s) in 8 MHz channel	Fixed SINR (dB)	Portable SINR (dB)	Mobile SINR (dB)
0	QPSK	0.113	0.227	0.133	0.663				
1	QPSK	0.151	0.301	0.176	0.881				
2	QPSK	0.183	0.365	0.214	1.069				
3	QPSK	0.236	0.472	0.276	1.381				
4	QPSK	0.300	0.600	0.351	1.755				
5	QPSK	0.369	0.739	0.432	2.161	3.41	4	4	4.6
6	QPSK	0.433	0.867	0.507	2.535	4.03	4.8	5	5.6
7	QPSK	0.519	1.037	0.607	3.034	4.84	6	6.2	6.8
8	QPSK	0.583	1.165	0.682	3.409	5.41	6.8	7	7.8
9	QPSK	0.668	1.336	0.782	3.908	6.05	8	8.2	9
10	16-QAM	0.334	1.336	0.782	3.908	6.05	7.8	7.8	8.4
11	16-QAM	0.366	1.464	0.856	4.282	6.79	8.4	8.4	9.2
12	16-QAM	0.414	1.656	0.969	4.844	7.79	9.2	9.2	10.2
13	16-QAM	0.478	1.912	1.119	5.593	8.92	10.4	10.4	11.4
14	16-QAM	0.538	2.152	1.259	6.295	10.04	11.6	11.4	13
15	16-QAM	0.602	2.408	1.409	7.043	11.16	12.4	12.4	14
16	16-QAM	0.645	2.579	1.509	7.543	11.91	13.2	13	15.2
17	64-QAM	0.430	2.579	1.509	7.543	11.91	13.8	13.4	15.8
18	64-QAM	0.444	2.664	1.558	7.792	12.64	14.4	14.4	17
19	64-QAM	0.508	3.048	1.783	8.915	14.32	15.6	15.4	19.6
20	64-QAM	0.551	3.304	1.933	9.664	15.44	16.8	16.4	22.8
21	64-QAM	0.593	3.560	2.083	10.413	16.57	17.8	17.2	

TABLE 4 (*end*)

MCS index	MOD	COD	Raw spectral efficiency (b/s/Hz)	Effective spectral efficiency (b/s/Hz)	Capacity (Mbit/s) in 5 MHz channel	Capacity (Mbit/s) in 8 MHz channel	Fixed SINR (dB)	Portable SINR (dB)	Mobile SINR (dB)
22	64-QAM	0.636	3.816	2.232	11.162	17.88	19.4	18.2	
23	64-QAM	0.699	4.192	2.452	12.262	19.35	22.8	21.8	
24	64-QAM	0.752	4.512	2.640	13.198				
25	64-QAM	0.784	4.704	2.752	13.759				
26	64-QAM	0.848	5.088	2.976	14.882				
27	64-QAM	0.880	5.280	3.089	15.444				
28	256-QAM	0.660	5.280	3.089	15.444				
29	256-QAM	0.684	5.472	3.201	16.006				
30	256-QAM	0.732	5.856	3.426	17.129				
31	256-QAM	0.764	6.112	3.576	17.878				
32	256-QAM	0.827	6.616	3.870	19.352				
33	256-QAM	0.859	6.872	4.020	20.101				
34	256-QAM	0.891	7.128	4.170	20.849				

TABLE 5

SINR to capacity mapping for 300 µs CP

MCS index	MOD	COD	Raw spectral efficiency (b/s/Hz)	Effective spectral efficiency (b/s/Hz)	Capacity (Mbit/s) in 5 MHz channel	Capacity (Mbit/s) in 8 MHz channel	Fixed SINR (dB)	Portable SINR (dB)	Mobile SINR (1) (dB)
0	QPSK	0.091	0.182	0.132	0.658				–
1	QPSK	0.122	0.245	0.177	0.887				–
2	QPSK	0.145	0.291	0.211	1.053				–
3	QPSK	0.191	0.383	0.277	1.386				–
4	QPSK	0.240	0.481	0.348	1.739				–
5	QPSK	0.301	0.603	0.436	2.181				–
6	QPSK	0.347	0.695	0.503	2.514	4.09	3.6	4	–
7	QPSK	0.428	0.855	0.619	3.097	4.77	4.6	4.8	–
8	QPSK	0.479	0.959	0.694	3.471	5.34	5.2	5.6	–
9	QPSK	0.548	1.097	0.794	3.970	5.96	6	6.4	–
10	QPSK	0.582	2.327	0.842	4.212	6.70	6.8	7.2	–
11	16-QAM	0.291	1.164	0.842	4.212				–
12	16-QAM	0.330	1.319	0.955	4.774				–
13	16-QAM	0.381	1.526	1.104	5.522	8.90	8.6	8.8	–
14	16-QAM	0.428	1.713	1.240	6.201	9.94	9.8	9.8	–
15	16-QAM	0.480	1.920	1.390	6.950	11.05	10.2	10.6	–
16	16-QAM	0.514	2.058	1.490	7.449	11.93	10.8	11	–
17	16-QAM	0.532	3.190	1.540	7.699	12.75	11.6	11.8	–
18	16-QAM	0.615	3.687	1.779	8.897	14.24	12.8	13	–
19	16-QAM	0.658	3.946	1.904	9.521	15.24	13.6	13.6	–
20	16-QAM	0.712	4.270	2.061	10.304	16.58	14.6	14.8	–
21	64-QAM	0.474	2.847	2.061	10.304	16.58	15	14.8	–

TABLE 5 (*end*)

MCS index	MOD	COD	Raw spectral efficiency (b/s/Hz)	Effective spectral efficiency (b/s/Hz)	Capacity (Mbit/s) in 5 MHz channel	Capacity (Mbit/s) in 8 MHz channel	Fixed SINR (dB)	Portable SINR (dB)	Mobile SINR (1) (dB)
22	64-QAM	0.509	3.053	2.211	11.053	17.89	15.8	15.6	–
23	64-QAM	0.567	3.402	2.463	12.314	19.26	17.2	16.8	–
24	64-QAM	0.607	3.643	2.637	13.187	20.73	18.2	17.8	–
25	64-QAM	0.634	3.804	2.754	13.770	22.36	19	18.2	–
26	64-QAM	0.679	4.072	2.948	14.739	23.96	20.6	19.4	–
27	64-QAM	0.702	4.210	3.048	15.239	24.77	21.4	19.8	–
28	256-QAM	0.549	4.394	3.181	15.904				–
29	256-QAM	0.592	4.736	3.429	17.144				–
30	256-QAM	0.618	4.943	3.579	17.893				–
31	256-QAM	0.665	5.320	3.852	19.258				–
32	256-QAM	0.692	5.537	4.008	20.041				–
33	256-QAM	0.716	5.726	4.145	20.727				–
34	256-QAM	0.827	6.618	4.791	23.956				–

(1) Not relevant. A CP of 300 μs is not suitable for mobile reception – see § 2.8.2.

The link-level simulations presented in the IBC paper [7] do not cover all configuration cases and all reception modes. Moreover, for fixed reception, they correspond to the use of one antenna, while for portable/mobile reception two antennas are assumed, leading to diversity gain in the receivers. As such, they provide an upper bound on the capacity associated to a given SINR value.

1.4 Capacity for key SINR values

Tables 3, 4 and 5 above provide an indicative mapping of the 5G Broadcast system capacity with the corresponding signal to noise and Interference ratio (SINR) in various reception environments.

Based on the information above, Tables 6, 7 and 8 give an indicative mapping of the key SINR values reflected in § 2.7 with the corresponding capacity (upper bound) for the different cyclic prefix (CP) values and target reception modes.

TABLE 6

Upper bound on capacity for 100 µs CP and key SINR values, in 8 MHz

SINR (dB)	Car mounted handheld in car capacity (Mbit/s) in 8 MHz channel	Handheld portable outdoor portable indoor handheld portable indoor capacity (Mbit/s) in 8 MHz channel	Fixed rooftop capacity (Mbit/s) in 8 MHz channel
0	–	–	N/A
5	3.41 (MCS 5)	3.41 (MCS 5)	N/A
10	6.79 (MCS 11)	7.79 (MCS 12)	N/A
15	11.91 (MCS 17)	12.64 (MCS 18)	N/A
20	16.57 (MCS 21)	17.88 (MCS 22)	N/A
25	19.35 (MCS 23)	19.35 (MCS 23)	N/A

TABLE 7

Upper bound on capacity for 200 µs CP and key SINR values, in 8 MHz

SINR (dB)	Car mounted handheld in car capacity (Mbit/s) in 8 MHz channel	Handheld portable outdoor portable indoor handheld portable indoor capacity (Mbit/s) in 8 MHz channel	Fixed rooftop capacity (Mbit/s) in 8 MHz channel
0	–	–	–
5	3.41 (MCS 5)	4.03 (MCS 6)	4.03 (MCS 6)
10	6.79 (MCS 11)	7.79 (MCS 12)	7.79 (MCS 12)
15	11.16 (MCS 15)	12.64 (MCS 18)	12.64 (MCS 18)
20	14.32 (MCS 19)	17.88 (MCS 22)	17.88 (MCS 22)
25	–	–	–

TABLE 8

Upper bound on capacity for 300 µs CP and key SINR values, in 8 MHz

SINR (dB)	Car mounted handheld in car capacity (Mbit/s) in 8 MHz channel	Handheld portable outdoor portable indoor handheld portable indoor capacity (Mbit/s) in 8 MHz channel	Fixed rooftop capacity (Mbit/s) in 8 MHz channel
0	–	-	-
5	–	4.77 (MCS 7)	4.77 (MCS 7)
10	–	9.94 (MCS 14)	9.94 (MCS 14)
15	–	16.58 (MCS 21)	16.58 (MCS 21)
20	–	24.77 (MCS 27)	22.36 (MCS 25)
25	–		

1.5 Indicative 5G Broadcast planning levels for SINR of 10 dB

The target percentage location differs depending on the reception mode. Usually, mobile reception requires 99% location percentage, while portable outdoor and fixed reception may require 95% location percentage. However, the planning levels shown in Table 9 are all calculated for 95% location percentage for sake of comparison only. The Table also shows planning levels for 70% location percentage, for information.

In addition, the roof top reception case is added as an indication, as the main target for 5G Broadcast is mobile and portable reception.

TABLE 9

Indicative 5G Broadcast planning levels for SINR of 10 dB

	5G Broadcast	**5G Broadcast**	**5G Broadcast**	**5G Broadcast**
	Car mounted	**Handheld in-car**	**Handheld portable outdoor**	**Fixed rooftop**
Frequency (MHz)	650	650	650	650
Minimum *C*/*N* required by system (dB)	10	10	10	10
Receiver noise figure (dB)	6	9	9	6
Equivalent noise bandwidth (MHz)	7.2	7.2	7.2	7.2
Receiver noise input power (dBW)	−129.4	−126.4	−126.4	−129.4
Minimum receiver signal input power (dBW)	−119.4	−116.4	−116.4	−119.4
Minimum equivalent receiver input voltage, 75 ohm (dBμV)	19.3	22.3	22.3	19.3
Antenna gain relative to half dipole (dB)	0.8	−7.9	−7.9	10.8
Feeder loss (dB)	0	0	0	4
Effective antenna aperture (dBm^2)	−14.8	−23.5	−23.5	−4.8
Minimum pfd at receiving location ($dB(W)/m^2$)	−104.6	-92.9	−92.9	−110.6
Minimum equivalent field strength at receiving location (dBμV/m)	41.2	52.9	52.9	35.2
Allowance for man-made noise (dB)	1	1	1	1
Penetration in loss (building or vehicle) (dB)	0	9	0	0
Standard deviation of the penetration loss (dB)	0	5	0	0
Diversity gain (dB)	0	0	0	0
Location probability (%)	70	70	70	70
Distribution factor	0.5244	0.5244	0.5244	0.5244
Standard deviation	5.5	5.5	5.5	5.5
Location correction factor (dB)	2.8842	2.8842	2.8842	2.8842
Minimum median equivalent field strength at reception height (1), 50% time and 50% locations (dBμV/m)	45.0	65.7	56.7	39.0
Location probability (%)	95	95	95	95
Distribution factor	1.6449	1.6449	1.6449	1.6449
Standard deviation	5.5	5.5	5.5	5.5
Location correction factor (dB)	9.04669	9.04669	9.04669	9.04669
Minimum median equivalent field strength at reception height (1), 50% time and 50% locations (dBμV/m)	51.2	71.9	62.9	45.2

(1) 10 m for fixed reception and 1.5 m for the other reception modes.

The required minimum median planning level for car mounted is significantly lower than for handheld portable outdoor (HHPO) reception, and this latter is significantly lower than the planning level for handheld in-car reception.

This gives an idea about the relative planning level requirements between the main reception modes of the 5G Broadcast system. However, actual network planning is not done based on these required planning levels, as it needs to consider interference between co-channel sites inside the same network and possible network gain in the case of SFN. The following sections explain the methodology and provide results of Monte Carlo simulation for coverage prediction of 5G Broadcast networks.

1.6 Transmission parameters

Three network types were agreed for the modelling of 5G Broadcast networks:

– Network type 1: High Power High Tower (HPHT).

– Network type 2: Medium Power Medium Tower (MPMT).

– Network type 3: Full cellular / Low Power Low Tower (LPLT).

NOTE – Antenna polarization has no incidence on simulation as both the transmitter and receiver are assumed to use the same polarization. This parameter is not described in the following paragraphs.

As the parameters for modelling the HPHT and MPMT networks are taken from real-life broadcast deployments, all the equivalent isotropically radiated power (EIRP) values reported in the following paragraphs are referenced by convention to an 8 MHz bandwidth (7.2 MHz effective channel). To use those EIRP values for a different 3GPP bandwidth, a specific correction factor must be applied as described in § 1.7.

1.6.1 Network type 1 parameters – HPHT

Table 10 describes the parameters used for the modelling of HPHT networks. Annex 2 provides useful analysis of inter-site distance of HPHT networks in Sweden, France and the United Kingdom.

TABLE 10

Parameters used for the modelling of HPHT networks

Network type	**HPHT**
Inter-site distance (km) – ISD	50, 60, 70, 80, 100, 120
EIRP (dBm)	76, 79, 82, 85 (1)
Antenna height above ground level (m)	200, 300, 350
Tilt (° positive below horizontal)	1, 2, 3 (2)
Environment type	Rural
Clutter height (m)	10

(1) Corresponding to 25 kW, 50 kW, 100 kW and 200 kW ERP respectively.

(2) Vertical antenna pattern according to ITU-R BT.2337 High Power for DVB-T/DVB-T2.

1.6.2 Network type 2 parameters – MPMT

Table 11 describes the parameters used for the modelling of MPMT networks.

TABLE 11

Parameters used for the modelling of MPMT networks

Network type	MPMT
Inter-Site Distance (km) – ISD	20, 30, 40, 50
EIRP (dBm)	62, 69, 72 (1)
Antenna height above ground level (m)	80
Tilt (° positive below horizontal)	0 (2)
Environment type	Rural
Clutter height (m)	10

(1) Corresponding to 1 kW, 5 kW and 10 kW ERP respectively.

(2) No consideration of the vertical antenna pattern in the calculation.

1.6.3 Network type 3 parameters – LPLT

Report ITU-R M.2292 [12]has been used as the source to identify LPLT network parameters (shown in Table 12).

TABLE 12

Parameters used for the modelling of LPLT networks – Report ITU-R M.2292

Network type	Full cellular – LPLT		
Environment type	**Rural**	**Suburban**	**Urban**
Inter-site distance (km) – ISD (1)	12	3	3
EIRP (dBm) (2)	57.4 / 59.4	57.4 / 59.4	57.4 / 59.4
Antenna height above ground level (m)	30	30	30
Tilt (° positive below horizontal)	3° (3)		
Clutter height (m)	10	10	20

(1) Calculated from a specified cell radius > 5 km (8 km typical) for macro rural scenario and 0.5–5 km (2 km typical) for macro urban/suburban scenario.

(2) 57.4 dBm corresponds to approximately 550 W EIRP. This value is derived from Base station EIRP/sector of 58 dBm in 10 MHz, with 0.6 dB reduction for the 8/10 MHz ratio. A 3 dB reduction is specified in Report ITU-R M.2292 to take account of an average base station activity factor of 50%; this reduction is not applied in the case of 5G Broadcast as the system is always active.

(3) Recommendation ITU-R F.1336 [13] (equation 1d) with 9.1 degrees 3 dB beamwidth in the elevation plane and $k = 0.3$.

1.7 Correction factor with respect to the channel bandwidth

When considering a different channel bandwidth, and more specifically in the case of 3GPP agreed system bandwidths, a correction must be applied to the EIRP values to keep the EIRP / MHz constant, as well as the resulting signal-to-noise ratio (SNR) in case the bandwidth is changed. The corresponding correction is given in Table 13.

TABLE 13

EIRP correction factor depending on channel bandwidth

Channel bandwidth (MHz)	1.4	3	5	6	7	8	10	15	20
Effective bandwidth (MHz)	1.08	2.7	4.5	5.4	6.3	7.2	9	13.5	18
Correction factor (dB)	−8.2	−4.3	−2.0	−1.2	–0.6	0	1	2.7	4

Note that some simulations were made for 5 MHz bandwidth, using a correction factor of −2.4 dB instead of −2.0 dB. This difference of 0.4 dB was due to the initial assumption (before the inclusion of the 8 MHz bandwidth in the related 3GPP standard) that the effective bandwidth of the 8 MHz variant of the 5G Broadcast signal was going to be the same as for DVB-T2 (7.77 MHz). However, when the 8 MHz bandwidth was included in the 3GPP standard, the effective bandwidth was set to 7.2 MHz as shown above. For this reason, the predicted coverage figures for these cases are conservative.

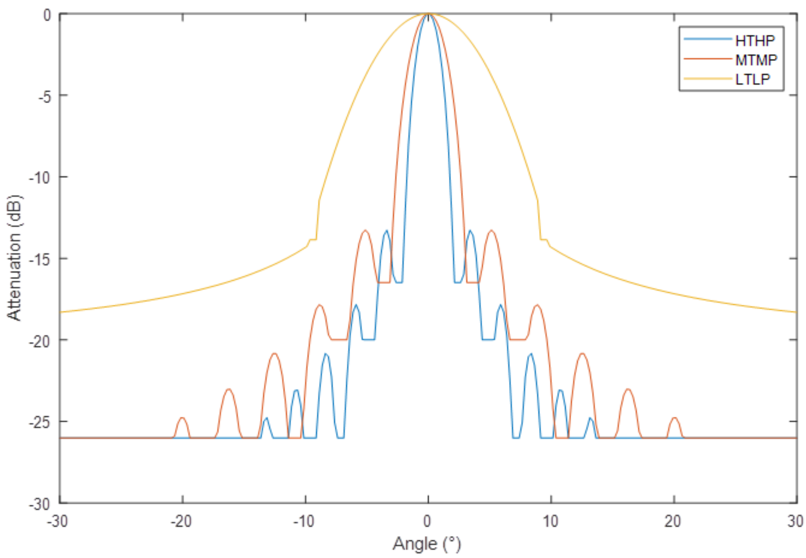
1.8 Reference vertical radiation patterns

Figure 1 illustrates the resulting vertical radiation patterns considered in the simulations according to the selected parameters.

NOTE – The MPMT vertical radiation pattern is given for reference only, as for MPMT no vertical radiation pattern is considered.

FIGURE 1

Vertical radiation patterns for the different types of networks (without tilt)



2 Theoretical network model, simulation methodology and results

2.1 Introduction

Theoretical network simulations are based on repeated regular hexagonal networks, where the central hexagon in the network is considered as the area of interest. Within this area of interest, SNR and

SINR are derived for a set of locations, considering different network topologies, frequency reuse patterns and reception conditions. The resulting SNR and SINR values for these locations help to build a view on the pairing of network topologies and reception modes.

Sections 2.2 to 2.5 give an overview of the parameters and assumptions taken into account in the simulations. Section 2.6 demonstrates the issue of coverage in national or regional border areas with reuse 1. The main body of results of the theoretical network simulations are presented in § 2.7 along with observations and related summaries. Section 2.8 provides analysis of two specific issues: the impact of practical antenna pattern and the Doppler performance requirements for mobile reception.

Finally, § 2.9 provides conclusions from simulation results on theoretical networks.

The set of results related to broadcast-only mode is based on a 5G Broadcast system using a 5 MHz wide channel at 600 MHz as the simulations were made prior to the standardisation in 3GPP of the 6, 7 and 8 MHz raster. The simulations for the hybrid broadcast/unicast operation were made after the above-mentioned standardization and therefore were made using an 8 MHz channel at 600 MHz. For this purpose, a constant radiated power per MHz was used, by applying the correction factors from Table 13, therefore both set of results are valid for the 8 MHz channel raster.

2.2 Network topologies and frequency reuse

The setup of the simulations typically relies on regular hexagonal networks. Several approaches are taken to establish these hexagonal networks, both in terms of geometry and possible frequency assignment.

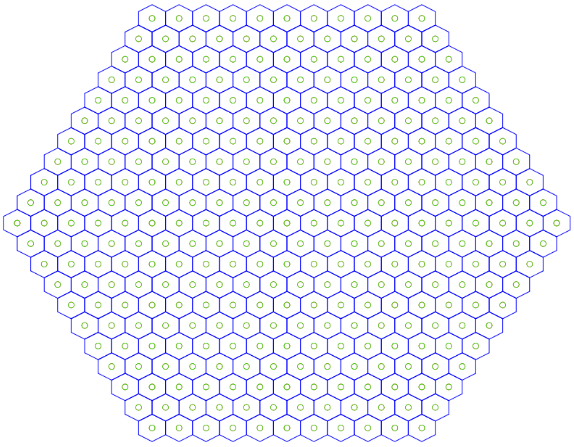
Regarding geometry, two options are considered:

Option 1: single topology network

– Option 1 is quite straightforward, using single topology networks to establish a layer of sites located on a regular grid on the area of interest, as shown in Fig. 2.
  - The geometry of a set of standard network topologies was defined based on a review of real operating networks.
  - These topologies and their associated parameters, described in detail in § 1.6, are split in the three traditional categories: HPHT, MPMT and LPLT.
  - The choice of one category and a set of associated parameters, allows to completely define the network parameters to be used for one simulation: inter-site distance (ISD), transmitter EIRP and antenna height, transmitting antenna characteristics. On this last item, while a vertical radiation pattern might be considered for some categories, an omnidirectional pattern is assumed in the horizontal plane, unless stated otherwise.

FIGURE 2

Single topology network layout (green dot: site, blue line: cell extent)



- The choice of one category and the associated ISD is a dimensioning factor in terms of network deployment cost. The relationship between the ISD and the site density is shown in Table 14: in general, the denser the network used to cover a given area, the higher are the associated deployment and running costs.

TABLE 14

Relationship between the ISD and the site density (see Note below the table)

ISD (km)	Cell area (km^2)	Site density / 10 000 km^2	Site density ratio with regard to 80 km ISD
3	7.79	1 283.0	711.1
12	124.71	80.2	44.4
20	346.41	28.9	16.0
50	2 165.06	4.6	2.6
80	5 542.56	1.8	1.0
100	8 660.25	1.2	0.6
120	12 470.77	0.8	0.4
150	19 485.57	0.5	0.3

NOTE – The site density ratio is based on the ISD of 80 km for HPHT used for the simulations results found in this Report.

Option 2: Mixed topology network

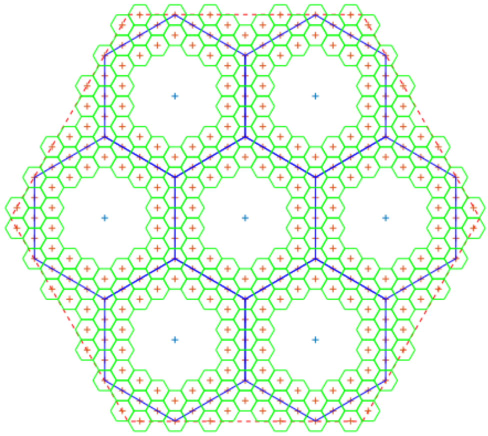
– Option 2 simulates real world deployments for broadcast networks, where a mix of topologies is found, generally between HPHT and MPMT sites. This approach is called Mixed topology, and relies on the following principles (an example of the application of these principles can be seen in Fig. 3):

- One main layer with a regular single topology network is first selected.
- One secondary layer defines a regular single topology network with a smaller ISD than in the main layer.
- Each layer has its own transmitter parameters (transmitter EIRP, antenna height, antenna characteristics) defined independently of the other layer.
- The arrangement of the main layer topology is based on the choice of a specific ISD.

- The arrangement of the secondary layer topology is based on the main layer topology, to end up with a regular arrangement between main and secondary layer sites:
  - ○ Secondary layer sites are positioned along each edge of the main layer cells.
  - ○ Each edge of the main layer cells is divided in a certain number of parts, which define the number of secondary layer cells per edge.
  - ○ Additional secondary layer cells are generated along the first set of cells created previously, leaving sparse areas around the main layer sites.

FIGURE 3

Mixed topology network layout (blue cross/line: main layer site/cell, red cross: secondary layer site, green line: secondary layer cell)



- The aim of the secondary layer is to bring a reinforced signal in the weakest areas of the main layer.

Once the geometry is defined, the frequency assigned to each cell in the network plays an important role in the assessment of the performance:

– For both single and mixed topology cases, it is possible to use a classical frequency reuse scheme:
  - frequency reuse 1[3], i.e. all sites in the network use the same frequency. In addition, it is considered in this case that all the sites are part of the same SFN, transmitting the same content in synchronisation; or
  - frequency reuse 3 or 4, as depicted in Fig. 4. In this case, a pure MFN approach is considered, i.e. each site is potentially transmitting a different content with no synchronisation constraint of any sort.

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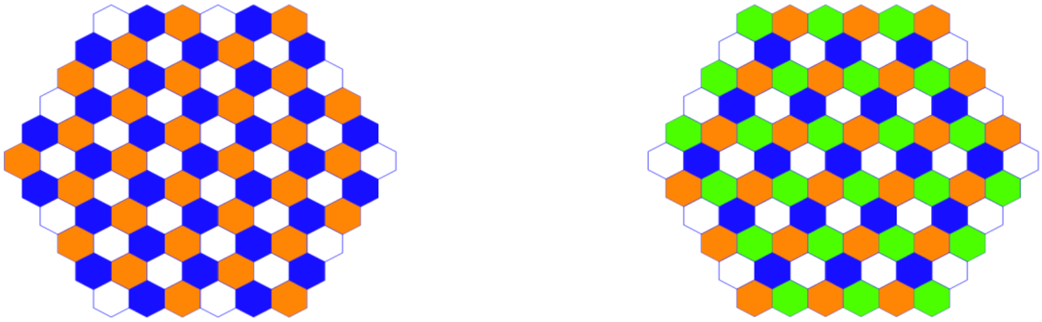
[3] In this Report, reuse 1 is:

– SFN inside the same editorial region (could be a full country or parts of a country for regional content).

– Co-channel between two different regions (across regional borders inside a country or across national border between two countries).

FIGURE 4

Frequency reuse 3 (left) and 4 (right)
Each colour represents a different frequency assignment



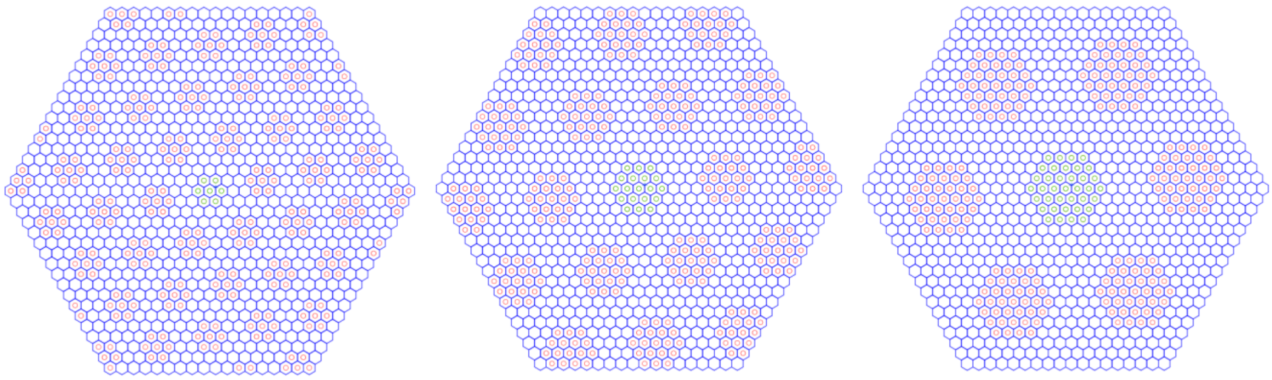
- The application of reuse 1 is straightforward for single and mixed topology cases; the application of reuse 3 and 4 is also straightforward for single topology cases. In the case of mixed topology networks, the application of reuse 3 or 4 is primarily done on the main layer; then, every site of the secondary layer which falls inside a cell of the main layer is assigned the same frequency as this main layer cell (secondary layer cells at the edge of primary layer cells can get two or three simultaneous frequency assignments, which is not a problem as only one frequency is analysed in this case), and assumed to form a SFN with the main layer cell they correspond to.

– In addition, for single topology cases, a mixed approach can be used for frequency assignment: the mix is between MFN and SFN situations, i.e. MFN clusters of SFNs can be considered, the MFN clusters adopting a frequency reuse 3 or 4, and all sites belonging to the cluster forming the same SFN (with the same content transmitted in sync), as can be found in some operational broadcast deployments. This approach provides a middle ground between a full SFN situation and a full MFN situation for a given network topology. To preserve the regularity characteristics of the original network topology, the clusters are formed from regular assemblies of sites: 7, 19, 37, … Furthermore, to limit the extent of each cluster, the size of the clusters can be constrained depending on the original network topology, e.g. only clusters of 7 sites for HPHT topology, clusters of 7 or 19 sites for MPMT topology and clusters of 7, 19 or 37 sites for LPLT topology.

Figure 5 illustrates such clustering approaches in the case of frequency reuse 3 between the clusters, showing only the clusters on the same frequency (clusters with red dots) as the central cluster (cluster with green dots).

FIGURE 5

Example of Reuse 3 MFN clusters of SFNs – Only the co channel clusters are shown (left to right: 7 sites cluster, 19 sites cluster, 37 sites cluster)



As can be seen in § 1.6, a limited set of possible parameters is defined for each network topology. However, when combined with the other variables in the simulation (choice of single / mixed topology network, frequency assignment and reception mode), this gives a potential of thousands of scenarios to explore. To make it possible to have a complete view on the performance of selected networks topologies and parameters to serve the various reception modes identified, only a subset of those thousands of possibilities was considered during the work associated with this Report. The corresponding parameters associated with the selected scenarios and the corresponding results are described in § 2.7.

2.3 Additional receiver characteristics

For fixed reception, a directional receiving antenna (using the discrimination shown in Recommendation ITU-R P.419-3, Figure 1) is considered, while for all other reception modes, a purely omnidirectional receiving antenna is considered. No polarisation discrimination is taken into account in this analysis, as the receiver is assumed to use the same polarisation as the transmitters, which are all using the same polarisation.

For the specific case of SFN reception, i.e. when several signals from the same SFN are received and need to be considered, several synchronisation strategies could be used in the receiver [3] [4]. In this study, the receiver is assumed to use a maximum *C*/*I* synchronization strategy (as defined in EBU Technical Review 295 [3]) which is an optimal strategy. In this case, the windowing function used to split the signals between useful and interfering parts inside the SFN is the function defined in § 3.5 of EBU Tech 3348 [2] using the 5G Broadcast system parameters from Table 1.

2.4 Propagation prediction method

Recommendation ITU-R P.1546-5 is used to predict wanted and interfering field strengths from the various transmitters to the locations considered in the simulations.

Only location variation is considered. Wanted signals are predicted using 50% of time curves from Recommendation ITU-R P.1546-5. Unwanted signals are predicted using 1.75% of time curves, to account for a simplified model for correlation between interfering signals as advised by ITU-R Working Party 6A in Document R12/6A/198 [5](page 4 “Simple method”).

2.5 Simulation methodology

The selection of parameters for a given network topology, the frequency reuse pattern (as described in § 2.2) and the reception mode (as described in § 1.2) form a complete scenario to be considered in a simulation run.

Whatever the simulation is, it is always based on the central 'cell' of the network using a Monte Carlo algorithm on a set of reception locations within this central cell:

– In the case of single topology networks with conventional reuse 1, 3 or 4, this cell is the central cell of the network (see Fig. 6, left).

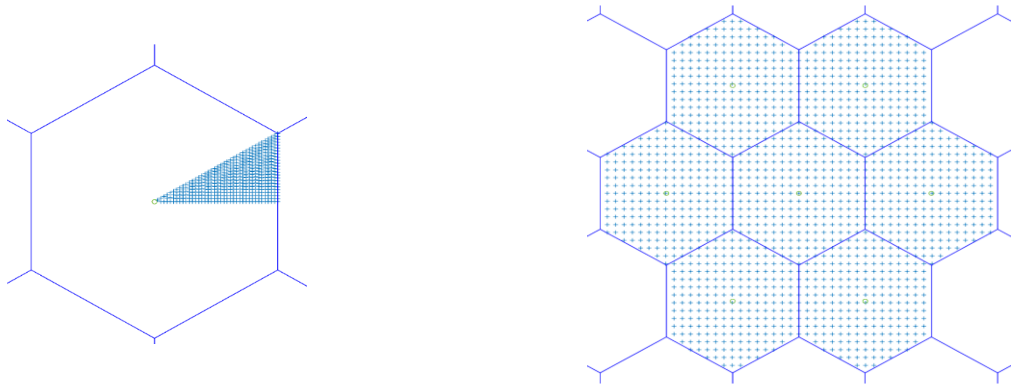
– In the case of single topology networks with MFN clusters of SFNs, this cell corresponds to the set of cells forming the central cluster (see Fig. 6, right).

– In the case of mixed topology networks, this cell corresponds to the central cell of the main layer (see Fig. 6, left).

This set of reception locations is derived from the central cell using a regular grid. Whenever possible, symmetry axes are used to reduce the number of such reception locations and speed up computations.

FIGURE 6

Examples of central cell sampling – Reception locations indicated as '+'
Left: using symmetries (single topology networks with conventional reuse, mixed topology networks)
Right: not using symmetries (single topology networks with MFN clusters of SFNs)



Each reception location is considered to form a small area of coverage of the network, the size of which depends on the network topology[4] as follows, due to computation time and memory constraints limits linked to the inter site distance / central cell area:

– HPHT topology: small area of 500 m × 500 m (general case) or 1000 m × 1000 m (for MFN clusters of SFNs).

– MPMT topology: small area of 250 m × 250 m (general case) or 500 m × 500 m (for MFN clusters of SFNs).

– LPLT topology for rural environments: small area of 150 m × 150 m or 250 m × 250 m (general case) or 500 m × 500 m (for MFN clusters of SFNs).

– LPLT topology for urban/suburban environments: small area of 50 m × 50 m (general case) or 100 m × 100 m (for MFN clusters of SFNs).

At each reception location, a Monte Carlo algorithm is applied to derive SNR and SINR values for the reception location and for a given percentage of locations (over the small area it represents) and

[4] In the case of mixed topology networks, the topology to consider is the one of the main layers.

percentage of time (usually taken as 95% of locations and 99% of time respectively for broadcast requirements). A simulator was developed to achieve this computation:

- The simulator does a Monte Carlo loop to derive statistics regarding location variation, introducing time variation aspects through the prediction model (wanted signals are predicted for 50% of time, unwanted signals are predicted for 1.75% of time following the advice by ITU-R Working Party 3K prescribed in the "Simple method" of ITU Document R12/6A/198 [5] that individual interfering field strength computed using Recommendation ITU-R P.1546-5 at 1.75% of time reflects the real correlation situation of interfering field strength and correspond to 1% of time for the aggregated field strength).
- The simulator can examine both the data part (useful payload carried by the Physical Multicast Channel – PMCH – of the 5G Broadcast system) and the signalling part CAS. However, the current simulations were only run on the data part, considering that the signalling part is not a limiting factor in the effective reception of the signal[5].

The Monte Carlo algorithm is applied at each reception location as follows:

1 Compute the median wanted and unwanted signal levels from each site at the reception location considering transmitter and receiver characteristics. Only signals originating from sites on the same frequency as the central cell are taken account of in this computation, since adjacent channel interference plays a secondary role.

2 For each location (Monte Carlo loop with N iterations, N taken as 10 000 in the simulations).

   a) Compute the shadowing factor (based on the applicable location standard deviation) for each site.[6]

   b) Correct the wanted / unwanted levels from each site with the corresponding shadowing factor.

   c) In case of SFN reception (reuse 1 or MFN clusters of SFN), apply the synchronisation strategy[7] to the signals originating from the sites in the SFN to derive wanted and unwanted intra SFN signals.

   d) Sum (using simple power sum) the wanted intra SFN signals and the unwanted (intra SFN and out of SFN) signals separately to derive the SNR and SINR values for the current location instance.

   e) Accumulate each SNR and SINR location instance value in a table.

3 Once the Monte Carlo loop is over, derive a cumulative distribution function (CDF) of SNR and a CDF of SINR from the accumulated values. The CDF for each pixel permits to calculate:

   a) the SINR corresponding to a fixed target Location Probability, or

   b) the Location Probability corresponding to a fixed target SINR.

Repeating the previous procedure over the whole set of reception locations allows a surface analysis to be built, with charts showing coverage area versus available SNR and SINR values at the wanted percentage of locations or coverage area versus location percentage values for a target SNR or SINR.

---

[5] Despite its robustness, the CAS signal can only use the legacy LTE numerology (15 kHz with normal cyclic prefix, i.e. Tu = 66.67 µs, CP = 4.7 µs). This may have in impact on SFN reception, due to the very short CP duration, depending on the behaviour of the receiver.

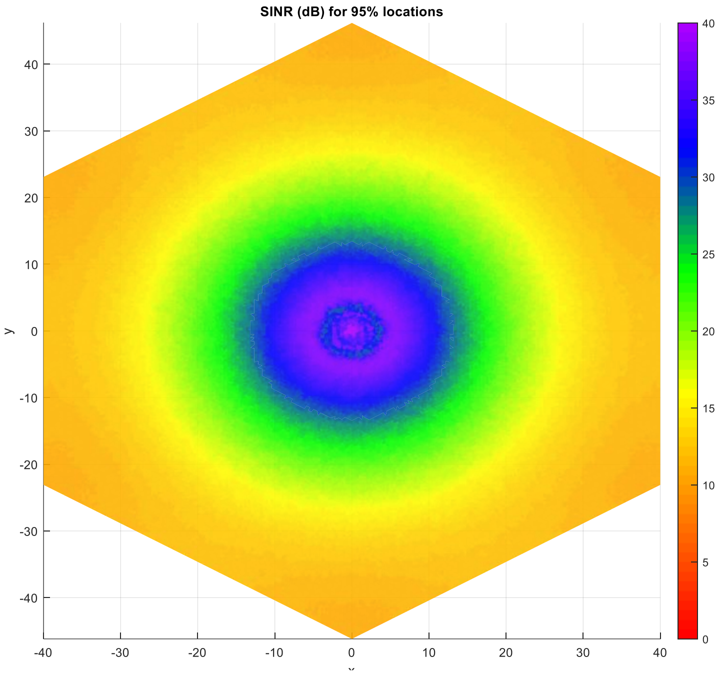
[6] The shadowing factors are assumed to be uncorrelated between the sites. In some cellular network simulations, an autocorrelation of the shadowing factors is indicated. This is not considered here.

[7] As theoretical networks are considered here, all transmitters in the SFN network are assumed to have an initial static delay set to 0 µs.

The following Figures show an example of the application of such a procedure for a single topology network simulation: Figure 7 shows the resulting computed SINR values for all reception locations considered across a central cell, in the form of a heat map (reconstructed thanks to symmetries when symmetries are used to derive the set of reception locations, using the original set of reception locations otherwise); based on these values, and selecting relevant SINR values, one can also derive a histogram representing the relative area covered for a given set of SINR values, as shown in Fig. 7.

FIGURE 7

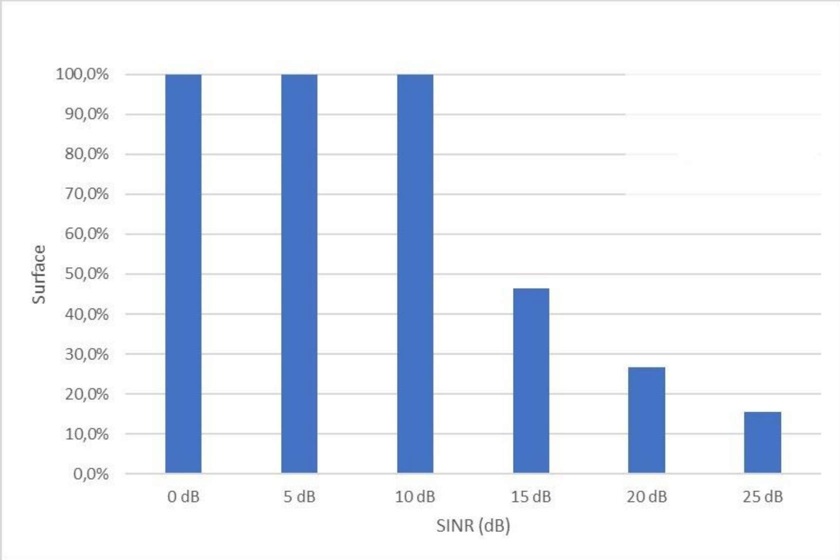
Computed SINR values for 95% of locations at reception locations across a central cell



Accumulating the resulting histogram (see Fig. 8) of different scenarios (e.g. change in reuse factor, usage of MFN clusters of SFNs, and others) allows a performance comparison of the different scenarios to be made.

FIGURE 8

Sample histogram resulting from the previous SINR computation, for outstanding SINR values



Setting a target location percentage to be exceeded in every pixel of the target coverage area is suitable for a broadcast system. For a native IP system like the 5G Broadcast system, that is implemented in a mobile device alongside a 5G unicast system, it is possible to implement a hybrid broadcast/unicast operation to seamlessly switchover to unicast (using the Mobile Broadband connection of the same device), if available, when the broadcast signal is not received with the required SINR. For further information on the hybrid broadcast/unicast reception with seamless switchover can be found in [10] and [11]. The following section shows an alternative way of assessing a 5G Broadcast network coverage that considers a possible complementary coverage using unicast, through seamless switching between the two services in the receiver.

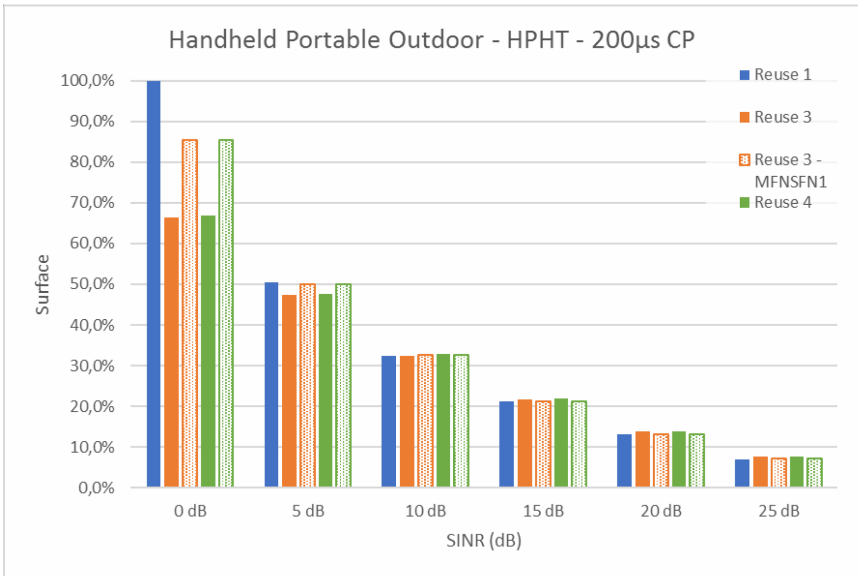
2.5.1 Specific analysis of Hybrid broadcast/unicast operation

In addition to the traditional planning objective of achieving full area coverage with 95% location probability in each pixel, this Report also considers planning objectives that suit a hybrid broadcast/unicast approach. LTE-based 5G Broadcast supports seamless switching between broadcast and unicast distributions of the same media asset. The network planning objective for the broadcast part may therefore be set to ensure an acceptable distribution of the location percentage (LP) across the coverage area for a fixed target SINR, instead of ensuring a fixed target location percentage in every pixel of the coverage area. This should result in fewer sites being required. 5G-Broadcast seamless switching prevents signal interruptions in unserved locations by transparently falling back to data delivery over the unicast mobile network. There is a need for a criterion to define the acceptable reduced LP for the above model. In real networks, the criteria could be the population coverage. In the theoretical network covered here, it could be the average LP across the network (see explanation further below).

The simulation methodology for broadcast-only operation results in tables, which show the distribution of SINR values of the pixels according to the percentage of surface covered for a fixed location probability (95%) shown in Fig. 9.

FIGURE 9

Example of simulation results (here for homogeneous HPHT networks with ISD = 80 km)



For the evaluation of the hybrid broadcast/unicast approach, the Monte Carlo simulation results are analysed with a different objective, which results in the distribution of LP and cell surface covered in % for the cell for a fixed given SINR, as shown in Fig. 10.

FIGURE 10

Example of simulation results (here for single topology HPHT layer for C/N = 15 dB)

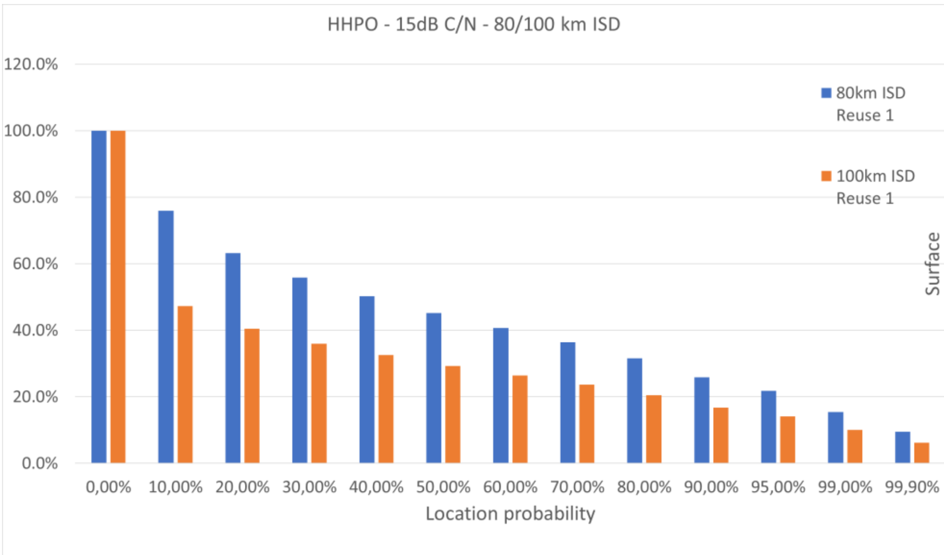


Figure 10 shows that the results of this representation are similar to the traditional approach used in Fig. 9 for the same configuration. The blue bar chart in Fig. 9 (frequency reuse 1) and the scenario parameters ISD 80 km, HTHP 80 dBm, 300 m height correspond to the scenario values in Fig. 10.

It can be seen in Fig. 9 that LP = 95% is exceeded in 21.8% of the pixels. This corresponds to the 21.8% cell coverage for 15 dB in Fig. 10.

It can be seen from Fig. 10 that lowering the LP target to 50% would increase the cell coverage only to 45.2%. Even a 10% LP percentage would only be exceeded in 76% of the pixels. Obviously, less good figures are obtained for ISD = 100 km (orange bars): 95% LP exceeded in 14.1% of the pixels, 50% LP exceeded in 29.2% and 10% LP exceeded in 47.3% of the pixels.

The analysis above is based on a cutoff value of the Location Percentage. In a real network analysis, it is possible to introduce a proportional calculation, by calculating the actual population covered in a pixel resulting from multiplying the total population of the pixel by its calculated Location Percentage. In a theoretical approach assuming a regular network, the only way to introduce a proportional calculation would be to assume a constant population density in every pixel of the coverage area.

Let this fixed density be: $d_{(inhabitants\ per\ pixel\ area)}$.

In N_{total} pixel in the network, the total population in the network is:

$$P_{total} = d \times N_{total}$$

In a pixel i where the calculated location percentage is LP_i, the actual proportional population coverage is: $d \times LP_i$.

The total coverage in population is:

$$(d \times LP_1 + d \times LP_2 + d \times LP_3 + \cdots d \times LP_{Ntotal})$$

or:

$$TotalCoverage_{population} = \sum_{i=1}^{N_{total}} d \times LP_i$$

The metric that would approach the proportional calculation of population coverage in a real network would then be:

$$(d \times LP_1 + d \times LP_2 + d \times LP_3 + \cdots d \times LP_{Ntotal})/d \times N_{total}$$

or:

$$ProportionalCoverage_{population} = \frac{1}{d \times N_{total}} \sum_{i=1}^{N_{total}} d \times LP_i$$

This finally gives:

$$(LP_1 + LP_2 + LP_3 + \cdots + LP_{Ntotal})/N_{total}$$

or:

$$ProportionalCoverage_{population} = \frac{1}{N_{total}} \sum_{i=1}^{N_{total}} LP_i$$

It can be seen that in a regular network this corresponds to the average location percentage in the network, that can be called LP_{ave}.

Having an average location percentage over the coverage area of LP_{ave}% from the broadcast network means that the unicast network will take over, on average, $(100 - LP_{ave})$% of the locations inside each pixel throughout the coverage area.

Applying this calculation to the results shown in Fig. 10 it gives:

– for single topology HPHT network with ISD = 80 km for C/N = 15 dB: LP_{ave} = 48.3%

– for single topology HPHT network with ISD = 100 km for C/N = 15 dB: LP_{ave} = 30.9%.

2.5.2 Network types used in the studies

For the study of broadcast-only network planning, the types of networks shown in Table 15 were used in studies.

TABLE 15

Types of networks simulated in the study of broadcast-only network planning

Type	Layer	ISD (km)	Antenna height (m)	EIRP (in 8 MHz channel)	Site density (per 10 000 km^2)
Single topology	HPHT	80	300	82 dBm/160 kW	1.8
Single topology	MPMT	20	80	62 dBm/1 585 W	28.9
Single topology	LPLT	3	30	59.4 dBm/871 W	1 283
Mixed topology	HPTP + MPMT (2 rings)	80 / 23.1	300/80	82 dBm/160 kW 69 dBm/7.9 kW	21.6

For the study of the hybrid broadcast/unicast network planning, the types of networks shown in Table 16 were simulated.

TABLE 16

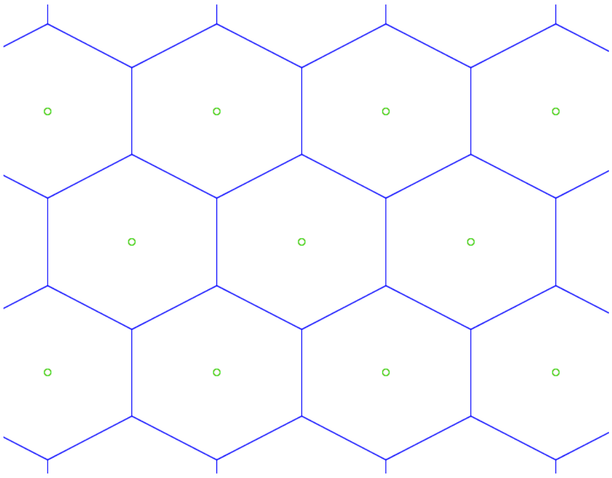
Types of networks simulated in the study of hybrid broadcast/unicast network planning

Type	Layer	ISD (km)	Antenna height (m)	EIRP (in 8 MHz channel)	Site density (per 10 000 km^2)
Single topology	HPHT	80	300	82 dBm/160 kW	1.8
Mixed topology	HPHT + MPMT (1 ring)	23.1	300/80	82 dBm/160 kW 69 dBm/7.9 kW	10.8
Mixed topology	HPTP + MPMT (2 rings)	80 / 23.1	300/80	82 dBm/160 kW 69 dBm/7.9 kW	21.6

The single topology case is illustrated with a simple hexagonal arrangement of the sites, as shown in Fig. 11.

FIGURE 11

Single topology network



The mixed topology cases are illustrated either with only one ring of MPMT sites placed at the edge of each HPHT coverage area or with two rings as shown in Fig. 12 and Fig. 13 respectively.

FIGURE 12

Illustration of the two-layer HPHT/MPMT network – adding one ring of MPMT sites at the edge of the HPHT cell

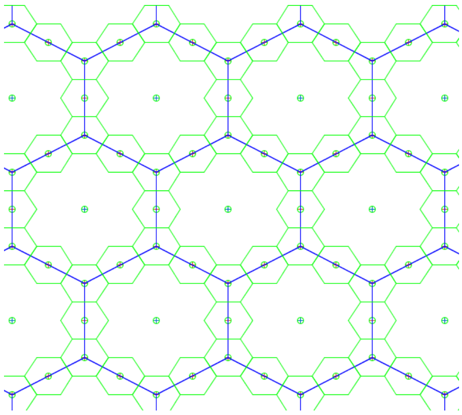
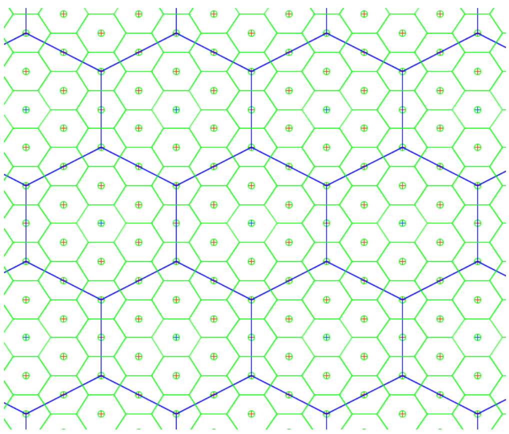


FIGURE 13

Illustration of the two-layer HPHT/MPMT network – adding two rings of MPMT sites from the edge of the HPHT cell inwards



2.6 Coverage of national or regional border areas

2.6.1 Background

This section shows the impact of single frequency operation across regional or national boundaries with different content in each region.

This topic was studied as part of work associated with CEPT Task Group 6[8], in around 2013, which explored the impact of single frequency use across regional boundaries primarily for fixed reception [6]. At that time, it was shown that it was not possible to operate reuse 1 networks in border areas and provide complete coverage for fixed reception.

As the TG6 work only considered fixed reception, similar work has been done in this section to cover some of the scenarios being considered as part of the 5G Broadcast studies, namely:

– HPHT, MPMT and LPLT network structures;

– Mobile (Car mounted) reception.

For the above scenarios, the reduction in availability (coverage) in cells adjacent or close to the border was investigated for single frequency operation across a regional or national boundary with different content in each region. The impact on cells/sectors, adjacent or near to a border has been assessed.

The case where an area is partly enveloped by a different region has been modelled. This has been represented by dividing the modelled area into four quadrants. Of these quadrants, three represent interfering regions and the fourth (lower left) is the wanted region (see Fig. 14 and §§ 1.1, 2.1 and 3.1 in Annex 2). In this situation, a wanted cell has interfering cells adjacent on four faces. The impact has been reported as a CDF of the SINR available across the area and a heat map of available SINR.

In addition, the case where a regional boundary is straight has been modelled with two sub cases: Vertical North South boundary (see §§ 1.3, 2.3 and 3.3 of Annex 2) and Horizontal East West boundary (see §§ 1.2, 2.2 and 3.2 of Annex 2). As the works concern networks based on hexagonal cells, there is a slight difference in interference between the two cases: one has an interfering cell adjacent on three faces of the hexagon, the other an interfering cell on two faces.

2.6.2 Results

Example results are provided in Figs 15 and 16. The full set of results for the three different network topologies, car mounted (i.e. mobile) reception and a 5 MHz bandwidth are provided in Annex 2.

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8 https://www.cept.org/ecc/groups/ecc/closed-groups/tg6/client/introduction

FIGURE 14

Network geometry corner (the green cells are the wanted region, red cells are the interfering region. The assessed cell is the central cell)

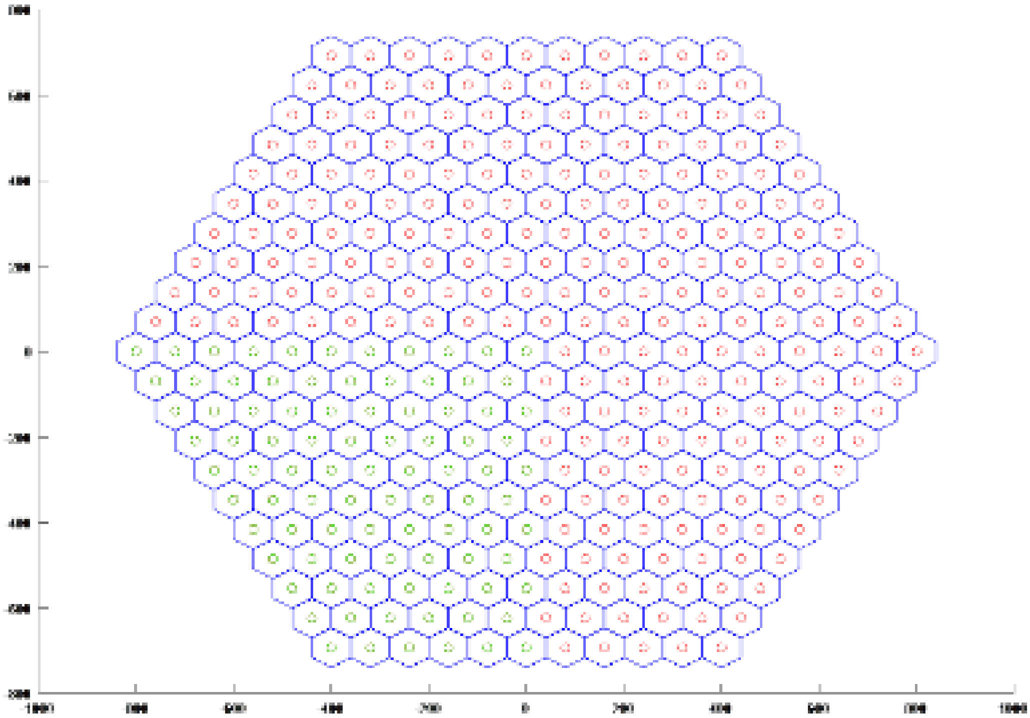


FIGURE 15

CDF for LPLT – corner regional boundary

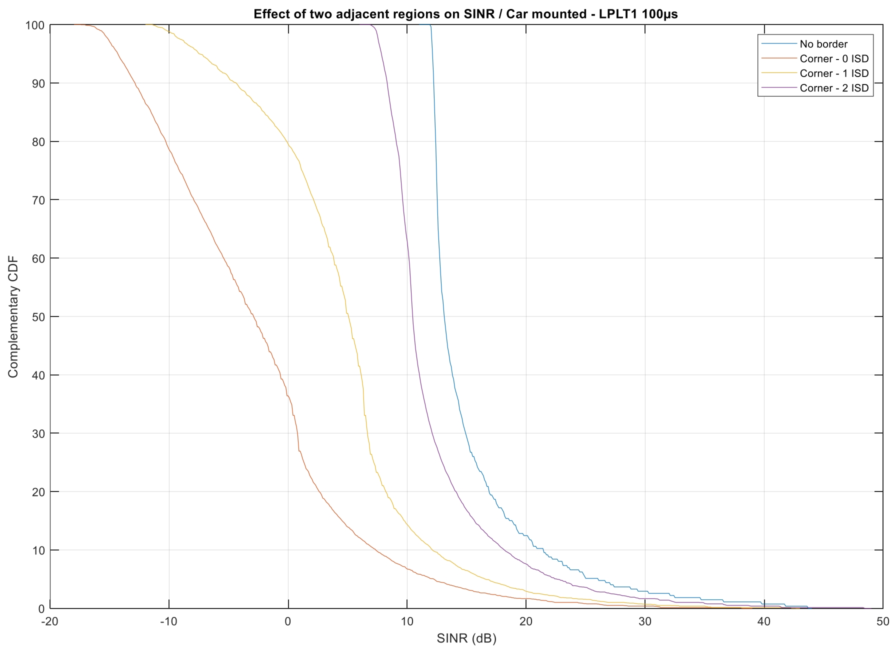
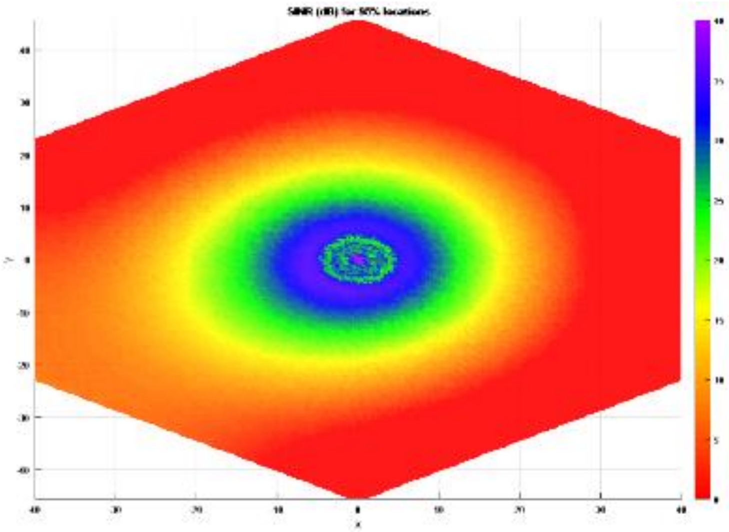


FIGURE 16

Network Geometry corner (the green cells are the wanted region, red cells are the interfering region. The assessed cell is the central cell)



2.6.3 Discussion

The results (Annex 2) show that for all network topologies (HPHT, MPMT and LPLT), coverage in border areas is reduced when compared with coverage away from the border. Coverage is compromised in a band running along the border.

- For HPHT networks, the first and second cells from the border are mainly impacted, while the third cell suffers almost no impact on its coverage as part of a reuse 1 national network. In terms of distance from the border, this represents roughly 2x ISD (Inter-site Distance of the HPHT network). For an ISD of 80 km, most considered in the current simulations, this represents 160 km. This order of distance would still allow a reuse 1 inside, but not across the whole territory of, a large country (France, Germany, Spain, Poland, etc.) but not in small countries (Luxembourg, Belgium, Croatia, etc.)
- For MPMT and LPLT networks, the first, second and third cells from the border are impacted. The impact is expected to be minimal on the fourth cell. In terms of distance from the border, this represents 3x ISD. For an MPMT ISD of 20 km, this represents 60 km from the border. For an LPLT ISD of 12 km, this represents 36 km. These distances are sufficiently low for medium size countries to allow some reuse 1 inside their territories.

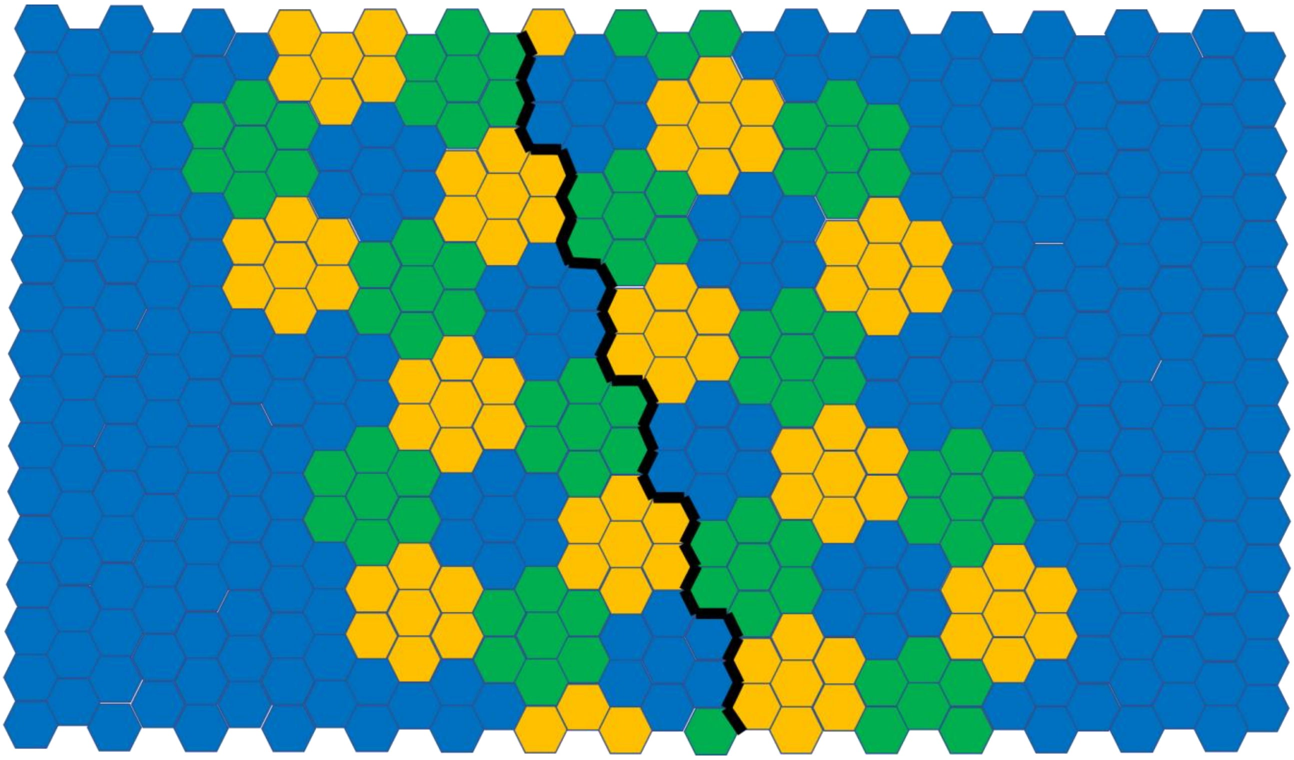
A straightforward solution in such border areas is to use different frequencies for SFNs that transmit different content (across national or regional borders). For LPLT and MPMT this probably means a frequency reuse of 3 is required. Figure 17 shows an illustration of using MFN with reuse 3 on both sides of a border while still using SFN inside each area at a distance from the border. For HPHT, given the ISD, a frequency reuse of 4 would be required when regions or countries are comparable in size to the coverage area of a station.

It may be possible to reduce the size of the impacted area by implementing closed SFNs[9]. This has not been investigated but it is believed that while it would reduce the size of the impacted area, it would not entirely eliminate the problem.

[9] A Closed SFN uses directional antenna patterns at transmitters located at its edge, oriented towards the centre of the SFN, to reduce the outgoing interference to neighbouring co-channel networks.

FIGURE 17

Illustration of an MFN at the border area with reuse 3 while SFN is used inside each country at a distance from the border



2.6.4 Conclusion

Regardless of the network configuration it is not possible to operate reuse 1 networks in border areas and provide continuous coverage. In border areas, full coverage requires either a higher frequency reuse, i.e. to use MFN in the concerned border areas, or a solution to reduce the size of co channel interference by implementing closed SFNs.

2.7 Simulation results and analysis

2.7.1 Networks assessment for broadcast-only operation

2.7.1.1 Car-mounted reception

Effect of the cyclic prefix and the frequency reuse on the coverage

Figures 18 and 19 show the percentage of surface covered for different target SINR values for car mounted reception using HPHT with 300 µs cyclic prefix (CP) and 200 µs CP respectively (see Table 1 for the different possibilities offered by 5G Broadcast).

Figures 20 and 21 show the same type of results but using MPMT. The main characteristics of these single topology networks are shown in Table 17.

FIGURE 18

Car mounted – HPHT – 300 µs CP

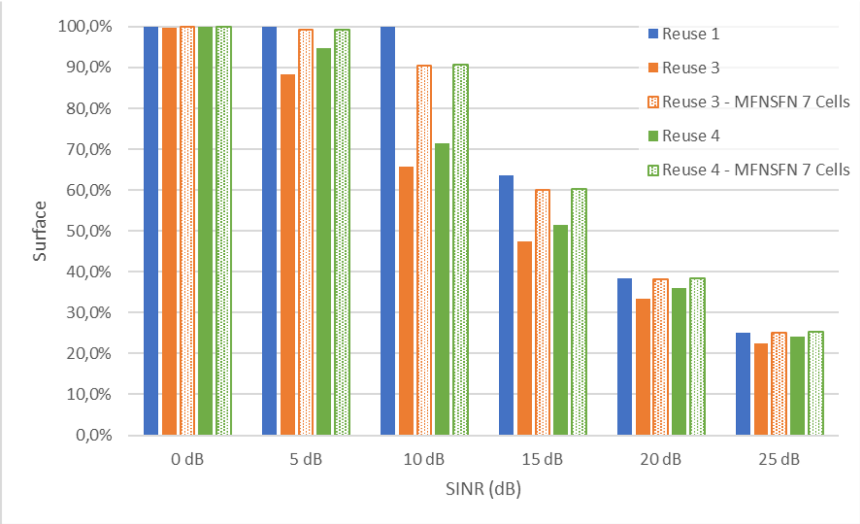


FIGURE 19

Car mounted – HPHT – 200 µs CP

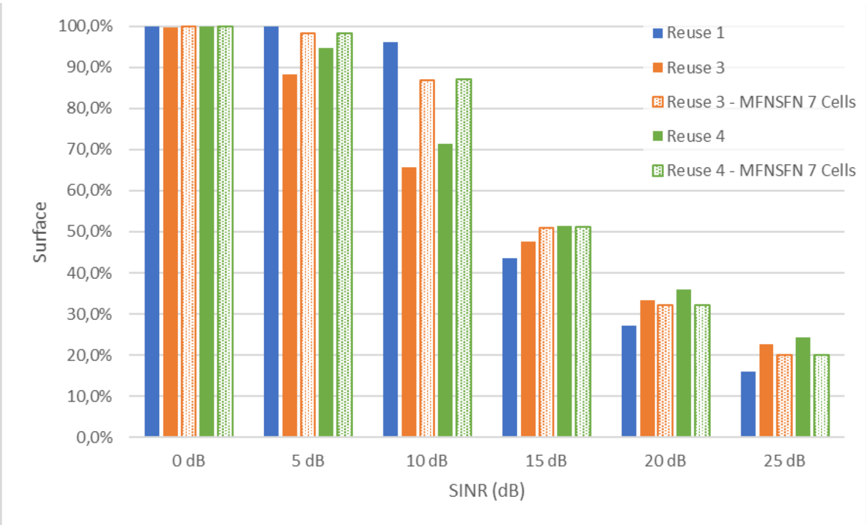


FIGURE 20

Car mounted – MPMT – 300 µs CP

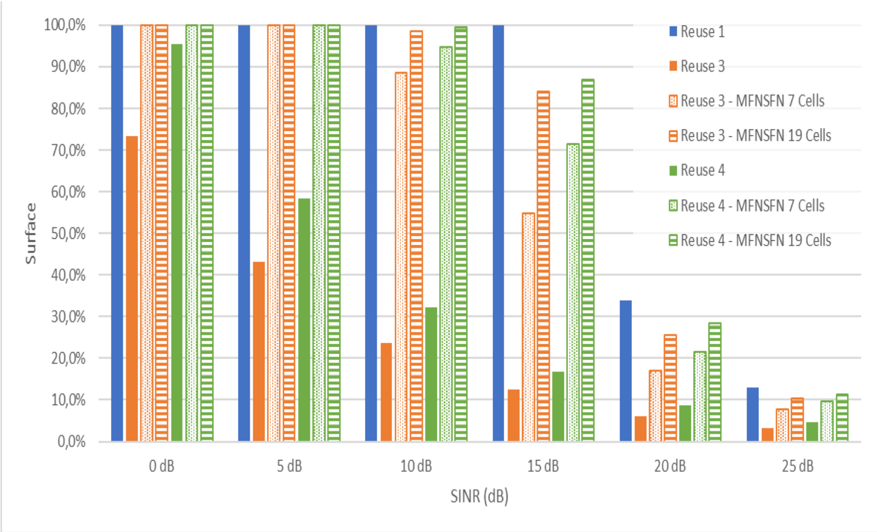


FIGURE 21

Car mounted – MPMT – 200 µs CP

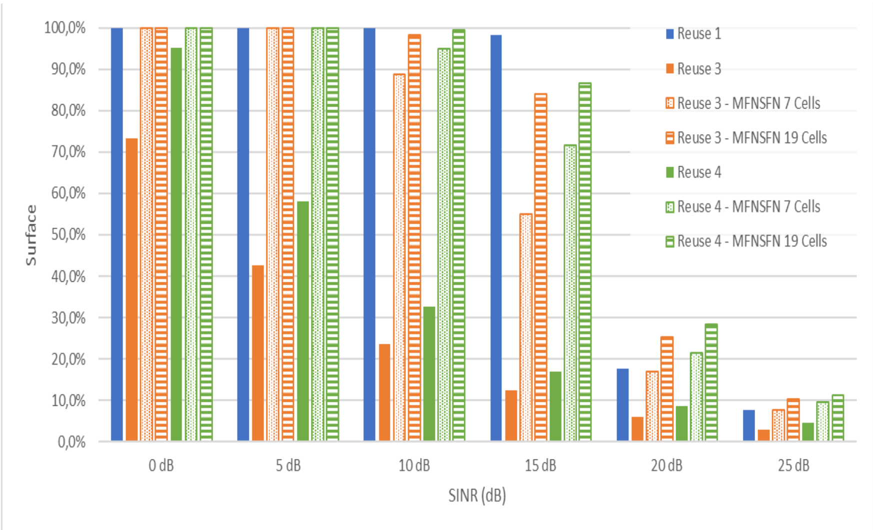


TABLE 17

Main parameters of the single topology HPHT and MPMT networks

Layer	**ISD (km)**	**Antenna height a.g.l. (m)**	**EIRP (in an 8 MHz channel)**	**Site density (per 10 000 km^2)**
HPHT	80	300	82 dBm/160 kW	1.8
MPMT	20	80	62 dBm/1585 W	28.9

Observations

a) The coverage of HPHT and MPMT networks for car mounted reception is mainly noise-limited due to low signal levels, this is evident from the low SINR figures obtained in the simulations. However, the coverage of reuse 1 (Single Frequency) Network is significantly better than reuse 3 and 4 (MFNs), due to the constructive contribution of signals inside the CP. The coverage of reuse 3 and 4 networks can be improved with the use of reuse 3 and 4 MFN clusters of SFNs (7 cells in HPHT, 19 cells in MPMT) compared to reuse 3 and 4 "pure" MFNs, due to both the constructive contribution of signals inside the CP and the reduction in co channel interference with the increased co channel separation distance.

b) Compared to a CP of 200 µs, increasing the CP to 300 µs improves, to some extent, the car mounted coverage of HPHT and of MPMT reuse 1 as it allows more signals to be constructive and fewer signals to be interfering; but the main limitation for the coverage remains the lack of signal level. Similarly, there is a small improvement in the coverage of reuse 3 and 4 MFN clusters of SFNs. As expected, increasing the CP does not have an impact on reuse 3 and 4 coverages, which correspond to "pure" MFNs.

The coverage improvement with a CP of 300 µs should be considered mindful of the limitation that it would impose on the speed of movement of the receivers (see § 2.8.2 on Doppler performance). The use of 200 µs for the CP, on the other hand, allows for reception at normal vehicle speeds.

c) An HPHT network alone would offer 10 dB SINR for car mounted reception in 87.1% to 96.1% of the target coverage area with 200 µs CP, and slightly more (90.6% to 100%) with 300 µs CP. For 15 dB SINR and higher, the improvement in coverage with 300 µs CP is more significant.

d) An MPMT network alone would offer 15 dB SINR in 86.6% to 98.1% of the target coverage area with 200 µs CP, and slightly more (86.8% to 100%) with 300 µs CP. For 20 dB SINR and higher, the improvement in coverage with 300 µs CP is more significant.

In summary, single topology HPHT and MPMT network types operating in broadcast-only mode have limitations in terms of coverage and available SINR for car mounted reception.

The use of mixed HPHT+MPMT networks is now evaluated.

Use of mixed topology network (HPHT+MPMT) to further improve the coverage and effect of increasing the EIRP

Figures 22 and 23 show the percentage of surface covered for different target SINR values for car mounted reception using a mixed HPHT+MPMT network having the main characteristics shown in Table 18 (see illustration of mixed topology networks in § 2.5.2).

A CP of 200 µs was adopted for these mixed topology networks, to favour high speed mobile reception. In addition, the effect of increased EIRP was tested by increasing the MPMT EIRP by 7 dB (indicated with "Revised Situation" in Fig. 23 compared to the "Base Situation" of Fig. 22, where no increase of the MPMT EIRP is considered). This EIRP adjustment would be needed to overcome the self-interference effect in the case the mixed topology network in SFN mode.

To better visualise the improvement achieved from the use of a mixed topology network, Figs 24 and 25 show a comparison of HPHT layer alone, MPMT layer without the HPHT, MPMT alone (full) and mixed HPHT+MPMT network. Both Figures consider a 7 dB increase in EIRP for the full MPMT network and for the MPMT component of the mixed topology network.

FIGURE 22

Car mounted – Mixed (base situation) – 200 µs CP

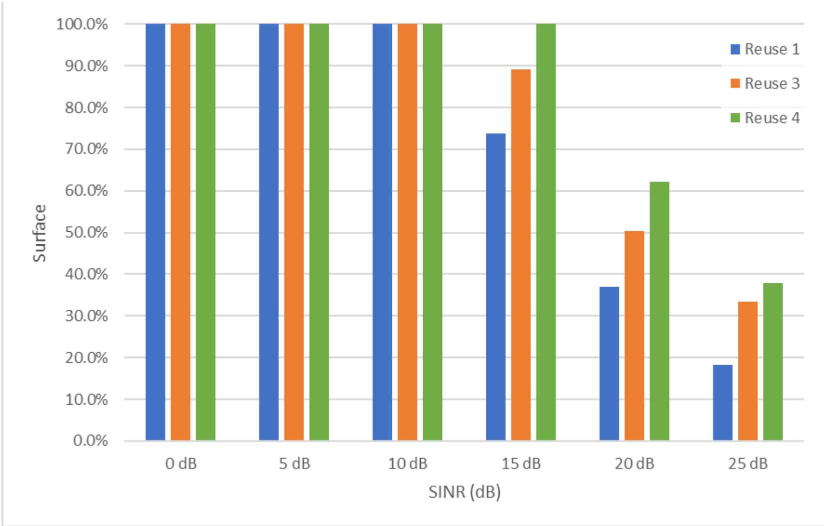


FIGURE 23

Car mounted – Mixed (revised situation) – 200 µs CP

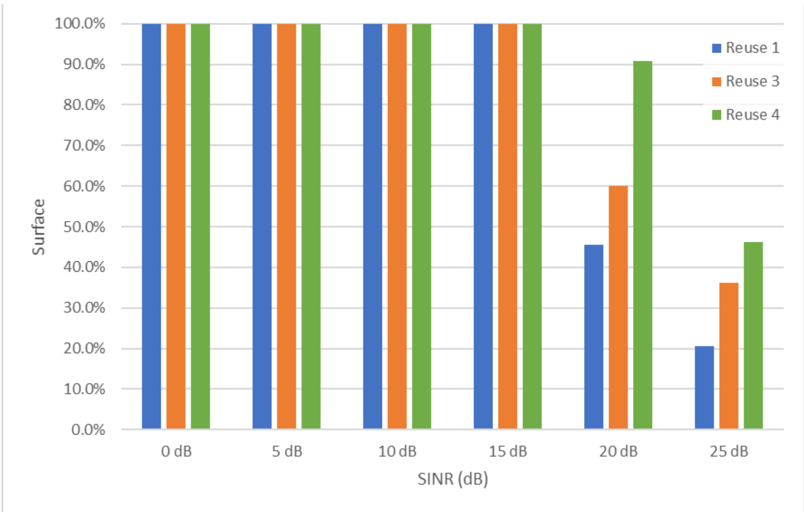


FIGURE 24

Car mounted – Comparison of layers (revised situation) – Reuse 1 – 200 µs CP

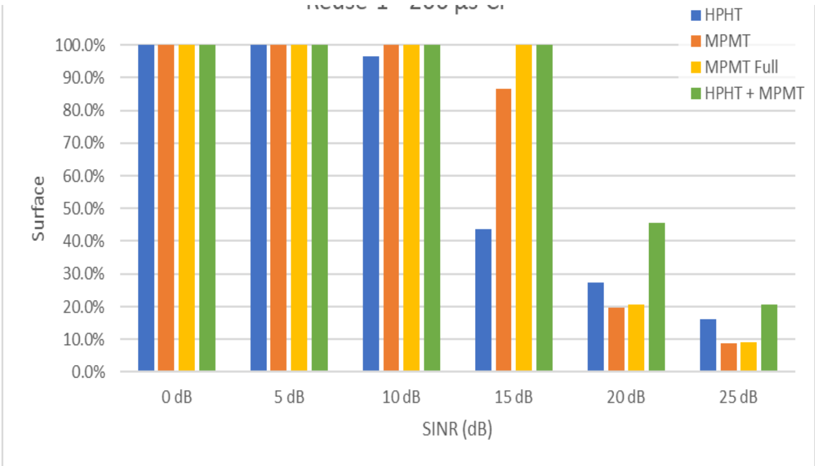


FIGURE 25

Car mounted – Comparison of layers (revised situation) – Reuse 4 – 200 µs CP

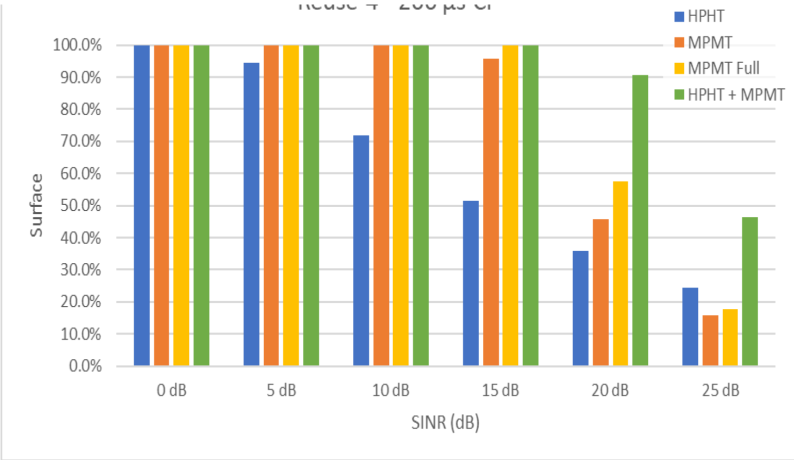


TABLE 18

Main parameters of the mixed topology network

Layer	ISD (km)	Antenna height a.g.l. (m)	EIRP (in an 8 MHz channel)	Site density (per 10 000 km^2)
HPHT	80	300	82 dBm/160 kW	1.8
MPMT base situation	23.1	80	62 dBm/1585 W	21.6
MPMT revised situation	23.1	80	69 dBm/7.9 kW	21.6

Observations

1 Compared to single topology networks in Figs 19 and 21 (reuse 1 pure SFN or reuse 3 or 4 pure MFNs), the mixed HPHT+MPMT networks in Fig. 22 offer a significant increase in coverage for the higher SINR figures (15 dB and above). The improvement shown in Fig. 23 is even more significant with the 7 dB increase of EIRP of the MPMT layer transmitters.

2 The increase of the EIRP of the MPMT layer offers a large improvement in the coverage, even with the MPMT layer alone. Figures 24 and 25 indicate that a full MPMT layer (using revised characteristics from Table 18) matches the overall coverage of the mixed topology network for a SINR up to 15 dB. However, for a SINR above 15 dB, the mixed topology network exceeds the coverage of any individual single layer. In particular, a mixed topology network with reuse 4 could achieve 20 dB SINR in 90% of the target area. These results indicate that most likely the number of MPMT sites can be reduced, while still ensuring a quasi-full coverage for an SINR of 15 dB.

In summary, a mixed topology HPHT+MPMT or a full MPMT 5G Broadcast network with the characteristics shown in Table 18 (MPMT revised situation) can offer a SINR of 15 dB to car mounted receivers in 100% of the target coverage area. This network can be operated either on a general basis or as a solution with reuse 3 or 4 close to the national or regional border areas. The density of sites in such a network is around 21.6 sites per 10 000 km^2 (1.8 HPHT + 19.8 MPMT sites per 10 000 km^2).

Use of LPLT single topology network for car mounted reception

Figures 26 and 27 show the percentage of surface covered for different target SINR values for car mounted reception using LPLT in suburban and urban areas, respectively. The main characteristics of these single topology networks are shown in Table 19.

FIGURE 26

Car mounted – LPLT suburban – 100 µs CP

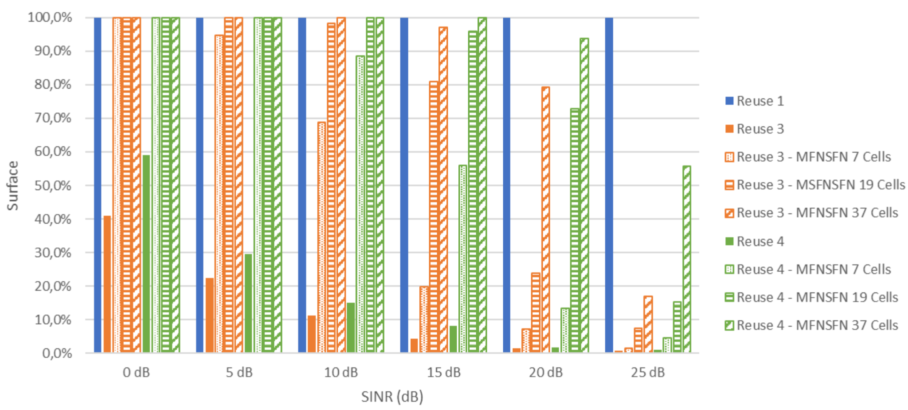


FIGURE 27

Car mounted – LPLT urban – 100 µs CP

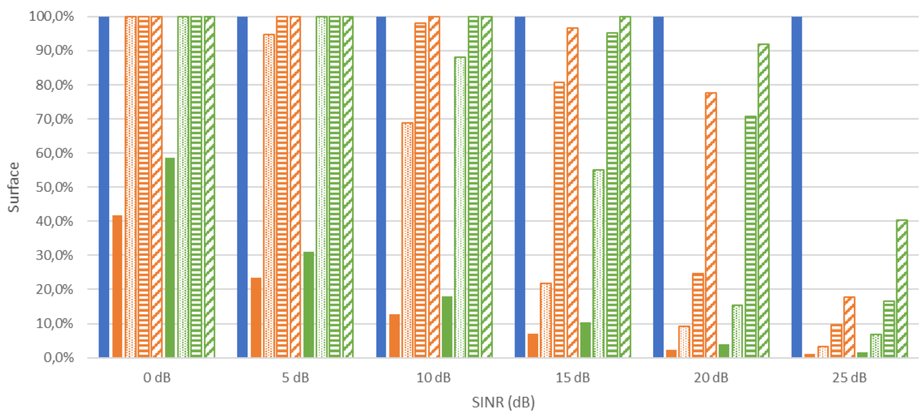


TABLE 19

The main parameters for the single topology LPLT networks

Layer	ISD (km)	Antenna height a.g.l. (m)	EIRP (in an 8 MHz channel)	Site density (per 10 000 km^2)
LPLT	3	30	59.4 dBm/871 W	1 283

Observations

A CP of 100 µs is suitable for LPLT. Reuse 1 offers the best coverage, ensuring 25 dB SINR in 100% of the target coverage area for car mounted reception for both urban and suburban environments.

For the coverage close to national or regional borders, reuse 3 and 4 with MFN clusters of SFNs (19 or 37 cells) can also offer quite high coverage figures: with reuse 4 MFN clusters of SFNs in urban areas, an area coverage of 92% can be achieved for a 20 dB target SINR.

In summary, an LPLT 5G Broadcast network with the main characteristics shown in Table 19 can offer an SINR of 15 dB to car mounted receivers in 100% of the target coverage area or 20 dB in 92% of the area for both suburban and urban environments. This network can be operated with reuse 1 inside the national territory, if possible, and with reuse 3 or 4 close to the national or regional border areas, using MFN clusters of SFNs with 37 cells or more.

2.7.1.2 Handheld portable outdoor reception

Effect of the cyclic prefix and the frequency reuse on the coverage

Figures 28 and 29 show the percentage of surface covered for different target SINR values for HHPO reception using HPHT with 300 µs CP and 200 µs CP respectively. Figures 30 and 31 show the same type of results but using MPMT. The main characteristics of these homogeneous networks are shown in Table 17 above.

FIGURE 28

Handheld portable outdoor – HPHT – 300 µs CP

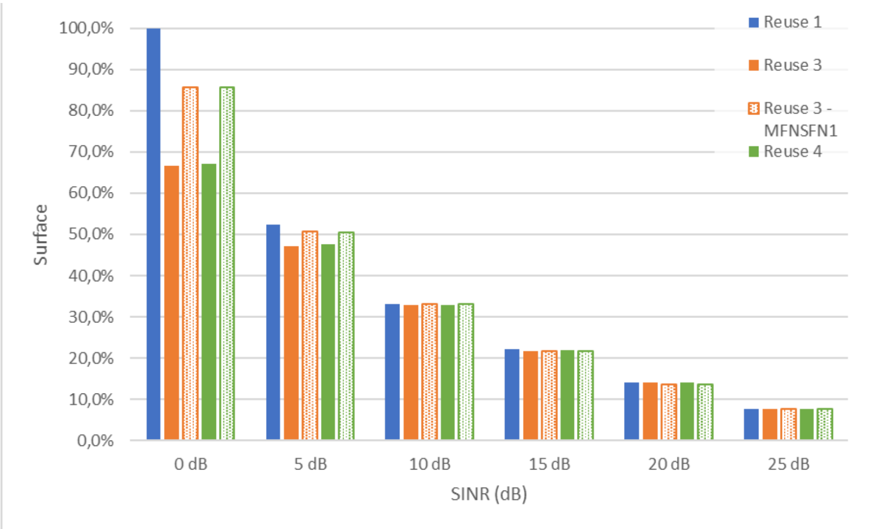


FIGURE 29

Handheld portable outdoor – HPHT – 200 µs CP

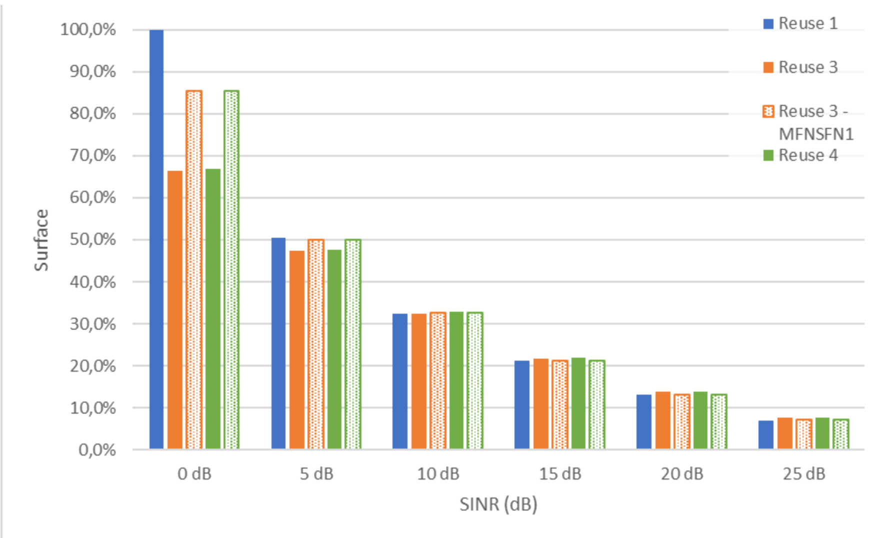


FIGURE 30

Handheld portable outdoor – MPMT 300 µs CP

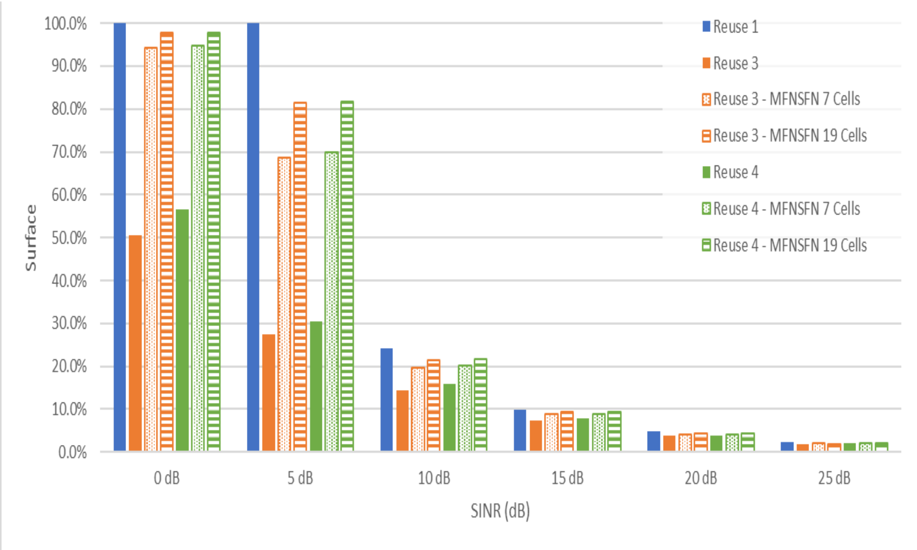
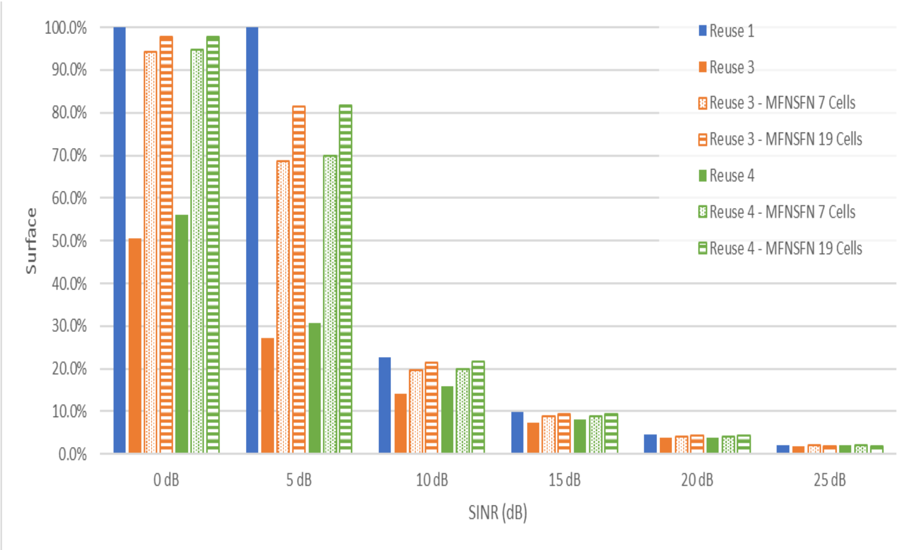


FIGURE 31

Handheld portable outdoor – MPMT 200 µs CP



Observations

1 Figures 28 and 29 show that the coverage of HPHT networks for portable outdoor reception are severely limited by noise due to low signal levels, this is evident from the low SINR figures obtained in the simulations and is due to the high signal margins required for portable reception with handheld receivers. This explains the absence of effect of increasing the CP from 200 µs (Fig. 29) to 300 µs (Fig. 28).

2 Figures 30 and 31 show that, for reuse 1, the coverage of MPMT networks is better than that of HPHT but is still quite limited in terms of achievable SINR figures. As in the case of Car-Mounted reception (Figures 20 and 21, above), the coverage can be significantly improved with the use of reuse 3 and MFN clusters of SFNs (7 cells in HPHT, 19 cells in MPMT), compared to reuse 3 and 4 "pure" MFNs, due to the constructive contribution of signals inside the Cyclic Prefix and the reduction in co-channel interference with the increased co-channel distance.

In summary, used individually, HPHT and MPMT network types have limitations in terms of coverage and available SINR for HHPO reception.

The use of mixed topology HPHT+MPMT networks is now evaluated.

Use of mixed topology network (HPHT+MPMT) to further improve the coverage and effect of increasing the EIRP

Figures 32 and 33 show the percentage of surface covered for different target SINR values for HHPO reception using a mixed topology HPHT+MPMT network having the main characteristics shown in Table 18, above (see illustration of mixed topology networks in § 2.4.2). A CP of 200 µs was adopted for these networks for consistency with the simulations for car-mounted reception. In addition, the effect of increased EIRP was tested by increasing the MPMT EIRP by 7 dB (indicated “Revised Situation” in Fig. 32, compared to the “Base Situation” of Fig. 33, where no increase of the MPMT EIRP is considered).

As above, to better visualise the improvement achieved from the use of a mixed topology network, Figs 34 and 35 show a comparison of HPHT layer alone, MPMT layer without the HPHT, MPMT alone (full) and mixed HPHT+MPMT. Both Figs 34 and 35 consider a 7 dB increase in EIRP for the full MPMT Network and for the MPMT component of the mixed network.

FIGURE 32

HHPO – Mixed (base situation) – 200 µs CP

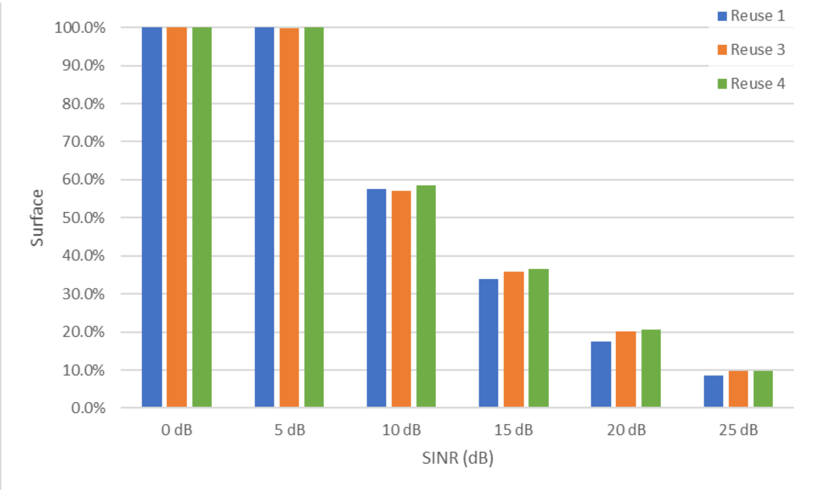


FIGURE 33

HHPO – Mixed (revised situation) – 200 µs CP

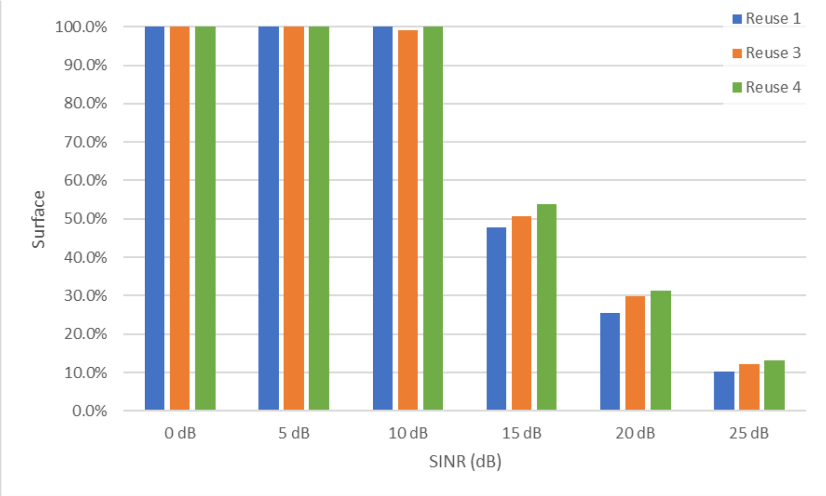


FIGURE 34

HHPO – Comparison of layers (revised situation) Reuse 1 – 200 µs CP

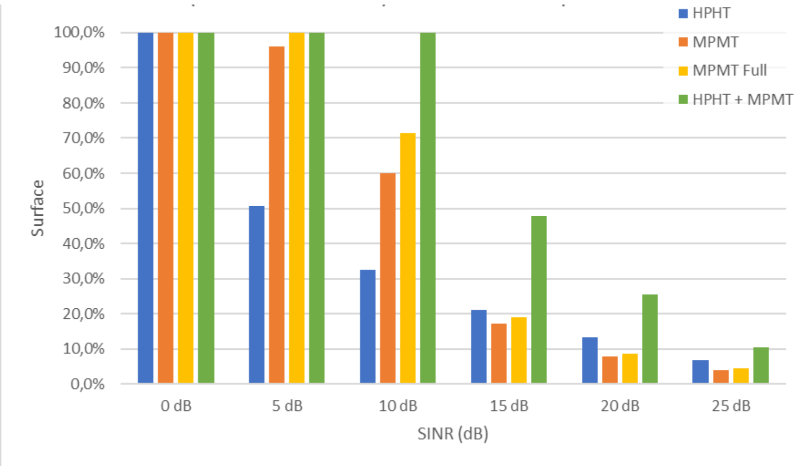
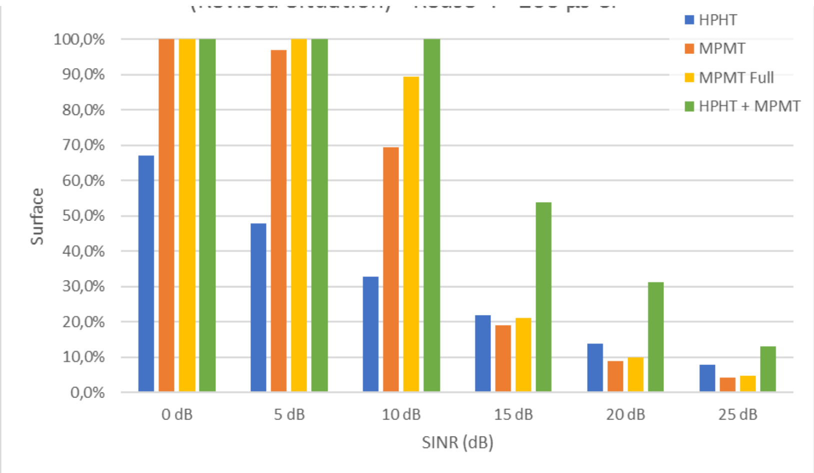


FIGURE 35

HHPO – Comparison of layers (revised situation) Reuse 4 – 200 µs CP



Observations

The mixed topology networks offer significantly improved coverage for HHPO reception compared to the single topology networks. In addition, increasing the EIRP of the MPMT layer by 7 dB (from 62 to 69 dBm) allows for a full area coverage with 10 dB SINR or around 50% coverage with 15 dB SINR.

In summary, a mixed topology HPHT+MPMT 5G Broadcast network with the characteristics shown in Table 18 (MPMT Revised situation) can offer a SINR of 10 dB to HHPO receivers in 100% of the target coverage area or 15 dB in around 50% of the target coverage area. This network can be operated either on a general basis or as a solution with reuse 4 close to the national or regional border areas. The density of sites in such a network is around 21.6 sites per 10 000 km^2 (1.8 HPHT + 19.8 MPMT sites per 10 000 km^2).

Use of LPLT single topology network for HHPO reception

Figures 36 and 37 show the percentage of surface covered for different target SINR values for HHPO reception using LPLT in suburban and urban areas, respectively. The main characteristics of these homogeneous networks are shown in Table 19.

FIGURE 36

HHPO – LPLT Suburban – 100 µs CP

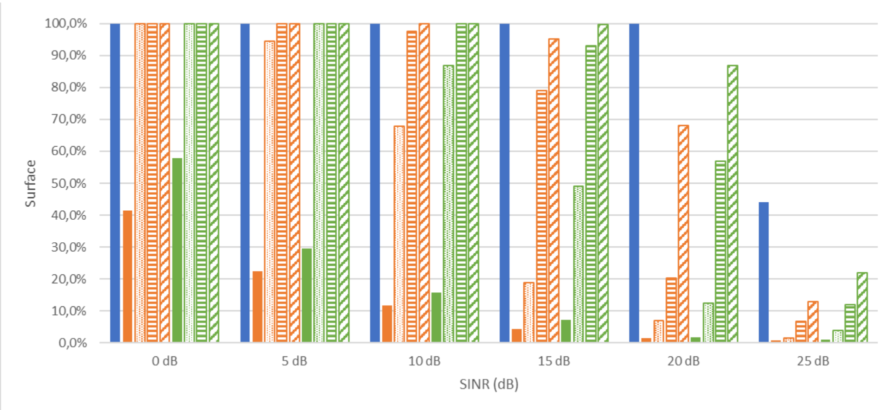
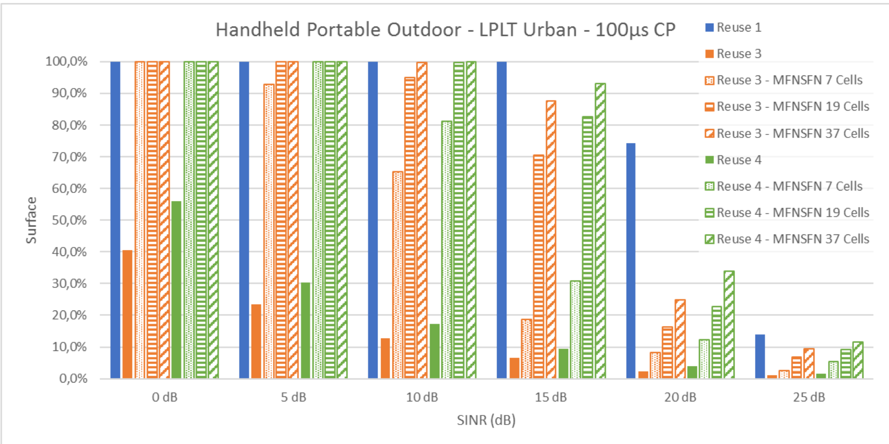


FIGURE 37

HHPO – LPLT Urban – 100 µs CP



Observations

A CP of 100 µs is suitable for LPLT. Reuse 1 offers the best coverage, ensuring 20 dB in 100% of the target coverage area in suburban or 15 dB in urban area for HHPO reception. For the coverage close to national or regional borders, reuse 3 and 4 MFN clusters of SFNs (19 or 37 cells) can also offer quite high coverage figures: with reuse 4 MFN clusters of SFNs in urban areas, area coverage of 92% can be achieved for a 15 dB target SINR.

In summary, an LPLT 5G Broadcast network with the main characteristics shown in Table 19 can offer a SINR of 15 dB to HHPO receivers in 100% of the target coverage area in suburban environment and 92% to 100% in urban environment. This network can be operated with reuse 1 inside the national territory, if appropriate, and with reuse 4 close to the national or regional border areas, using MFN clusters of SFNs with 37 cells.

2.7.1.3 Handheld in car reception

Use of LPLT single topology network for handheld in car reception

Figures 38 and 39 show the percentage of surface covered for different target SINR values for handheld in car reception using LPLT in suburban and urban areas, respectively. The main characteristics of these networks are shown in Table 19.

FIGURE 38

Handheld in car – LPLT Suburban – 100 µs CP

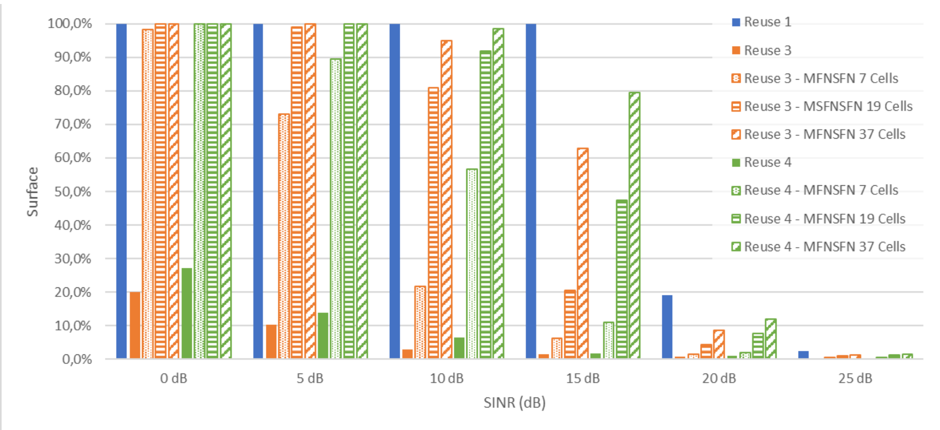
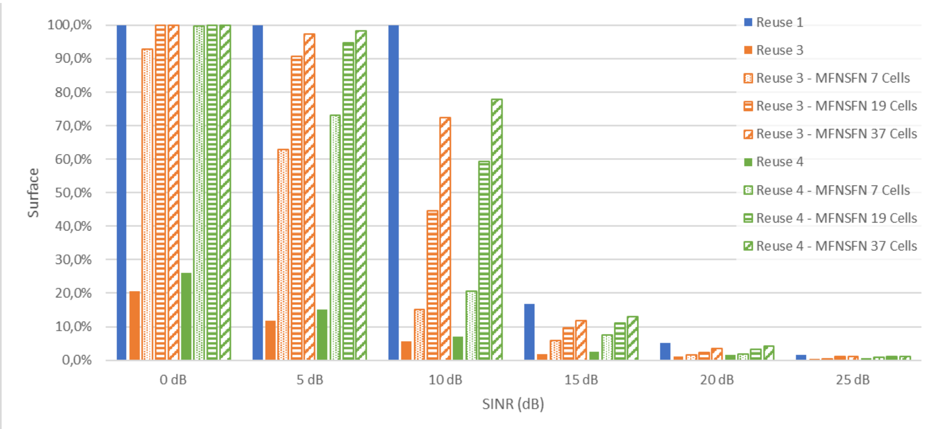


FIGURE 39

Handheld in car – LPLT Urban – 100 µs CP



Observations

The additional margin required for handheld in car reception compared with car mounted reception imposes further difficulties to insure a sufficient area coverage. For this reason, only the LPLT network type has been evaluated.

Similar to the use of LPLT network for car mounted reception, a CP of 100 µs is suitable. Reuse 1 offers the best coverage, ensuring 15 dB in 100% of the target coverage area for handheld in car reception for suburban environment and 10 dB in 100% of the target coverage area for urban environment. Reuse 4 with MFN clusters of SFNs (37 cells) can offer quite high coverage figures, reaching 98.5% area coverage for SINR of 10 dB in suburban areas. This coverage is however limited to 77.8% for SINR of 10 dB in urban areas.

In summary, an LPLT 5G Broadcast network with the main characteristics shown in Table 19 can offer a SINR of 10 dB to handheld in car receivers in 98.5% to 100% of the target coverage area in a suburban environment and 77.8% to 100% in an urban environment. This network can be operated with reuse 1 inside the national territory, if appropriate, and with reuse 4 close to the national or regional border areas, using MFN clusters of SFNs with 37 cells.

2.7.1.4 Fixed rooftop reception

Effect of the frequency reuse on the coverage

Figures 40 and 41 show the percentage of surface covered for different target SINR values for fixed rooftop reception using HPHT and MPMT network, respectively. Only a CP of 300 µs was used in this assessment. The main characteristics of these single topology networks are shown in Table 17.

FIGURE 40

Fixed – HPHT – 300 µs CP

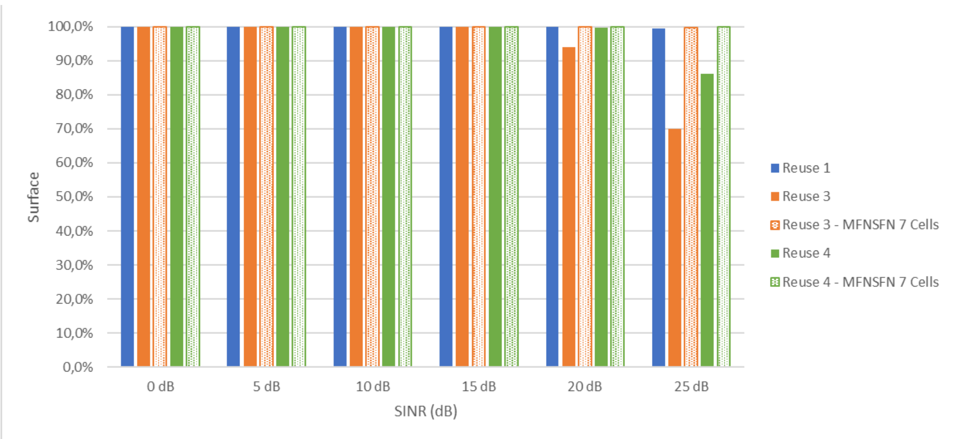
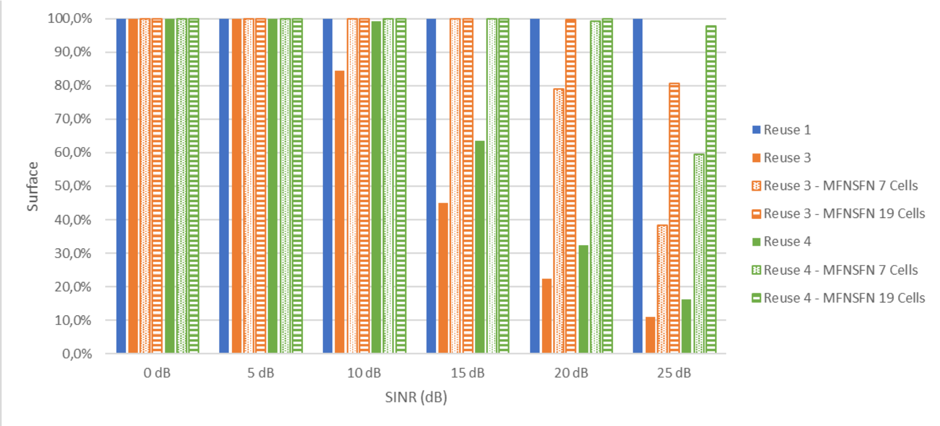


FIGURE 41

Fixed – MPMT – 300 µs CP



Observations

Figures 40 and 41 show that HPHT and MPMT networks can offer up to 25 dB SINR with a near full area coverage for fixed rooftop reception either with reuse 1 or with reuse 4 MFN clusters of SFNs (7 cells in HPHT, 19 cells in MPMT). The area coverage rate exceeds 99.5% with HPHT and 97.8% with MPMT.

In summary, an HPHT or an MPMT 5G Broadcast network with the main characteristics shown in Table 17 can offer an SINR of 25 dB to fixed rooftop receivers in 99.5% and 97.8% of the target coverage area, respectively. This network can be operated with reuse 1 inside the national territory, if appropriate, and with reuse 3 for HPHT or 4 for MPMT close to the national or regional border areas, using MFN clusters of SFNs with 7 cells for HPHT and 19 cells for MPMT. Reuse 4 MFN clusters of SFNs offers an equivalent area coverage to reuse 1 full SFN.

2.7.2 Networks assessment for hybrid broadcast/unicast scenario

In this section the analysis of coverage is carried out using the simulation method described in § 2.5. In brief, a fixed target SINR is set and the number of pixels in the total area of coverage is calculated where the location percentage exceeds a level set as parameter. This parameter is varied from 0% to 99.9%. In addition, the average location percentage over all the pixels in the coverage is calculated. In a Hybrid broadcast/unicast network, the level of required coverage from unicast depends on the average location percentage calculated above. The higher this average location percentage is, the lower the required coverage from unicast will be. The broadcast network operator (BNO) can therefore set the target average location percentage depending on the technical and cost factors related to its network, and on the coverage and capacity of the unicast mobile network in the concerned area.

For example, an average location percentage over the coverage area of 90% means that the unicast network will take over, in average, 10% of the locations inside the pixels throughout the coverage area.

To be noted that in real situations, the BNOs usually select the sites in a way to optimize the population coverage. In a theoretical network, the population is assumed to be uniformly distributed. Therefore, the population coverage of a real broadcast network will in general be higher than the population coverage calculated in a theoretical network. This means that the results obtained with the theoretical network analysis are generally conservative. They should be better for real networks.

In the next sections are considered first the single topology networks and then mixed topology networks. In each case, are considered the Car Mounted (CM), the HHPO and the HHIC reception modes. Regarding the target SINR values set in the following simulations, two distinct MCS are selected from Table 4 (which corresponds to 200 µs CP) and used the related Portable SINR value (applicable to HHPO reception mode) and the Mobile SINR value (applicable to car mounted and handheld in car reception modes). The selected MCS variants with their parameters, including the SINR values set in simulations, are shown in Table 20.

TABLE 20

Selected MCS Indexes and their parameters for the simulations related to Hybrid broadcast/unicast operations

MCS index	MOD	COD	Raw spectral efficiency (b/s/Hz)	Effective spectral efficiency (b/s/Hz)	Capacity (Mbit/s) in 5 MHz channel	Capacity (Mbit/s) in 8 MHz channel	Fixed SINR (dB)	Portable SINR (dB)	Mobile SINR (dB)
9	QPSK	0.668	1.336	0.782	3.9	6.1	8	**8.2**	**9**
16	16-QAM	0.645	2.579	1.509	7.5	11.9	13.2	**13**	**15.2**

A frequency reuse 4 was considered for all the simulated configurations, as this corresponds to a more realistic situation than a frequency reuse 1 in case of real implementation in the sub-700 MHz band in Region 1. To be noted that in the case of mixed topology HPHT/MPMT networks, the MPMT transmitters located inside the coverage area of an HPHT transmitter are assumed to be operating in SFN with that HPHT transmitter.

2.7.2.1 Results for single topology HPHT network

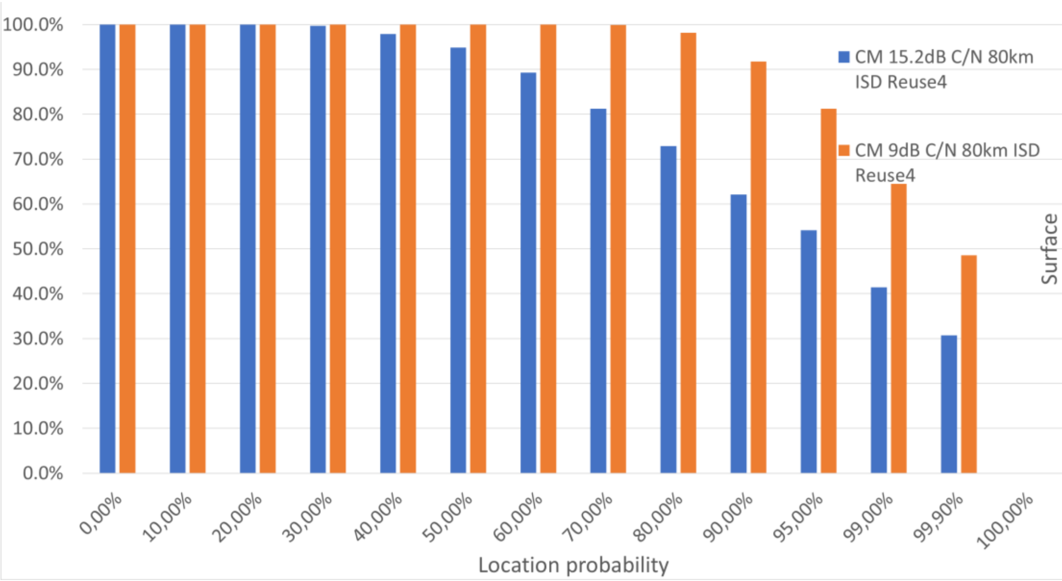
In Figs 42, 43 and 44, the simulation results for single HPHT topologies are shown for the three reception modes.

As a reminder, the site density for an HPHT network with 80 km ISD is 1.8 sites per 10 000 km^2.

For Car Mounted (CM) reception mode

FIGURE 42

Car mounted, 9 dB/15.2 dB SINR, 80 km ISD



Average Location Percentage LP_{ave} (Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

CM SINR = 9 dB, ISD 80 km → LP_{ave} = 97%

CM SINR = 15.2 dB, ISD 80 km → LP_{ave} = 87%

It can be seen from these results that the average location percentage in the coverage area is relatively high, even for the higher target SINR.

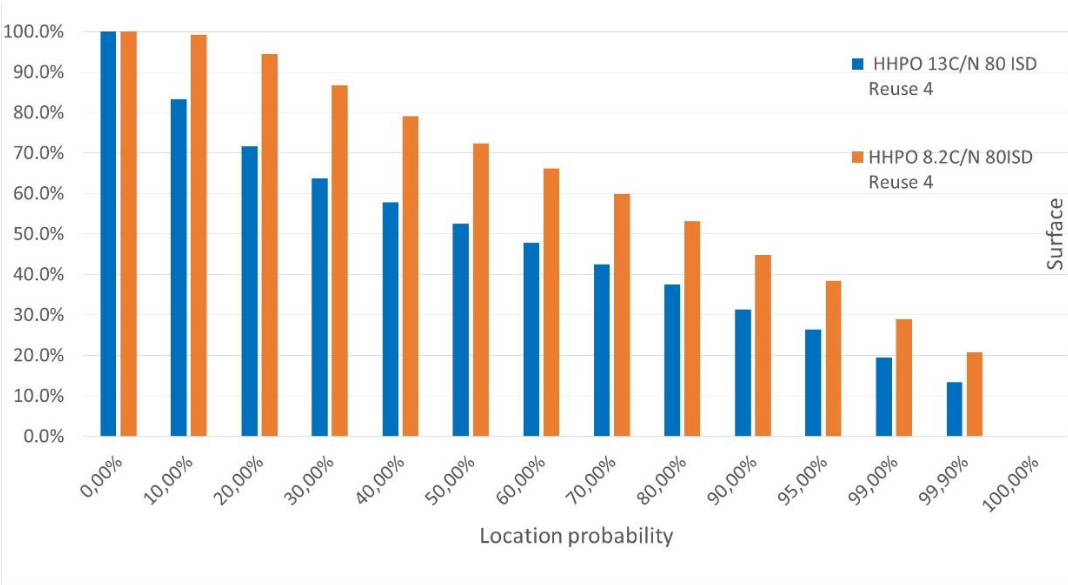
In a Hybrid broadcast/unicast configuration, the unicast network will need to take over the content delivery in 13% of the locations inside each pixel on average for the 15.2 dB SINR and 3% of the locations inside each pixel in average for the 9 dB SINR.

In a broadcast-only network, for the larger SINR of 15.2 dB, it is noted that only around 54% (respectively 81% for the SINR of 9 dB) of the pixels have more than 95% location percentage, which would not be enough with a broadcast-only network, as in this latter case, all pixels, including those at the edge of coverage, should have 95% location percentage.

For HHPO reception mode

FIGURE 43

HHPO, 8.2 dB/13 dB SINR, 80 km ISD



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

HHPO SINR = 8.2 dB, ISD 80 km → LP_{ave} = 74%

HHPO SINR = 13 dB, ISD 80 km → LP_{ave} = 54%

In the case of HHPO, the average location percentage is quite low compared to the CM case above, which is expected mainly because of the poor handheld receiver antenna gain in the HHPO case.

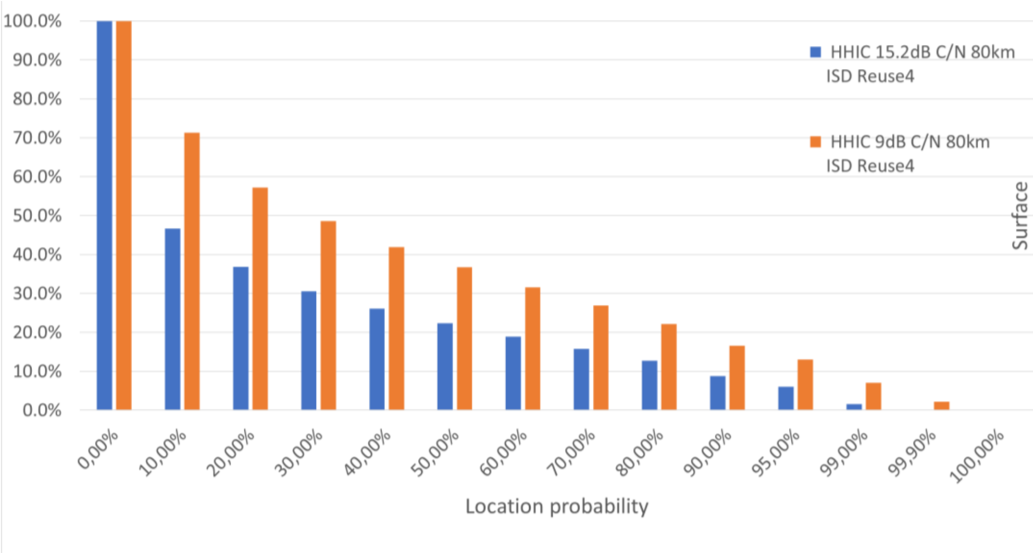
In a Hybrid broadcast/unicast configuration, the unicast network will need to take over the content delivery in 46% of the locations inside each pixel on average for the 13 dB SINR and around 26% of the locations inside each pixel in average for the 8.2 dB SINR.

In a broadcast-only network, for the larger SINR of 13 dB, it is noted that only around 26% of the pixels have more than 95% location percentage, which would not be enough with a broadcast-only network, as in this latter case, all pixels, including those at the edge of coverage, should have 95% location percentage.

For Handheld In Car (HHIC) reception mode

FIGURE 44

Handheld in car, 9 dB/15.2 dB SINR, 80 km ISD



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

HHIC SINR = 9 dB, ISD 80 km → LP_{ave} = 41%

HHIC SINR = 15.2 dB, ISD 80 km → LP_{ave} = 26%

As expected, the handheld in car reception mode is the most difficult, due to the additional car entry loss and the poor handheld receiver antenna gain.

In a Hybrid broadcast/unicast configuration, the unicast network will need to take over the content delivery in 74% of the locations inside each pixel on average for the 15.2 dB SINR and 59% of the locations inside each pixel in average for the 9 dB SINR. This requires robust coverage and high capacity of the unicast network over large parts of the HPHT coverage area.

The following sections shows the results of simulations for mixed topology HPHT/MPMT networks, first by adding only 1 ring of MPMT sites inside the HPHT coverage area, then by adding 2 rings.

2.7.2.2 Results for mixed HPHT/MPMT (1 ring) topology

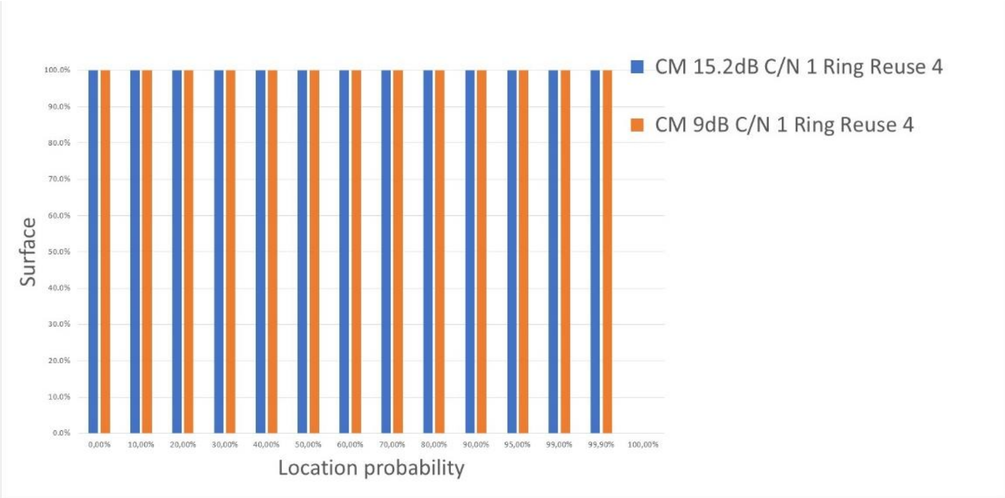
Figures 45, 46 and 47 show the simulation results for the Mixed HPHT/MPMT (1 ring) topology for the three reception modes.

As a reminder, this network topology is illustrated in Fig. 12 above. The site density of this network is 10.8 sites per 10 000 km^2.

For Car Mounted (CM) reception mode

FIGURE 45

Car mounted, 15.2 dB/9 dB SINR, 1 additional ring



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

CM SINR = 9 dB, ISD 80 km → LP_{ave} = 100%

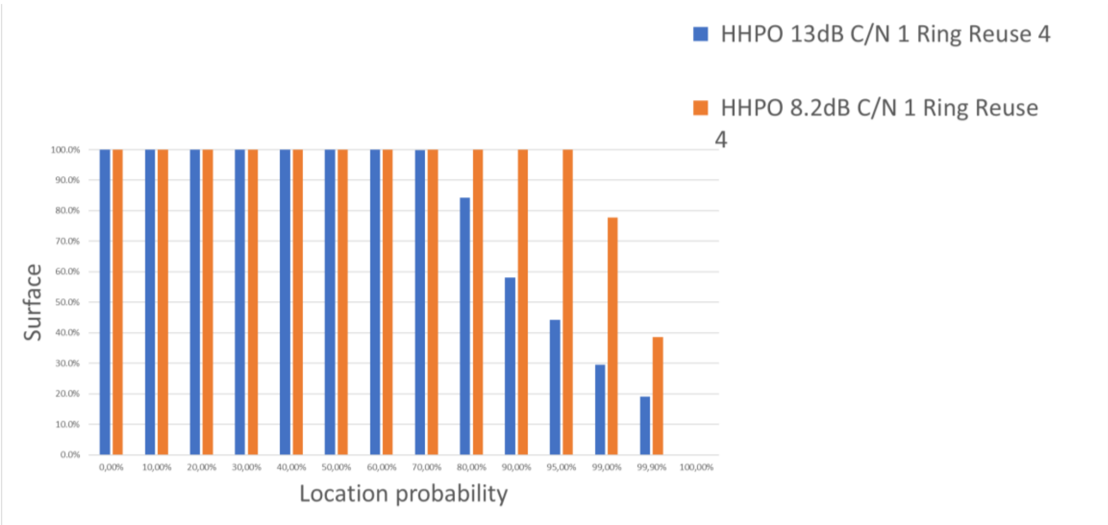
CM SINR = 15.2 dB, ISD 80 km → LP_{ave} = 100%

By adding only one ring of MPMT sites to each HPHT, the result improves significantly, with a full coverage even for the higher SINR value.

For HHPO reception mode

FIGURE 46

HHPO, 13 dB/8.2 dB SINR, 1 additional ring



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

HHPO SINR = 8.2 dB, ISD 80 km → LP_{ave} = 99%

HHPO SINR = 13 dB, ISD 80 km → LP_{ave} = 91%

By adding only one ring of MPMT sites to each HPHT site, the average location percentage increases significantly compared to the single HPHT case.

In a Hybrid broadcast/unicast configuration, the unicast network will need to take over the content delivery in 9% of the locations inside each pixel on average for the 13 dB SINR and 1% of the locations inside each pixel in average for the 8.2 dB SINR.

In a broadcast-only network, for the larger SINR of 13 dB, only around 45% of the pixels have more than 95% location percentage, which would not be enough for a standard broadcast coverage, as in this latter case, all pixels, including those at the edge of coverage, should have 95% location percentage.

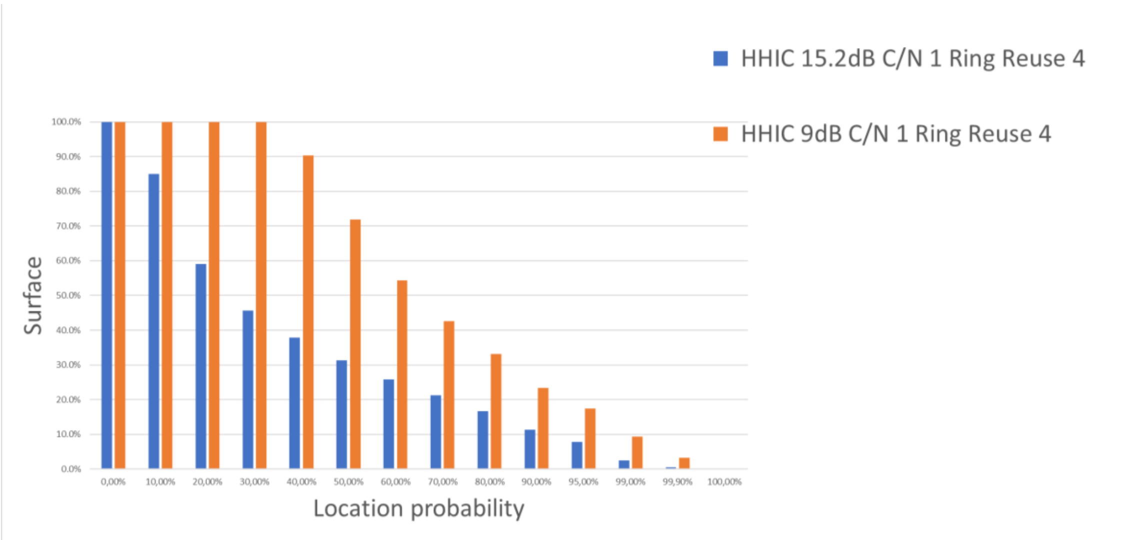
A hybrid broadcast/unicast network with only one ring of MPMT sites in each HPHT coverage area would therefore provide an acceptable coverage for a target SINR of 13 dB.

For sake of comparison with the results of simulations for broadcast Only operation (see Fig. 33 above), the LP_{ave} for 15 dB SINR is calculated. It reached 78% with only one ring of MPMT sites (this corresponds to required coverage by unicast in 22% of the locations in each pixel on average). Looking at Fig. 33, it can be seen that in a Broadcast Only operation (with a target LP of 95% everywhere) roughly 53% of surface coverage is reached with two rings of MPMT sites for 15 dB SINR target. The use of Hybrid broadcast/unicast operation in this case of HHPO reception, allows a substantial saving in number of sites (site density reduced from 21.6 to 10.8 sites per 10 000 km^2).

For Handheld In Car (HHIC) reception mode

FIGURE 47

Handheld in car, 15.2 dB/9 dB SINR, 1 additional ring



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

HHIC SINR = 9 dB, ISD 80 km → LP_{ave} = 67%

HHIC SINR = 15.2 dB, ISD 80 km → LP_{ave} = 39%

For this most demanding case of handheld in car reception, the addition of only one ring of MPMT sites in the HPHT coverage area increases the average location percentage from 26% to 39% for the 15.2 SINR and from 41% to 67% for the 9 dB SINR. In a Hybrid broadcast/unicast configuration, the unicast network will need to take over the content delivery in 61% of the locations inside each pixel on average for the 15.2 dB SINR and 33% of the locations inside each pixel in average for the 9 dB SINR. This requires robust coverage and high capacity of the unicast network over large parts of the HPHT coverage area.

The following sections show the results of adding two rings of MPMT sites to each HPHT site.

2.7.2.3 Results for mixed HPHT/MPMT (2 rings) topology

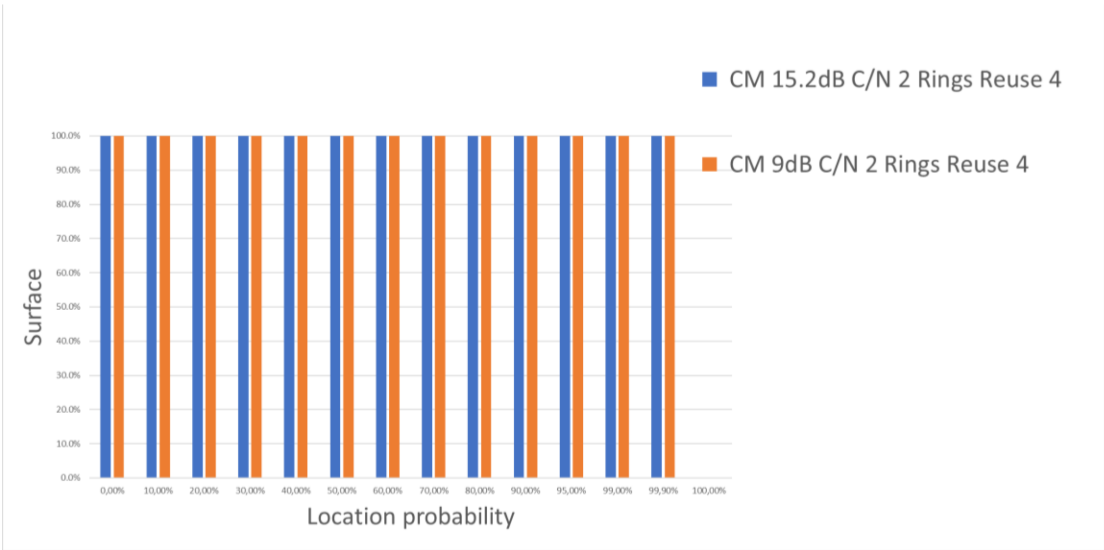
Figures 48, 49 and 50 show the simulation results for the Mixed HPHT/MPMT (2 rings) topology for the three reception modes.

As a reminder, this network topology is illustrated in Fig. 13 above. The site density of this network is 21.6 sites per 10 000 km^2.

For Car Mounted (CM) reception mode

FIGURE 48

Car mounted – 15.2 dB/9 dB SINR – 2 additional rings



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave}):

CM SINR = 9 dB, ISD 80 km → LP_{ave} = 100%

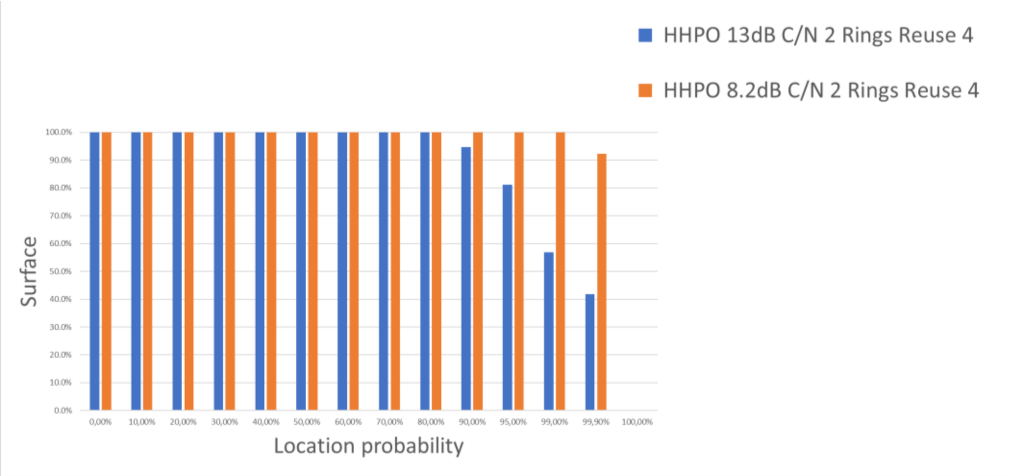
CM SINR = 15.2 dB, ISD 80 km → LP_{ave} = 100%

This is just for noting, as a full coverage was already reached with one ring of MPMT sites, see § 2.7.2.2.

For HHPO reception mode

FIGURE 49

HHPO, 13 dB/8.2 dB SINR, 2 additional rings



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

HHPO SINR = 8.2 dB, ISD 80 km → LP_{ave} = 100%

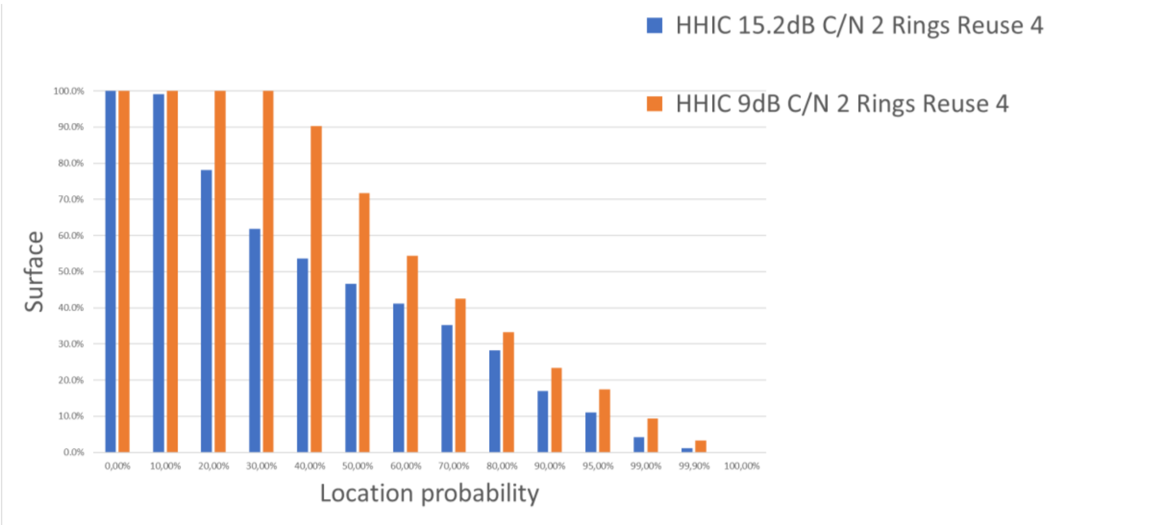
HHPO SINR = 13 dB, ISD 80 km → LP_{ave} = 98%

Compared to the results for HHPO with one ring of MPMT sites in § 2.7.2.2, it can be seen that the average location percentage approaches 100% for both SINR values, which minimizes the required coverage by the unicast network. To be noted that for the higher SINR of 13 dB, only around 83% of the pixels have more than 95% location percentage, which would not be enough with a broadcast-only network, as in this latter case, all pixels, including those at the edge of coverage, should have 95% location percentage.

For Handheld In Car (HHIC) reception mode

FIGURE 50

Handheld in car, 15.2 dB/9 dB SINR, 2 additional rings



Average Location Percentage LP_{ave}

(Note: Average unicast coverage Location Percentage = 100 – LP_{ave})

HHIC SINR = 9 dB, ISD 80 km → LP_{ave} = 83%

HHIC SINR = 15.2 dB, ISD 80 km → LP_{ave} = 51%

In this most demanding case of handheld in car reception, the addition of two rings of MPMT sites to each HPHT site doubles the average location percentage that was obtained with one ring (41% and 26% for 9 dB and 15.2 dB SINR respectively). For the higher SINR of 15.2 dB, this means that in a Hybrid broadcast/unicast operation, the unicast network will need to take over the delivery of content in almost half of the locations in each pixel on average.

Note that for SINR of 15.2 dB, only around 11% of the pixels have more than 95% location percentage, which is far from sufficient with a broadcast-only network, as in this latter case, all pixels, including those at the edge of coverage, should have 95% location percentage.

2.8 Specific analysis

2.8.1 Impact of practical antenna pattern

The generic studies to assess 5G Broadcast coverage are based on idealised, omnidirectional antenna patterns, where networks use HPHT and MPMT infrastructure and an optimized tri-sector pattern for LPLT sites. However, the real-world implementation of 5G Broadcast could be based both on existing antennas and on new antennas, where it is possible and cost-effective to install such new antennas. For the range of site topologies considered in this report (LPLT, MPMT and HPHT) the currently implemented antennas have been designed to meet existing network requirements and direct use by 5G Broadcast may lead to sub-optimum performance.

For sites that are currently in use for conventional broadcasting, a single antenna array comprising several individual radiating elements aims to provide uniform azimuthal coverage over the required arc; often a full 360 degrees. In reality, due to constraints in practical antenna design, a ripple of up to 4 dB is the best that can generally be achieved, and the existing broadcast sites may be optimised for conventional broadcasting and for 5G Broadcast.

For sites that are currently used by the Mobile Network, the situation is rather different. Generally, the antennas are constructed from arrays of elements providing 120 degree ‘sector’ azimuthal coverage. Where coverage is required over a full 360 degrees, three such antennas are mounted at 120-degree intervals around the structure. Where specific geographical areas are targeted, sector antennas may be oriented accordingly. The existing unicast mobile network can select and energise these sector antennas independently and so any interaction between adjacent sectors is not important – the base station scheduler may ensure that adjacent antennas are not used on the same resource block at the same time. However, if this arrangement of sector antennas is simultaneously powered from a single transmitter, as may be the case for 5G Broadcast applications, the interaction between adjacent antennas should be considered as this may lead to a compromise in the overall performance.

The sector antennas typically used by mobile systems are not designed to operate as arrays. If used for 5G Broadcast, such arrays would have deep nulls in the radiated pattern, which may compromise coverage. Measures to mitigate this loss in coverage may be required. Existing broadcast antenna systems have already been optimised for coverage. See Annex 3 for more information.

The impact on coverage could be reduced by increasing the EIRP, adopting an increased phase delay between sector antennas (cyclic delay diversity), a combination of the two or building a new antenna with a better pattern. Each has a cost implication that needs to be weighed against the potential loss in coverage. See Annex 3 for more information.

2.8.2 Estimate of Doppler performance

For a 5G Broadcast system targeting mobile reception, system Doppler performance is important as, via the carrier spacing and hence the choice of CP, it can drive the network design.

Doppler is an issue for broadcast systems. Digital audio broadcasting (DAB) systems largely avoid the problem because of the low frequency employed, around 200 MHz. DTT systems are typically designed for fixed reception where Doppler is generally not a problem. DTT systems designed for portable/mobile reception (as, for example, in Germany) employ increased carrier spacing (fewer carriers i.e. larger frequency spacing between carriers) and hence smaller SFN size along with more dense networks (reduced spacing between transmitters).

The ISD in an SFN is dependent on the length of the CP. The larger the ISD, the longer the CP needs to be, and correspondingly a longer symbol time is needed. However, longer symbol time, which is a function of the inverse of the carrier spacing, will result in degraded Doppler performance and lower speed limits for mobile reception.

Without doing detailed and complicated link-level simulations, the calculation of Doppler performance for OFDM-based broadcast systems can be estimated from methods described in [9], which investigate the Inter Carrier Interference (ICI, or FFT leakage) as a function of Doppler. This work focused on DVB-T/T2 but the methodology is applicable to any OFDM system, including 5G Broadcast.

The report of this work contains an extensive mathematical analysis but ends up with a formula for the resultant *C*/*I* of an OFDM system with 1 kHz carrier spacing:

$$C/I = 58.6 - 20\log_{10}(f_d) \quad \text{dB}$$

where:

f_d: Doppler frequency in a Rayleigh fading channel in Hertz.

For example, 100 Hz Doppler results in a $C/I = 58.6 - 40 = 18.6$ dB. If the required *C*/*N* of the system is known, it is easy to calculate the *C*/*N* degradation. Usually, a 3 dB increase of required *C*/*N* is used when presenting the Doppler frequency limits and corresponding speed limits. The maximum theoretical Doppler may also be calculated.

Modifications

- Changing the FFT (symbol time) will change the constant 58.6 in the equation. For example, 500 Hz carrier spacing (16k FFT) will reduce the value by 6 dB, and for 250 Hz carrier spacing (32k FFT) by 12 dB, resulting in constant values of 52.6 dB and 46.6 dB, respectively.
- Other symbol times may be scaled correspondingly; for example, a factor 2 corresponds to 6 dB, means that, for example, a factor of 1.8 should be 4 (6 dB in linear scale) × 1.8/2.0. Converted back to dB scale the correction to 58.6 would be 5.6 dB.

ICI is, however, not the only limitation. Additionally, the limitations created by the channel estimation (determined by the Pilot Patterns) need to be determined. These Scattered Pilot Patterns are used for channel estimation in the receiver, in frequency and in time[10]. But in the case of 5G Broadcast the FFT leakage (ICI) seems to be the main limitation, at least for the OFDM variants of interest in SFNs.

In Tables 21, 22 and 23, the maximum Doppler and speed limitation for 5G Broadcast are derived for three proposed 5G Broadcast modes operating at 600 MHz.

[10] The repetition pattern in frequency is denoted Dx or Df, while the repetition pattern in time is denoted Dt or Dy.

TABLE 21

Maximum Doppler frequency and speed
Symbol period 400 µs, cyclic prefix 100 µs, Df(Dx) 2, Dt(Dy) 1 (see footnote 10)
Channel estimation max Doppler 1 250 Hz

Req *C*/*N* (dB) Rayleigh	Channel estimation Doppler max (Hz)	FFT leakage Fd max	Max Doppler (Hz)	Max speed (km/h)
0	1 250.0	1 202.3	1 202.3	2 164
5	1 250.0	676.1	676.1	1 217
10	1 250.0	380.2	380.2	684
15	1 250.0	213.8	213.8	385
20	1 250.0	120.2	120.2	216
25	1 250.0	67.6	67.6	122

TABLE 22

Maximum Doppler frequency and speed
Symbol period 800 µs, cyclic prefix 200 µs, Df(Dx) 3, Dt(Dy) 2 (see footnote 10)
Channel estimation max Doppler 625 Hz

Req *C*/*N* (dB) Rayleigh	Channel estimation Doppler max (Hz)	FFT leakage Fd max	Max Doppler (Hz)	Max speed (km/h)
0	625	602.6	602.6	1 085
5	625	338.8	338.8	610
10	625	190.5	190.5	343
15	625	107.2	107.2	193
20	625	60.3	60.3	108
25	625	33.9	33.9	61

TABLE 23

Maximum Doppler frequency and speed
Symbol period 2700 µs, cyclic prefix 300 µs, Df(Dx) 3, Dt(Dy) 1 (see footnote 10)
Channel estimation max Doppler 185.2 Hz

Req *C*/*N* (dB) Rayleigh	Channel estimation Doppler max (Hz)	FFT leakage Fd max	Max Doppler (Hz)	Max speed (km/h)
0	185.2	186.2	185.2	333
5	185.2	104.7	104.7	188
10	185.2	58.9	58.9	106
15	185.2	33.1	33.1	60
20	185.2	18.6	18.6	34
25	185.2	10.5	10.5	19

In conclusion, a CP of 200 µs seems to be required to ensure mobile reception with reasonable maximum speed.

2.9 Conclusions from the simulation results on theoretical networks

2.9.1 Broadcast-only networks

2.9.1.1 Car mounted reception

It should be possible to ensure 15 dB SINR for 5G Broadcast car mounted receivers with full rural area coverage using a mixed HPHT+MPMT network with HPHT EIRP similar to current typical DTT HPHT networks and with MPMT EIRP slightly higher than current typical DTT MPMT networks. The required site density is around 22 sites per 10 000 km^2 (2 HPHT sites and 20 MPMT sites).

Reuse 1 should be used where possible, and reuse 3 or 4 MFN clusters of SFNs should be used where reuse 1 cannot be implemented, typically at regional and national borders. A CP of 200 µs is recommended to allow reception at normal vehicle speeds. In these conditions, in an 8 MHz channel, a capacity up to 12 Mbit/s could be achieved, using MCS16.

A full LPLT network could provide 15 dB SINR for 5G Broadcast car mounted receivers with full urban and suburban area coverage. Considering the large site density for this type of network (ISD = 3 km, corresponding to 1 283 sites per 10 000 km^2). This corresponds to around 14 LPLT sites for an urban area of 105 km^2 like Paris or Barcelona, or 115 LPLT sites for an urban area of 900 km^2, like Berlin. Its use may be limited to the coverage of urban and suburban areas with reuse 1, with rural areas being more efficiently covered by mixed HPHT+MPMT networks as described above, with a site density around 21.6 sites per 10 000 km^2. The same capacity as above, i.e. up to 12 Mbit/s in 8 MHz, could be achieved, using MCS16.

2.9.1.2 Handheld portable reception

The same mixed HPHT+MPMT network described above, with a site density of around 22 sites per 10 000 km^2 would also ensure 15 dB SINR for HHPO reception, but in 50% of rural areas. It should be noted that the coverage in terms of population in rural areas could be higher than the area coverage if the choice of the sites is made adequately.

A complementary reuse 1 LPLT network, as described above, is necessary in suburban and urban areas to ensure 15 dB SINR for HHPO in these areas. In these conditions and using the same MCS 16 as for car mounted, a capacity up to 12 Mbit/s could be achieved in 8 MHz. Using MCS18 would is also possible with 15 dB SINR in HHPO, offering up to 13 Mbit/s.

2.9.1.3 Handheld in car reception

5G Broadcast handheld in car reception with 15 dB SINR is not achievable across a full area for any of the analysed network types. The coverage for this type of reception would be limited to best effort.

2.9.2 Hybrid broadcast/unicast reception

The Hybrid broadcast/unicast operation allows complementing the coverage with the unicast network in those locations not served by the broadcast network. The criteria used to define the required unicast complementary coverage is the actual population coverage of a real Broadcast network (calculated with the proportional calculation method, which weighs the population of every pixel with the coverage location percentage in the pixel). For a theoretical, regular network, this corresponds to the average location percentage over all the pixels in the coverage area. The higher this average location percentage is, the lower use of the unicast will be. The broadcaster or BNO can therefore set the target average location percentage depending on the technical and cost factors related to their network, and on the coverage and capacity of the unicast mobile network in the concerned area.

For example, an average location percentage over the broadcast coverage area of 90% means that the unicast network will take over 10% of the locations inside each pixel on average throughout the coverage area.

To be noted that in real situations, the BNO usually selects the sites in a way to optimize the population coverage. In a theoretical network, the population is assumed to be uniformly distributed. Therefore, the population coverage of a real broadcast network will in general be higher than the population coverage calculated in a theoretical network. This means that the results obtained with the theoretical network analysis in this study are generally conservative.

2.9.2.1 Car mounted reception

For this reception mode, a single topology HPHT network (with site density of 1.8 site per 10 000 km^2) offers a high level of average location percentage throughout the entire coverage area. The complementary coverage from the unicast network will be needed only for a small part in each pixel. More precisely, to ensure 15.2 dB SINR, unicast will need to take over the content delivery in 13% of the locations inside each pixel on average.

The addition of one ring of MPMT sites towards the edge of the HPHT coverage area (with site density of around 11 sites per 10 000 km^2) would provide a full area coverage, without the need for complementary coverage using unicast. In these conditions, in an 8 MHz channel, a capacity up to 12 Mbit/s could be achieved, using MCS16.

2.9.2.2 HHPO reception

As indicated in the results for broadcast-only operation above, a broadcast network consisting of one HPHT layer and one MPMT layer with two rings of MPMT sites in each HPHT coverage area (site density around 22 sites per 10 000 km^2), will roughly ensure 15 dB SINR for HHPO reception in 50% of rural areas. This corresponds to pixels of the theoretical network coverage area where the location percentage is 95% or more.

In a hybrid broadcast/unicast operation, it is possible to reach a full coverage with only one ring of MPMT sites in each HPHT coverage area (site density 11 sites per 10 000 km^2) by using unicast to complement coverage in 9% of the locations inside each pixel on average to ensure 13 dB SINR.

For an SINR of 15 dB (to compare with the broadcast-only networks above), with only one ring of MPMT sites, it would be necessary to complement the coverage using unicast in 22% of the locations inside each pixel on average.

The addition of a second ring of MPMT sites inside the HPHT coverage area (site density around 22 sites per 10 000 km^2) would ensure full coverage while reducing further the required complementary coverage by the unicast network to around 2% in terms of location percentage in each pixel in average, to ensure an SINR of 13 dB.

To ensure an SINR of 15 dB with a second ring of MPMT sites, the required complementary coverage by the unicast network would be 10% in terms of location percentage in each pixel in average.

These results show that increasing the target SINR by 2 dB (from 13 to 15 dB) has required doubling the number of MPMT sites to maintain the required complementary coverage from unicast to 10%. The consequential change in capacity from 13 to 15 dB is from around 12 Mbit/s to around 14 Mbit/s in 8 MHz.

2.9.2.3 Handheld in car reception

This is the most demanding reception mode examined in this theoretical analysis. In the case of broadcast-only network it was concluded that full coverage is not achievable with any network types. With a hybrid broadcast/unicast operation using a mixed topology HPHT with two MPMT rings (site density around 22 sites per 10 000 km^2), it would be necessary to complement the coverage with unicast in around 50% of the locations in each pixel on average to ensure 15.2 dB SINR.

2.9.3 General observations

These results show that the Hybrid broadcast/unicast operation offers a flexibility in the deployment of the 5G Broadcast network. This flexibility can be exploited by means of progressive number of sites. For a SINR target of 13 dB, the following progressive implementation can be foreseen:

a) Start with a HPHT single topology network. The required complementary coverage from unicast in an average percentage of locations in each pixel is around 10% for Car mounted, 46% for HHPO and around 70% for handheld in car reception.

b) Adding a layer with one ring of MPMT sites in suitably selected areas (densely populated, close to Edge of coverage, etc.). This may ensure almost full coverage without any required coverage from unicast for car mounted reception but would still require unicast coverage in an average percentage of locations in each pixel of around 9% for HHPO and around 60% in each pixel for handheld in car reception.

c) Finally adding a second ring to the MPMT layer in further selected areas. This would further reduce the required complementary unicast coverage in each pixel to an average of 2% for HHPO and around 50% for handheld in car reception.

This flexibility also allows to progressively increase the SINR while adding additional broadcast sites, to minimize the required complementary coverage by unicast. For example:

d) Starting with HPHT only with a target SINR of 8 dB (by selecting the relevant MCS) would set the requirement for complementary unicast coverage to 2% for car mounted reception, 26% for HHPO reception and 60% for handheld in car reception.

e) When a first MPMT layer is added in suitably selected areas, the target SINR can be increased to 13 dB (by modifying the MCS). The required complementary unicast coverage will almost be 0% for car mounted reception, around 10% for handheld portable reception and less than 60% for handheld in car reception.

f) When additional medium and low power sites are added in further selected areas, the target SINR can be increased to 15 dB (by modifying the MCS). The required complementary unicast coverage will still be 10% for HHPO and less than 50% for handheld in car reception.

3 Real networks

One of the key drivers for broadcasters' and broadcast network providers' interest in adopting 5G Broadcast is making their content available to handheld devices such as mobile phones and tablets.

A critical question is whether the existing broadcast infrastructure used for DAB or DTT, possibly supplemented with cellular type networks, can be used to provide such handheld services using 5G Broadcast. Therefore, simulations have been carried out based on existing real network sites to see if this could be an option and under what conditions this would be feasible.

Three cases of 5G Broadcast networks based on existing broadcast infrastructure have been modelled.

The first case is in Italy, where a network is based upon a network developed for the former DVB-H implementation on existing Digital Video Broadcasting — First Generation Terrestrial (DVB-T) channel 38 national SFN, augmented by mobile operator sites, has been studied.

The second case concerns Denmark, where a network based on the national DAB network has been studied.

The third case concerns Germany, where the coverage of a 5G Broadcast network entirely based on existing DTT Broadcast infrastructure was studied.

3.1 Italy

The coverage of a 5G Broadcast network based on the existing DVB-T channel 38 SFN network[11] augmented by additional MNO sites has been assessed.

3.1.1 5G Broadcast sites

This network, consisting of 821 sites, is a real existing national broadcasting network (BNO) designed for fixed reception that provides useful roof top coverage to more than 94% of the national population. It consists of a mixture of HPHT, MPMT and LPLT.

To extend coverage for handheld/mobile use, the network was augmented by two sets of existing Mobile Network Operator (MNO) sites. The first set (1 037) of MNO sites is a large part of those that were used in one of the two former DVB-H networks in Italy. A second set of (1 253) MNO sites is considered to complete the coverage (see Table 24).

TABLE 24

Sites considered for the 5G Broadcast Network in Italy

Sites	North – Centre (reg. 1-10)	Centre – South (reg. 11-20)	Italy
BNO	458	363	821
MNO part #1	581	456	1 037
MNO part #2	596	657	1 253
Total	1 635	1 476	3 111

3.1.2 5G Broadcast planning assumptions

For coverage modelling, the BNO sites used existing Effective radiated power (ERP) and the MNO sites used an ERP of 200 W[12] (328 W EIRP). The propagation model used is ITU-R P.1812 for 1% time with coverage step of 100 m. Digital Terrain Model (DTM) and clutter[13] definition is 100 m × 100 m.

To optimise coverage, SFN delay “fine tuning” is done in all the sites of the network.

Coverage was calculated for HHPO (1.5 m a.g.l. using the parameters in Table 25, considering different values of *C*/*N* or SINR and starting with a CP of 200 µs, in line with the 5G Broadcast system parameters Variant 4 (Table 1) and with the reception parameters of Scenario 3 for HHPO (Table 2). Some results with 300 µs CP are also presented.

Moreover, additional calculation was done for Car Mounted (CM) using the reception parameters of Scenario 1 for car mounted (Table 2).

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[11] This is one of the two former DVB-H Networks which is now operating in DVB-T, 8k, 64-QAM, code 3/4, IG 1/4, SFN mode. At the time of writing (2024) this network operates with more than 1 400 sites.

[12] Licensing requirements in Italy limit the ERP that can be readily deployed.

[13] The propagation model has been tuned (for the current ITU-R P.1812 model) to the clutter using field measurement data obtained (in years 2007-2008) from the DVB-H former network. These “fine-tuning” measurements were limited to the area of the City of Milan and surrounding municipalities, including some rural “flat” areas, but should be considered as valid for the whole country, also. The results are in line with further measurements carried out in 2024 for a 5G Broadcast SFN trial in Lombardy and Milan.

TABLE 25

Calculation parameters

Scenario	1	3
Reception parameters	Car Mounted (CM)	HHPO
Type of reception	Mobile	Portable
Path type	Land/Sea	Land/Sea
Receiver height (m)	1.5	1.5
Bandwidth (MHz)	5	5
Receiver noise figure (dB)	6	9
Receiver feeder loss (dB)	0	0
Other losses (dB)	1	1
Frequency	610 MHz (CH 38)	610 MHz (CH 38)
Receiver antenna gain, including body loss and receiver diversity gain (dBi)	3	5.8
Receiver strategy for signals from the same SFN	Maximum *C*/*I*	Maximum *C*/*I*
Location variation standard deviation (dB)	5.5	5.5

Table 26 shows the values of field strength that are required for different *C*/*N* or SINR and as a function of the "location probability"[14], using the parameters presented in Table 25.

The values of field strength presented in Table 26, together with the DTM and the clutter[15], were used for the calculation of the coverage at 1.5 m.

Any "small area" that satisfies the requirement on the given location percentage is considered as covered with all its surface and its population. Vice versa, in any "small area" where this requirement is not satisfied, all its surface and all its associated population are considered as not covered.

To obtain the 'useful coverage', one additional *C*/*(N+I)* calculation is needed using the appropriate values of SINR and Field strength threshold wanted, to identify the percentage of the coverage that is 'lost', due to the SFN self-interference.

Unless otherwise specified, all the 'coverages' specified from here onwards should be understood as 'useful coverages', whereby the percentage of self-interference is already considered, subtracting its value from the (gross) coverage.

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[14] Location probability is the percentage of receiving locations inside any 'small area' (typically 100 m by 100 m) of the coverage where a given field strength is achieved or exceeded.

[15] E.g. in the Urban Environment, the height of the building is assumed as "20 m" and, from the measurement done, 3 dB of additional clutter attenuation was also factored in.

TABLE 26

Example of calculations of the 'minimum median field strength'

Values	5G Broadcast HHPO				5G Broadcast Car mounted (CM)			
SINR (dB)	**5**	**10**	**15**	**20**	**5**	**10**	**15**	**20**
Boltzmann's constant *k* (Ws/K)	1.38E-23				1.38E-23			
Absolute temperature T_0 (K)	290				290			
Equivalent noise bandwidth (Hz)	5.00E+06				5.00E+06			
Thermal noise power (dBm)	–107.0				–107.0			
Noise figure (dB)	9.0				6.0			
KTBF (dBm)	**–98.0**				**–101.0**			
Input resistance (ohm)	75				75			
Other losses (dB)	1.0				1.0			
SINR and other losses (dB)	**6.0**	**11.0**	**16.0**	**21.0**	**6.0**	**11.0**	**16.0**	**21.0**
Min. Rx input power (dBm)	**–92.0**	**–87.0**	**–82.0**	**–77.0**	**–95.0**	**–90.0**	**–85.0**	**–80.0**
Min. equiv. Rx input voltage (dBμV)	16.8	21.8	26.8	31.8	13.8	18.8	23.8	28.8
Frequency (MHz)	610				610			
Rx feeder loss (dB)	0.0				0.0			
Rx ant. gain (incl. diversity) iso (dBi)	–5.8				3.0			
Rx antenna gain over a dipole (dBd)	–7.9				0.9			
Antenna factor (75 Ω) (dB)	29.9				21.1			
Height loss (dB)	0.0				0.0			
Min. field strength (dBμV/m)	**47**	**52**	**57**	**62**	**35**	**40**	**45**	**50**
Standard deviation σ (dB)	5.5				5.5			
Location probability 70%								
Location correction factor (dB)	3				3			
Min. median field strength (dBμV)	**50**	**55**	**60**	**65**	**38**	**43**	**48**	**53**
Location probability 90%								
Location correction factor (dB)	7				7			
Min. median field strength (dBμV)	**54**	**59**	**64**	**69**	**42**	**47**	**52**	**57**

3.1.3 5G Broadcast coverage predictions

In this section, results obtained for handheld receivers and HHPO reception with CP 200 μs, SINR 15 dB and 90% Location Probability are initially presented.

The BNO Broadcast network provides the basic HHPO coverage of 59.4% of the population of all Italy. Example coverage of North Italy is provided in Fig. 51 (coverage is higher than for South Italy) and the population covered is 68.1%. See Table 27 for additional results.

TABLE 27

Coverage in the north, south and all of Italy for two combinations of network HHPO, Loc. 90%, CP 200 µs

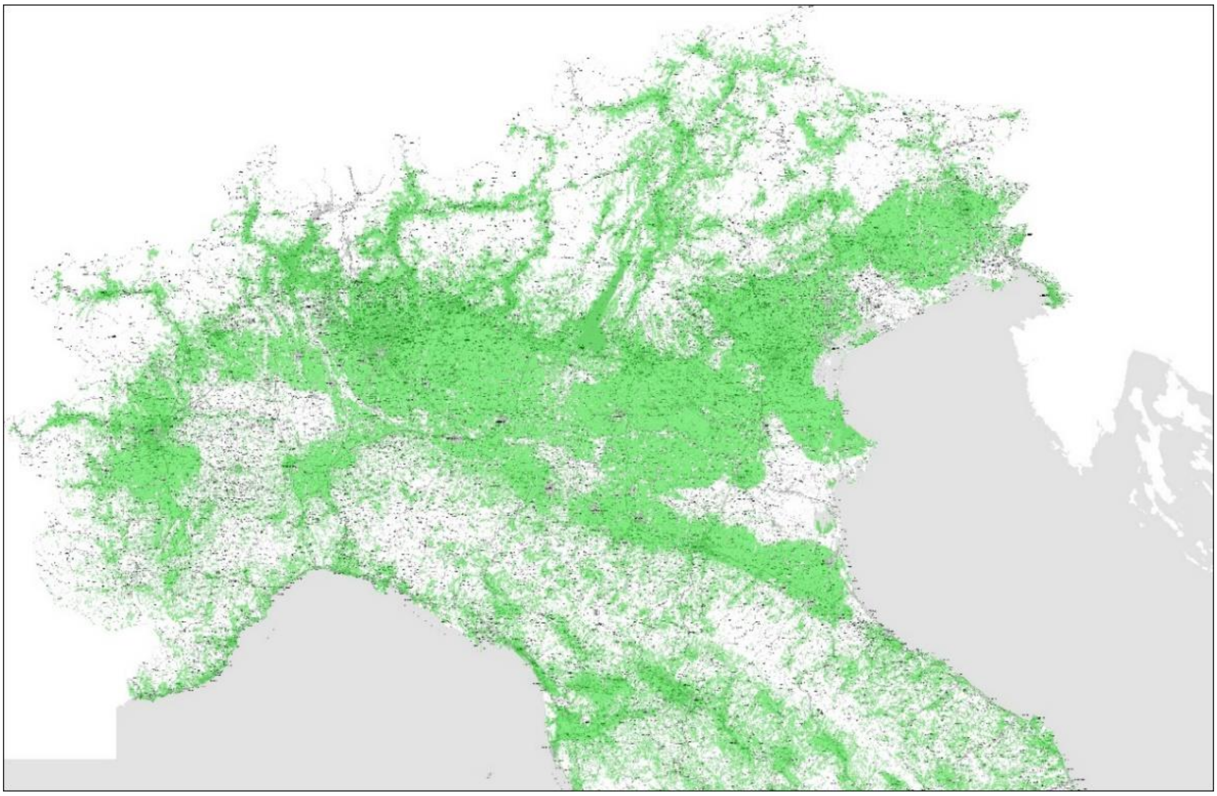
Network	SINR (dB)	Threshold E (dBµV/m)	Coverage (%)			Interference (%)			Useful (%)		
			North	South	Total	North	South	Total	North	South	Total
BNO	15	64	69.0	50.6	60.4	0.9(1)	1.1(1)	1.0(1)	68.1	49.5	59.4
BNO+MNO #1 and #2	15	64	90.8	82.9	87.1	2.2(1)	2.2(2)	2.2(2)	88.6	80.7	84.9

(1) Calculated value (delay optimization for all sites).

(2) Hypothesis.

FIGURE 51

North Italy BNO useful coverage, SINR 15 dB, location probability 90%



The coverage of the BNO network can be enhanced by the addition of MNO sites.

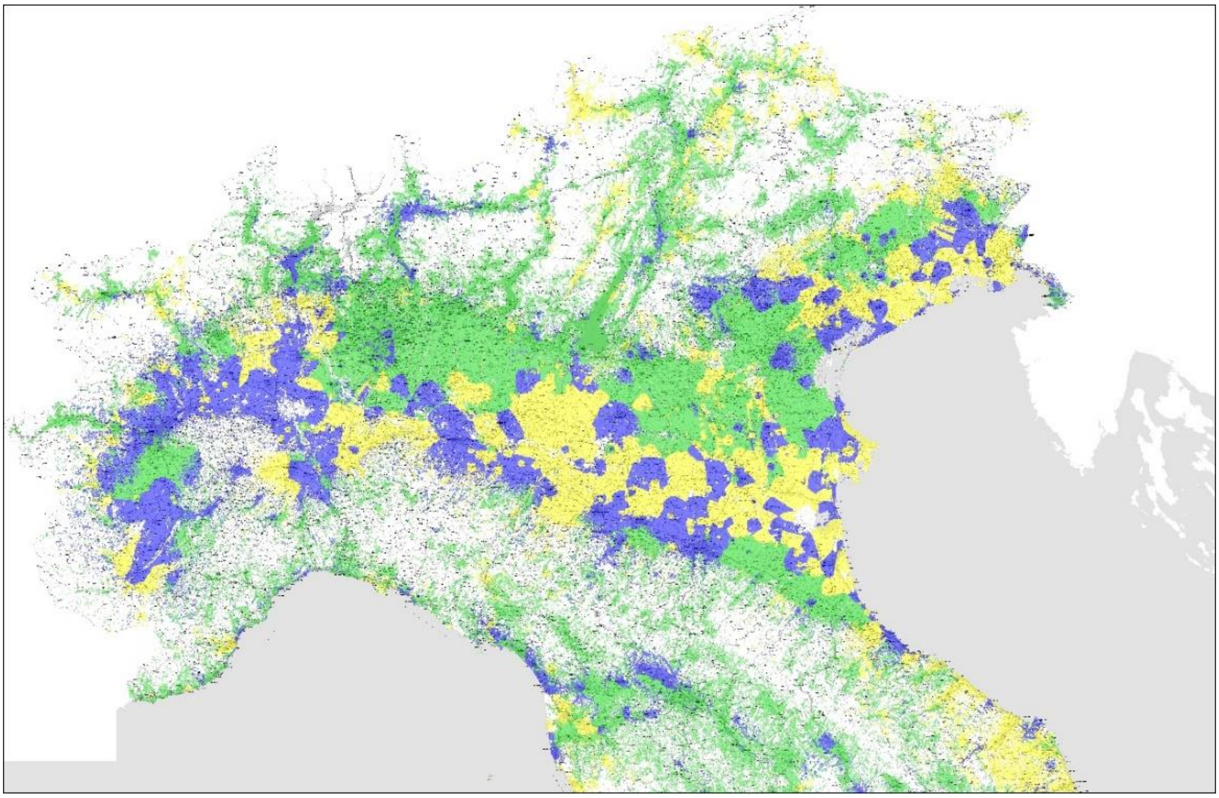
In the north of Italy, using a combination of the different sites, BNO and MNO part #1 cover 82.0% of the population, while BNO, MNO part #1 and MNO part #2 cover 88.6% (Table 27 shows the detailed results for BNO network alone and BNO+MNO #1 and #2).

Figure 52 shows the coverage with the “best server” at a given location between the BNO and the two MNO sets of sites.

BNO coverage (green) is 43.6% of the total coverage; MNO#1 (blue) is 32.6%; MNO#2 (yellow) is 12.4%.

FIGURE 52

North Italy BNO+MNO#1+MNO#2 "Best Server" useful coverage, SINR = 15 dB



Overall useful coverage (in terms of percentage of population) of the network combinations is given in Table 28 (70% location probability), Table 29 (90% location probability) and Table 30 (95% location probability).

The coverage depends on the required location probability over the 'small areas' ((Pixel) that comprise the useful coverage[16].

[16] E.g. if the requirement is 90% of location probability, any 'small area' (or 'pixel') with percentage of locations < 90% is considered as 'not covered': therefore, all its surface and the associated population is considered as 'not covered'.

If all the percentages are counted (and, e.g. any pixel covered at 50% of its location 'contributes' for the 50% of its surface and population to the whole coverage and so on), in case of the network composed by BNO + MNO part #1 and #2, the value 87.4% of useful coverage for SINR = 15 dB becomes 89.0% (see Table 28).

TABLE 28

Coverage of the network combinations (location probability 70%)

SINR Sites	North Italy (HHPO) (reg. 1-10) 200 µs – Loc 70% 5 dB	10 dB	15 dB	20 dB
BNO	94.8	90.6	79.8	63.1
MNO part #1	84.3	78.6	66.5	51.2
MNO part #1 and #2	87.6	83.2	74.9	60.2
BNO + MNO part #1	96.1	94.0	89.0	79.1
BNO + MNO part #1 and #2	**96.7**	**95.0**	**91.4**	**83.0**

TABLE 29

Coverage of the network combinations (location probability 90%)

SINR Sites	North Italy (HH PO) (reg. 1-10) 200 µs – Loc 90% 5 dB	10 dB	15 dB	20 dB
BNO	92.3	83.5	68.1	49.8
MNO part #1	80.8	71.3	56.1	41.4
MNO part #1 and #2	85.4	79.7	68.5	51.8
BNO + MNO part #1	94.9	91.5	83.9	70.0
BNO + MNO part #1 and #2	**95.8**	**93.7**	**88.6**	**76.3**

TABLE 30

Coverage of the network combinations (location probability 95%)

SINR Sites	North Italy (HH PO) (reg. 1-10) 200 µs – Loc 95% 5 dB	10 dB	15 dB	20 dB
BNO	89.8	78.2	60.9	42.6
MNO part #1	77.9	66.0	50.9	34.6
MNO part #1 and #2	84.0	76.9	63.3	45.6
BNO + MNO part #1	94.0	89.3	79.9	63.7
BNO + MNO part #1 and #2	**95.3**	**92.7**	**85.9**	**70.3**

As additional information, in 2024 some other calculations were made, also in view of possible "hybrid networks"[17] and, therefore, to consider the main points herewith summarized:

- For each pixel, to consider the sum of each location percentage multiplied by the population in that pixel. In the following of the document this method is named as "Proportional count" or "P count". This is complementary to the (typical) methods that, for each target LP, consider only those pixels that have a LP greater than (or equal to) the target LP. In the following of the document this method is named as "Threshold sum".
- To consider the coverage of other selections of sites in Real Networks.

As a first example, Fig. 53 shows the resulting useful percentage of population coverage[18] in the North Italy of the BNO network with 458 sites operating in SFN, as function of the location percentages calculated with "Threshold sum" and with "Proportional Count" (or LP "sum").

FIGURE 53

North Italy coverage of population (BNO network with 458 SFN sites)
Function of SINR, location percentages and "Proportional count"

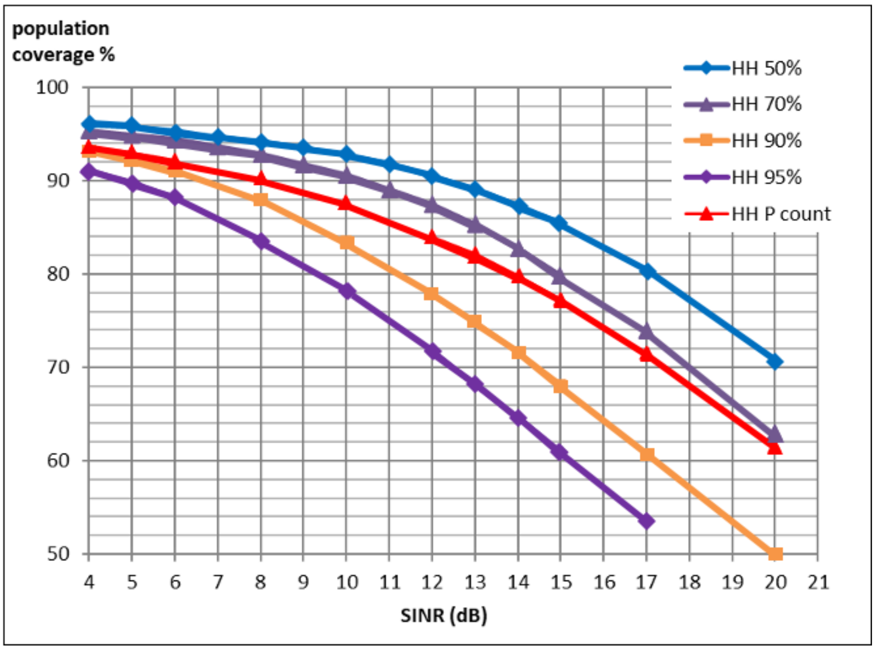


Figure 54 shows the HHPO coverage using only a part of the BNO network with 132 of the 458 sites, while Fig. 55 gives details about the SFN interference, as function of the various parameters[19].

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[17] Unicast distribution to user equipment is provided where 5G-Broadcast transmission is not available.

[18] Data are those presented in Tables 28, 29 and 30, plus additional results for other SINR values.

[19] As already stated, all the presented Tables and Figures already count this SFN auto-interference.

FIGURE 54

North Italy coverage of population (BNO network with 132 SFN sites)
Function of SINR, location percentages and "Proportional count"

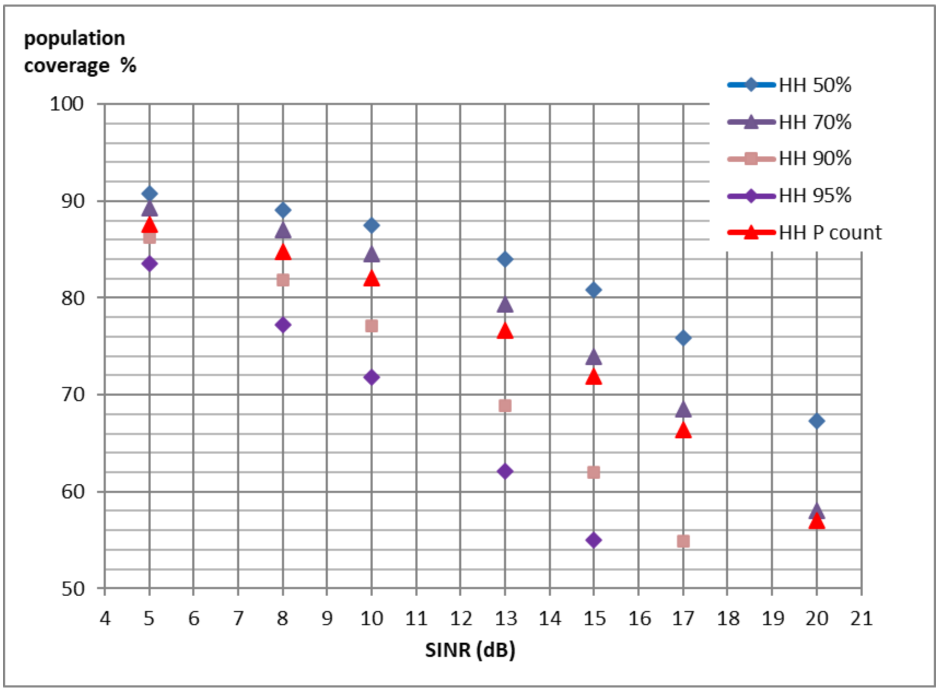
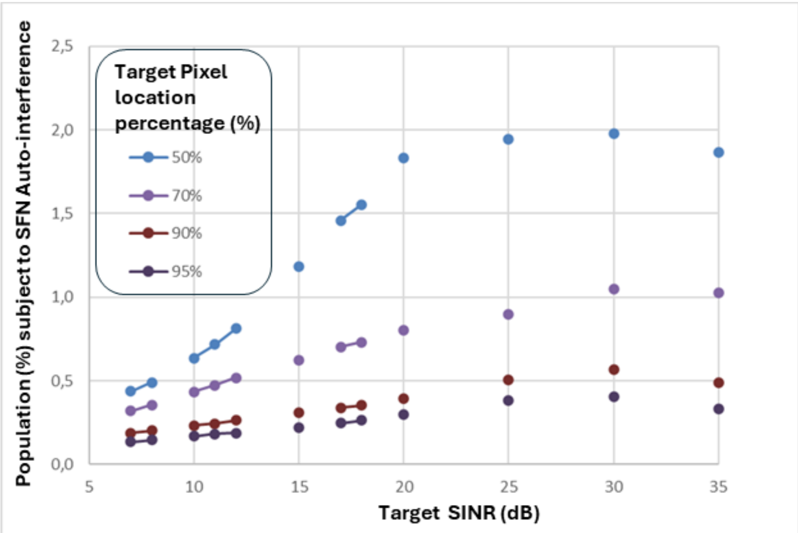


FIGURE 55

Example of SFN auto-interference calculation (BNO network with 132 main sites)
Function of SINR and location percentage of the pixels

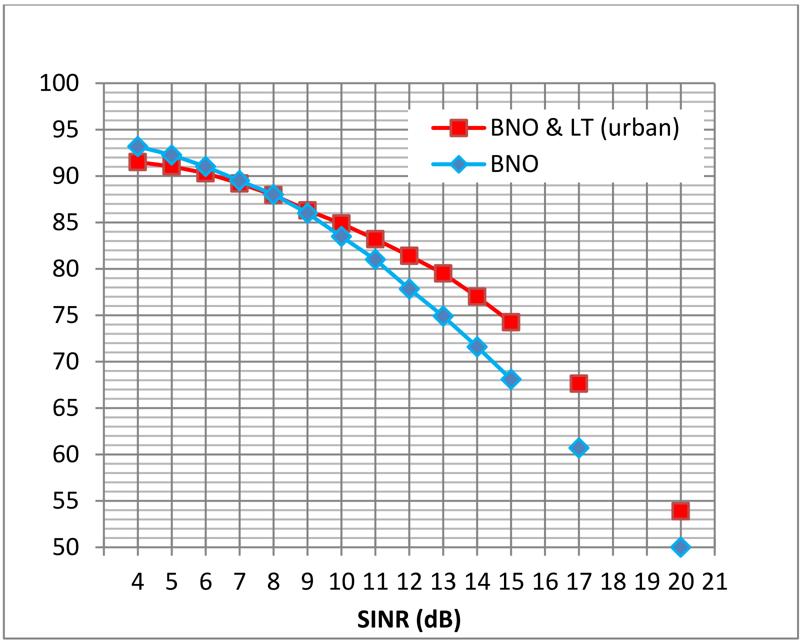


In addition, Fig. 56 shows the results of HHPO population coverage with a new network configuration using the selection of 132 BNO Transmitters and 326 LPLT additional urban sites. The total number of sites is 458 and Fig. 56 also compares this configuration with the one composed by the 458 BNO broadcasting site only.

As expected, the "BNO only" solution has a wider coverage (especially in rural areas) and offers a better coverage for lower SINR, while the solution with MNO LPLT is preferrable for higher value of SINR and for the coverage of urban areas.

FIGURE 56

North Italy HHPO coverage with two network configurations (458 sites composed of 132 BNO sites and 326 LPLT urban sites), function of SINR - location percentage 90%



The relative timing of sites for optimising coverage is important, as shown in Figs 57 and 58.

In case of CP = 200 µs, SINR 15 dB and 90% of location probability, the percentage of usefully covered population increases by the order of 7% (from 81.8% with 'zero delay' to 88.6% with 'optimised site timing').

Note that this coverage would be of the order of 90% but, even with all the optimizations done, a percentage of the order of 1.0%-2.0% for the SFN self-interference remains, reducing the useful coverage. This percentage is also in line with the results presented in Figs 55 and 56 for a more limited network.

The positive effect of the 'site timing' for the SFN coverage is clearly visible in Northern Italy, in the flat areas between all the major HPHT Broadcasting Sites (e.g. between Turin and Milan, Milan and Verona, Bologna and Venice).

FIGURE 57

Optimised relative site timing

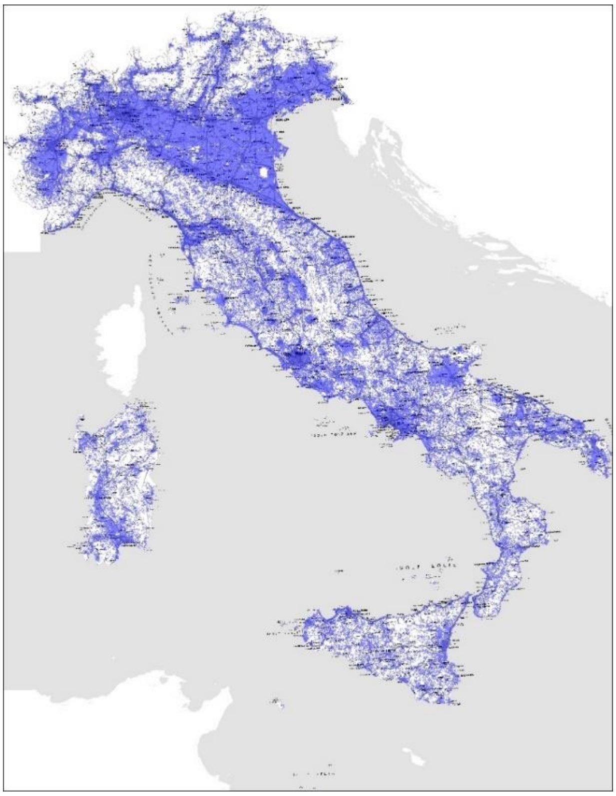
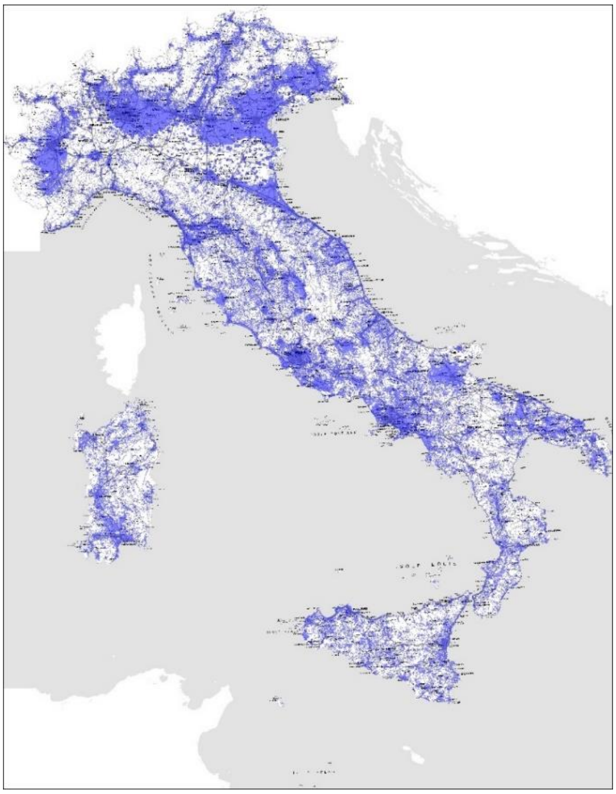


FIGURE 58

All sites co timed (zero delay)



The impact of extending the cyclic prefix on coverage was also investigated (see Table 31 for the coverage of the population in Northern Italy).

Italic values in the Table are the estimated advantage of adopting a CP of 300 μs rather than 200 μs. This gain is usually[20] greater when the number of sites increases and for higher values of SINR.

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20 When considering only the two sets of MNO sites, the maximum advantage is around SINR = 15 dB, which decreases for greater values of SINR. In this implementation, LPLT sites of MNOs are (relatively) near one to each other and, especially for high values of *C*/*N*, their coverage is limited by the received field strength, rather than by the effect of the SFN auto-interference "outside the CP".

TABLE 31

Coverage for two different CP values (% of population)

	North Italy (HHPO) (reg. 1-10) 200 µs – Loc 90%				**North Italy (HHPO) (reg. 1-10) 300 µs – Loc 90%**			
SINR	**5 dB**	**10 dB**	**15 dB**	**20 dB**	**5 dB**	**10 dB**	**15 dB**	**20 dB**
Sites								
BNO	92.3	83.5	68.1	49.8	*92.4*	*83.7*	*68.4*	*50.1*
					0.1	*0.2*	*0.3*	*0.3*
MNO part #1	80.8	71.3	56.1	41.4	*80.9*	*71.8*	*56.7*	*42.1*
					0.1	*0.5*	*0.6*	*0.7*
MNO part #1 and #2	85.4	79.7	68.5	51.8	*85.7*	*81.0*	*70.5*	*53.6*
					0.3	*1.3*	*2.0*	*1.8*
BNO + MNO part #1	94.9	91.5	83.9	70.0	*95.0*	*91.9*	*84.9*	*71.5*
					0.1	*0.4*	*1.0*	*1.5*
BNO + MNO part #1 and #2	95.8	93.7	88.6	76.3	*95.9*	*94.3*	*90.3*	*79.1*
					0.1	*0.6*	*1.7*	*2.8*

Finally, the coverage of car mounted is considered. Table 32 shows the results of the useful coverage for CM 95% locations, 200 µs and different network combination. Values in *italics* are the estimated percentage of SFN auto interference.

Note that the useful coverage CM for 95% locations is very similar to the useful coverage CM for 99% locations and the HHPO for 50% of locations.

TABLE 32

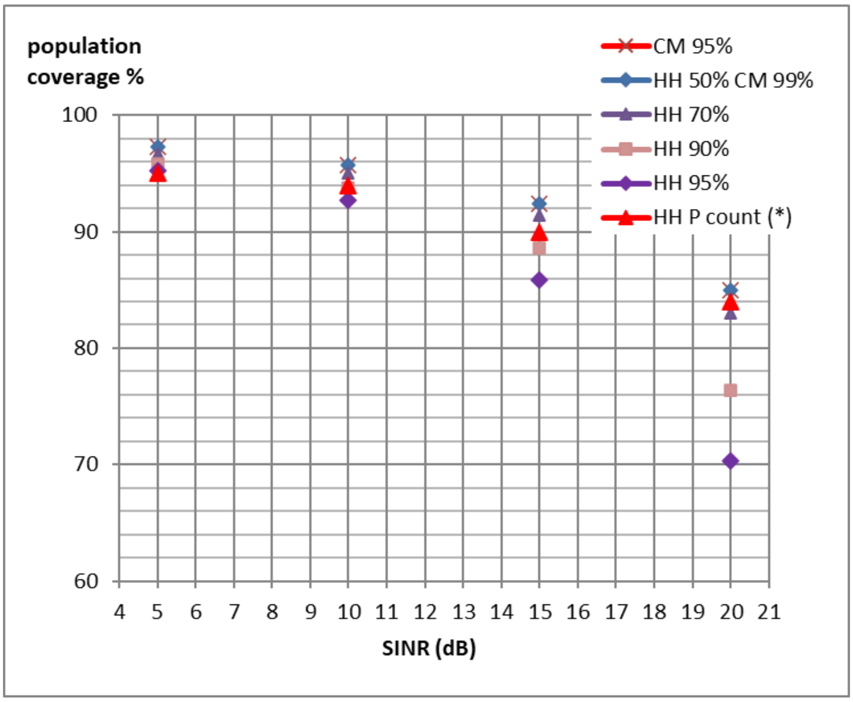
Coverage for car mounted receiving condition (% of population)

	North Italy (Car mounted) ***(reg. 1-10) 200 µs – Loc 95%***				**North Italy (Handheld PO)** ***(reg. 1-10) 200 µs – Loc 95%***			
SINR	**5 dB**	**10 dB**	**15 dB**	**20 dB**	**5 dB**	**10 dB**	**15 dB**	**20 dB**
Sites								
BNO	95.6	92.5	84.5	69.2	89.8	78.2	60.9	42.6
	0.5	*1.0*	*2.3*	*3.2*	*0.5*	*0.6*	*0.7*	*0.6*
MNO part #1	85.5	80.8	70.5	55.9	77.9	66.0	50.9	34.6
	0.4	*1.5*	*4.4*	*5.4*	*0.7*	*1.3*	*1.4*	*2.9*
MNO part #1 and #2	88.5	84.3	76.7	63.0	84.0	76.9	63.3	45.6
	0.6	*2.3*	*6.0*	*11.5*	*0.5*	*1.8*	*2.7*	*2.5*
BNO + MNO part #1	96.5	94.8	90.4	81.3	94.0	89.3	79.9	63.7
	0.2	*0.7*	*2.5*	*5.8*	*0.2*	*0.6*	*1.3*	*2.0*
BNO + MNO part #1 and #2	**97.1**	**95.5**	**92.2**	**84.7**	**95.3**	**92.7**	**85.9**	**70.3**
	0.2	*0.7*	*2.6*	*7.2*	*0.2*	*0.6*	*2.0*	*3.4*

For the network composed by BNO + MNO part #1 and #2 sites, Figure 59 shows a graph of the results as a function of some possible receiving conditions and for different SINR values. Moreover, additional results for CM and HHPO can be obtained with a simple interpolation of other available data.

FIGURE 59

Coverage for CM and HH for different location probability and SINR values (BNO + MNO part #1 + MNO part #2)



(*) "proportional count" figures are only indicative.

3.1.4 Conclusions

The coverage of BNO and MNO sites of a broadcast-only SFN (reuse 1) network is considered satisfactory with a CP of 200 µs. BNO coverage is important to reduce the overall number of sites that are needed. The MNO sites are important to cover with continuity inside urban zones. The SFN static delay of all the sites always needs to be optimized ('fine tuning' of the sites and of their relative 'static delays' is mandatory).

The complete broadcast-only SFN (reuse 1) network composed of BNO and MNO sites, can give a useful coverage greater than 92% of population with 15 dB SINR (location probability 95%) for car mounted reception.

For HHPO, this network can give a useful coverage around 93% of population with 10 dB of SINR (location probability 95%) or around 86% of population with 15 dB of SINR (location probability 95%).

The complete network for the central-northern part of Italy (Regions 01-10), as considered in the study (area of around 152 000 km^2) consists of 1635 sites, composed as follows:

458 BNO sites (including HPHT, MPMT and LPLT sites). These sites represent 28% of the total number of sites. They can alone give a useful coverage for HHPO reception of around 78% of population with 10 dB SINR (location probability 95%) and 61% of population with 15 dB SINR (location probability 95%). Considering the surface of the concerned area (north Italy), this BNO network has a site density of 30 sites per 10 000 km^2.

1 177 MNO sites (581 MNO part #1 + 596 MNO part #2). These sites represent 72% of the total number of sites. They cover an additional 25% of population with the same SINR (15 dB), Location probability (95%) and reception mode (HHPO). They increase the total site density to 107 sites per 10 000 km^2.

The results are dependent on the requirement for the location statistical distribution over any of the specified 'small areas' (or 'pixel of coverage'), typically a square with a side of 100 m that comprise the coverage. Adopting a too large percentage of 'location probability' for a given receiving condition may lead to an underestimate of its actual coverage, especially for SINR values of the order of 15 dB or greater.

Considering 'hybrid broadcast/unicast' operation with seamless switching in the receiver between 5G Broadcast and unicast, the 'proportional count' of the covered population by the 458 BNO sites alone gives 78% of population coverage with 15 dB of SINR. The 1177 MNO sites considered above can cover in unicast an additional 12% of the population. This ensures the same coverage of population as the 'complete' network with a significantly reduced number of sites (basically 28% of the total required number of sites).

However, in 'hybrid broadcast/unicast' operation, the MNO Unicast part cannot serve unlimited number of end-users as the complete 5G-Broadcast Network can. On the other hand, MNO sites in this study are mainly placed into urban areas, where the 'end-user density' is greater. Simulations (Fig. 56 in the study) showed that a configuration where some BNO sites (among the 458 BNO sites above) are replaced with urban MNO sites can improve the population coverage, for higher SINR target levels.

Finally, the study showed that extending the CP from 200 μs to 300 μs helps to synchronize the SFN sites but will compromise the performance in case of mobile reception.

To be noted that Italy has a difficult terrain to cover, which explains the initially high density of the BNO sites considered in the study and the even higher density of MNO sites considered to extend the coverage.

A significantly different example in terms of surface and terrain shape to cover is Denmark, considered hereafter.

3.2 Denmark

3.2.1 Introduction

This section contains results of calculations of 5G Broadcast coverage using the Danish Radio (DR) Digital TV broadcast infrastructure. The purpose is to analyse the 5G Broadcast coverage achievable using existing HPHT and MPMT broadcast sites. The idea is that areas not covered by the 5G Broadcast network could be covered by unicast using Mobile Telecom networks.

3.2.2 Values and settings

Calculations are made for the following reception conditions:

a) Mobile Car Mounted (MO).

b) Handheld Portable Outdoor (HHPO).

c) Handheld In Car (HHIC).

Planning parameters are in agreement with Table 2: Reception parameters used in the simulations for each of the agreed scenarios). The main parameters are shown in Table 33.

TABLE 33

Main reception parameters used in the study

Parameter/Setting	Mobile Car mounted	HHPO	HHIC
Rx antenna gain (dBi)	0	−5.8	−5.8
Car Entry loss /std dev (dB)	–	–	9 /3
Receiver noise figure (dB)	6	9	9
Antenna height (m)	1.5	1.5	1.5
C/N (MCS 9) (dB)	9	8.2	9
C/N (MCS 16) (dB)	15.2	13	15.2
Lognormal standard dev (dB)	5.5	5.5	5.5
Population count	50-100% proportional count		

3.2.3 Transmitter site characteristics

Table 34 shows the characteristics of the HPHT and MPMT sites used in the study.

TABLE 34

Main characteristics of the sites

HPHT sites	
Antenna height (m)	190-300
ERP (kW)	50
MPMT sites	
Antenna height (m)	50-150
ERP (kW)	2-5

Three different network scenarios are calculated:

a) 12 HPHT sites.

b) 12 HPHT sites + 15 MPMT sites.

c) 12 HPHT sites + 46 MPMT sites.

Population coverage for the different network scenarios is calculated using proportional counting, i.e. (coverage probability) × (population in pixel) for coverage probabilities above 50%. Population in pixels where coverage probability is below 50% is not counted.

The following sections show results of coverage calculations for the network scenarios above operating in national SFN and then in three regional SFNs each using different frequency (MFN cluster of SFNs).

3.2.4 Results for national SFN

3.2.4.1 Result in tables

Tables 35, 36 and 37 show the percentage of population covered with the three scenarios listed above for the different reception parameters and systems variants retained for the study.

TABLE 35

Percentage population (proportional counting) covered with 12 HPHT sites

Results percentage population	**Proportional counting**	
Case	**MCS 9**	**MCS 16**
Mobile (MO) (9 and 15.2 dB)	95.1	90.8
Hand held portable outdoor (HHPO) (8.2 and 13 dB)	90.3	82.7
Hand held in car (HHiC) (9 and 15.2 dB)	69.4	46.3

TABLE 36

Percentage population (proportional counting) covered with 12 HPHT sites + 15 MPMT sites

Results percentage population	**Proportional counting**	
Case	**MCS 9**	**MCS 16**
Mobile (MO) (9 and 15.2 dB)	97.5	95.1
Hand held portable outdoor (HHPO) (8.2 and 13 dB)	95.3	92.1
Hand held in car (HHiC) (9 and 15.2 dB)	86.5	70.6

TABLE 37

Percentage population (proportional counting) covered with 12 HPHT sites + 46 MPMT sites

Results percentage population	**Proportional counting**	
Case	**MCS 9**	**MCS 16**
Mobile (MO) (9 and 15.2 dB)	98.9	97.5
Hand held portable outdoor (HHPO) (8.2 and 13 dB)	98.7	97.2
Hand held in car (HHiC) (9 and 15.2 dB)	93.8	79.3

3.2.4.2 Results in graphs

Figures 60 and 61 show the same results as above but in the form of graphics.

FIGURE 60

Percentage population (proportional counting) for MCS 9

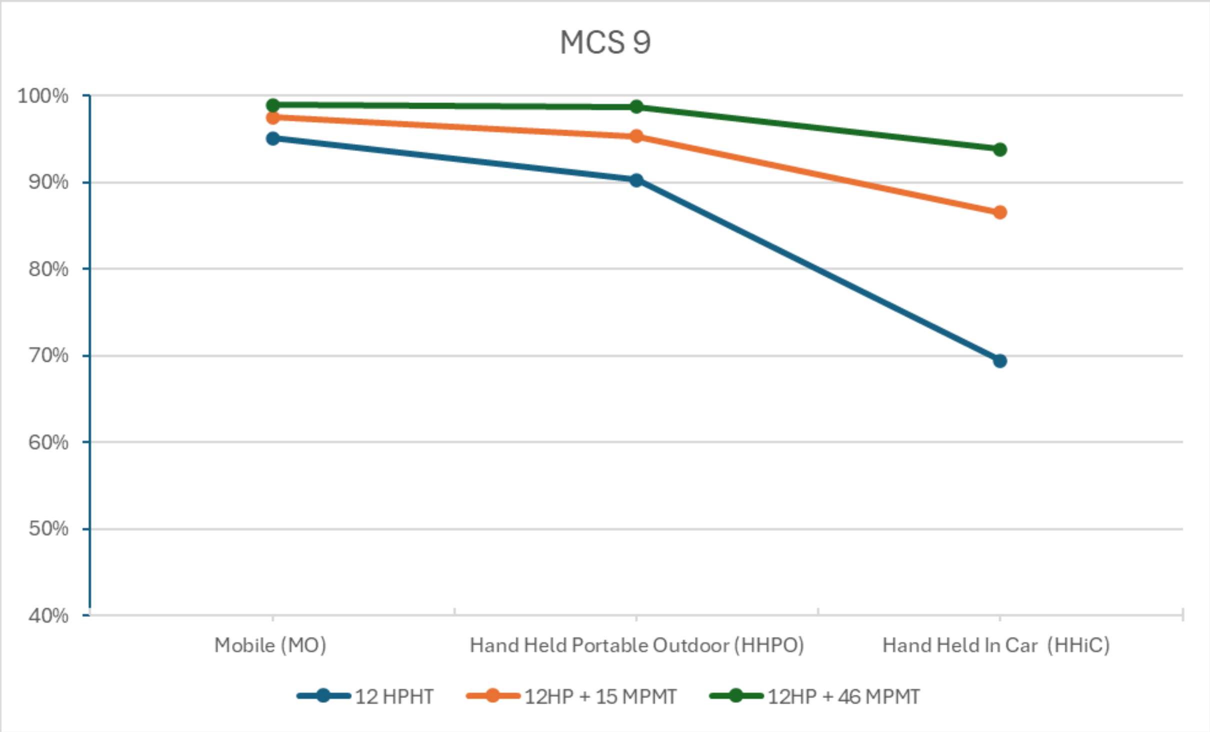
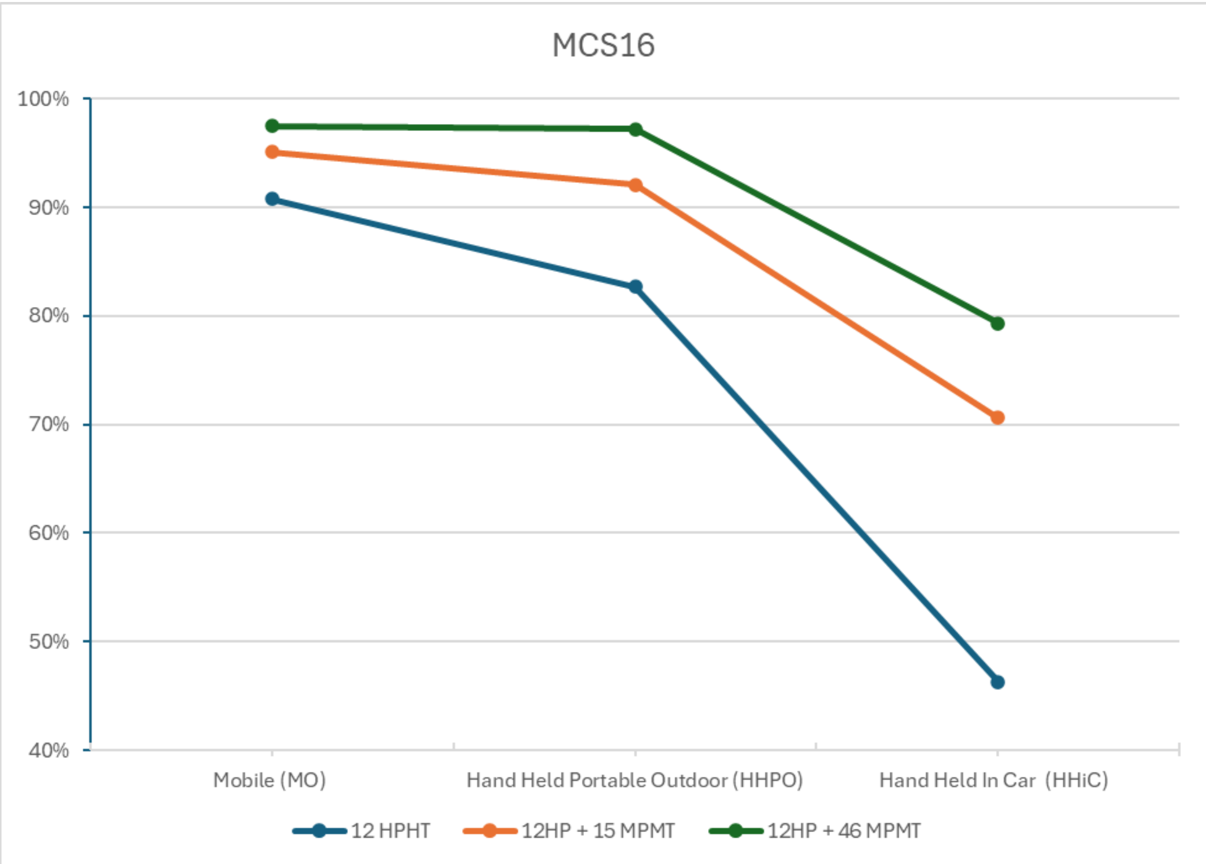


FIGURE 61

Percentage population (proportional counting) for MCS 16



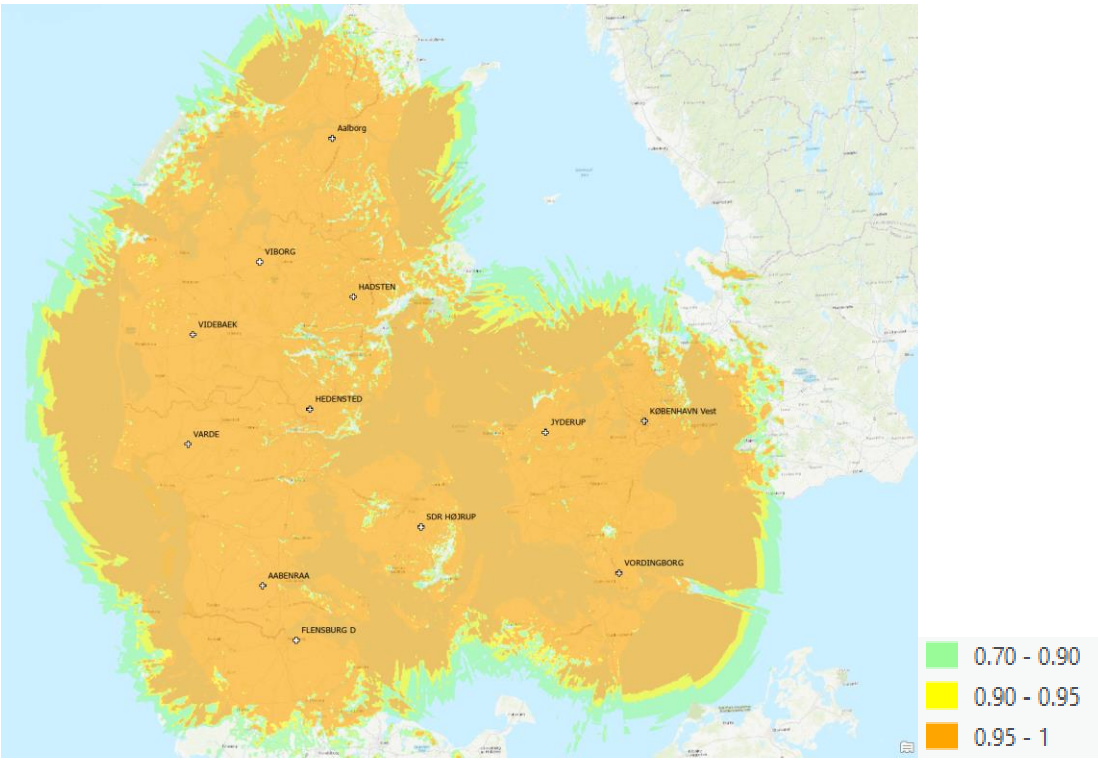
3.2.4.3 Results in maps

3.2.4.3.1 Coverage maps for 12 HPHT sites

Figures 62 and 63 show the coverage maps with 12 HPHT sites for the highest MCS (MCS 16) and for the two 'extreme' cases of reception mode: car mounted and handheld in car respectively.

FIGURE 62

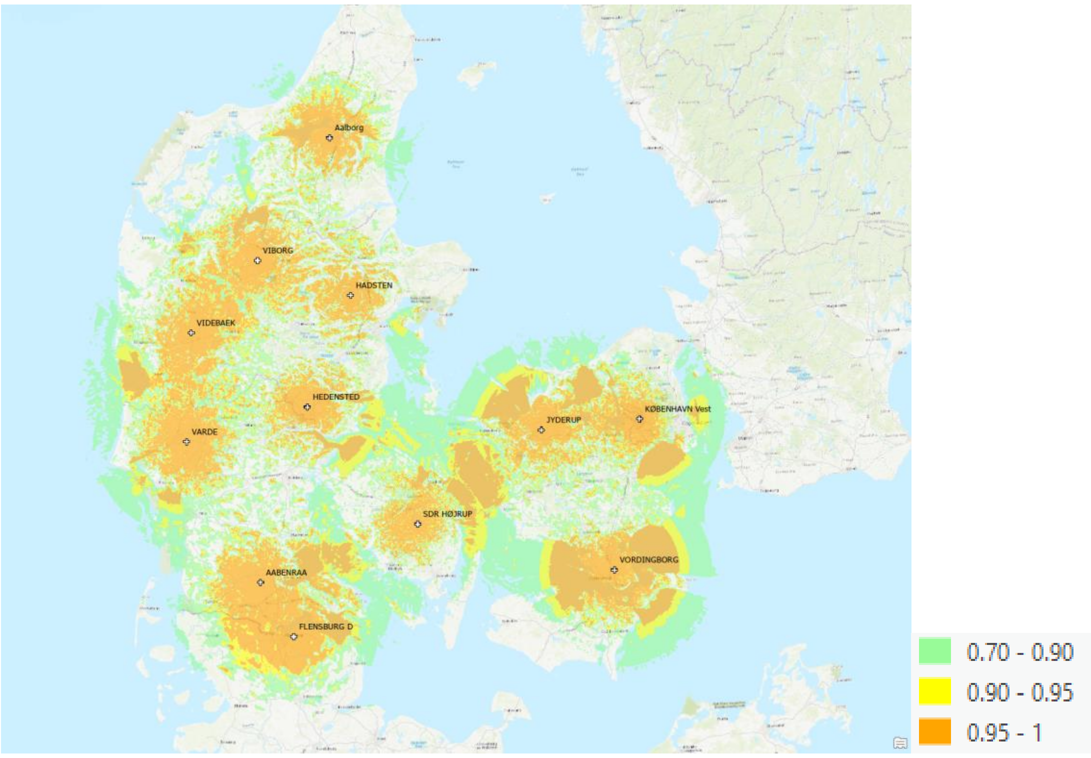
Car mounted MCS 16 – 90.8% of population



NOTE – Legend shows cut-off at 95% locations.

FIGURE 63

Handheld in Car MCS 16-46.3% of population



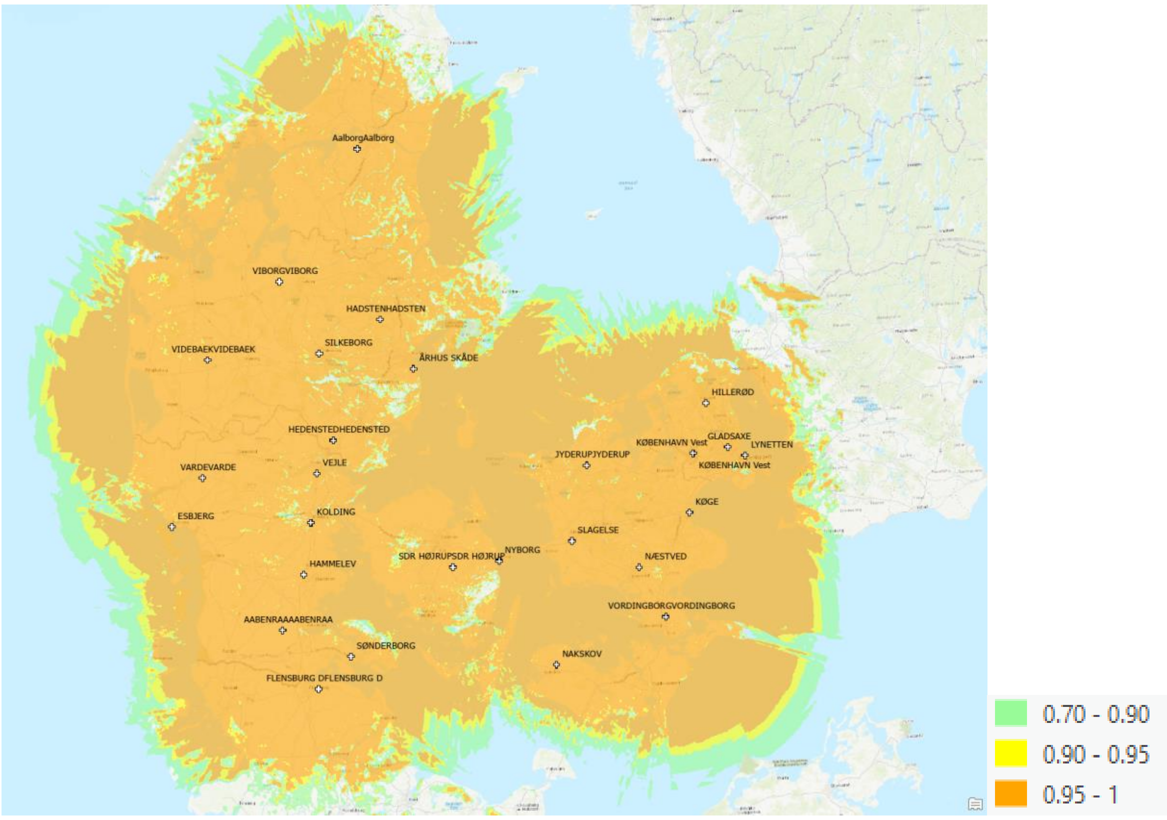
NOTE – Legend shows cut-off at 95% locations.

3.2.4.3.2 Coverage maps for 12 HPHT + 15 MPMT sites

Figures 64 and 65 show the coverage maps with 12 HPHT sites for the highest MCS (MCS 16) and for the two 'extreme' cases of reception mode: Car mounted and handheld in car respectively.

FIGURE 64

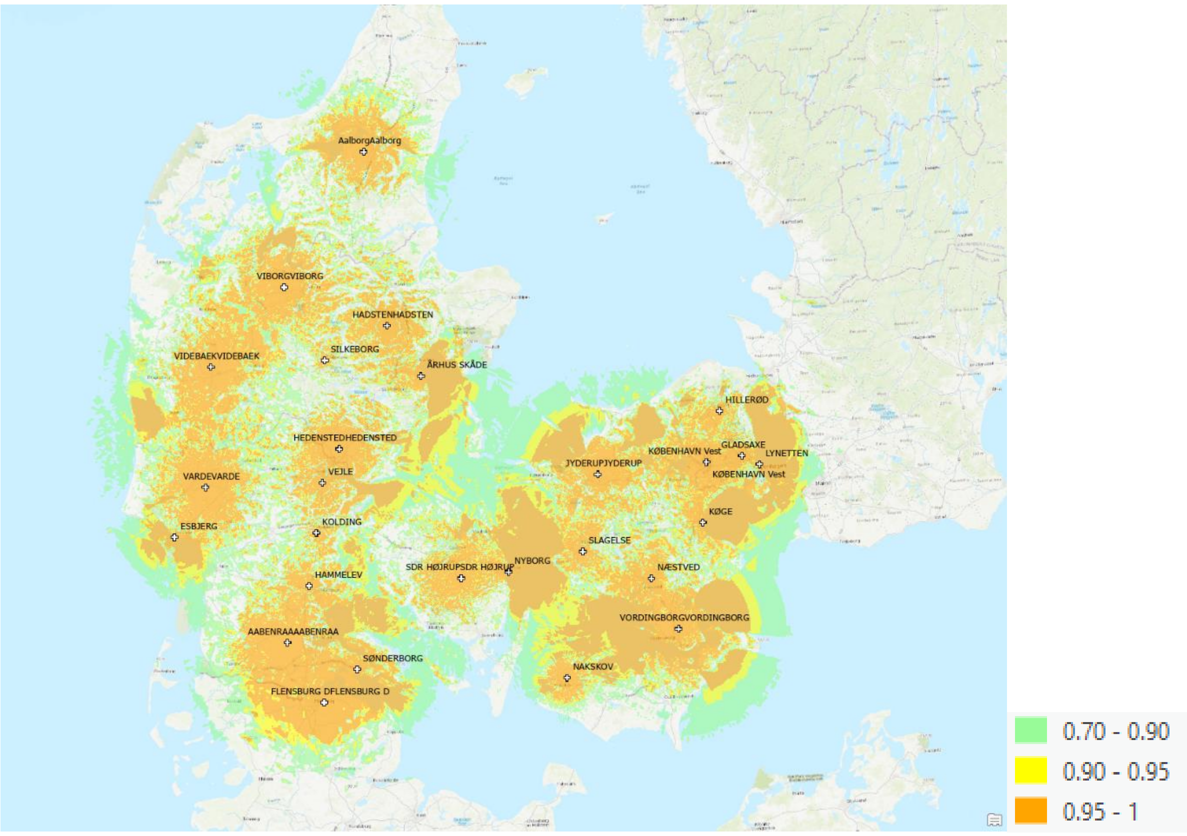
Car mounted MCS 16 – 95.1% of population



NOTE – Legend shows cut-off at 95% locations.

FIGURE 65

Handheld in Car MCS 16 - 70.6% of population



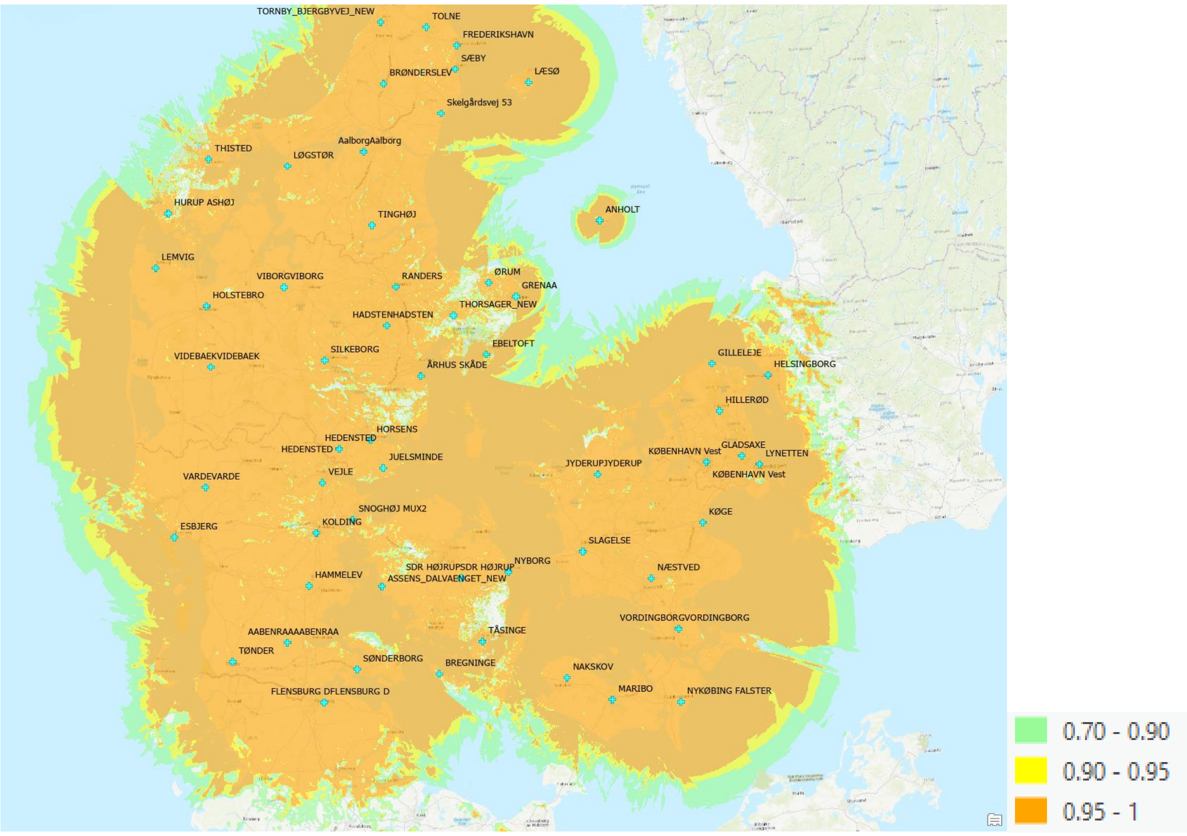
NOTE – Legend shows cut-off at 95% locations.

3.2.4.3.3 Coverage maps for 12 HPHT + 46 MPMT sites

Figures 66 and 67 show the coverage maps with 12 HPHT sites for the highest MCS (MCS 16) and for the two 'extreme' cases of reception mode: Car mounted and handheld in car respectively.

FIGURE 66

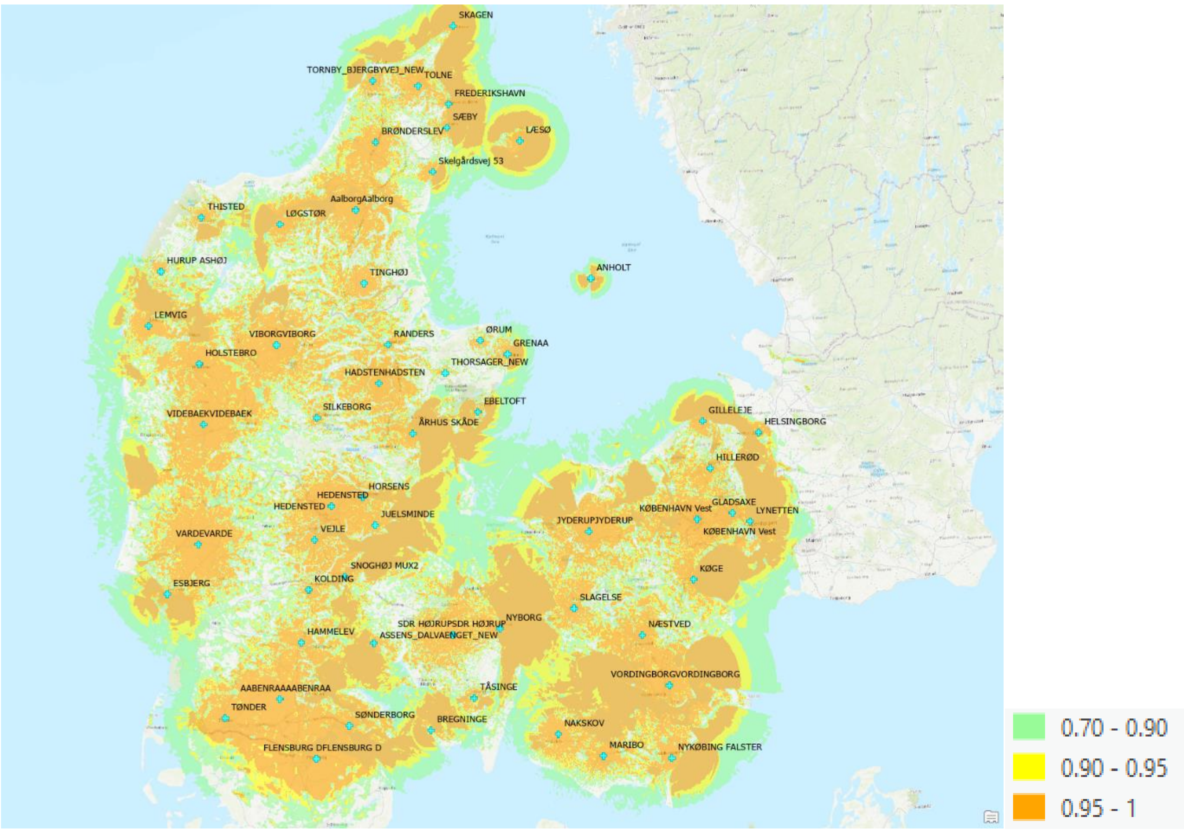
Car mounted Coverage MCS16 – 97.5%



NOTE – Legend shows cut-off at 95% locations.

FIGURE 67

Handheld in Car MCS16 – 79.3% of population



NOTE – Legend shows cut-off at 95% locations.

3.2.5 National SFN split into three different areas

The calculations are made using the LTE-based 5G terrestrial broadcast standard, with a symbol time of 800 µs and 200 µs guard interval. The limited length of the guard interval creates SFN self-interference in the relatively large national SFN used in the study above. Self-interference is noticeable already at 50% of time propagation calculations. In the current work no calculations have been done with higher percentage of time propagation. The main reason for the SFN self-interference is that there are several sea paths.

To complement the previous results, a few calculations are made when the large SFN is split into three parts, each using different frequencies. This will not eliminate SFN self-interference completely, but will reduce it substantially, as the number and length of sea paths between co-channel sites are significantly reduced.

Figures 68, 69 and 70 show the three selected areas.

FIGURE 68

Area 1: Eastern islands – 14 transmitters

FIGURE 69

Area 2: Southern part of Jylland – 18 transmitters

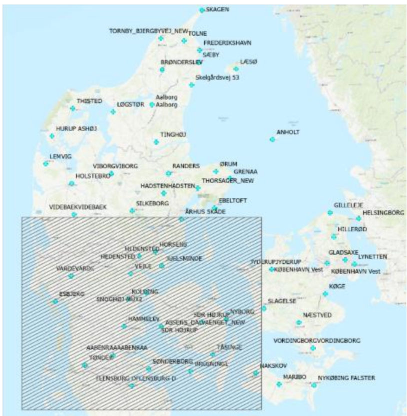


FIGURE 70

Area 3: Northern part of Jylland – 26 transmitters

The additional calculations are made only for the case of 12 HPHT + 46 MPMT transmitters. The results are presented in Table 38, together with the results for the national SFN presented earlier. It is important to note that both results are based on 50% of time propagation.

TABLE 38

Percentage population (proportional counting) covered with 12 HPHT+46 MPMT sites, planned in one MFN of three SFNs, compared to the results of National SFN studies above

Results percentage population	"3SFNs"	National SFN	"3SFNs"	National SFN
Case	**MCS 9**		**MCS 16**	
Mobile (MO) (9 and 15.2 dB)	99.1	98.9	98.2	97.5
HHPO (8.2 and 13 dB)	98.8	98.7	97.6	97.2
HHIC (9 and 15.2 dB)	93.8	93.8	79.5	79.3

From the results above it can be seen that the coverage is slightly improved when splitting up the national SFN. This is due to the reduction in SFN self-interference. But difference is however quite small in terms of population coverage.

3.2.6 Comments and conclusions

- In a hybrid broadcast/unicast operation, with seamless switchover in the receiver between the broadcast and the unicast received signal, spots with location probability below say 70%, or even 90%, will need to rely on unicast signal provided by the mobile network.
- Assuming a hybrid broadcast/unicast operation, the existing broadcast infrastructure consisting in HPHT and MPMT sites in Denmark (surface area: 42 952 km^2) seems to provide sufficient coverage, calculated using proportional population count, for the Mobile car mounted and HHPO reception cases, i.e. above 90% of population served for the three cases:
  a) 12 HPHT sites (site density: 3 sites per 10 000 km^2) 90.8% for car mounted – 82.7% for HHPO;
  b) 12 HPHT +15 MPMT sites (site density: 7 sites per 10 000 km^2) 95.1% for car mounted – 92.1% for HHPO;
  c) 12 HPHT + 46 MPMT sites (site density: 14 sites per 10 000 km^2) 98.2% for car mounted – 97.6% for HHPO.
- HHIC reception is the most difficult case due to the Car entry loss. A larger complementary coverage using unicast would be required to ensure sufficient coverage.

A third example, for Germany, with large territory and a different broadcasting infrastructure than both examples above, is dealt with in the following section.

3.3 Germany: Case study on a conversion of DTT network

3.3.1 Background of the study

This case study considers coverage of a 5G Broadcast network entirely based on existing DTT broadcast infrastructure in Germany. This infrastructure provides portable indoor coverage and portable outdoor coverage of DVB-T2 (HEVC) for many households.

The aim of this study is to compare existing DVB-T2 (HEVC) coverage with handheld outdoor reception using LTE-based 5G Broadcast according to 3GPP Release 16.

It is noted that additional sites to fill holes in LTE-based 5G Broadcast coverage were not considered since this would require a much more detailed analysis of each individual SFN and existing transmission sites for such a purpose.

3.3.2 German broadcast infrastructure and DTT coverage

In Germany, DTT networks have existed for more than 20 years. DVB-T started in 2002 in Berlin and from 2004 on in many other areas throughout the entire country. The aim was to provide portable indoor coverage in densely populated areas, portable outdoor coverage in surrounding areas and coverage for fixed reception elsewhere.

These basics were kept when all networks were migrated to DVB-T2 HEVC between 2017 and 2019. System and codec advantages of this migration and of a complete frequency replanning went into a release of the 700 MHz band, coverage improvements, better picture quality (Full HD) and better mobility.

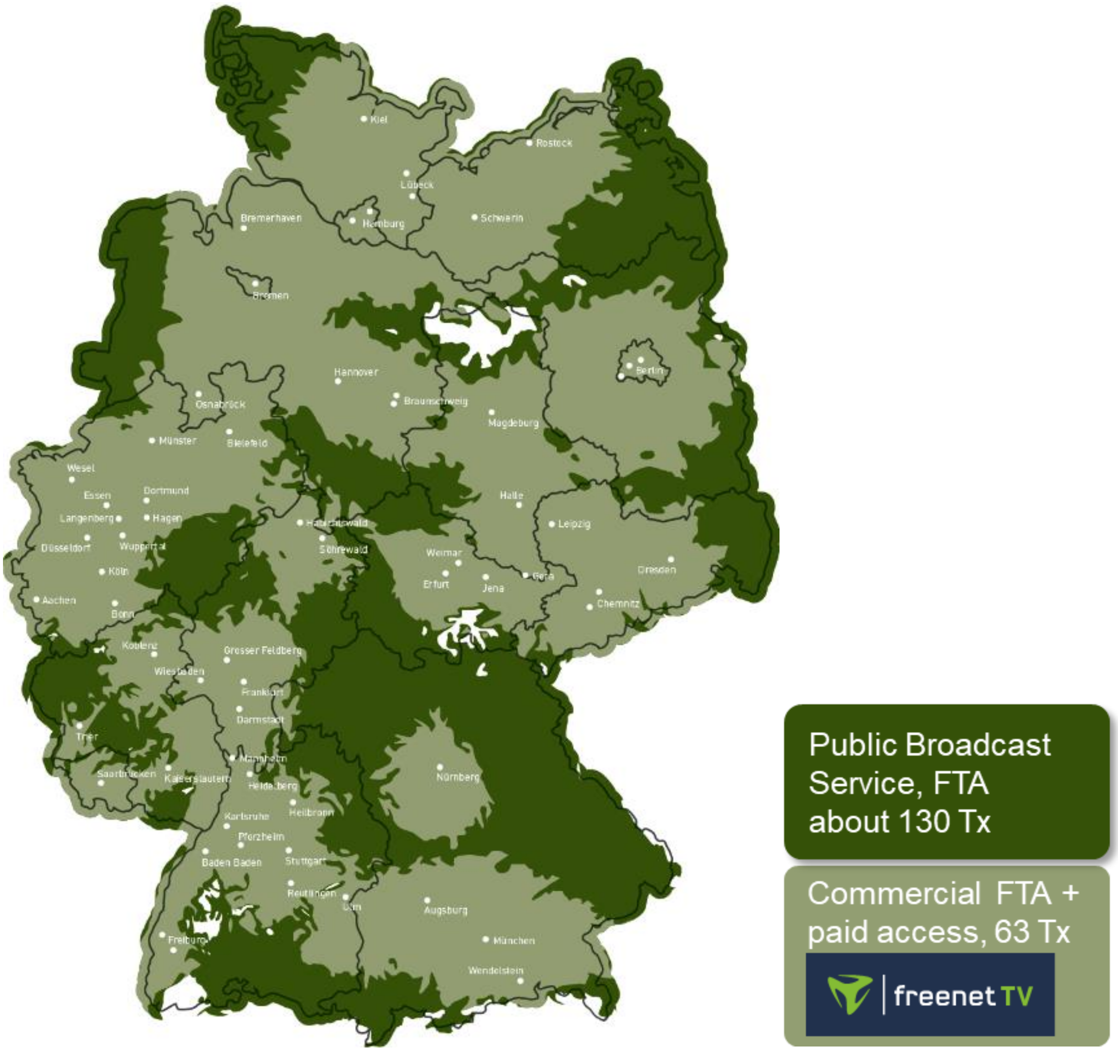
The current networks consist of more than 130 sites for Public Broadcast Services (PBS, three multiplexes) and 63 sites for the commercial platform (another three multiplexes).

The entire network structure can be considered as HPHT with some MPMT sites. More than 60% of sites of one PBS network transmit an ERP of 40 kW or above and more than 20% between 10 kW and 40 kW. The antenna height corresponds to these high ERP values.

A schematic coverage prediction for Fixed DVB-T2 reception by these networks is provided in Fig. 71, with coverage by PBS networks in dark green and by commercial platform in light green. It is noted that while networks of PBS multiplexes and system parameters differ slightly amongst each other, the three networks of the commercial platform as well as their system parameters are the same.

FIGURE 71

Fixed reception of one PBS Mux (dark green) and fixed reception of the commercial platform on top of fixed reception PBS (i.e. both PBS and commercial; light green)



The study tried to answer the question: "What happens if one uses existing DVB-T2 sites for 5G Broadcast and simply 'convert' them to provide 5G Broadcast HHPO coverage?"[21] No antenna or timing optimization were made to reduce potential SFN self-interference.

3.3.3 Coverage predictions

3.3.3.1 Planning tool, propagation model and data bases

All simulations were done with a planning software developed in-house and used for more than two decades for planning of different broadcast services, in particular digital TV services (e.g. DVB-T, DVB-H and DVB-T2) and digital Radio services (e.g. DAB+).

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[21] Note: The focus was on using the same infrastructure. This does not mean that a DVB-T2 mux is to be "converted", i.e. any effect of using another UHF channel within individual SFN has been neglected.

All field strength predictions of individual transmitters were made using a propagation model developed within Deutsche Telekom[22], tuned to clutter and height data in Germany using a huge amount of field measurement data.

The resolution used for all data bases was 5 arcsec, and the following geographical databases were used:

- terrain elevation data;
- clutter data, which includes 13 different clutter classes representing different kind of areas (e.g. dense urban, urban, industrial, forest); and
- population data.

The wanted field strength has been calculated using 50% of time propagation.

3.3.3.2 Planning parameters

Several planning parameters and data are used in coverage prediction. One way to consider them is by subdivision into following categories:

a) Tool and planning tool specific parameters, e.g.:
   - propagation-specific parameters (model); and
   - data bases (terrain, clutter).

b) System and device-specific parameters, e.g.:
   - system bandwidth, *C*/*N*, cyclic prefix/guard interval; and
   - device-related parameters like antenna gain and noise figure.

One parameter which is to be highlighted is receiving antenna height. Due to the general planning goal in Germany for portable DTT reception, an antenna height of 1.5 m was used for receiving antenna right from the beginning of DTT planning activities in Germany more than 25 years ago. The wanted field strength of each individual transmitter is calculated at 1.5 m, taking into account clutter and terrain data in an appropriate way[23].

3.3.3.2.1 5G transmission modes and planning parameters

Several aspects influence the choice of system-specific parameters for broadcast networks, in this case for LTE-based 5G Broadcast:

- According to the business model, a certain number of programs is to be provided. This results in a certain (overall) capacity required, leading to a (minimum) transmission mode called Modulation Coding Scheme (MCS).
- The available infrastructure and network topology on one hand and frequency resources on the other have an impact on the number of SFN, their size and the Cyclic Prefix (CP) to be used to avoid/minimize self-interferences.

Investigations on potential business models, based e.g. on representative interviews of potential customers, led to the conclusion that “TV on the Go” might be especially of interest for people on the move, e.g. while waiting at a bus or train station or within public transport systems. Therefore, mobility might be another key issue, with an impact on MCS and CP.

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[22] Eibert, T.F.; Kuhlmann, P.: Notes on Semiempirical Terrestrial Wave Propagation Modelling for Macrocellular Environments – Comparisons with Measurements; IEEE Transactions on Antennas and Propagation, Vol.51, No.9, Sept. 2003.

[23] The way this is done differs from tool to tool. Some tools apply an additional attenuation to the calculated field strength at each pixel, according to so-called land-usage class, other add a certain height to the terrain.

The CP used in this study was 200 µs, due to the topology (inter-site distance) of the existing DTT infrastructure and to allow for a certain mobility.

When assessing coverage, the possible impact of CAS in LTE-based 5G Broadcast was not considered. To allow the receiver to correctly interpret the broadcast content, the CAS in LTE-based 5G Broadcast needs to be received and decoded. The CAS should in theory be very robust.

3.3.3.2.2 Comparison of planning parameters and expected study results

Three different MCS were simulated, which were considered attractive for different reasons. The results are presented as coverage plots for these three MCS, in a similar way as for DVB-T2 (location probability).

Many parameters used for both predictions, DVB-T2 and 5G Broadcast, are the same. Only a few of them differ, which can be considered in general as 'losses' and summed up for comparison. The result is shown in Table 39.

TABLE 39

Planning parameters used for the study

Parameter	DVB-T2	5G BC
SINR (dB)	~17	
Noise figure (dB)	6	
Antenna gain (dBd)	0	
Building entry loss (dB)	15 (13… 17)	
Sum of losses (dB)	Portable outdoor 23 (+4)	Handheld outdoor
	Portable indoor 38	27 / 33 / 36

The SINR for DVB-T2 corresponds to the one used for the commercial platform, and the three values for 5G Broadcast correspond to MCS 11, MCS 18 and MCS 21, respectively. An additional 4 dBs are used by the planning tool for DVB-T2 portable outdoor to account for polarization mismatch and body loss.

The following can be observed:

a) The sum of all losses in predictions for DVB-T2 portable outdoor coverage is close to the sum of losses for 5G Broadcast when using MCS 11 (about 27 dB).

b) The sum of all losses in predictions for DVB-T2 portable indoor coverage is slightly above the sum of losses for 5G Broadcast with MCS 21 (38 dB vs 36 dB).

Therefore, an expected outcome of the simulation was, that:

c) What is currently covered by DVB-T2 in portable outdoor would be provided as handheld outdoor coverage for 5G Broadcast if MCS 11 were used.

d) What is currently covered by DVB-T2 in portable indoor would be provided as handheld outdoor coverage for 5G Broadcast if MCS 21 were used.

It should be noted that data rate was not part of this study. However, data rates of all three 5G Broadcast MCS are below those which are provided via DVB-T2 networks in Germany, planned and implemented for portable DTT reception.

3.3.4 Simulation results

The study started with an example in Berlin.

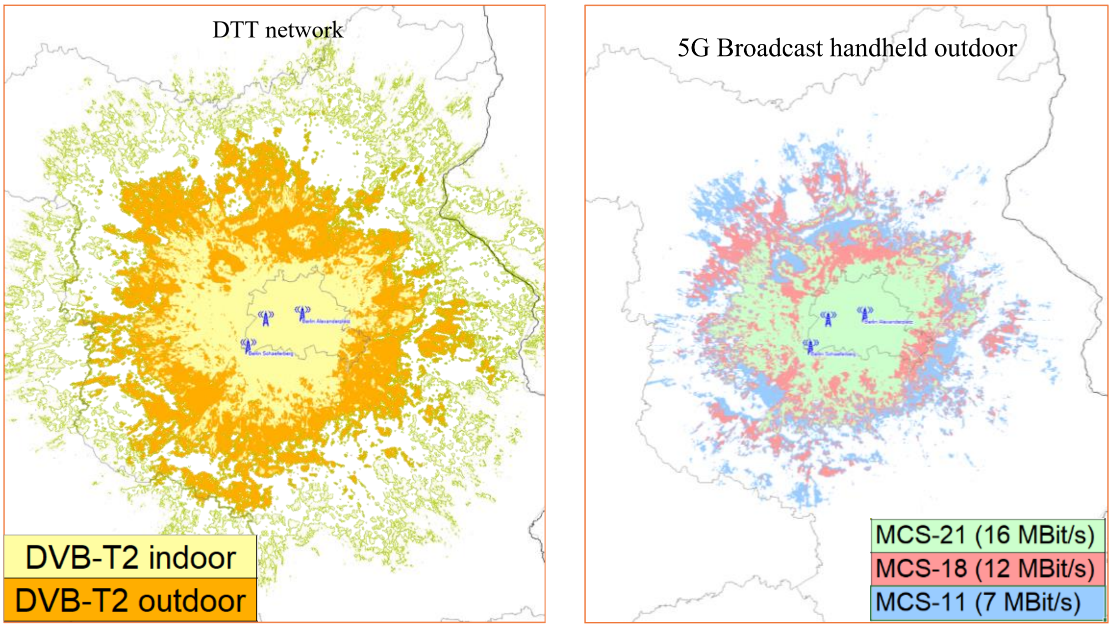
Figure 72 shows simulation results for a network with three DTT sites in Berlin, with an ERP of up to 50 kW and in one case more than 350 m transmission height (Berlin Alexanderplatz).

Figure 72 left shows the simulation results for DTT coverage (portable indoor, portable outdoor), Figure 72 right shows the results for 5G Broadcast coverage (handheld outdoor) for three different MCS values.

FIGURE 72

DTT versus 5G Broadcast coverage (Berlin)

DTT coverage (portable indoor and portable outdoor, left) versus 5G Broadcast coverage (handheld outdoor, right) for three different MCS values

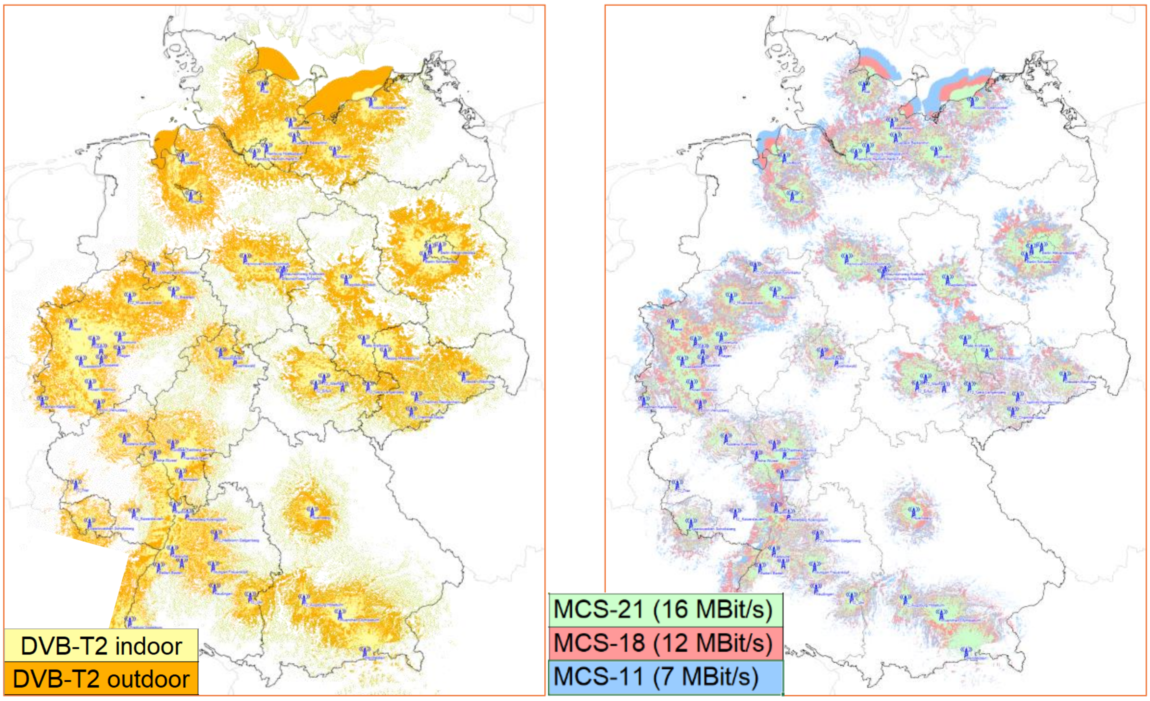


This example of Berlin was then extended to the entire country, i.e. one network of the commercial DTT platform and channels which are currently in use. The results of these simulations are provided in Fig. 73.

Figure 73 left shows simulation results for DVB-T2 coverage (portable indoor and portable outdoor), Figure 73 right results for 5G Broadcast coverage (handheld outdoor) for three different MCS values.

FIGURE 73

DTT versus 5G Broadcast coverage (whole country)
DTT coverage (portable indoor and portable outdoor, left) versus 5G Broadcast coverage (handheld outdoor, right) for three different MCS values



For these coverage predictions, the amount of population coverage for each individual coverage can be evaluated using an appropriate geo-referenced data base.

The results are shown in Fig. 74 left for DVB-T2 and Fig. 74 right for 5G Broadcast. All red bars provide an information on population coverage for each individual reception mode or MCS and individual percentages are provided on top. Black bars provide an indication for the data rate which could be transported by a 5G Broadcast network.

FIGURE 74

Population coverage and data rate
DVB-T2 portable indoor and 5G Broadcast (left) and for DVB-T2 portable outdoor and 5G Broadcast (right)

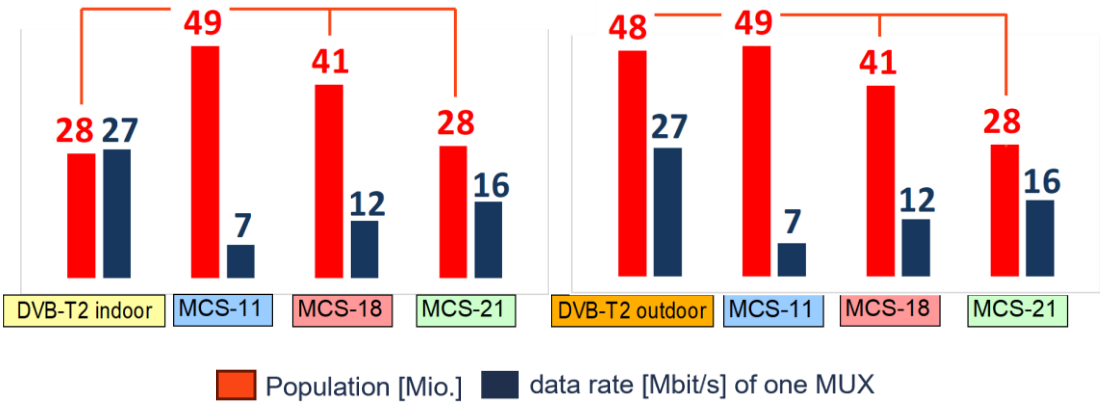


Figure 74 left shows that DVB-T2 indoor coverage is quite similar to 5G Broadcast handheld outdoor coverage with MCS 21, whereas Fig. 74 right shows that DVB-T2 outdoor coverage corresponds quite well to 5G Broadcast handheld outdoor coverage with MCS 11.

3.3.5 Conclusions

The aim of this study has been to compare existing DVB-T2 (HEVC) coverage in Germany with HHPO reception using LTE-based 5G Broadcast according to 3GPP Release 16 and provided by the same network as the DVB-T2 coverage. This does not mean that DVB-T2 networks are to be ‘converted’. The intention was to study a network which is based on the same infrastructure. Effects of using other UHF channels within each individual SFN were not considered. The considered broadcast network consisted of 63 sites.

The study focused on a few MCS for LTE-based 5G Broadcast which were considered interesting for more detailed business planning. It confirmed expectations following a rough assessment of planning parameters in § 3.3.3.2.2: if the same sites are used which currently provide DVB-T2 coverage, LTE-based 5G Broadcast handheld outdoor coverage (in Germany) will be:

1) similar or better than portable indoor coverage DVB-T2 for lower MCS; and/or

2) similar or smaller than portable outdoor coverage DVB-T2 for high MCS.

Any MCS or 5G Broadcast system variant which needs a similar SINR than one of the MCS used in this study would lead to similar results. This might be the case e.g. if SINR improves for a bandwidth of 8 MHz, for which there are some indications from the 5G Media2Go-Trial in Stuttgart (see also Report ITU-R BT.2526, Annex 3).

The data rate which can be provided by such network will be lower than what is known from DVB-T2 in Germany[24]. On the other hand, codecs improved already and will improve, and there are other mechanisms which allow for a viable business model.

In summary, a task in network and business planning is to find the best compromise between good coverage and enough data rate for a viable business model.

4 Overall conclusions

The studies carried out in this Report on networks based on theoretical regular topologies and on real existing sites in three European countries (Italy, Denmark and Germany) aimed at assessing the coverage of different types of 5G Broadcast networks and their frequency planning (HPHT, MPMT, LPLT, single topology and mixed topology) for different 5G system variants (Modulation and Coding Schemes).

Following completion of these studies for broadcast-only networks, a method was defined that allows planning a Hybrid broadcast/unicast network. This method consists in the following:

– for the theoretical networks, to calculate the average location percentage of the pixels (small areas) throughout the coverage area and use it to set the level of complementary coverage required from the unicast network;

– for the networks based on real sites, to calculate the population coverage using the proportional count, by multiplying for each pixel the population of the pixel by the calculated location percentage of the concerned pixel. This means that the remaining population will need to be served by the unicast network.

[24] DVB-T2 system variants used in Germany are more robust than in many other countries, due to the aim to provide portable DTT coverage.

In Hybrid broadcast/unicast mode, the implementation of seamless switching between broadcast and unicast in 5G Broadcast receivers allows complementing the coverage by the unicast network in those locations not served by the broadcast network. The level of the complementary coverage depends on the actual coverage of the broadcast and the unicast networks. This hybrid operation provides a flexibility that can be used in several manners:

a) Through a progressive coverage of the 5G Broadcast network at maximum capacity, with high complementary coverage by unicast in the start, and decrease while adding more broadcast sites (trade-off broadcast coverage versus unicast complementary coverage).

b) Through progressive capacity of the 5G Broadcast network while increasing the 5G Broadcast coverage to minimize the required complementary coverage by unicast (trade-off broadcast capacity versus complementary unicast coverage).

In terms of numerical results, the studies in this Report showed that:

1) Relying on a broadcast-only network would require a mixed network topology (HPHT/MPMT) with a site density in the order of 22 sites per 10 000 km^2 (2 HPHT sites and 20 MPMT sites) to ensure up to 15 dB of SINR in all pixels of the targeted coverage area, for car mounted and HHPO reception modes, offering up to 12 Mbit/s in 8 MHz. Such a network can only ensure low coverage for handheld in Car reception.

2) Relying on a hybrid broadcast/unicast network by introducing the seamless switching in the 5G Broadcast receiver allows starting with low site density, e.g. 2 HPHT sites per 10 000 km^2 and progressively extending the coverage by adding MPMT sites where needed. Eventually, a mixed network topology (HPHT/MPMT) with a site density in the order of 11 sites per 10 000 km^2 would offer a high level of population coverage with up to 15 dB of SINR for car mounted and HHPO reception, while requiring less than 10% complementary coverage by unicast. Here also, bitrates of 12 Mbit/s in 8 MHz can be achieved.

3) Serving HHIC is very challenging. A broadcast-only network would not allow reaching any significant coverage for HHIC reception that offers 15 dB SINR. Introducing the hybrid broadcast/unicast operation, with a broadcast network of 22 sites per 10 000 km^2 would require complementing the coverage using unicast in around 50% of the locations in each pixel on average.

These conclusions have been supported by real case studies presented in this Report even if every real case is different as it depends on, among other factors, the terrain morphology and the existing broadcast network infrastructure.

In the case of Italy, a broadcast-only network would require up to 1 635 sites to cover the central-northern part of Italy (107 sites per 10 000 km^2) with 15 dB SINR for HHPO reception. On the other side, using the Hybrid broadcast/unicast approach with seamless switching in the receiver between broadcast and unicast, allows covering 78% of the population in northern Italy with only 458 sites, while complementing the coverage with unicast for additional 12% of the population. This translates in a site density of 30 sites instead of 107 sites per 10 000 km^2.

The study in Italy also showed the importance of optimizing and fine tuning of the SFN static delay.

In the case of Denmark, where the terrain is rather flat, which facilitates area coverage, the study showed that the use of hybrid broadcast/unicast operation allows covering more than 90% of the population with a site density of 14 sites per 10 000 km^2, for car mounted reception and HHPO reception using a 5G Broadcast system variant requiring 15 dB of SINR. The study also showed that the HHIC reception is quite difficult to ensure and would imply a need for large complementary coverage by unicast.

The presence of many large sea paths in Denmark increases the difficulty of operating national SFNs. The study showed that splitting the national SFN into three clusters of sub-national SFNs operating between them in MFN reduces the risk of SFN self-interference and therefore improves the coverage.

In the case of Germany, the approach consisted in considering the same infrastructure as an existing DTT network (63 sites covering 48 Million people with DVB-T2 in portable outdoor reception or 28 million people in portable indoor reception) and assessing the level of coverage and data rates that could be achieved with 5G Broadcast for HHPO reception compared to those currently offered with DTT.

The results showed that with the assumptions of the study, LTE-based 5G Broadcast handheld outdoor coverage (in Germany) will be:

– similar or better than portable indoor coverage DVB-T2 for lower MCS; and/or

– similar or smaller than portable outdoor coverage DVB-T2 for high MCS.

The data rates with such 5G Broadcast network will be lower than the DVB-T2 data rates, due to the need for more robust Modulation and Coding schemes to ensure reception with handheld receivers. On the other hand, codecs improved already and will improve, and there are other mechanisms which allow for a viable business model.

Regarding the other parameters of relevance for network planning, studies on both theoretical and real networks showed that a cyclic prefix of 200 µs offers the best compromise between the need to ensure mobile reception with reasonable maximum speed and the constraint of long delays in large SFNs.

The use of the same frequency and the same editorial content in SFN mode between all sites and layers offers the best performance, as a result of the gain offered by such networks. However, SFNs may not be implementable over very large areas due to risk of self-interferences (depending on Cyclic Prefix), to editorial content change across borders, and to the current interleaved use of spectrum for DTT imposed by the Geneva 2006 Agreement (GE06) or by bilateral and multilateral cross border agreements outside GE06 area. Therefore, a mixture of MFN and SFN would be required, within the constraints of relevant agreements.

5 References / Bibliography

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Annex 1

Intersite distance

To better understand the inter-site distance (ISD) of HPHT networks, an analysis of such sites in Sweden, France and the United Kingdom was carried out. Given coordinates of sites, the distance to the nearest neighbours can be derived using Delaunay triangulation.

Care needs to be taken to filter (to remove false, not valid) sides of the generated triangles, illustrated in Fig. A1-1. In the case of Sweden, with the false sides included, the average ISD for the 57 HPHT sites is 105 km, removing false sides the ISD reduces to 93 km (see Fig. A1-2).

FIGURE A1-1

ISD of HPHT sites in Sweden

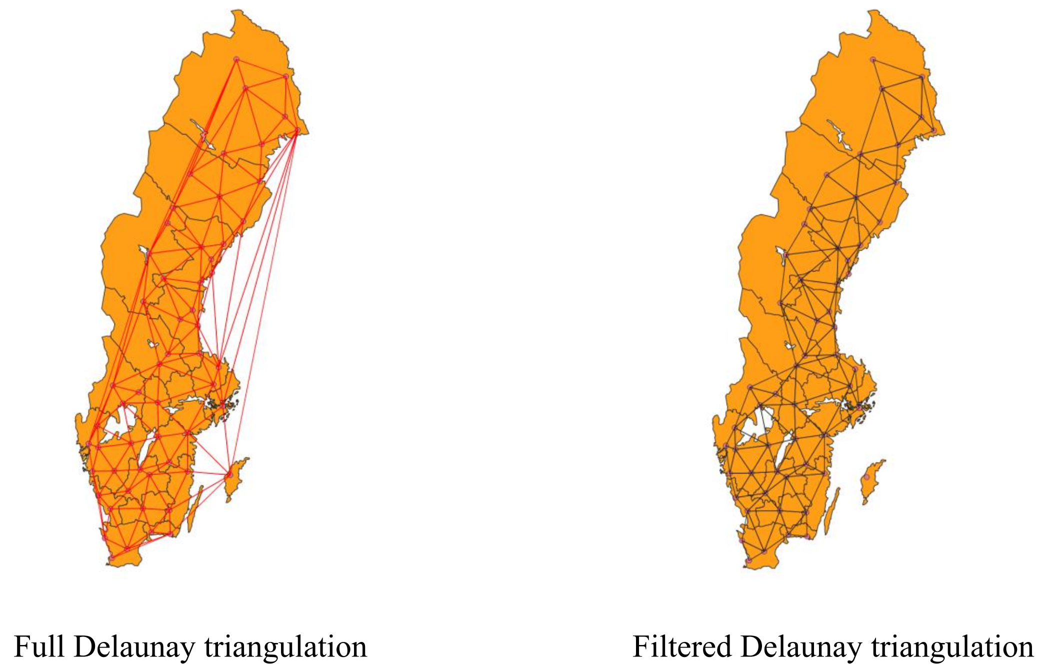
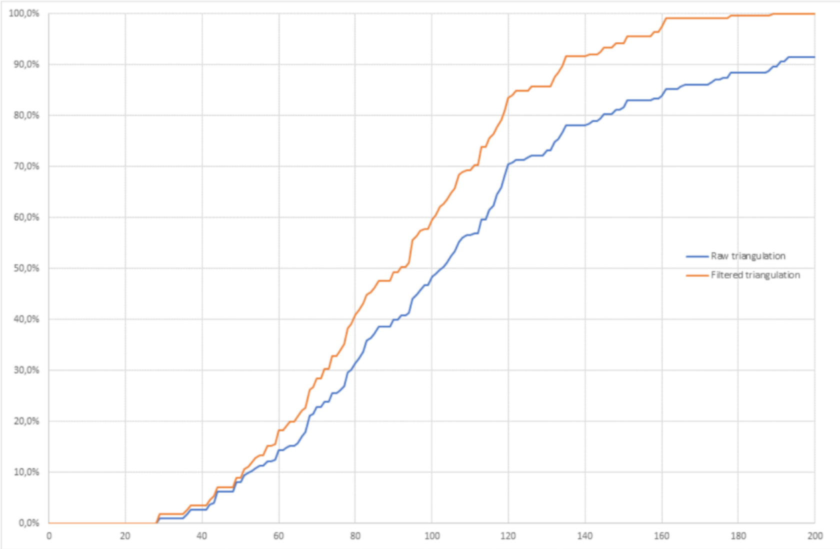


FIGURE A1-2

CDF of HPHT ISD in Sweden



Triangulation for the 112 main French sites with false links at the edge removed, Fig. A1-3, provides a median ISD value of 82 km, Fig. A1-4. Terrain and population play a part in the site spacing. Low ISD values can be found in Paris, the Alps and the Jura, high ISD values around Toulouse Pic-du-Midi (Southeastern France).

FIGURE A1-3

ISD of HPHT Sites in France

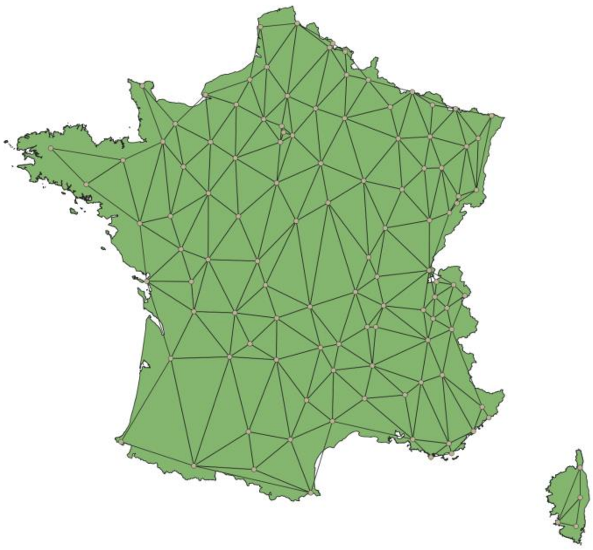
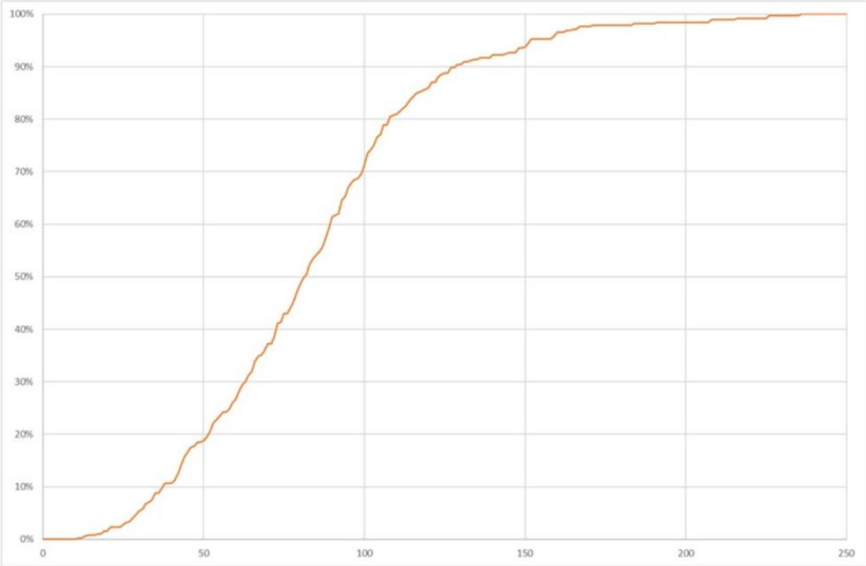


FIGURE A1-4

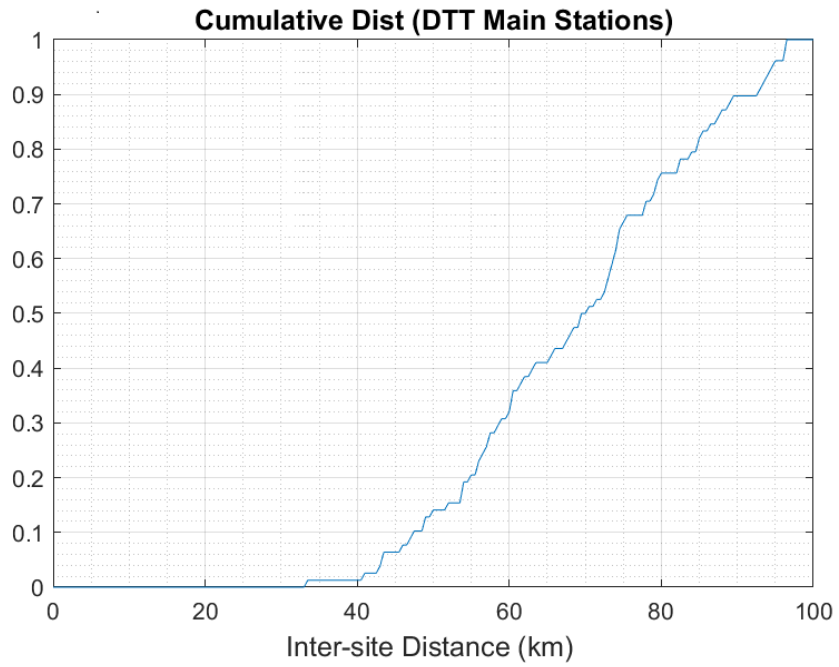
CDF of HPHT ISD France



Triangulation for the 50 main United Kingdom sites with links over 100 km removed provides a median ISD value of 73 km (see Fig. A1-5).

FIGURE A1-5

CDF of HPHT ISD United Kingdom



Taking the results for Sweden, France and the United Kingdom, and recognising that there is a spread in results and that values for other countries may differ significantly, for generic studies an ISD for HPHT sites of 80 km could be used.

Annex 2

Results of coverage simulations at national or regional borders

1 HPHT results rural reception (80 km ISD)

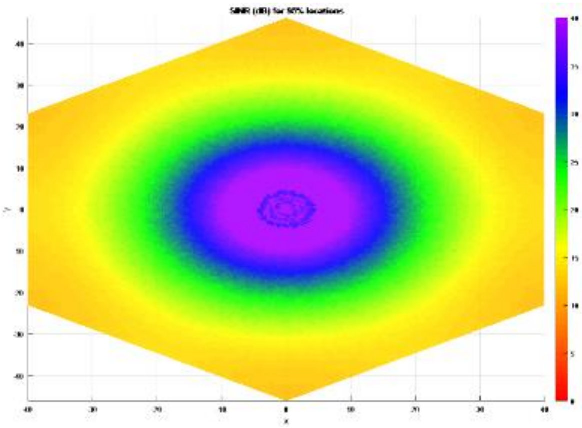
The scenario is based on a HPHT network topology with the following characteristics:

– Rural reception.
– 80 km ISD.
– 300 m antenna height.
– 2° antenna tilt.
– 79.6 dBW EIRP.
– 300 µs Cyclic Prefix duration.

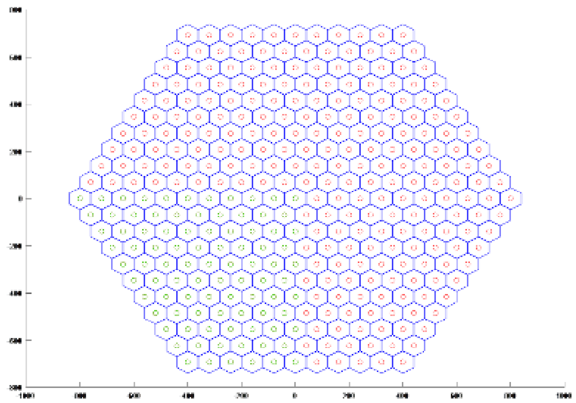
1.1 Corner regional boundary results

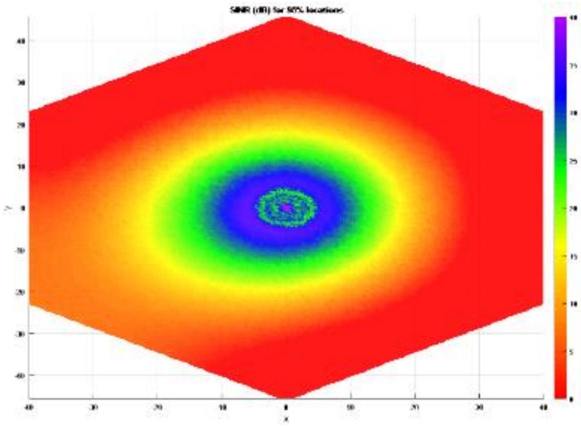
FIGURE A2-1

Original situation (no boundaries)

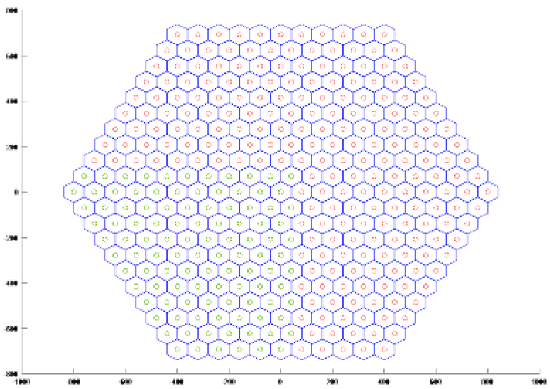


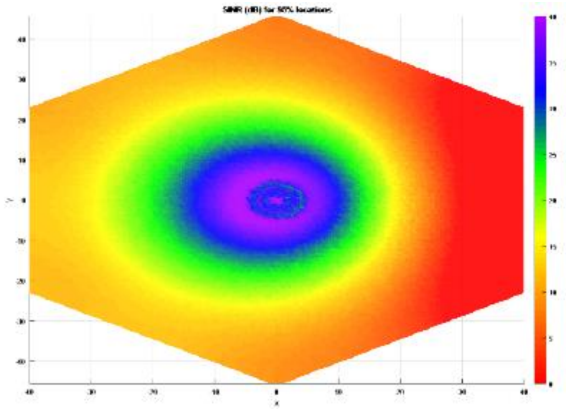
Corner – 0 ISD



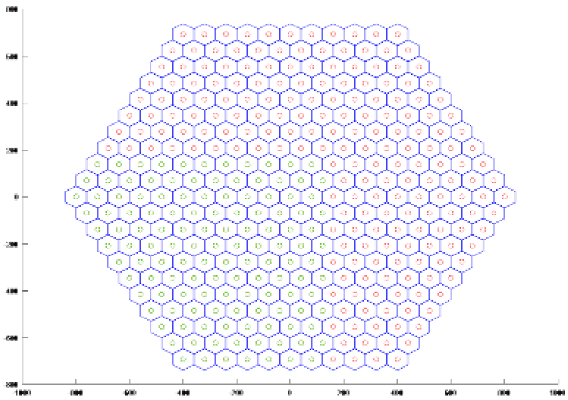


Corner – 1 ISD





Corner – 2 ISD



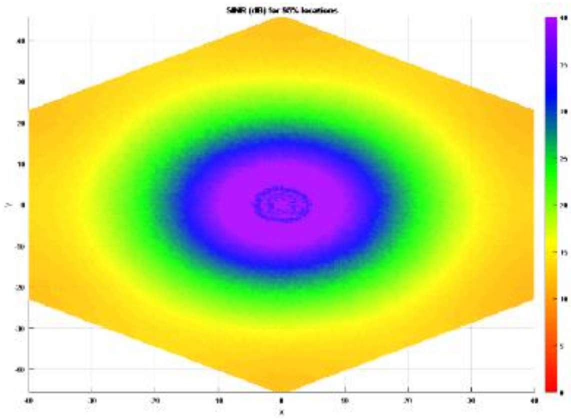
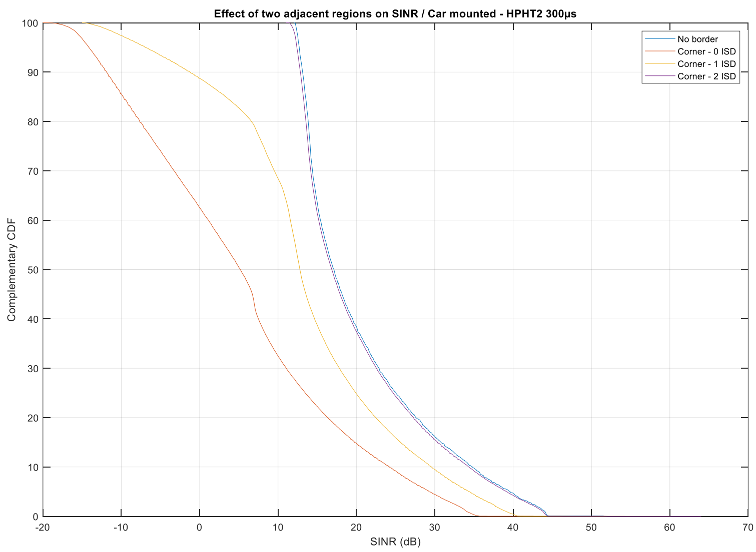


Figure A2-2 compares the resulting complementary CDF of SINR for the four situations presented above.

FIGURE A2-2

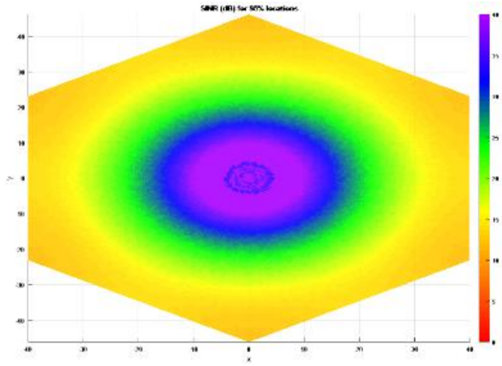
Corner regional boundary results for HPHT



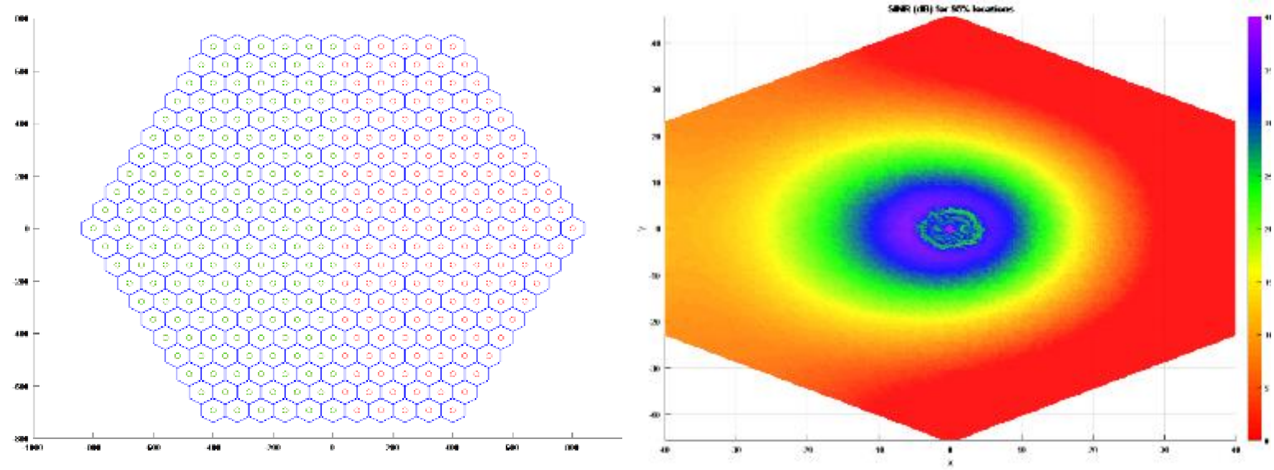
1.2 Straight regional boundary (East/West separation)

FIGURE A2-3

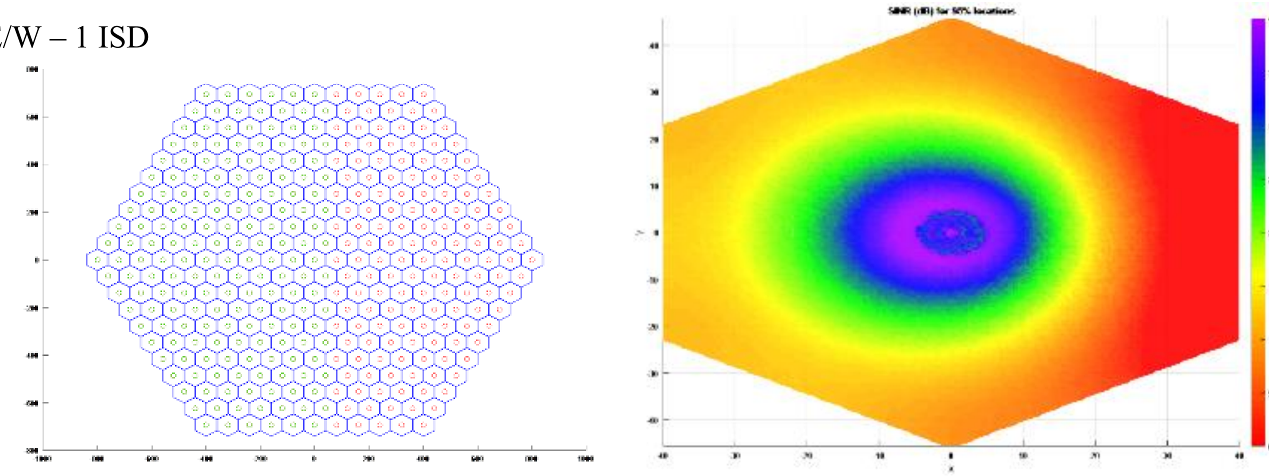
Original situation (no boundaries)



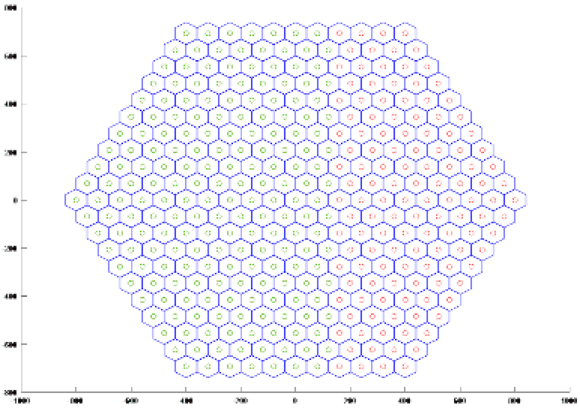
E/W – 0 ISD



E/W – 1 ISD



E/W – 2 ISD



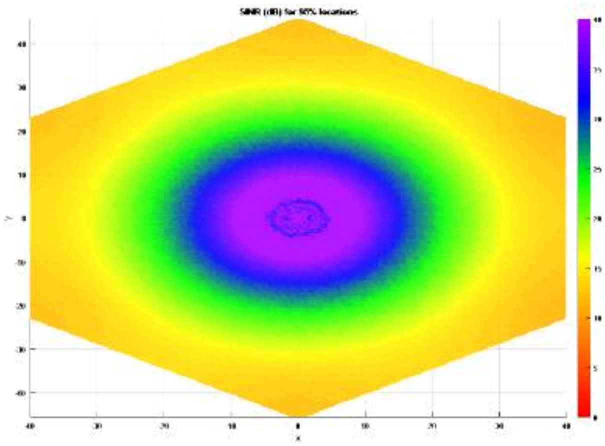
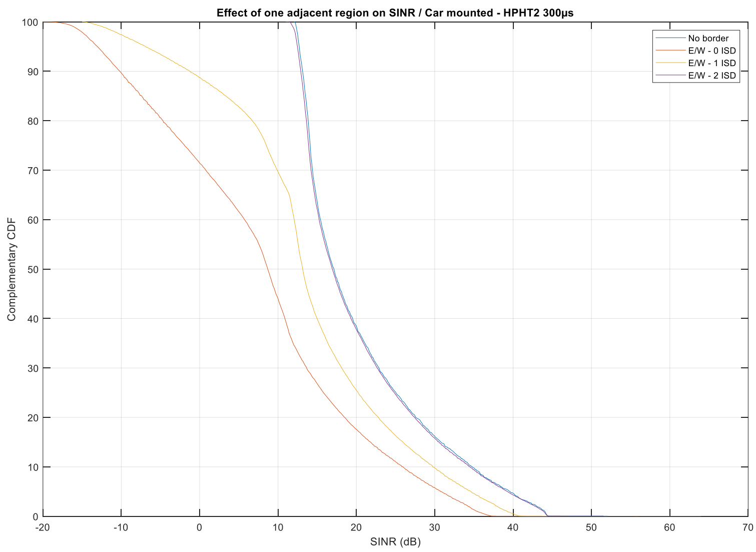


FIGURE A2-4

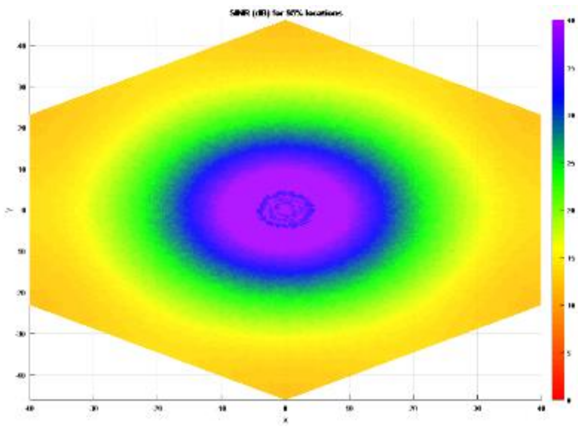
Straight E/W boundary region results comparison for HPHT



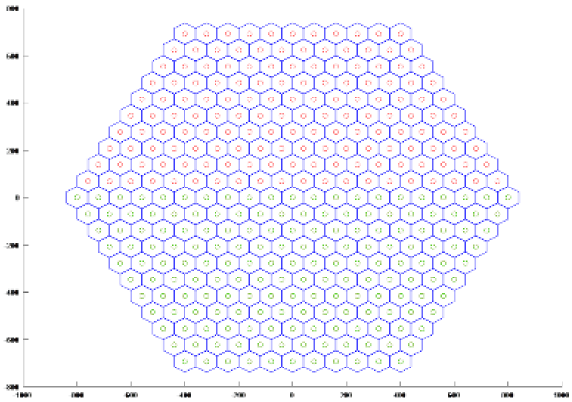
1.3 Straight regional boundary results (North/South separation)

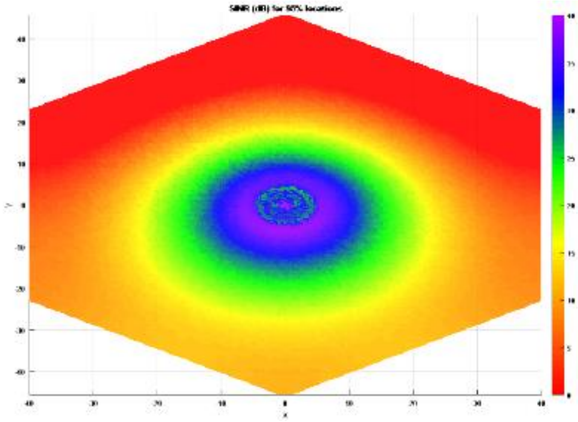
FIGURE A2-5

Original situation
(no boundaries)

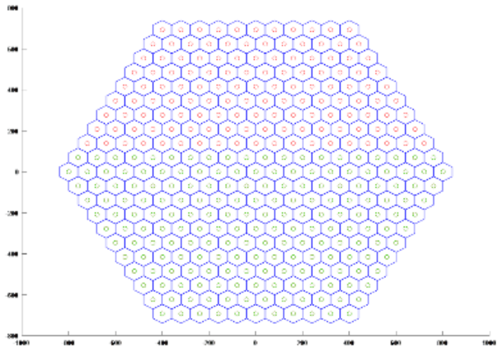


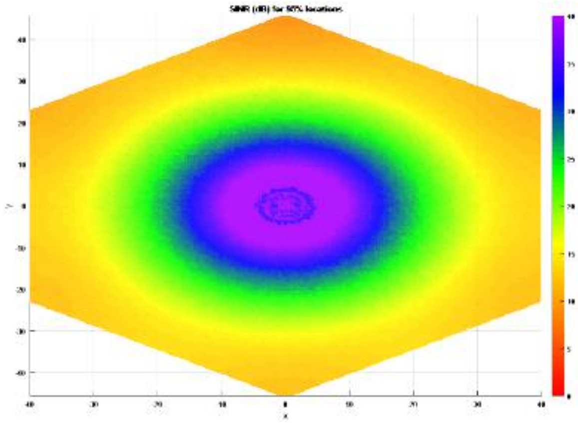
N/S – 0 ISD



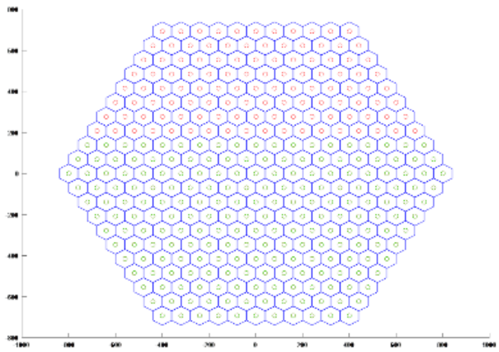


N/S – 1 ISD





N/S – 2 ISD



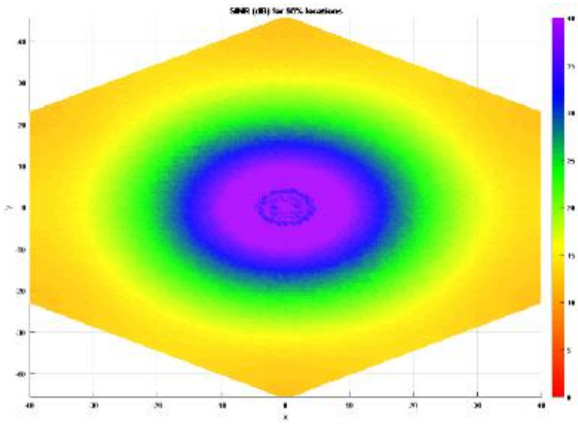
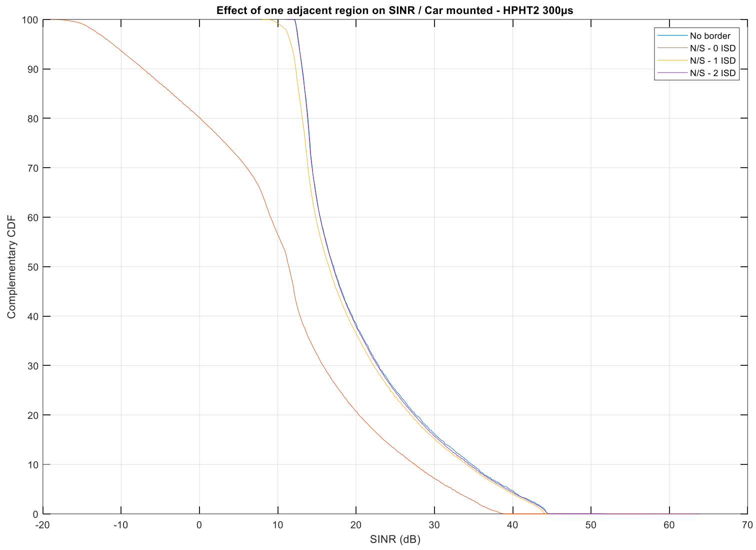


FIGURE A2-6

Straight N/S boundary region results comparison for HPHT



2 MPMT results rural reception (20 km ISD)

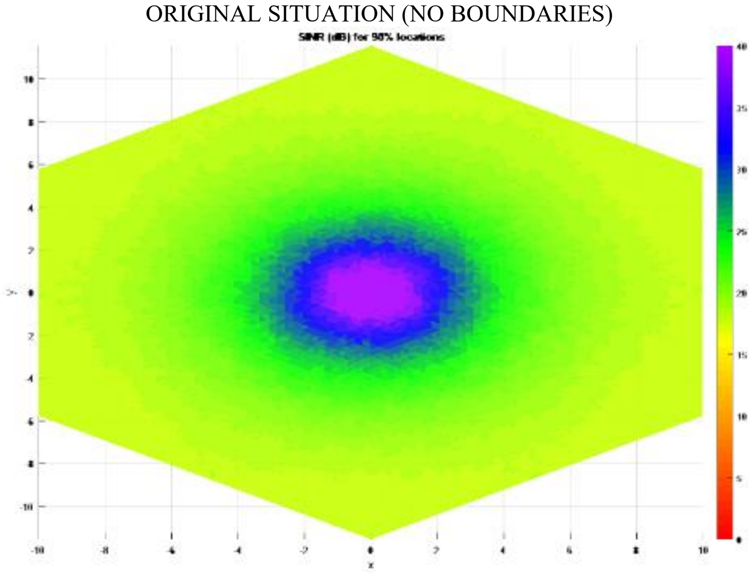
The scenario is based on a MPMT network topology with the following characteristics:

- rural reception;
- 20 km ISD;
- 80 m antenna height;
- no antenna tilt (and no vertical pattern);
- 59.6 dBW EIRP;
- 300 µs Cyclic Prefix duration.

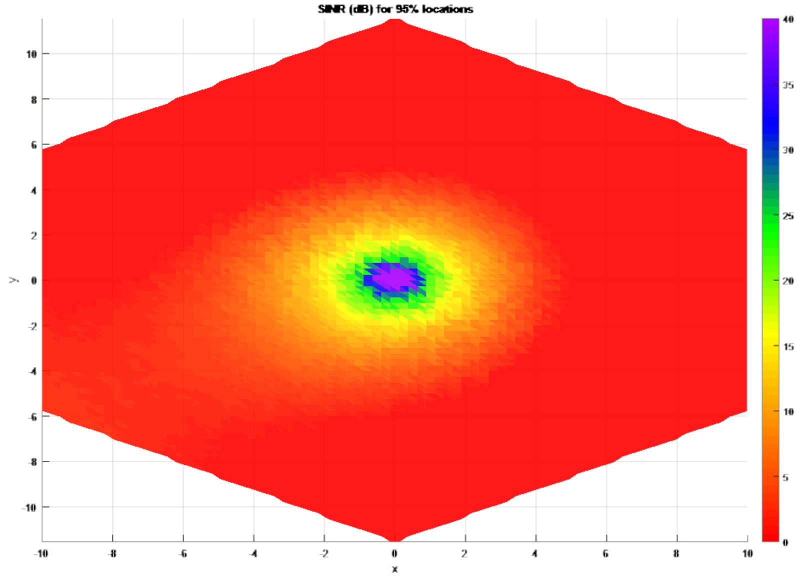
2.1 Corner regional boundary results

FIGURE A2-7

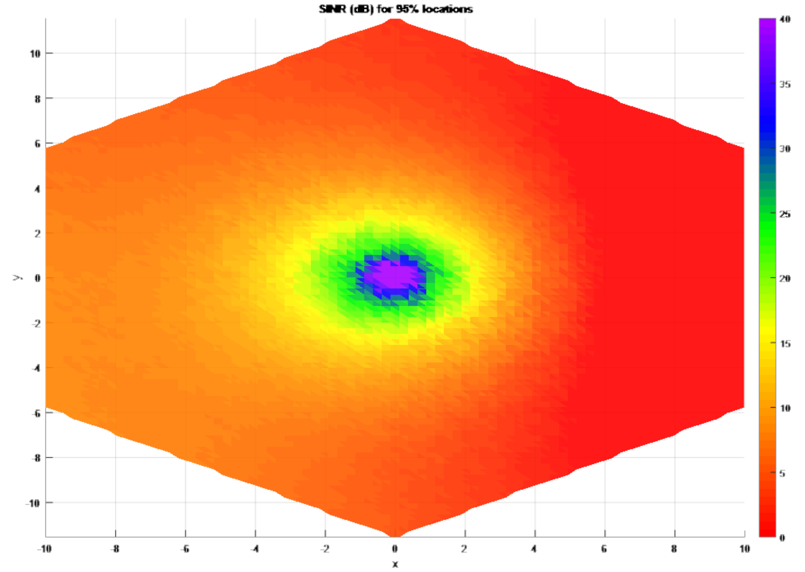
ORIGINAL SITUATION (NO BOUNDARIES)



CORNER – 0 ISD



CORNER – 0 ISD



CORNER – 2 ISD

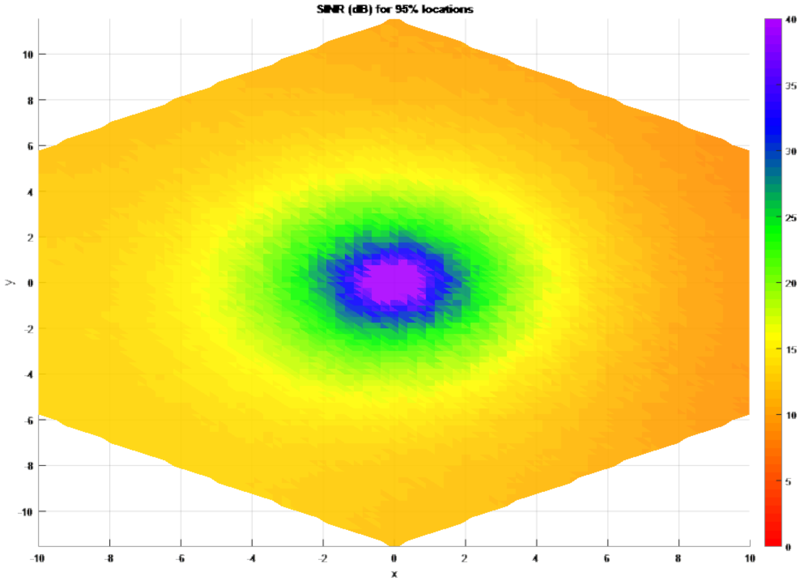
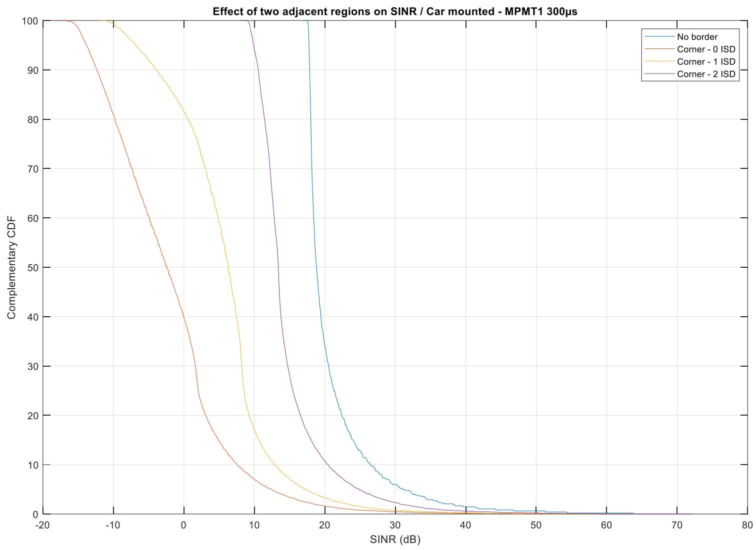


Figure A2-8 compares the resulting complementary CDF of SINR for the four situations presented above.

FIGURE A2-8

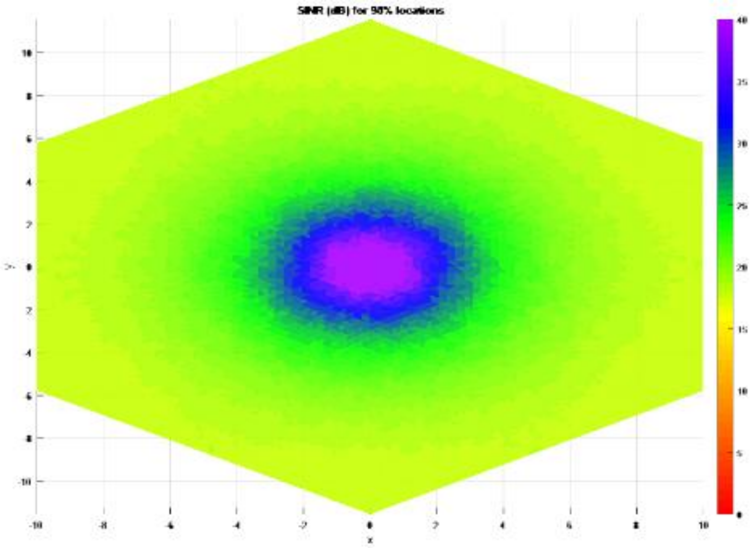
Corner regional boundary results for MPMT



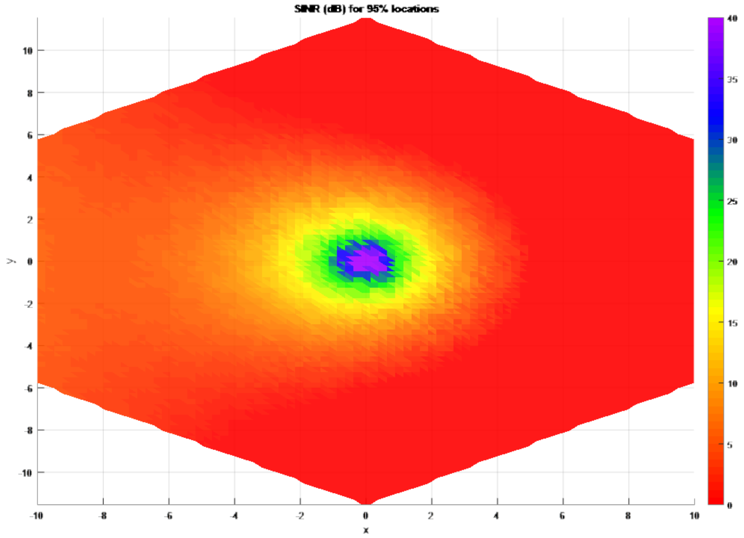
2.2 Straight regional boundary (East/West separation)

FIGURE A2-9

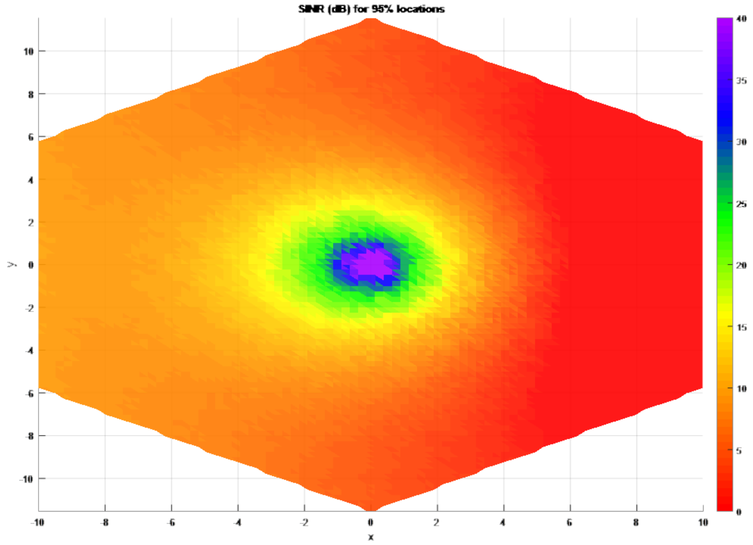
ORIGINAL SITUATION (NO BOUNDARIES)



E/W – 0 ISD



E/W – 1 ISD



E/W – 2 ISD

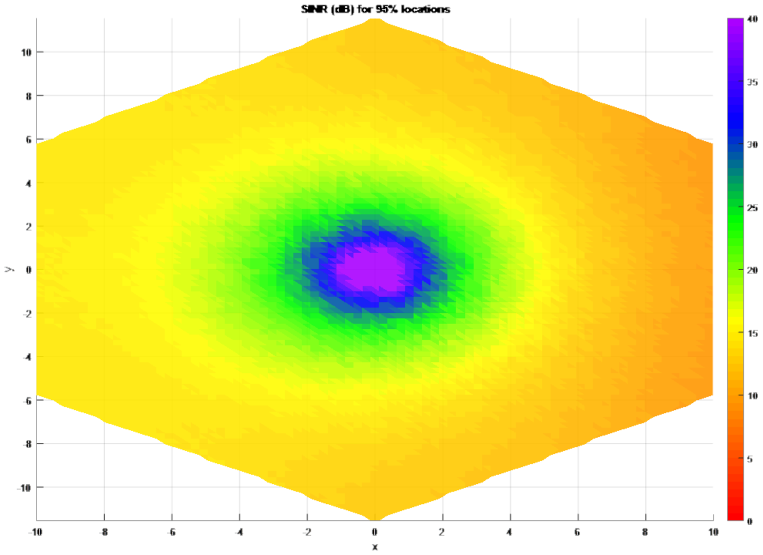
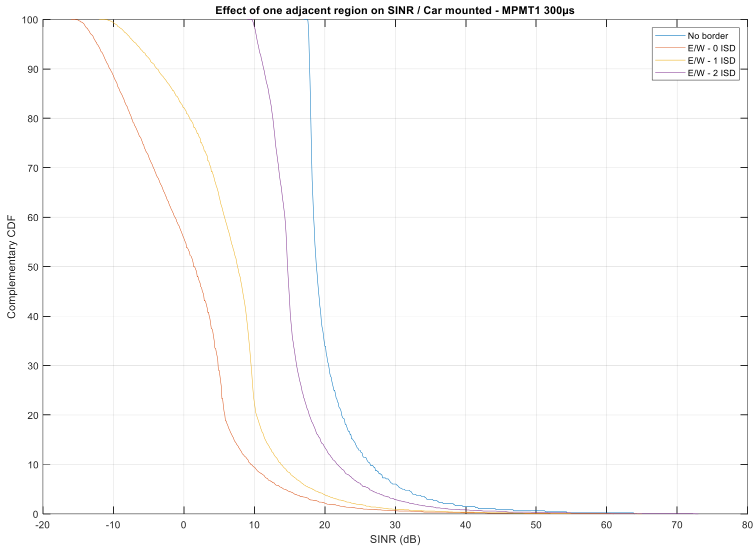


FIGURE A2-10

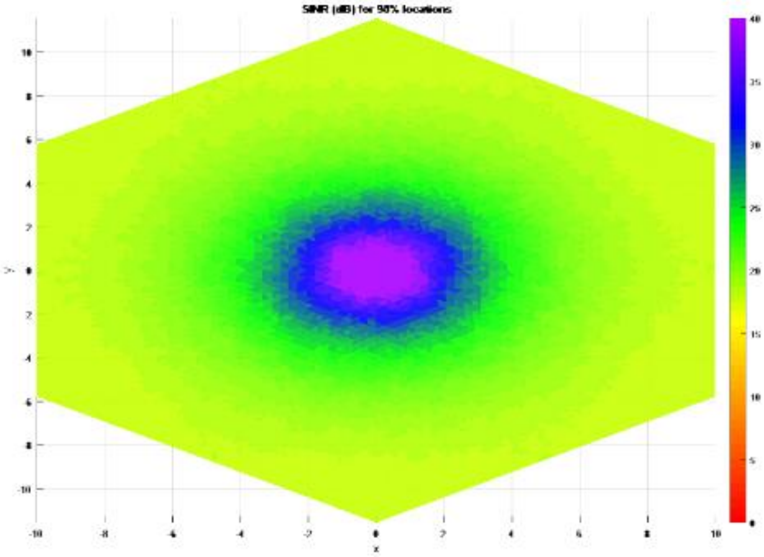
Straight E/W boundary region results comparison for MPMT



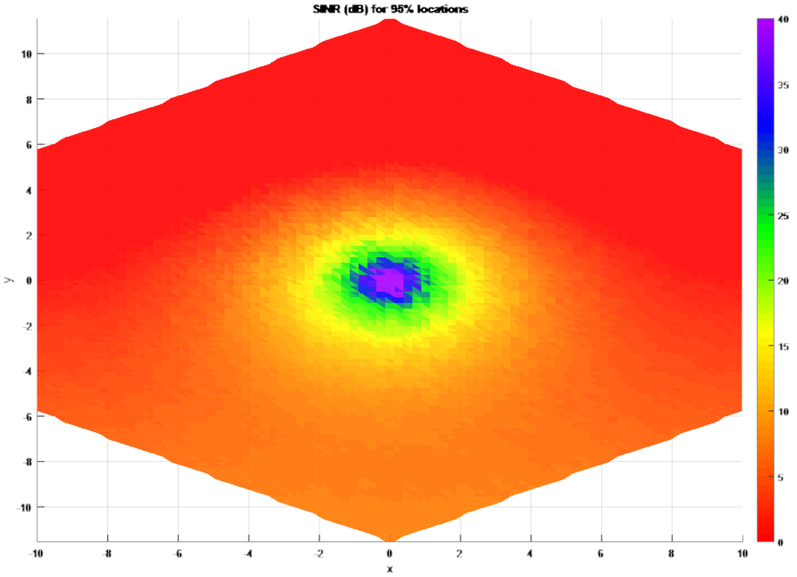
2.3 Straight regional boundary results (North/South separation)

FIGURE A2-11

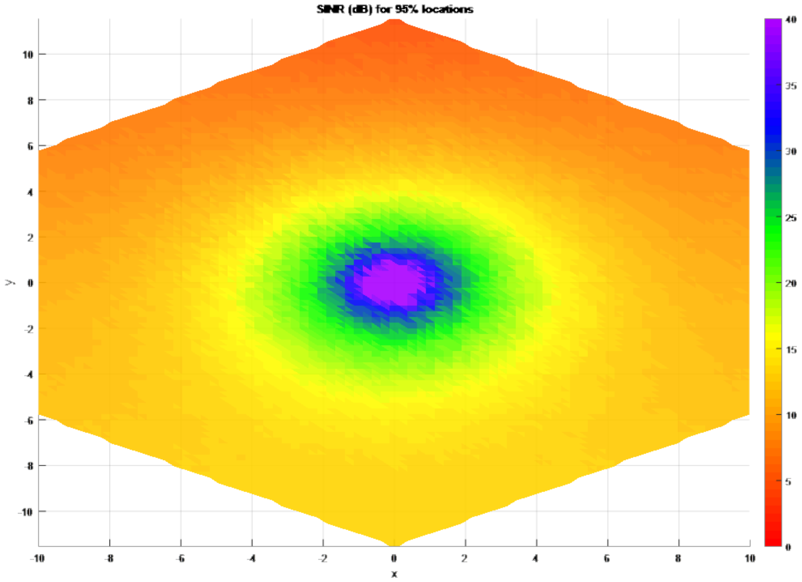
ORIGINAL SITUATION (NO BOUNDARIES)



N/S – 0 ISD



N/S – 1 ISD



N/S – 2 ISD

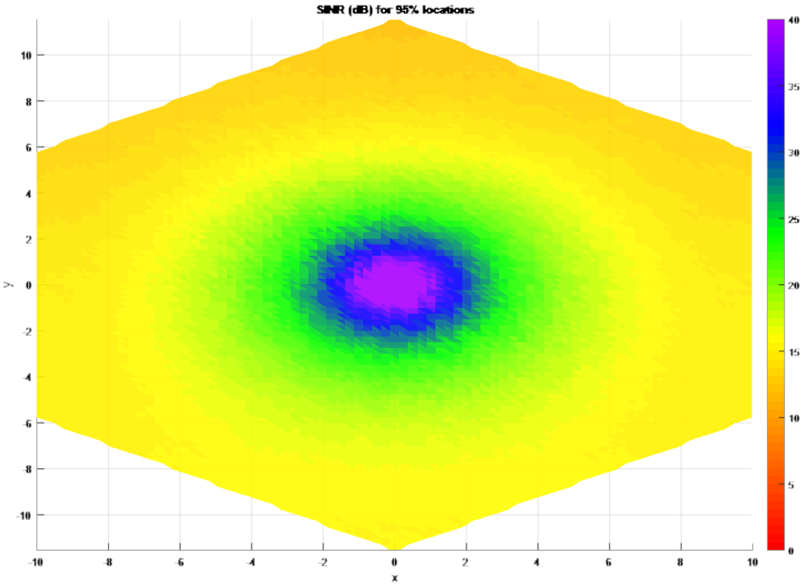
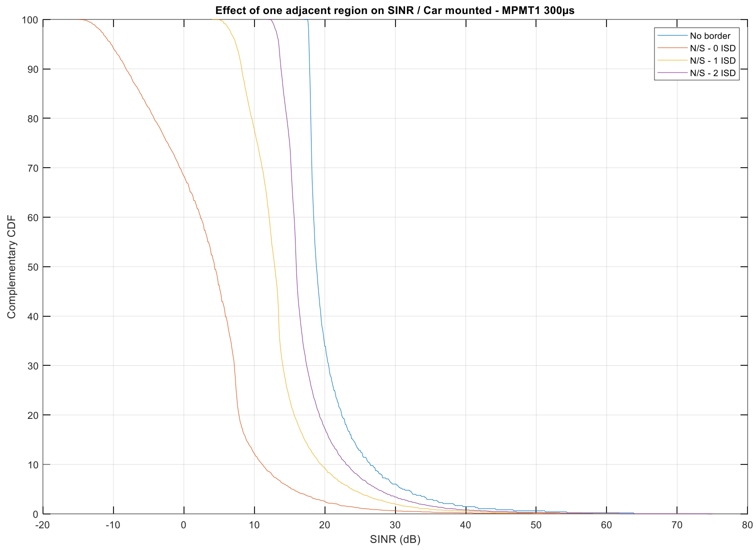


FIGURE A2-12

Straight N/S boundary region results comparison for MPMT



3 LPLT results rural reception (12 km ISD)

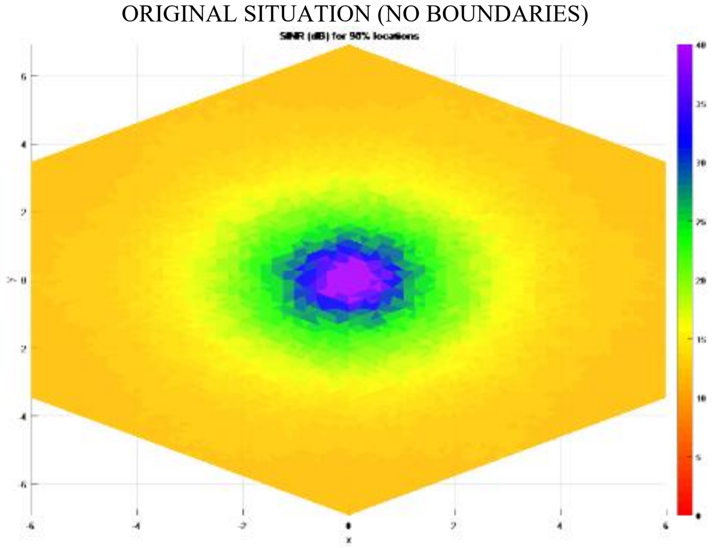
The scenario is based on a LPLT network topology with the following characteristics:

- Rural reception.
- 12 km ISD.
- 30 m antenna height.
- 3° antenna tilt.
- 57 dBW EIRP.
- 100 µs Cyclic Prefix duration.

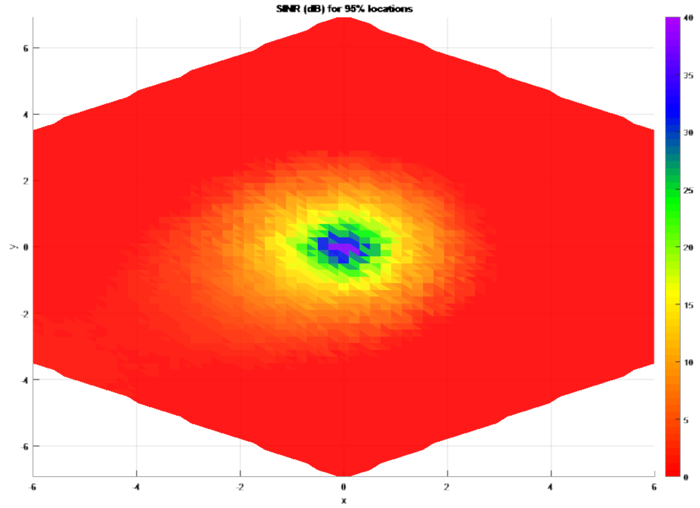
3.1 Corner regional boundary results

FIGURE A2-13

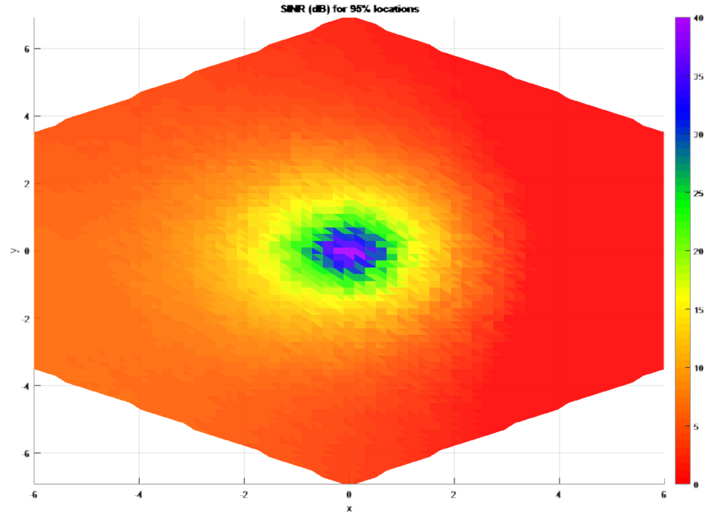
ORIGINAL SITUATION (NO BOUNDARIES)



CORNER – 0 ISD



CORNER – 1 ISD



CORNER – 2 ISD

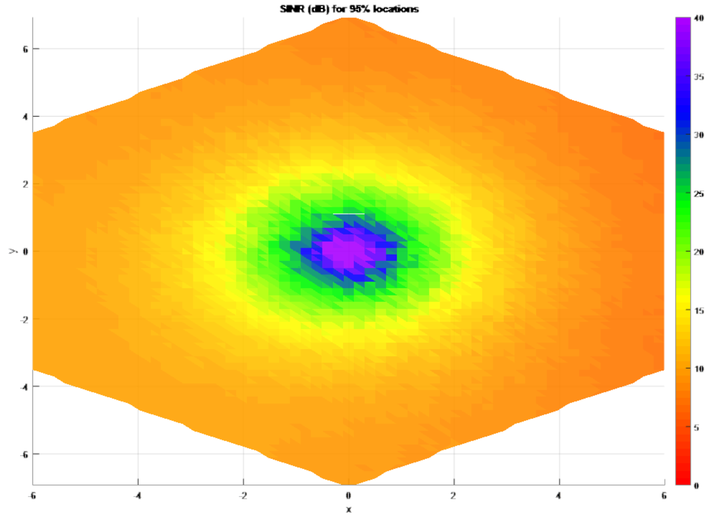
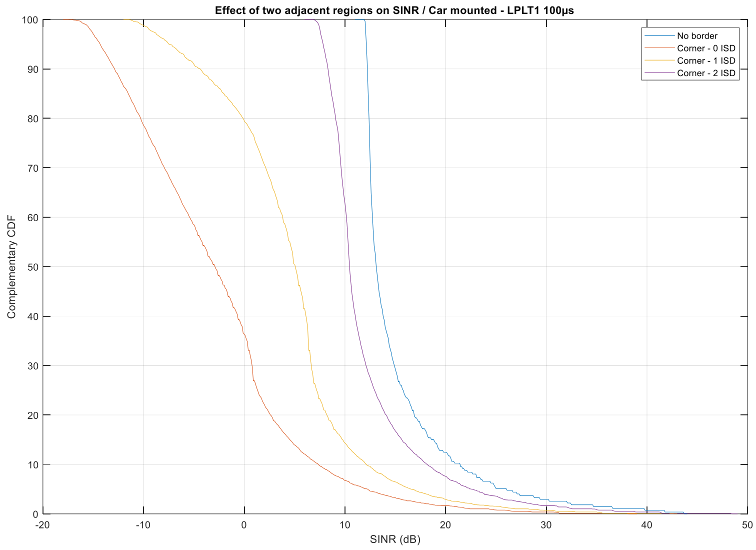


Figure A2-14 compares the resulting complementary CDF of SINR for the four situations presented above.

FIGURE A2-14

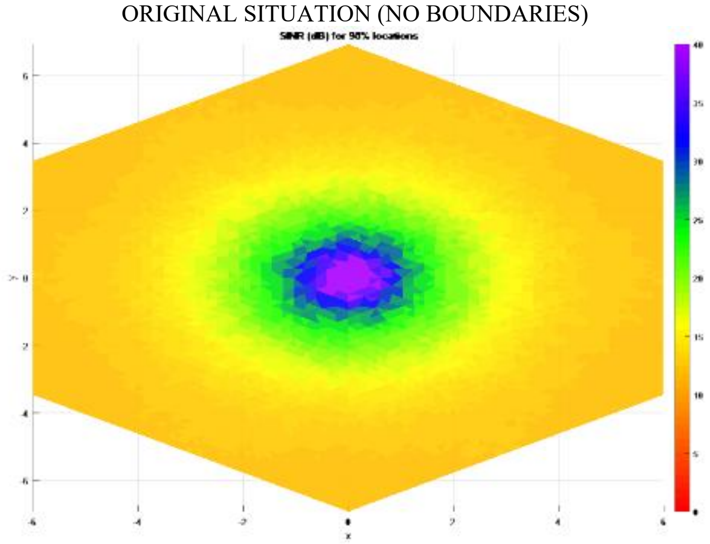
Corner regional boundary results for LPLT



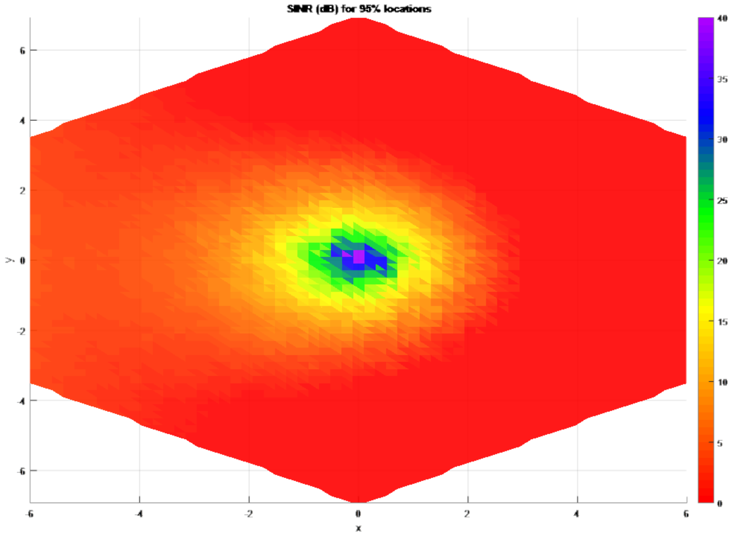
3.2 Straight regional boundary (East/West separation)

FIGURE A2-15

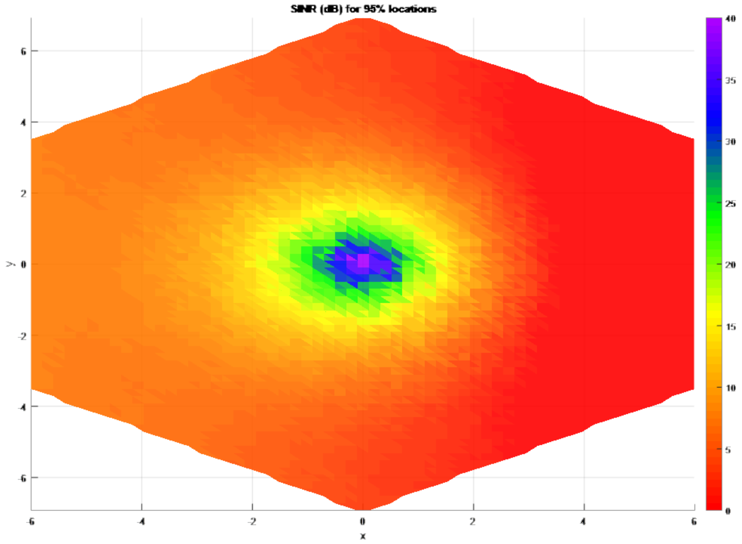
ORIGINAL SITUATION (NO BOUNDARIES)



E/W – 0 ISD



E/W – 1 ISD



E/W – 2 ISD

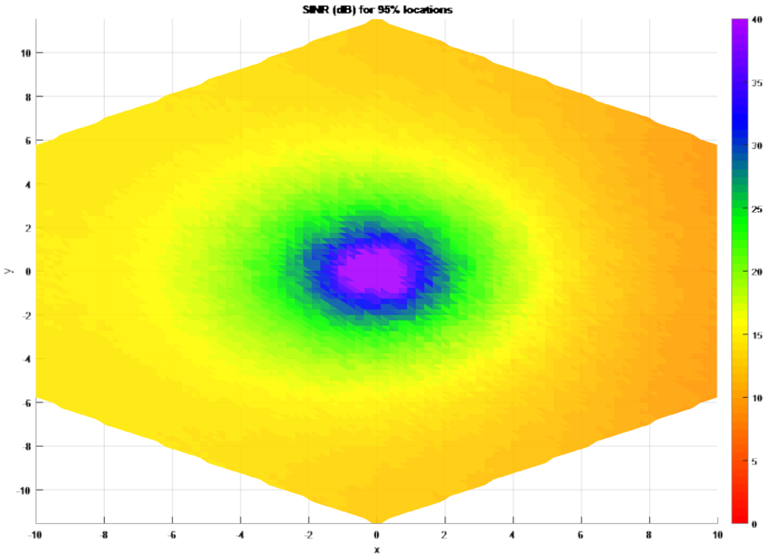
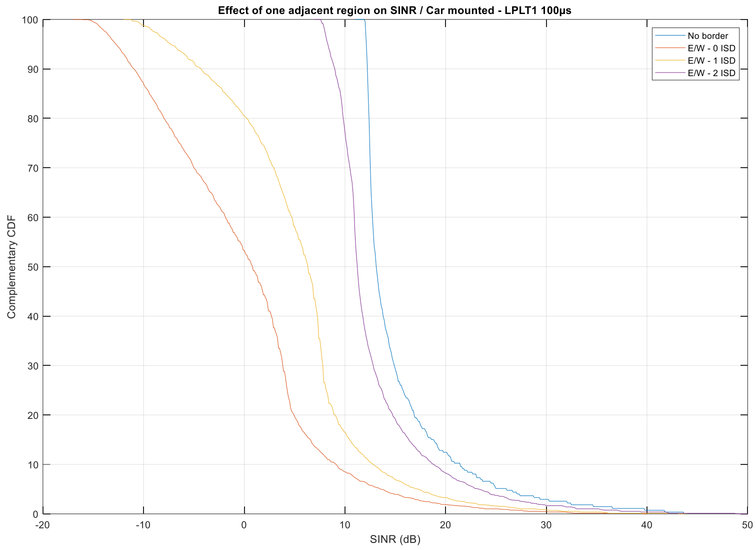


FIGURE A2-16

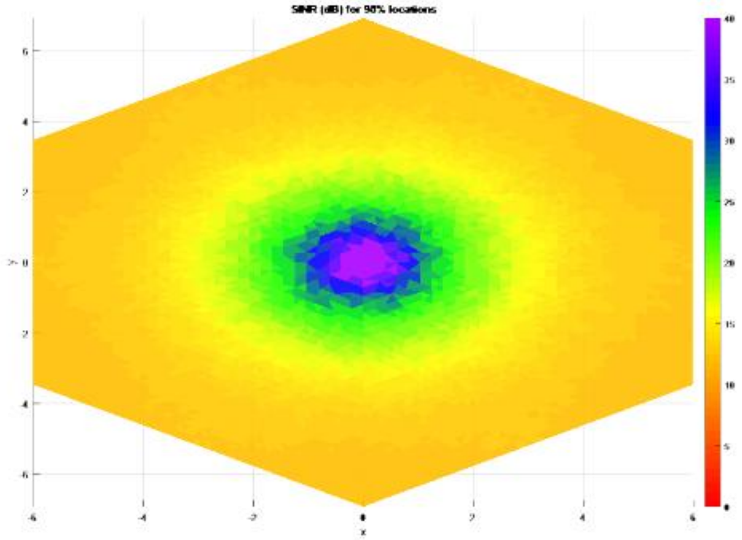
Straight E/W boundary region results comparison for LPLT



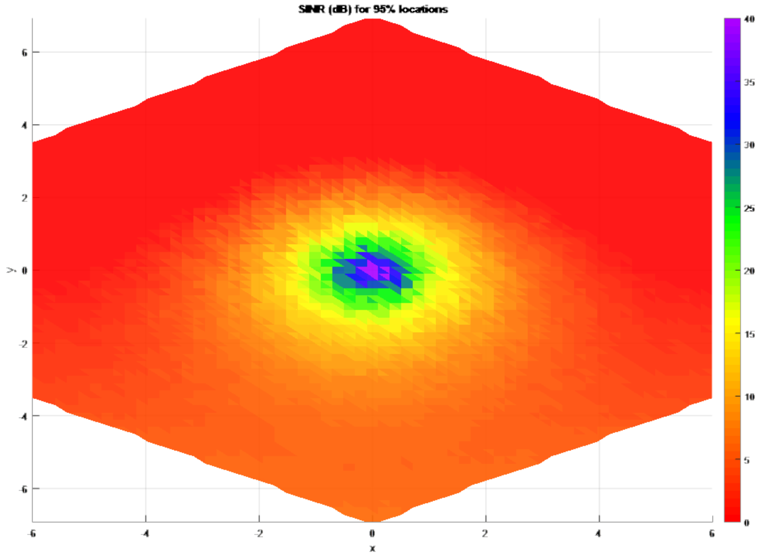
3.3 Straight regional boundary results (North/South separation)

FIGURE A2-17

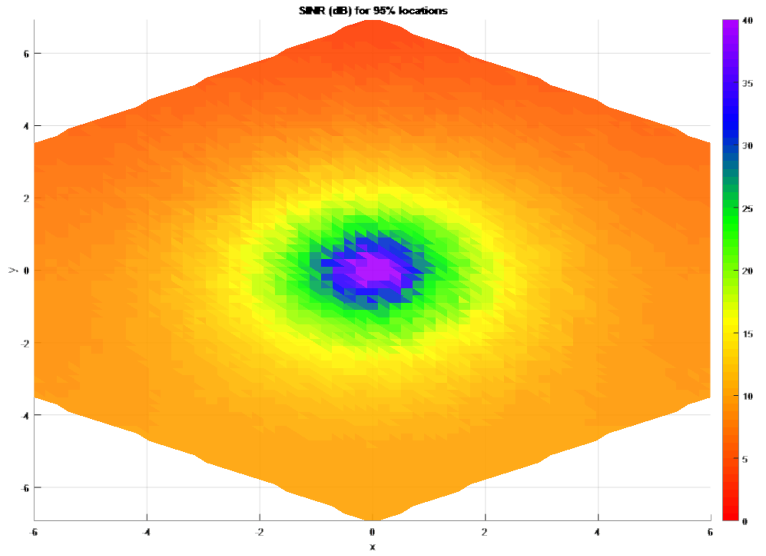
ORIGINAL SITUATION (NO BOUNDARIES)



N/S – 0 ISD



N/S – 1 ISD



N/S – 2 ISD

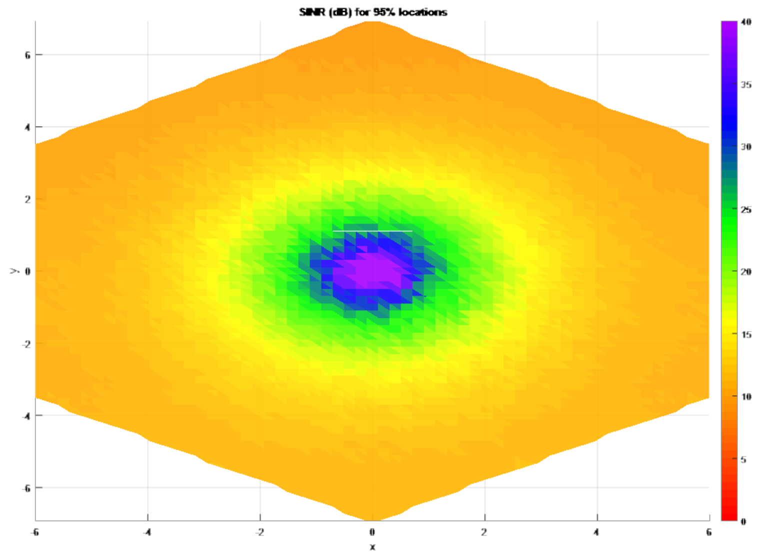
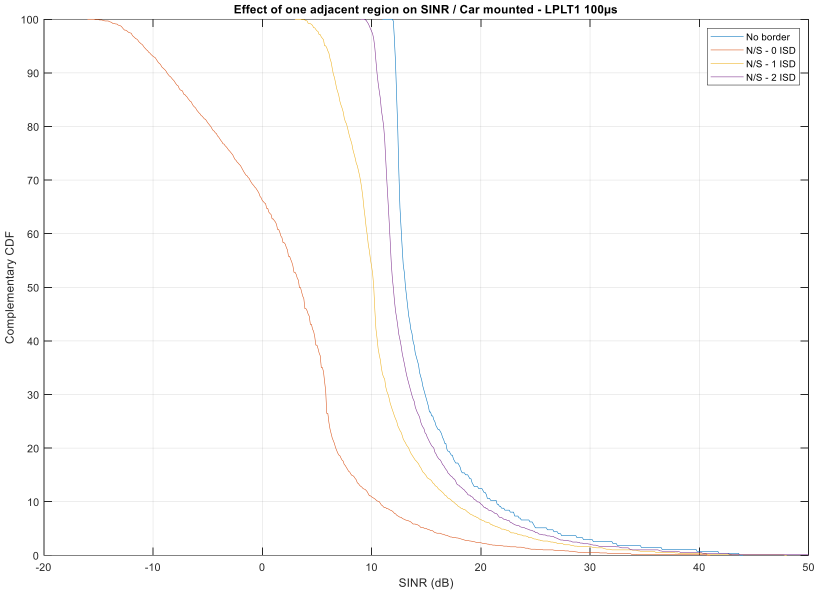


FIGURE A2-18

Straight N/S boundary region results comparison for LPLT



Annex 3

Simulation of the Impact of practical antenna pattern

1 Introduction

This Annex compares the effect on margin and coverage of using an antenna on LPLT, MPMT and HPHT sites that is subject to practical limitations rather than on ideal antenna characteristics. The range of antenna variation that exists means it is impractical to model all options, particularly in the case of LPLT, so a single example has been simulated to show its potential impact. For the LPLT case the antenna modelled is shown in Fig. A3-6, for the HPHT and MPMT cases a typical ’omnidirectional’ Broadcast antenna incorporating a 4 dB ripple was assessed.

2 Generic case

The results on coverage of using practical antennas (realisable using existing infrastructure) rather than idealised antennas are shown in Figs A3-1 to A3-5. In all cases there is a reduction in coverage; however where there is an overlap in coverage and a surfeit of margin for a given SINR, there may be no real impact on coverage. Examples where coverage for a given SINR is maintained are LPLT suburban and LPLT urban where SINR is 20 dB or less, LPLT rural where SINR is 5 dB or less, MPMT and HPHT rural where the SINR is 10 dB or less.

FIGURE A3-1

Car Mounted – LPLT suburban – 100 µs CP – Ideal vs Practical

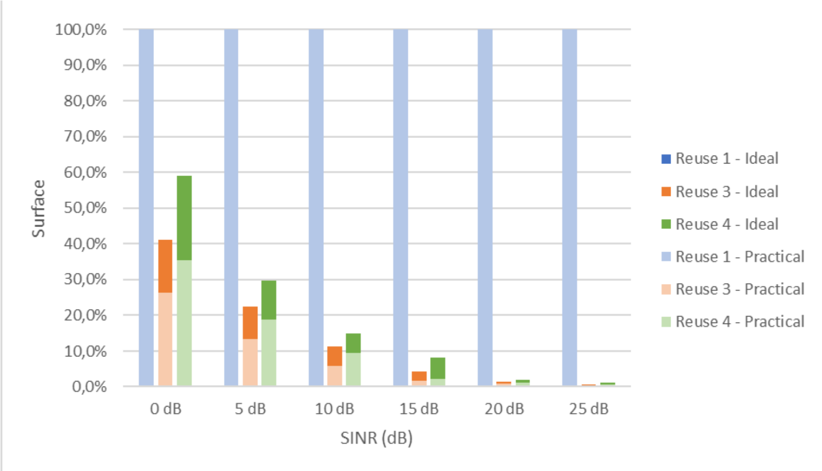


FIGURE A3-2

Car Mounted – LPLT urban – 100 µs CP – Ideal vs Practical

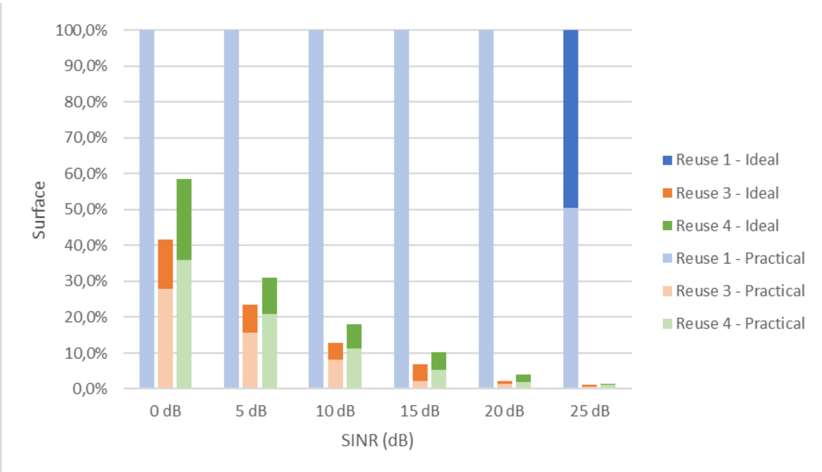


FIGURE A3-3

Car Mounted – LPLT rural – 100 µs CP – Ideal vs Practical

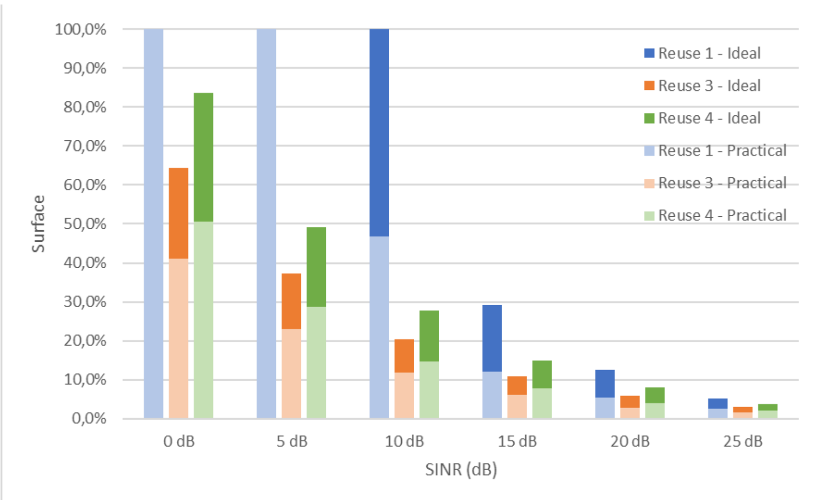


FIGURE A3-4

Car Mounted – MPMT– 200 µs CP – Ideal vs Practical

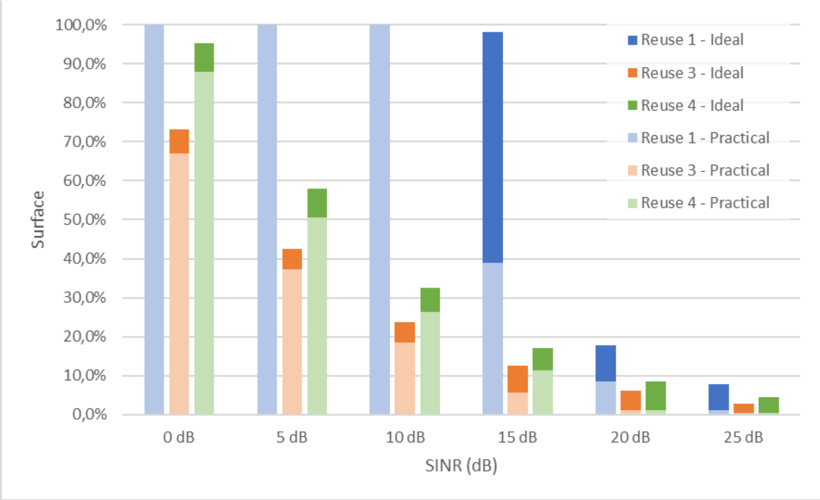
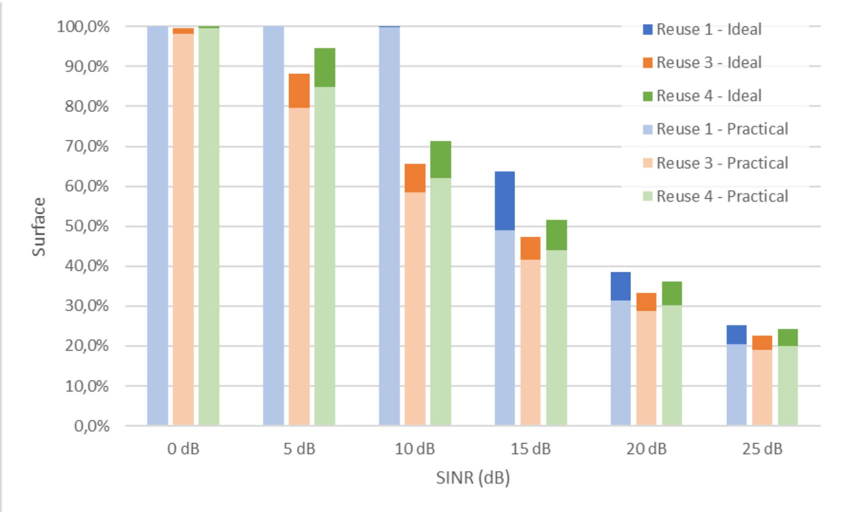


FIGURE A3-5

Car Mounted – HPHT – 300 µs CP – Ideal vs Practical



3 'Real' case

The coverage of an example 5G Broadcast network, based on an actual network, was simulated. The network consists of 130 LPLT sites operated as an SFN. It is designed to provide 95% population indoor coverage when using idealized antenna diagrams. The details of the modelled network are as follows:

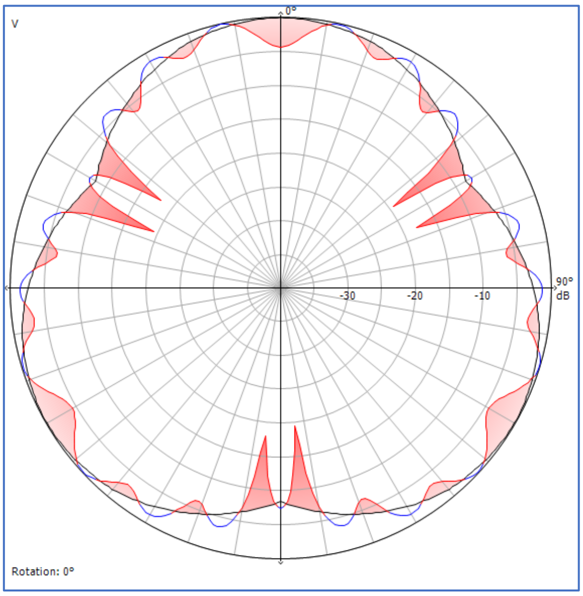
- Extent of area: 30 km × 30 km, approximately 1 000 km^2
- Environment: Dense Urban 20%, Urban 30% and Suburban 30%
- Type of reception: Handheld Indoor
- Number of sites: 130
- Antenna heights: 20 – 40 m
- Target population coverage: 95%
- EIRP of Sites 500 – 1000 W
- Total population within AOI about 7 million
- Total capacity of network About 10 Mbit/s

SFN system parameters were set in such way that no SFN self-interference is present, symbol time is 800 µs and CP is 200 µs. Planning parameters were as specified in § 1.

The antenna patterns used in the modelling are shown in Fig. A3-6. The difference between the two idealized and distorted patterns are shown in red.

FIGURE A3-6

Modelled antenna patterns idealized and distorted



4 Results

The original network using the 'idealized' antenna patterns provided the target 95% indoor population coverage. Repeating the coverage calculation using the practical antenna pattern provided 73% indoor population coverage. This indicates that the impact on coverage of a practical antenna pattern could be significant. It was estimated that about 30 additional sites would be needed to restore 95% population coverage. Alternatively, an increase of power of about 4 dB would be needed to restore coverage back to the original 95% population. Coverage plots for the two scenarios modelled are shown in Figs A3-7 and A3-8.

FIGURE A3-7

Idealized antenna 95% indoor population coverage

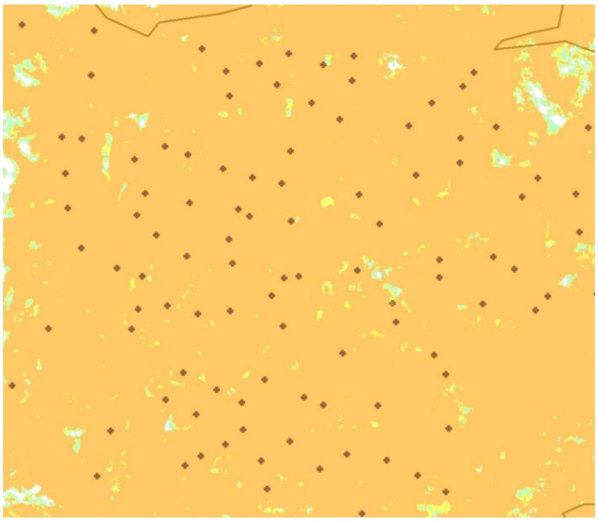
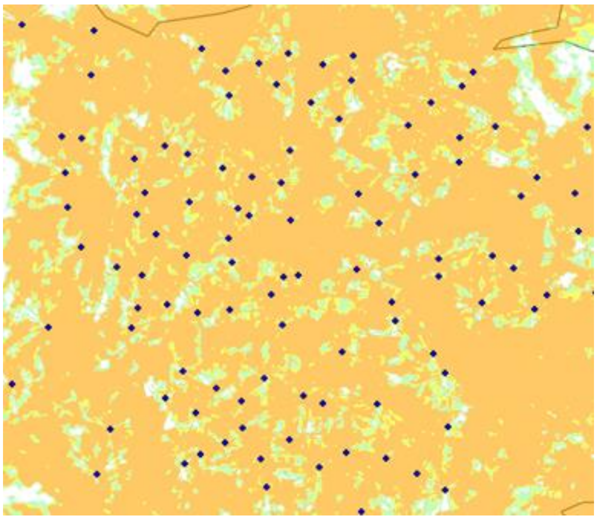


FIGURE A3-8

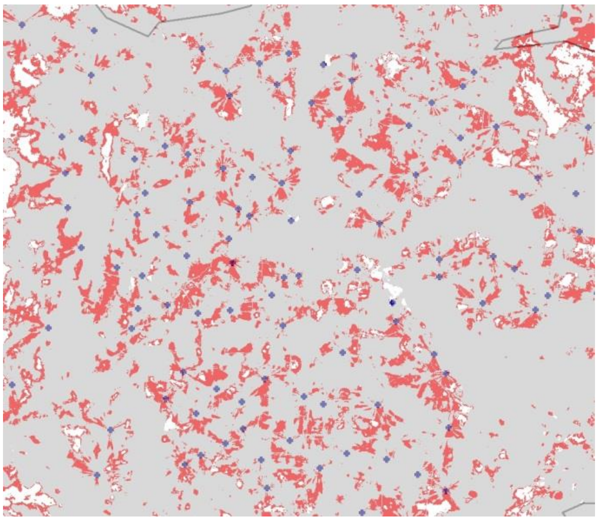
Practical antenna 73% indoor population coverage



The difference between the two predictions, i.e. the areas (red) where coverage is lost due to the change in antenna pattern, is shown in Fig. A3-9.

FIGURE A3-9

Difference plot



5 Discussion

Broadcast antenna patterns, whilst not providing true omnidirectional coverage, are optimised to minimise nulls (ripple) in the patterns. Consequently, the impact on SINR at the edge of coverage of using practical patterns rather than 'idealised' omnidirectional patterns is small but not insignificant. For mobile antenna systems comprised of sector antennas, the impact, if not mitigated, could be significant at the edge of coverage. The impact on coverage could be reduced by increasing the EIRP, adopting an increased phase delay between sector antennas (cyclic delay diversity), a combination of the two or building a new antenna with a better pattern. Each has a cost implication that needs to be weighed against the potential loss in coverage.

6 Conclusion

The sector antennas typically used by mobile systems are not designed to operate as arrays. If used for 5G Broadcast, such antennas would have deep nulls in the pattern, which may compromise coverage. Measures to mitigate this loss in coverage may be required. Existing broadcast antenna systems have already been optimised for coverage.