

# Satellite Digital Multimedia Broadcasting – Performance Assessment with Radio Network Planning Tool

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**Abstract**— Several technologies for providing mobile broadcast services are currently emerging. Besides terrestrial-only architectures as DVB-H the hybrid satellite & terrestrial system approach of S-DMB offers an interesting alternative in terms of coverage and cost-efficiency. In order to assess the S-DMB radio coverage in different environments an off-the-shelf planning tool for terrestrial radio networks has been adapted to consider satellite transmitters and the W-CDMA air interface. This S-DMB radio planning tool allows the investigation of the S-DMB performance in terms of coverage and system margin for pure satellite as well as hybrid satellite and terrestrial repeater configurations within various environments (rural, urban and indoor). Such investigations are used to trade the open radio parameters of the S-DMB system architecture and to gain knowledge concerning the required density of the terrestrial repeaters in order to provide sufficient coverage in urban and indoor environments. In order to allow performance comparisons between the WCDMA and the OFDM air interface the S-DMB radio planning tool has been upgraded accordingly.

## I. INTRODUCTION

### A. System Overview

PROVIDING broadcast services to mobile user terminals (as e.g. Mobile TV) is becoming a hot topic since it is expected to create significant revenue opportunities for both the media and mobile industries [1]. The Satellite Digital Multimedia Broadcast (S-DMB) system studied in the European IST project MAESTRO [2] aims to provide multimedia services to the mobile user on a cost effective way by the full-fledge integration with terrestrial 3G UMTS networks. The S-DMB system is based on the concept of a hybrid satellite and terrestrial architecture operating in the IMT2000 core frequency band allocated to Mobile Satellite Systems, as shown in Fig. 1. S-DMB relies on the W-CDMA radio interface defined for UMTS terrestrial networks to achieve a coherent combination of satellite and terrestrial signals. Accordingly, the system is predestinated to minimise impacts on the 3G cellular user terminal, which is very important to limit the overall system costs.

The basic S-DMB system architecture [2] is presented in Fig. 2. The hub includes 3G radio access network equipment and 3G core network functions. It takes as input the incoming multimedia services from the broadcast/multicast service centre. This information stream is fed to a Node B

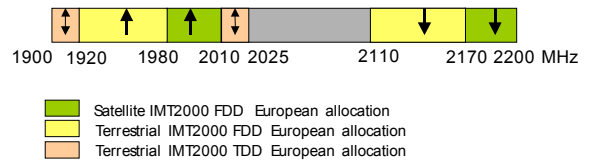


Fig. 1. Satellite bands within IMT2000 core bands

modem in order to build the S-DMB W-CDMA downlink carrier, which is modulated with a specific radio frequency sub-system onto two Fixed Satellite System (FSS) frequency band (Ka or Ku band) 5 MHz carriers: one for the direct satellite path (hub → satellite → handset), and the other one for the indirect satellite path (hub → satellite → repeater → handset).

The purpose of the S-DMB system is to provide datacast capacity for various mobile network operators. This capacity can be used to deliver cost effective streaming and download services directly to mobile handsets over nation-wide spot beams. The umbrella cells give the advantage to integrate a wide and scattered audience which significantly reduces the retail service fee.

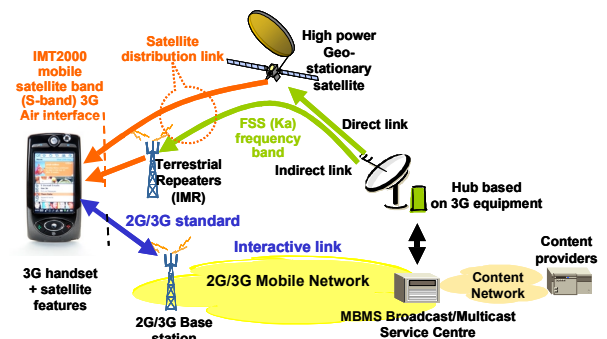


Fig. 2. S-DMB system architecture

The system infrastructure will typically aim at an average availability above 95 % in outdoor environments in order to address the 3G handset mass market. For this purpose it relies on very high power, transparent, geo-stationary satellites with large deployable antennas. Depending on the selected on-board configuration (from two to six spot beams), the EIRP per beam will reach values up to 72 dBW.

The deployment of low power, frequency-conversion gap-fillers will ensure coverage in urban environments including the penetration into buildings. By co-siting of the repeaters with 2G and 3G base stations, the effort for the deployment will be reduced.

In such a “single frequency same code” radio network configuration, the satellite might be seen as a complementary signal source serving users in rural and suburban areas, while terrestrial Intermediate Module Repeaters (IMRs) operating at the same frequency as the satellite are used to amplify the signal in urban scenarios. A typical satellite configuration allows to offer coverage over 6 umbrella cells with a broadcast capacity of 768 kbit/s per umbrella cell. The system capacity can be increased up to 2.3 Mbit/s per umbrella cell by adding further frequency channels.

The satellite and the gap fillers are designed to be transparent to new features and waveforms introduced in the 3GPP standard. An improvement in terms of capacity can be expected by adapting the S-DMB system concept to the OFDM air interface, which is investigated in the second part of the paper.

### B. S-DMB Radio Planning Tool

In order to assess the S-DMB radio coverage for different configurations and in various environments, an off-the-shelf planning tool for terrestrial radio networks has been adapted to consider satellite transmitters and the W-CDMA air interface (as originally planned for the S-DMB system). The planning tool allows the user to define an individual S-DMB network configuration comprising the satellite segment, an arbitrary number of IMRs and the specification of the user equipment. Based on the accurate prediction of the satellite and repeater radio channels in terms of power delay profiles the defined S-DMB network is evaluated.

The calculated channel profiles form the basis of the S-DMB system simulation, which includes a detailed modelling of the user equipment and leads to predictions of the S-DMB coverage and other performance measures as e.g. the system margin. According to this description there are two basic parts of the S-DMB RNPT (as depicted in Fig. 3), which will be explained in detail in the following chapters.

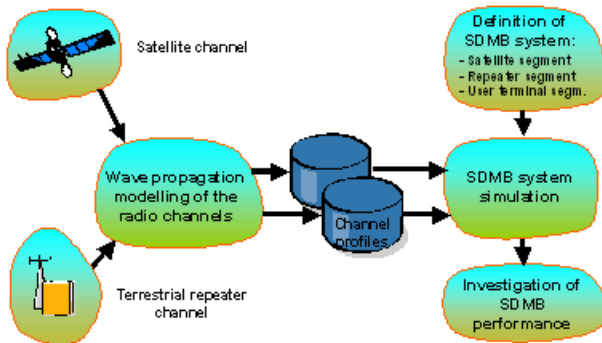


Fig. 3. Basic structure of the S-DMB radio planning tool

In order to allow performance comparisons between the WCDMA and the OFDM air interface, the S-DMB radio planning tool has been upgraded accordingly. The upgrade includes a new system simulation module (replacing the WCDMA module including the Rake receiver), while the wave propagation module providing the channel profiles for different transmitter-receiver configurations can be reused.

## II. RADIO CHANNEL AND WAVE PROPAGATION MODELLING

The performance of wireless communication systems depends in a fundamental way on the mobile radio channel. In general, the transmission is subject to multipath propagation, i.e. the signal from the transmitting antenna propagates along different paths to the antenna of the (mobile) receiver. In many cases there is no direct line-of-sight (LOS) and the only paths connecting transmitter and receiver are reflected, diffracted and scattered at a number of different obstacles (see Fig. 4).

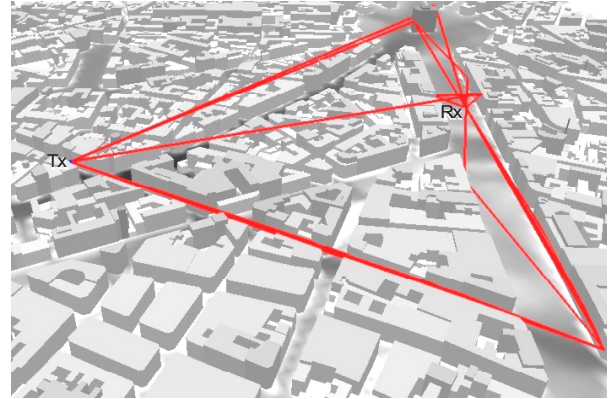


Fig. 4. Multipath propagation in urban environment

Since the phases of the waves are randomly distributed, the superposition of these contributions causes constructive and destructive interference (i.e. small-scale fading) which leads to rapidly fluctuating signal levels over very small distances. While the small-scale fading is random, the large-scale variations occur due to fundamental changes of the propagation paths (e.g. larger distances, different obstacles). Typically, the local average of the received power is computed by averaging signal measurements over an interval of 10 to 20 wave lengths, which corresponds to movements of the receiver of 1.5 m to 3 m at a frequency of 2 GHz.

The multipath propagation leads to dispersion of the signal in the time domain, which can be characterised by the corresponding delay spread of the radio channel. Since the delays of the multipath contributions are distinct, the frequency transfer function is subject to amplitude fluctuation, i.e. frequency selective fading. This behaviour is described by the corresponding coherence bandwidth, which is inversely proportional to the delay spread of the channel. Depending on the relation between signal bandwidth and coherence bandwidth, the wireless channel can be considered either as flat or frequency selective.

In case of mobile terminals, i.e. moving receivers, an additional time variance of the radio channel is superposed (similar in case of moving scatterers), which leads to short-term fluctuations (small-scale fading) described by the parameter coherence time. This effect corresponds to the dispersion in the frequency domain, which is characterised by the Doppler spread of the channel (inversely proportional to the coherence time). When the Doppler spread is

comparable to the signal bandwidth the channel is termed time selective (characterised by fast fading), otherwise the channel is non-selective and is subject to slow fading only.

In general, two types of wave propagation models can be distinguished: deterministic and empirical (statistical) models. When using deterministic models (i.e. ray-optical) a site-specific result is obtained by taking into account the specific environment (buildings, terrain profile). Empirical models provide more general characterisations of the mobile radio channel based on the evaluation of measurement data without taking into account a specific environment.

#### A. Ray-Optical Model

Deterministic models utilise physical phenomena in order to describe the propagation of radio waves. Herewith the effect of the actual environment is taken into account by using vector building data (plus terrain profile). A radio ray is assumed to propagate along a straight line influenced only by the present obstacles which lead to reflection, diffraction and the penetration of these objects. This approach represents the concept of Geometrical Optics (GO). In general, either the ray tracing or the ray launching algorithm is used for the determination of the rays between transmitter and receiver. However, the main disadvantage of both algorithms consists in their prohibitively large computation time.

For the determination of valid rays between transmitter and receiver, the S-DMB tool includes a sophisticated ray tracing algorithm [4] for urban environments, which is based on a preprocessing of the building data (in order to reduce the computation time significantly). The ray-optical model allows a site-specific prediction of the radio channel for satellites and terrestrial repeaters and has been validated by numerous measurement campaigns [5]. Due to the ray-optical approach it is possible to consider the time-dispersive behaviour of the radio channel in a deterministic sense.

#### B. Empirical Models

The empirical models provide average channel profiles based on the evaluation of measurement data without performing a site-specific prediction. These statistical models try to reproduce the behaviour of the radio channel in order to estimate the performance of different system implementations [6]. Empirical impulse response models are usually defined as tapped delay line models including a limited number of paths with individual amplitude and delay (both referring to the dominant path).

Such an empirical channel model has been implemented in the S-DMB planning tool according to [7] for the satellite channel (basically to investigate the coverage over wide areas where no building data is available). This model provides different parameter sets depending on the environment (urban, suburban or rural) and the satellite elevation angle. The wideband channel model uses three submodels describing the different parts of the impulse response depending on the echo delay: direct path, near

echos and far echos. The superposition of all echos leads to the satellite wideband channel. More details with respect to the empirical channel model for the satellite domain are given in [7].

For the simulation of the terrestrial channels over wide areas based on clutter (plus topographical) databases the well-known Okumura-Hata model [8] is used together with predefined channel profiles (e.g. ITU Vehicular A [9]).

### III. S-DMB SYSTEM SIMULATOR

The S-DMB system simulator superposes the radio channels of the corresponding satellite and repeater links and considers the given air interface of the system and the defined receiver properties. By taking into account the predicted path loss delay profiles and the various parameters (link budget, time delay) of the defined satellite and repeater network (see Fig. 3) the coverage situation can be analysed. For this purpose target values concerning  $E_b/N_t$  (for WCDMA) or SIR (for OFDM) are utilised which can be derived by corresponding link level simulations.

#### A. WCDMA Simulation Approach

For the evaluation of the coverage in case of the WCDMA air interface the rake receiver included in the user equipment is modelled in a detailed manner.

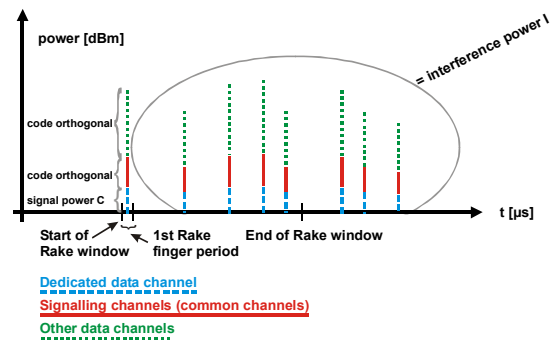


Fig. 5. Signal and interference power in a single rake finger

First the power delay profiles are sorted according to increasing delay (as indicated in Fig. 5), then the temporal structure of the rake receiver (starting and ending time of the rake window plus resolution) is determined. The impinging contributions are analysed concerning different parameters as rake window size, resolution and number of rake fingers. Maximum ratio combining of the best rake fingers determines the  $E_b/N_t$  value at a specific location. Further details concerning the WCDMA simulation approach are given in [3]. The comparison with the corresponding  $E_b/N_t$  target allows to evaluate the S-DMB coverage for a given service and throughput.

#### B. OFDM Simulation Approach

Digital Video Broadcast for Handheld terminals (DVB-H) has been defined by the DVB forum [12]. Based on the DVB-T standard, it implements specific features mainly to meet power consumption constraints and reception in mobile

and handheld user scenarios. This technology uses OFDM air interface and offers high capacity-per-carrier capabilities, ranging for a mobile environment from 5 Mbit/s (QPSK and code rate 1/2) up to 13 Mbit/s (16 QAM, code rate 2/3) on a single 8 MHz channel. The use of an additional transmission protection, which is strongly recommended in adverse propagation environment, limits the useful capacity. However the values are still far beyond the WCDMA capabilities in terms of capacity. According to this higher bandwidth efficiency it is intended to adopt the OFDM air interface also for the S-DMB system.

The OFDM air interface intends to combat the multipath fading channel by using a long symbol duration together with a high number of subcarriers for parallel transmission. The subcarriers are modulated with a corresponding modulation scheme (e.g. QPSK or 16-QAM) and protected by an appropriate code (with code rate e.g. 1/2 or 2/3). The OFDM concept implements a guard interval (which is a fraction of the symbol duration, e.g. 1/4 or 1/8) in order to avoid intersymbol interference due to multipath propagation.

Usually the guard time is chosen larger than the expected delay spread, which is however challenging for the hybrid satellite and repeater architecture of the S-DMB system due to the inherent propagation delays when feeding the terrestrial repeaters. On the other hand, in order to avoid interference between the OFDM subcarriers, the symbol duration shall be small compared to channel coherence time, which is inversely proportional to the Doppler Spread. The Doppler Spread depends on the velocity of the mobile terminal and the orientation of the different multipath signal components in relation to the movement of the mobile terminal. Basically the Doppler shift results in a phase rotation of the signal constellation (e.g. 16-QAM, see Fig. 6).

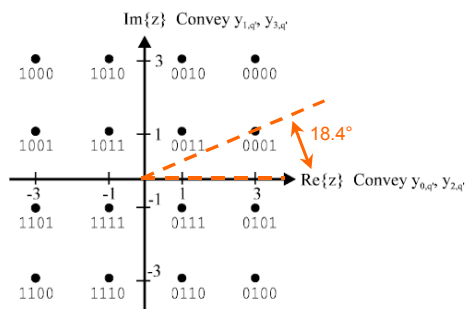


Fig. 6. Signal constellation for 16-QAM

To ensure successful demodulation of the signal this phase shift has to be below a certain max. angle. Thus the Doppler Spread limits the velocity up to which the corresponding service can be received. These two opposing criteria for the symbol duration (long enough to avoid intersymbol interference and sufficiently short in order to not face intercarrier interference) require a trade-off for the determination of appropriate OFDM system parameters [10].

To get an idea what level of interference is introduced when the multipath delay exceeds the guard time, in [11]

three constellation diagrams are analysed that were derived from a simulation of an OFDM link with 48 subcarriers, each modulated by using 16-QAM. The undistorted 16-QAM constellation as presented in Fig. 6 is observed whenever the multipath delay is below the guard time. If the multipath delay exceeds the guard time by a small 3% fraction of the useful symbol duration, the subcarriers are not orthogonal anymore, but the interference is still small enough to get a reasonable received constellation. However if the multipath delay exceeds the guard time by 10 % of the useful symbol duration the interference is so large that the constellation is seriously blurred, causing an unacceptable error rate.

Accordingly, the following scaling factors are introduced in order to distinguish between contributions to the signal power and contributions to the interference power. Depending on the delay of the multipath component (arrival before or after the guard interval), either the signal or the interference power is increased. The corresponding weighting functions are depicted in Fig. 7.

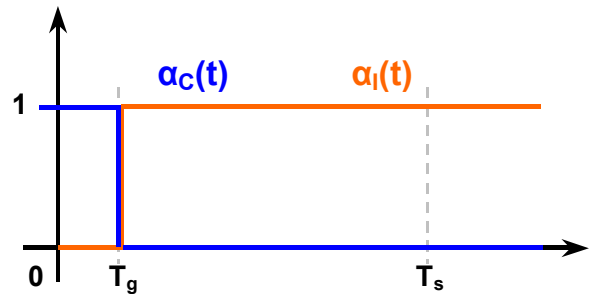


Fig. 7. Weighting functions for separating multipath contributions in signal power  $C$  and interference power  $I$  leading to the  $SIR = C/(I+N)$

For pure terrestrial networks (e.g. for DVB-H in [12]) the interfering contributions are often neglected, i.e. by analysing the  $C/N$  only, as it is assumed that the guard interval is larger than the maximum channel delay spread. In contrast to this the hybrid satellite/repeater architecture will generate large delay spreads where the delayed signal components must be taken into account as interference if arriving after the guard interval. Therefore the above presented weighting functions are introduced.

By taking into account the propagation and processing delays the  $SIR$  depending on the receiver location (and the guard interval) can be computed (see Fig. 7). The evaluation of  $BLER$  versus  $SIR$  curves (based on link level simulations), which depend on the modulation and coding scheme allows the derivation of the min. required  $SIR$ . Such values are used as input for the S-DMB radio planning tool. In general, the OFDM system is characterised by the parameters noise bandwidth, symbol duration, guard interval, number of subcarriers and noise figure as well as power threshold of the OFDM receiver.

For the S-DMB system the OFDM parameters have to be adapted to the 5 MHz channel bandwidth operation (see Fig. 1). OFDM parameters for DVB-H over this bandwidth are proposed in [13] and are given in Table I.

TABLE I: OFDM PARAMETERS FOR 5 MHz OPERATION [13].

Mode	2K	4K	8K
FFT size	2048	4096	8192
Useful symbol duration	358.4 $\mu$ s	716.8 $\mu$ s	1433.6 $\mu$ s
Guard interval [ $\mu$ s]	11.2/22.4/ 44.8/89.6	22.4/44.8/ 89.6/179.2	44.8/89.6/ 179.2/358.4
Subcarrier separation	2790 Hz	1395 Hz	697.5 Hz
Modulated subcarriers	1705	3409	6817
Data subcarriers	1512	3024	6048
OFDM bandwidth	4.75 MHz	4.75 MHz	4.75 MHz

#### IV. SIMULATION RESULTS

The baseline S-DMB architecture which is considered in this paper consists of 3 deployed satellites providing 6 nationwide spot beams over Europe (2 beams per satellite). The simulations focus on a single satellite beam ( $10^\circ$  east) with an default EIRP of 72 dBW (default interbeam interference C/I ratio of 12 dB) and a handheld user terminal with 0 dBi antenna gain (3 dB loss in the case of satellite reception due to polarisation mismatch). The urban environment of Munich has been investigated in this paper visualising the S-DMB coverage for outdoor and indoor scenarios, both in case of satellite only and hybrid (i.e. satellite plus repeater) architecture. The individual parameters of the considered S-DMB network concerning satellite segment, terrestrial repeater (IMR) segment and user equipment segment are listed in Table II. The simulations have been performed both for the WCDMA and OFDM system approach.

TABLE II: BASIC CONFIGURATION OF THE S-DMB NETWORK.

Satellite Segment	
Orbital height	36000 km
Longitude	$10^\circ$ East
Tx power per beam	63 dBm
Tx frequency [MHz]	2197.5
Antenna gain	39 dBi
Interbeam interference C/I	12 dB
Terrestrial Repeater (IMR) Segment	
Number of repeaters	3
Number of sectors per site	3
Tx power per sector	30 dBm
Tx frequency [MHz]	2197.5
Antenna pattern max. gain	18.5 dBi
Antenna pattern HPBW	$60^\circ$
User Equipment Segment	
Handheld antenna gain	0 dBi
Loss for pol. mismatch (satellite)	3 dB
Receiver noise figure	6 dB
Receiver threshold	-117 dBm
Fast fading margin	0 dB

##### A. S-DMB Network Based on WCDMA

For the WCDMA system it is assumed to transmit two traffic channels with a data rate of 384 kbit/s each in parallel on one frequency carrier. This is presented in Table III together with the parameters considered for the rake receiver.

TABLE III: CONFIGURATION OF THE WCDMA SYSTEM.

Satellite Segment and Repeater Segment	
Number traffic codes	2
Data rate per traffic code	384 kbit/s
% of power per code	46.2 %
% of power for signalling	7.6 %
User Equipment Segment	
Rake window size	20 $\mu$ s
Rake resolution capabilities	$\frac{1}{4}$ chip
Number of rake fingers	6
$E_b/N_t$ target satellite reception	10 dB
$E_b/N_t$ target hybrid reception	7 dB

Based on the vector building data the ray-optical wave propagation model has been utilised. The simulations performed in the Munich environment can be distinguished in two cases: the pure satellite case and the case with additional deployment of terrestrial repeaters in order to investigate the coverage improvements introduced by the IMRs. The coverage results computed by the S-DMB RNPT are presented in Fig. 8 for the hybrid satellite plus IMR network. For the hybrid network approach additionally the indoor coverage has been evaluated by elongating the rays into the buildings and assuming an overall building penetration loss of 20 dB (a typical but averaging figure without distinguishing between different rooms). The deployment of a terrestrial repeater network (configuration as indicated in Table II and Fig. 8) leads to sufficient coverage even within the buildings. Table IV presents the corresponding coverage results.

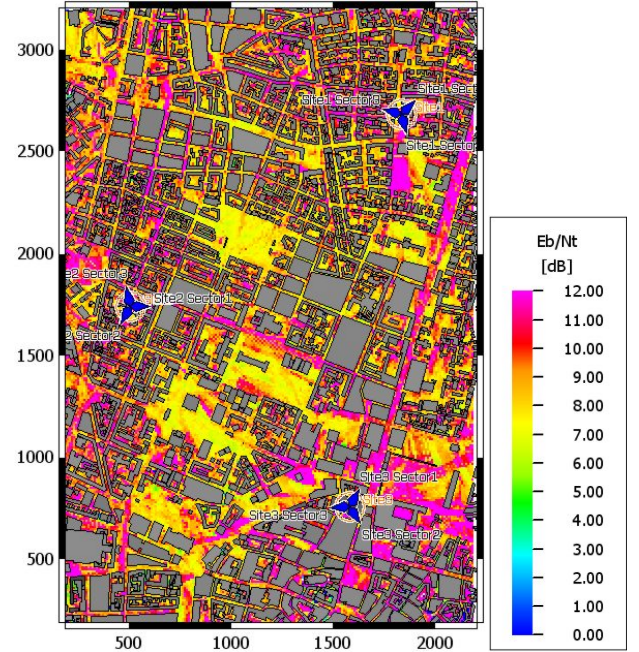


Fig. 8. S-DMB coverage in Munich for hybrid network (WCDMA)

TABLE IV: S-DMB COVERAGE IN MUNICH FOR WCDMA.

Outdoor coverage for pure satellite case	61 %
Outdoor coverage for satellite + IMRs	96 %
Outdoor + indoor coverage for satellite + IMRs	93 %

### B. S-DMB Network Based on OFDM

In order to compare the OFDM and WCDMA air interfaces similar simulations have been carried out for OFDM, i.e. the same network configuration as indicated in Table II and Fig. 8 have been assumed. Concerning the OFDM parameters the 2K mode is selected as given in Table II with guard interval T/4 of 89.6  $\mu$ s, sufficient for the given network and scenario. The coverage is investigated for four different modulation and coding schemes (see Table V), by taking into account the corresponding SIR targets.

TABLE V: SIR TARGETS FOR TYPICAL OFDM REFERENCE RECEIVER IN URBAN ENVIRONMENT[12].

Modulation	Coderate	Bitrate	SIR target
QPSK	1/2	4.98 Mbit/s	9.5 dB
QPSK	2/3	6.64 Mbit/s	12.5 dB
16-QAM	1/2	9.95 Mbit/s	15.5 dB
16-QAM	2/3	13.27 Mbit/s	18.5 dB

Fig. 9 shows the SIR map for outdoor and indoor pixels in case of hybrid, i.e. satellite and repeater architecture. The simulation results for the different modulation and coding schemes are presented in Table VI. The 95 % coverage target is reached even within indoor environments for the QPSK mode with 1/2 rate coding (due to the terrestrial repeaters). A similar coverage as in the WCDMA case, but due to the OFDM approach with significantly higher throughput.

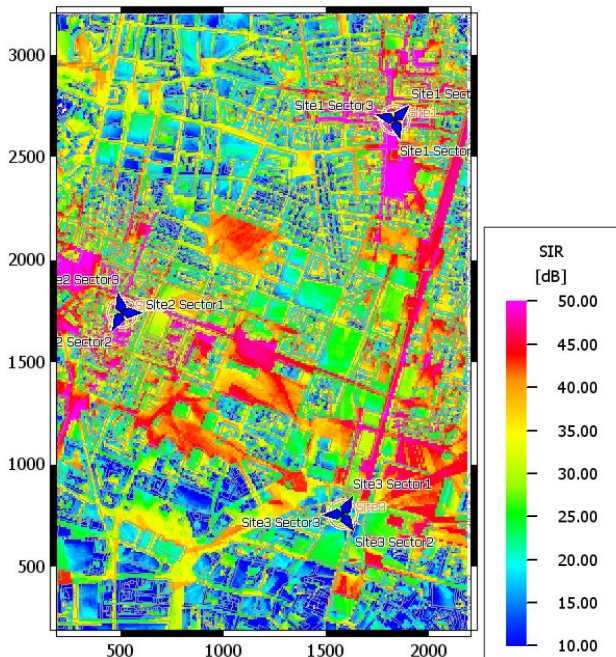


Fig. 9. S-DMB coverage in Munich for hybrid network (OFDM)

TABLE VI: S-DMB COVERAGE IN MUNICH FOR HYBRID OFDM NETWORK.

Modulation	Coderate	Outdoor	Outdoor +Indoor
QPSK	1/2	98.7 %	95.4 %
QPSK	2/3	98.0 %	92.1 %
16-QAM	1/2	96.8 %	86.6 %
16-QAM	2/3	95.0 %	79.1 %

However, in case of a pure satellite system a significant performance degradation is observed. While in the WCDMA case a coverage of about 60 % (outdoor) is achieved, the same satellite and user equipment link budget is no longer sufficient for OFDM, i.e. the SIR target is not reached even in LOS scenarios. Therefore the link budget has to be improved, e.g. by higher antenna gain of the user terminal.

### V. CONCLUSION

This paper presents an overview of the Satellite Digital Multimedia Broadcast (S-DMB) system concept with hybrid satellite & terrestrial network architecture and a radio network planning tool for the assessment of coverage and deployment aspects. The simulation approach based on accurate 3D ray-optical wave propagation modelling and the consideration of the WCDMA or OFDM air interface is described in detail. Simulations in the urban scenario of Munich have been carried out, indicating the coverage performance for the WCDMA and the OFDM system approach based on the presented system assumptions.

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