Radio Network Planning Tool for Satellite Digital Multimedia Broadcast

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ABSTRACT

In order to assess the SDMB radio coverage in different environments an off-the-shelf planning tool for terrestrial radio networks has been adapted to consider satellite transmitters and further extended according to the current specification of the SDMB system. This SDMB radio planning tool allows the investigation of the SDMB performance in terms of coverage, E_b/N_t and system margin for pure satellite as well as hybrid satellite and terrestrial repeater configurations within various environments (rural, urban and indoor). Such investigations will be used to trade the open radio parameters of the SDMB 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.

I INTRODUCTION

Overview

Satellite Digital Multimedia Broadcast (SDMB) aims to provide multimedia services to the mobile user on a cost-effective way by the interworking of satellite systems with terrestrial networks. The SDMB system is based on the concept of a hybrid satellite/terrestrial architecture and relies on the W-CDMA radio interface defined for UMTS terrestrial networks to achieve a coherent combination of satellite and terrestrial signals. 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 areas and to enhance indoor penetration, i.e. in those areas where the satellite signal is subject to shadowing [1].

Concept of the SDMB Radio Network Planning Tool (RNPT)

The planning tool allows the user to define an individual SDMB 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 SDMB network is evaluated.

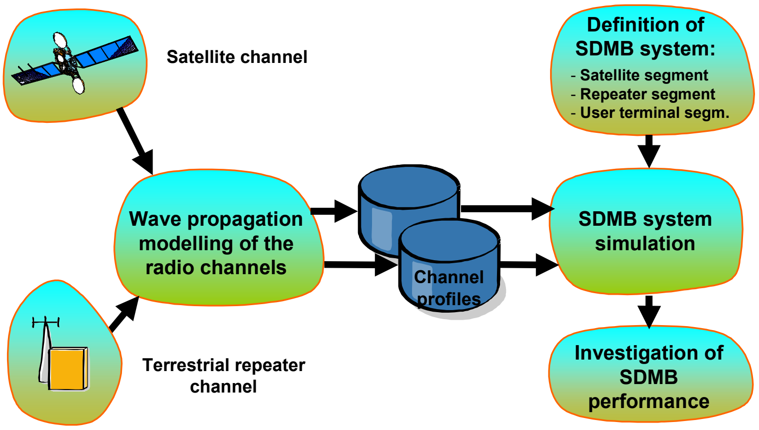

Fig. 1. Basic structure of the SDMB radio network planning tool

The calculated channel profiles form the basis of the SDMB system simulation, which includes a detailed modelling of the user equipment and leads to predictions of the SDMB coverage and other performance measures as mentioned above. According to this description there are two basic parts of the SDMB RNPT (as depicted in Fig. 1) which will be more detailed in the following chapters.

Wave Propagation Modelling of the Satellite and Terrestrial Channel

Wave propagation models form the basis of radio network planning in order to determine the coverage situation. Radio transmission in urban environments is subject to strong multipath propagation (see Fig. 2). Dominant characteristics are the reflection at walls, diffraction around corners, shadowing due to buildings and the wave guiding in street canyons (for terrestrial transmitters). Penetration is important if additionally the indoor scenarios should be taken into account. To consider these effects and as the SDMB system utilises a rake receiver at the user terminal the usage of a deterministic ray-optical model which is capable of predicting the channel profiles is preferable. The ray-optical model implemented in the RNPT allows a site-specific prediction of the radio channels for satellites and terrestrial IMRs [2].

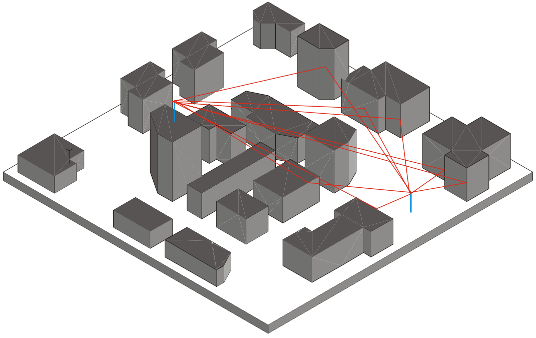

Fig. 2. Wave propagation scenario in a typical urban environment

SDMB System Simulation

The SDMB system simulator superposes the radio channels of the corresponding satellite and repeater links 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. For the evaluation of the coverage the rake receiver included in the user equipment is modelled in a detailed manner. The impinging contributions are analysed according to different parameters as rake window size, resolution and number of rake fingers. Maximum ratio combining of the best rake fingers determines the SDMB radio coverage for a specific location and a given service. Based on this flexible realisation of the SDMB RNPT it is possible to investigate various SDMB architectures and to trade the open parameters of the satellite segment, terrestrial repeater segment and the user terminal segment.

II WAVE PROPAGATION MODELS FOR THE SDMB RNPT

Wave propagation models are mandatory for radio network planning in order to predict the coverage situation as well as to determine multipath effects. In a first step the propagation environment has to be digitized leading to a database which describes the considered scenario in an adequate way. The phenomena which influence the propagation of radio waves include different mechanisms as reflection, diffraction and penetration. By using mathematical approximations for these physical propagation phenomena both empirical and deterministic approaches have been developed.

As the SDMB planning tool shall be utilised in different environments first of all these different propagation scenarios and the corresponding wave propagation models have to be clarified.

Propagation Environments and Underlying Databases

The environments of interest for the SDMB radio network planning tool are ranging from indoor scenarios (i.e. specific buildings) over urban environments up to wide or rural areas (a considerable part of a satellite beam region, i.e. thousands of km^2). Hence wave propagation prediction methods are required covering the whole range of different scenarios. The basis for any wave propagation model is a database which describes the propagation environment. While for the prediction of wide (rural) areas the database includes terrain height information and land usage data, for the urban environments building shapes and building heights are taken into account. The required databases for the different scenarios will be detailed in the following chapters.

Topographical and Clutter Databases for Wide (Rural) Environments

Wide areas are commonly described in terms of land usage and topography. To evaluate the forward propagation including (multiple) diffraction over terrain obstacles the knowledge of the terrain profile is required. Fig. 3 (on the left) describes the digital elevation data in the vicinity of Stuttgart.

Additionally, morphological data is considered in the wave propagation model by empirical correction values in order to improve the accuracy of the model. Different morphological properties are distinguished, e.g. urban, suburban, forest, water and open. In Fig. 3 (on the right) an example for such a clutter database is given for the surrounding area of Stuttgart. Topographical databases as well as clutter databases consist of pixel data with a specific resolution (depending on the extension of the described area in the range between 50 m and 500 m). According to the large extension of these databases for the prediction grid usually similar values concerning the resolution are taken.

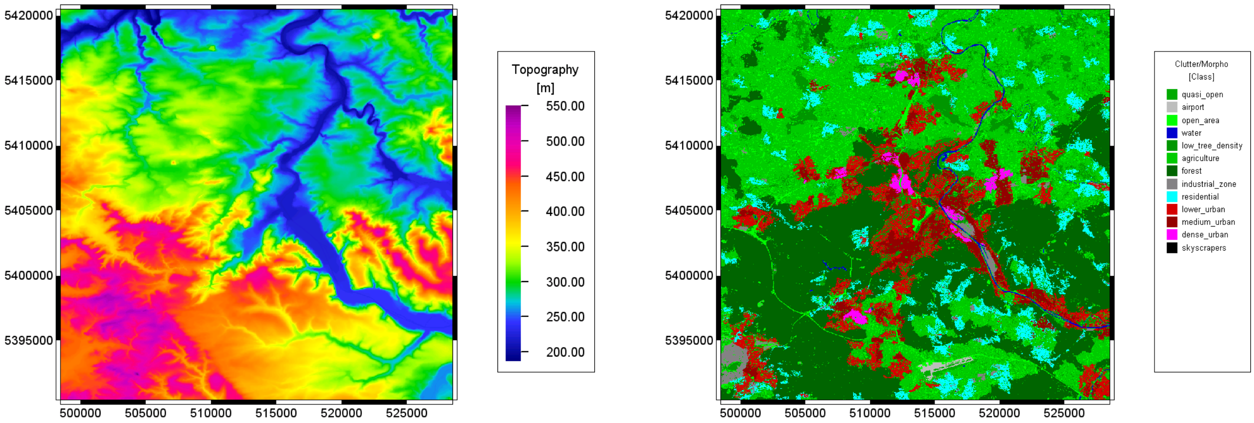

Fig. 3. Topographical (left) and clutter (right) database describing the area of Stuttgart

Building Databases for Urban and Suburban Environments

For urban and suburban areas usually building oriented databases are utilised. In order to get a more accurate description of the environment, the building data are stored in vector format. Every building is modelled as a vertical cylinder with polygonal ground plane and an uniform height above street level. With this approach vertical walls and horizontal flat roofs are considered. Additionally, the material properties (parameters influencing the reflection, diffraction and penetration loss) of the outer building walls can be taken into account. If the urban area is not sufficiently flat additionally the terrain profile as presented in Fig. 3 must be taken into account. Fig. 4 (on the left) shows an example of such an urban building database in vector format (Munich). Typical resolutions for the prediction grid in urban environments are in the range of 10 m.

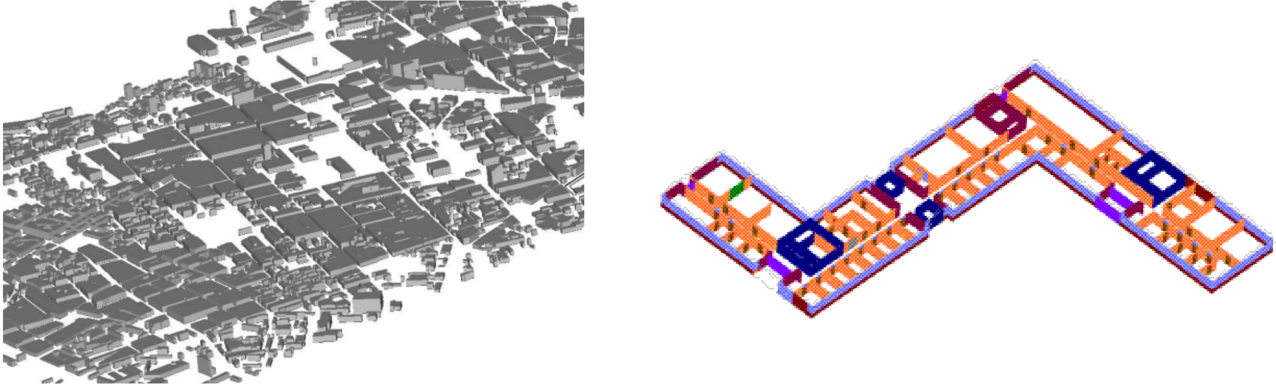

Fig. 4. Building database describing an urban (left) and an indoor scenario (right)

Building Databases for Indoor Scenarios

The penetration of the electromagnetic waves into the buildings is basically influenced by the layout of the building, i.e. by the interior building structure. According to this, it is mandatory to define a more detailed format for indoor building databases. This type of databases is based on a 3D-vector format including all walls, doors, and windows. All elements inside the building as well as the outer walls are described in terms of plane elements. Every wall is e.g. represented by a plane and its extent and location is defined by its corners. Additionally, for each element individual material properties can be taken into account (which are relevant for the computation of the penetration loss). Fig. 4 (on the right) shows an example for such a 3D building database. In order to resolve the different rooms within indoor environments resolutions in the range of 1 m are required for the prediction.

Wave Propagation Models

In general, two types of wave propagation models can be distinguished: deterministic and empirical (statistical) models. When using deterministic models (i.e. ray-optical models) 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 transmitter-receiver configuration. The different types of wave propagation models will be detailed in the following chapters.

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. 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 SDMB tool includes a sophisticated ray tracing algorithm 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 terrestrial repeaters and satellites. The algorithm is briefly described in the following, more details are given in [2].

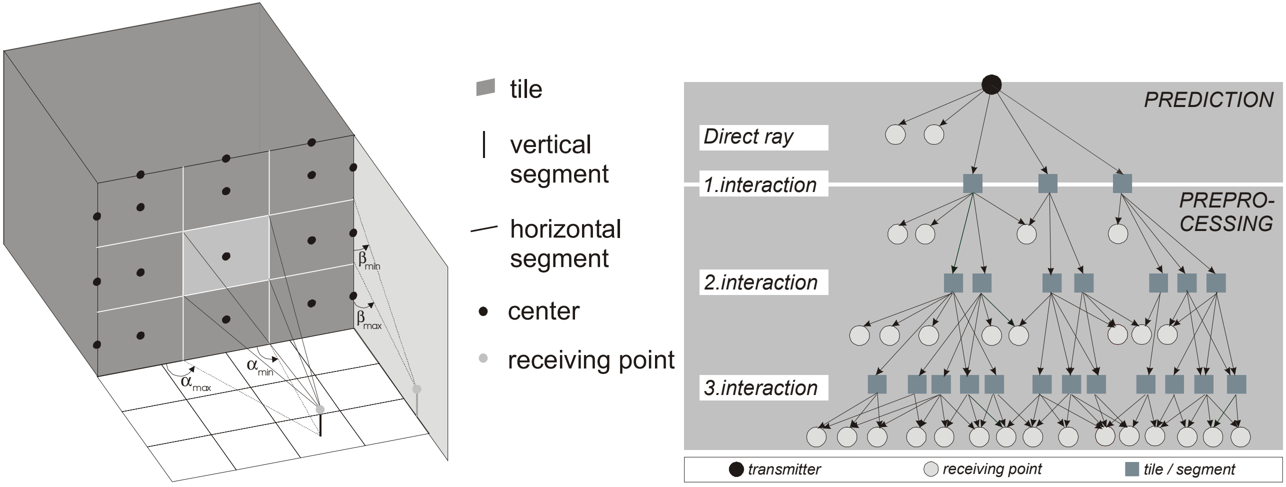

Fig. 5. Tiles and segments of a wall (left), tree structure of visibility relations (right)

The largest part of the computation time is required for the determination of valid rays between transmitter and receiver. As the building database is fixed and only the position of the transmitter changes, the overwhelming part of the different rays remains unchanged, only the rays between the transmitting antenna and primary obstacles or receiving points in line-of-sight change. This is the basis for a “database preprocessing”. In a first step the walls of the buildings are divided into tiles (reflections and penetrations) and the edges (diffractions) into horizontal and vertical segments (as indicated in Fig. 5 on the left). After this, the visibility conditions between these different elements (possible rays) are determined and stored in a file. Fig. 5 (left) shows the visibility relation between a central tile and a receiving point.

The result of this preprocessing can be represented in the shape of a “visibility tree” as given in Fig. 5 on the right. Each branch of this tree represents a visibility relation between two different elements. For a different transmitter location only the uppermost branches in this tree must be computed again, i.e. determining which elements are in line-of-sight to the transmitter. With such a tree structure path finding can be done easily by processing all visible elements and checking if the specific conditions for reflection (penetration) and diffraction are fulfilled. The remaining computation time after the preprocessing is many orders of magnitude lower than that needed for the conventional analysis without preprocessing [3].

For the computation of each ray's contribution, not only the path length has to be considered but also the loss due to the interaction of the electromagnetic waves with the existing obstacles, i.e. due to reflection, diffraction and penetration. The total path loss of a ray is given by the sum of the free space path loss and the losses due to interaction. For the prediction rays with a maximum number of three interactions are taken into account including up to two diffractions.

Based on the evaluation of the computed rays different results can be computed for satellites as well as terrestrial repeaters. Fig. 6 (left) shows the availability of the LOS link for a GEO satellite (10° east) in the city of Stuttgart (blue colour indicates LOS, white colour NLOS, the buildings are in grey). By adding the powers of the different rays assuming that the different contributions are not correlated (without taking into account the rake receiver) the path loss for a specific transmitter can be calculated. Fig. 6 (right) describes such a path loss prediction for a terrestrial repeater operating at 2197.5 MHz installed on top of one of the tallest buildings at 40 m in the city centre of Stuttgart. However, as input for the SDMB system simulation the channel profile for each point in the area under investigation is required.

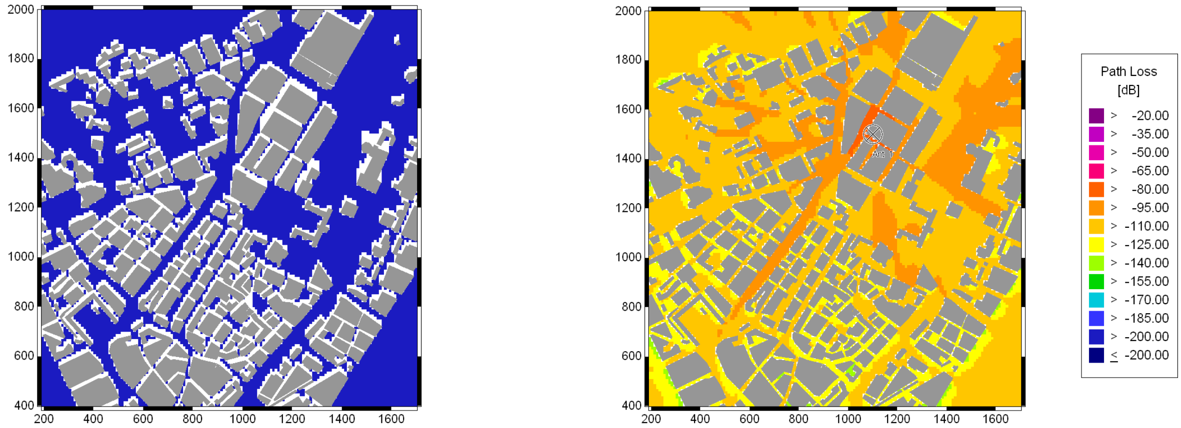

Fig. 6. LOS plot for GEO satellite at 10° east (left), path loss prediction for repeater (right)

Empirical Model

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 [4]. Empirical impulse response models are usually defined as tapped delay line models including a limited number of paths with individual amplitude and delay (both refering to the dominant path). Such an empirical channel model has been implemented in the SDMB planning tool according to [5] for the satellite channel (basically to investigate the coverage in rural areas). 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 echoes and far echoes. The superposition of all echoes leads to the satellite wideband channel. More details with respect to the empirical channel model for the satellite domain are given in [5].

III SDMB SYSTEM SIMULATOR

Overview

The SDMB system simulator superposes the radio channels of the corresponding satellite and repeater links 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. For the evaluation of the coverage the rake receiver included in the user equipment is modelled in a detailed manner. The impinging contributions are analysed according to different parameters as rake window size, resolution and number of rake fingers. Maximum ratio combining of the best rake fingers determines the SDMB radio coverage for a specific location and a given service and throughput [1]. The simulation is controlled by the defined settings for the satellite segment, the terrestrial repeater (IMR) segment and the user terminal segment.

Simulation Approach

Based on the thermal noise density, the defined user terminal noise figure and the bandwidth of the SDMB system the receiver noise power is calculated. Additionally the contributions due to interbeam- and intersystem-interference are considered. In the next step the path loss delay profiles from the satellite(s) and the terrestrial repeaters (IMR, if deployed) are superposed and sorted according to increasing delay (see Fig. 7). At this point also the adaptation of power and delay of the individual contributions is performed. Concerning the power there is a distinction between the signalling channel power and the different channel code powers. All contributions are adapted according to the settings of transmitting power (per code), transmitter antenna gain, handheld antenna gain, handheld correction factor or car kit antenna gain (depending on the type of the user terminal). Concerning the adaptation of the delays the processing delays of satellite and repeaters as well as the propagation delays from the satellite to the indvidual repeaters are taken into account (by geometrical evaluation).

Rake Receiver

After the power delay profiles are sorted according to increasing delay (as indicated in Fig. 7), the temporal structure (starting and ending time of the rake window plus resolution) of the rake receiver is determined. The beginning of the rake window is given by the first contribution above the defined threshold. The duration of the rake window defines the ending time. The calculated power delay profiles are converted to this temporal structure of the rake receiver (according to the specified temporal resolution). Each contribution is assigned either to a specific rake finger if the delay falls into the rake window or to the additional interference power if the contribution arrives out of the rake window. If there is more than one contribution within one rake finger the superposition is either performed coherently or by adding the powers. The C/I within a specific rake finger is computed for each channel code as it might be different due to non-uniform power distribution over the different data channels. Here the only contribution to the signal power is the power of the dedicated data channel as indicated in Fig. 7.

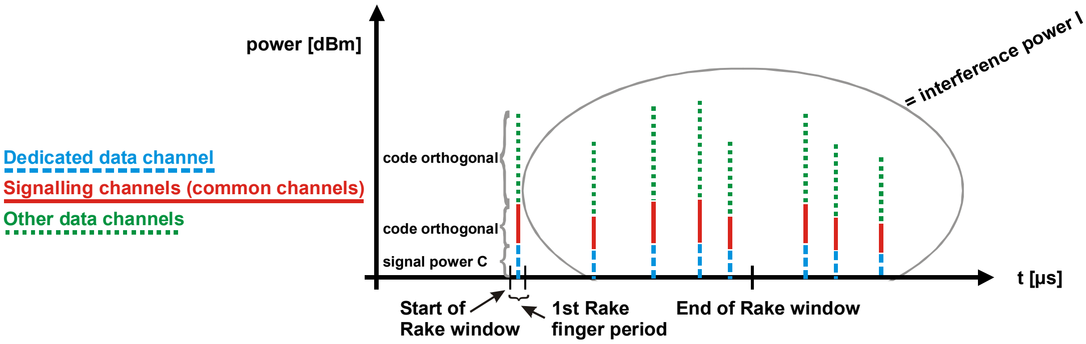

Fig. 7. Example for contributions to signal and interference power in a single rake finger

After the calculation of C/I for each rake finger the N best rake fingers are determined (as specified). These best fingers are maximum ratio combined according to (1) as the rake receiver performs a correction of the phase rotation for each finger (i.e. after the correction all rake contributions are phase adjusted). Equation (1) describes the maximum ratio combining for two contributions with signal power P_i and interference power I_i (both in linear scale):

$$(C/I)_{total} = 10 \cdot \log\left((P_1 + P_2)^2 / (P_1 \cdot I_1 + P_2 \cdot I_2)\right) \qquad (1)$$

Based on the resulting C/I value the different outputs are calculated for each defined data channel. Due to the fact that there might be a non-homogenous power distribution among the different data cannels and the channels might provide different data rates the results are in general channel specific:

- The E_b/N_t is computed by adding the processing gain of the data channel to the calculated $(C/I)_{total}$. According to the addition of the processing gain the defined data rates have to be interpreted as user netto bit rates [6].
- Concerning the received signal power CRx in logarithmic scale the coherent super-position of the channel code power of the N best rake fingers is performed (i.e. for two contributions):
$$CRx_{total} = 20 \cdot \log\left(P_1^{1/2} + P_2^{1/2}\right) \qquad (2)$$
- The interference power is given by the total received wideband power including signal power CRx and thermal noise power P_N. This means in logarithmic scale:
$$I_{total} = 10 \cdot \log\left(P_1 + P_2 + \ldots + P_n + P_{Intersystem} + P_{Interbeam} + P_N\right) \qquad (3)$$
- Noise rise is defined as the ratio of the total received wideband noise plus interference power to the noise power. Therefore the noise rise factor results as difference between the total received noise plus interference power and the receiver noise power in logarithmic scale:
$$NoiseRise = I_{total} - 10 \cdot \log P_N \qquad (4)$$

For the calculation of the SDMB coverage additionally the fast fading margin is considered. If the instantaneous E_b/N_t value is larger than the corresponding E_b/N_t target plus fast fading margin the investigated receiver location has sufficient coverage. Finally the outputs of the simulator can be visualised in the SDMB planning tool.

IV RESULTS

SDMB Network

The baseline SDMB 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° east) with an EIRP of 72 dBW (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). It is assumed to transmit two traffic channels with a data rate of 384 kbps each in parallel on one frequency carrier operating at 2197.5 MHz. Two different environments have been investigated: rural and urban. The individual parameters of the considered SDMB network concerning satellite segment, terrestrial repeater (IMR) segment and user equipment segment are listed in Table 1.

Table 1. Basic configuration of the investigated SDMB networks

Satellite Segment		Terrestrial Repeater (IMR) Segment		User Equipment Segment	
Orbital height	36000 km	Number of repeaters	3	Handheld antenna gain	0 dBi
Longitude	10° East	Number of sectors per site	3	Loss for pol. mismatch (sat.)	3 dB
Tx power per beam	63 dBm	Tx power per sector	30 – 35 dBm	Receiver noise figure	6 dB
Tx frequency	2197.5 MHz	Tx frequency	2197.5 MHz	Rake window size	20 µs
Antenna gain	39 dBi	Antenna pattern max. gain	18.5 dBi	Rake resolution capabilities	¼ chip
Interbeam interference C/I	12 dB	Antenna pattern HPBW	60°	Number of rake fingers	6 / 12
Number traffic codes	2	Number traffic codes	2	Rake receiver threshold	-117 dBm
Data rate per traffic code	384 kbps	Data rate per traffic code	384 kbps	E_b/N_t target satellite reception	10 dB
% of power per code	46.2 %	% of power per code	46.2 %	E_b/N_t target hybrid reception	7 dB
% of power for signalling	7.6 %	% of power for signalling	7.6 %	Fast fading margin	0 dB

Rural Environments

The simulations in rural environments have been performed for different locations over Europe (latitudes of Seville, Rome, Stuttgart, Stockholm) in order to assess the influence of the satellite elevation angle by using the empirical propagation model according to [5]. As the repeater deployment is intended for urban scenarios only, no IMRs are considered in the rural case. The percentage of pure satellite coverage in rural environments depending on the defined values for EIRP per beam and E_b/N_t target is given in Fig. 8 for different latitudes. An EIRP of 76 dBW can be achieved at the center of the satellite beam while 72 dBW will be available at the edge of the satellite spot beam. According to the results presented in Fig. 8 the influences of the satellite elevation angle, the available satellite power (EIRP) per beam and the required E_b/N_t target are clearly visible.

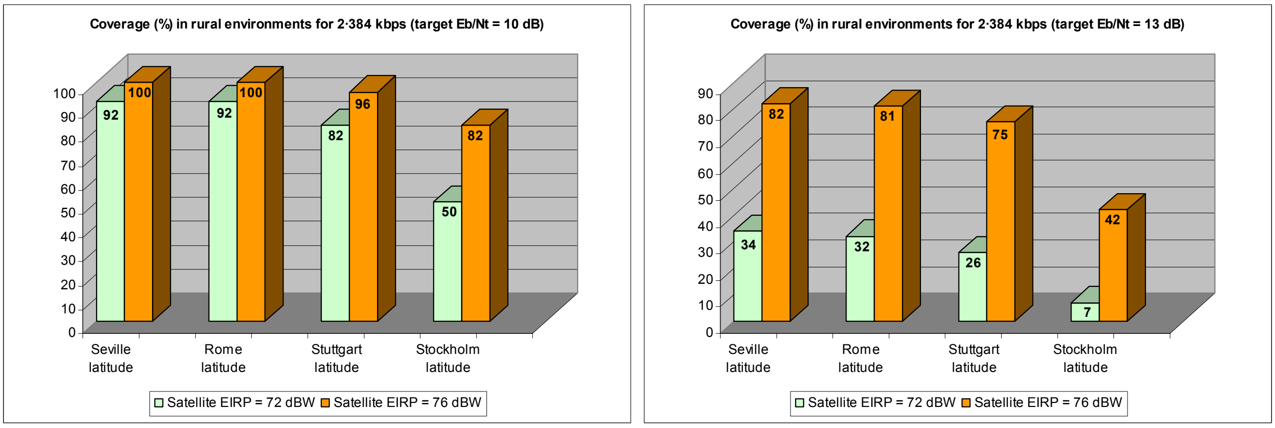

Fig. 8. Coverage in rural environments for different values of EIRP and E_b/N_t target

Urban Scenario

The coverage in urban environments has been analysed in the scenario of Munich. 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. For the hybrid satellite and repeater network two options concerning the rake receiver have been investigated by increasing the number of rake fingers from 6 to 12.

The coverage results computed by the SDMB RNPT for the urban scenario of Munich are presented in Fig. 9 for the pure satellite case on the left and for the hybrid satellite plus IMR network on the right (green indicates coverage). Table 2 gives the individual coverage percentages depending on network type and number of utilised rake fingers.

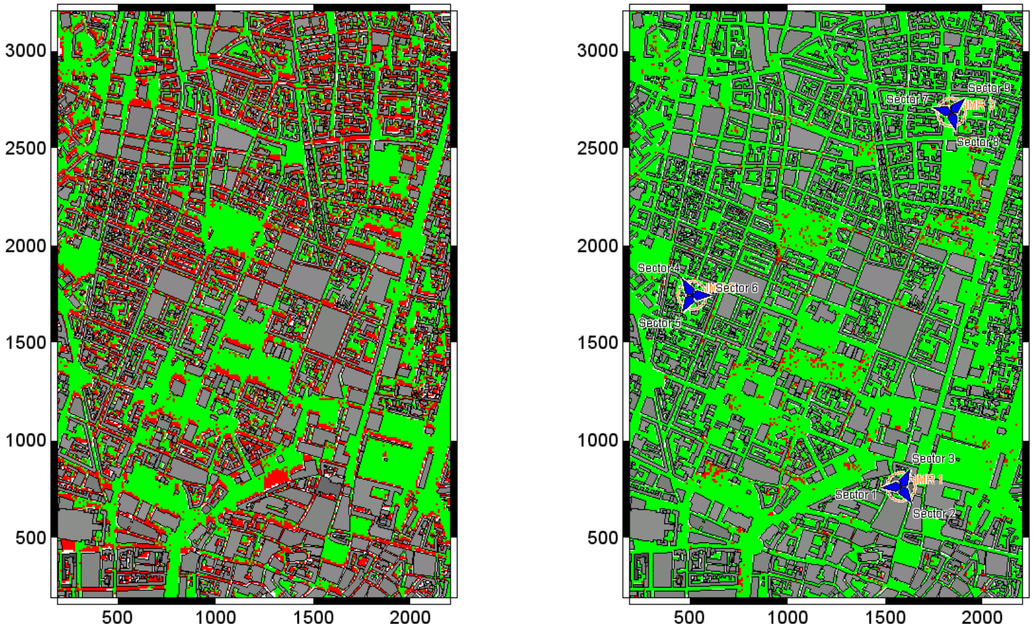

Fig. 9. Coverage in Munich for pure satellite (left) and hybrid network (right)

For the hybrid network approach (i.e. satellite plus terrestrial repeaters) additionally the indoor coverage has been evaluated by elongating the rays into the buildings and assuming an overall building penetration loss of 20 dB (without consideration of the indoor walls). The deployment of a terrestrial repeater network (configuration as indicated in Table 1 and Fig. 9) leads to sufficient coverage even within the buildings. A certain improvement in terms of coverage can be achieved by increasing the number of rake fingers from 6 to 12 (see Table 2) if IMRs are deployed.

Table 2. SDMB coverage in urban environment (Munich)

Outdoor coverage for pure satellite case (6 rake fingers)	61 %
Outdoor coverage for satellite + IMRs (6 rake fingers)	96 %
Outdoor coverage for satellite + IMRs (12 rake fingers)	99 %
Outdoor + indoor coverage for satellite + IMRs (6 rake fingers)	93 %
Outdoor + indoor coverage for satellite + IMRs (12 rake fingers)	97 %

ACKNOWLEDGEMENTS

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