SDMB Deployment and Coverage Investigation with Radio Network Planning Tool

Reiner Hoppe, Michel-Guy Françon, and Gerd Wölfle

***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.**

***Index Terms*—Satellite systems, SDMB coverage planning, wave propagation modelling, rake receiver.**

I. INTRODUCTION

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].

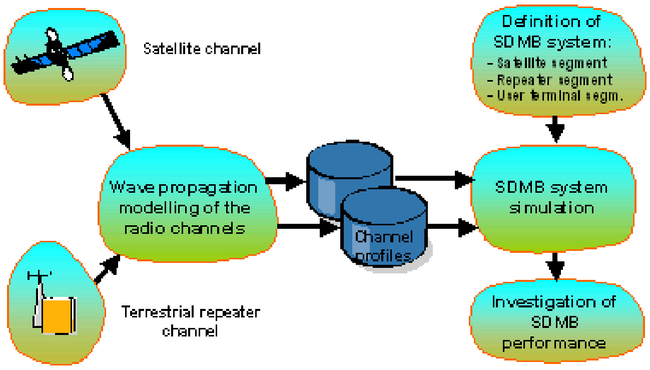

Fig. 1. Basic structure of the SDMB radio network planning tool.

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.

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 e.g. the E_b/N_t margin. 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.

II. WAVE PROPAGATION MODELLING

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.

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. 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

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receiver the SDMB tool includes a sophisticated ray tracing algorithm [2] 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 [3].

B. *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 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 [5].

III. SDMB SYSTEM SIMULATOR

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 at a specific location for 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.

A. *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. 2). 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).

B. *Rake Receiver*

After the power delay profiles are sorted according to increasing delay (as indicated in Fig. 2), the temporal structure (starting and ending time of the rake window plus resolution) of the rake receiver is determined.

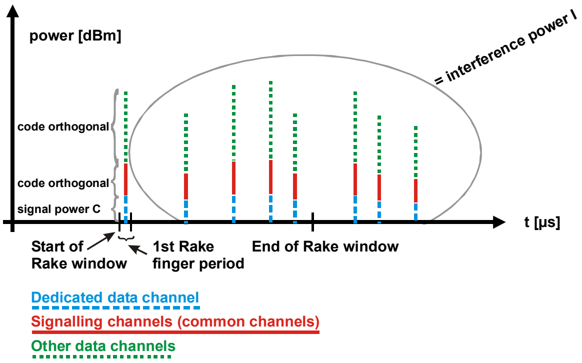

Fig. 2. Signal and interference power in a single rake finger.

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. 2.

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):
$$CRx_{total} = 20\cdot\log\left(P_1^{1/2} + P_2^{1/2}\right) \quad (2)$$
- 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:
$$I_{tot.} = 10\cdot\log\left(P_1+..+P_n + P_{Intersystem} + P_{Interbeam} + P_N\right)(3)$$
- 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:
$$NoiseRise = I_{total} - 10\cdot\log P_N \quad (4)$$

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. SIMULATION RESULTS

A. *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 I.

TABLE I
BASIC CONFIGURATION OF THE INVESTIGATED SDMB NETWORK

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

B. *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. 3 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. 3 the influences of the satellite elevation angle and the available satellite power (EIRP) per beam are clearly visible.

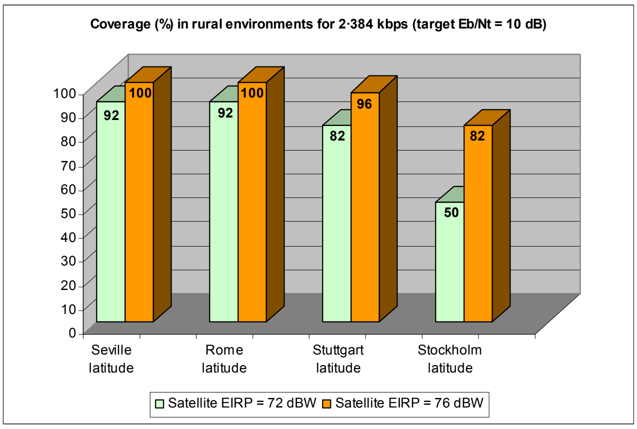

Fig. 3. Coverage in rural environments for different values of EIRP.

C. 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. 4 for the pure satellite case and in Fig. 5 for the hybrid satellite plus IMR network (green indicates coverage). Table II gives the individual coverage percentages depending on network type and number of utilised rake fingers.

Fig. 4. Coverage in Munich for pure satellite network.

TABLE II
SDMB Coverage in urban Environment

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 %

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 I and Fig. 5) 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 II). If three traffic codes at 384 kbps are transmitted within the hybrid network the coverage is reduced to 58 % and 59 % (for 6 and 12 rake fingers), respectively. However, if the E_b/N_t target is reduced from 7 to 6 dB the achieved coverage is increased to 88 %. Especially for high throughputs the coverage is very sensitive on the E_b/N_t target.

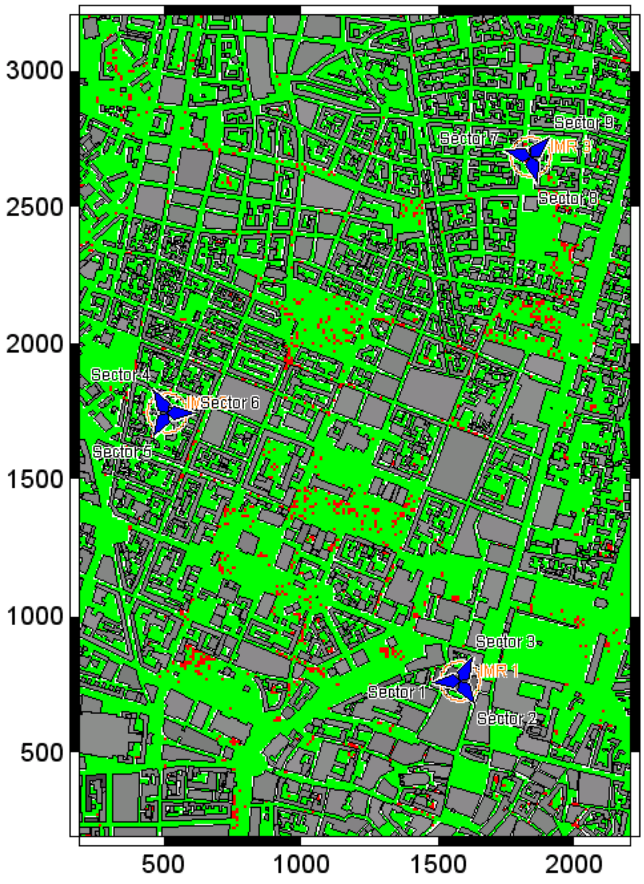

Fig. 5. Coverage in Munich for hybrid (satellite plus IMR) network.

In case of terrestrial repeater deployment the coverage is rather independent of the satellite power (if the IMR power is above a certain level, e.g. 30 dBm). Generally the coverage can be improved, especially concerning indoor penetration, if the transmitting powers of the IMRs are increased. However, in case of high IMR density the SDMB network is limited by the interference. Therefore the deployment of the repeaters (IMRs) and the configuration of the Tx power has to be handled with care. For the given throughput (2 x 384 kbps) it was observed that the outdoor coverage could be improved by reducing the interference level, i.e. the number of IMRs (only in case of high repeater density).

Further investigations have analysed the influence of the Rake receiver parameters on the SDMB performance. As presented in Table 2 there is a coverage improvement when increasing the number of Rake fingers (from 6 to 12). The performance gain when increasing the Rake window from 20 to 40 µs is limited within urban environments as in this case the IMR signals will be dominant compared to the satellite signal. A higher coverage improvement can be expected at the border of the IMR area (e.g. when moving from the urban to the suburban area) where the satellite signal and the IMR signal are on the same level.

D. Interference from T-UMTS Network

In order to assess the influence of the terrestrial UMTS network on the SDMB coverage in urban environment an additional scenario in Monaco has been investigated. The Monaco scenario has been selected as the locations and configurations (sectorisation, Tx power, antenna pattern) of the T-UMTS nodeBs have been kindly provided by Monaco Telecom (see Fig. 6).

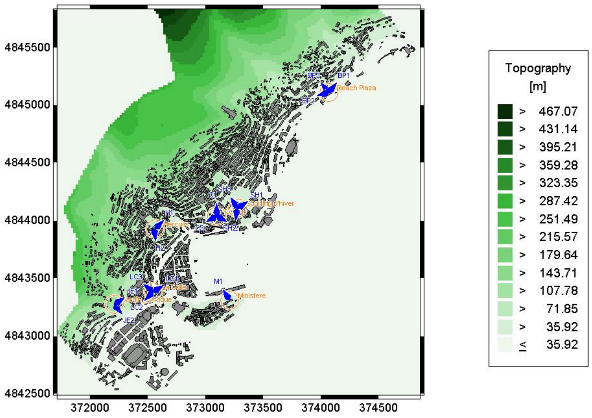

Fig. 6. T-UMTS network in Monaco.

Concerning the interference a worst case scenario has been assumed, i.e. each sector is transmitting 40 dBm at center frequency of 2167.5 MHz. For SDMB one of the three channels between 2170 and 2185 MHz can be envisaged. Three different cases have been investigated. The first and reference scenario neglects the interference introduced by the T-UMTS network. The second case simulates a distance in the frequency domain between T-UMTS and SDMB systems of 10 MHz while the third case assumes that the SDMB system operates on the neighboring frequency channel (i.e. 5 MHz distance of center frequencies). Depending on the frequency separation an adjacent channel interference ratio (ACIR) of 43 dB and 33 dB was taken into account, respectively.

TABLE III
SDMB COVERAGE IN CASE OF T-UMTS NETWORK

	Satellite only	Satellite + 1IMR	Satellite + 2 IMRs	Satellite + 3 IMRs
No T-UMTS network	71 %	91 %	92 %	96 %
T-UMTS network in 2^{nd} band, i.e. 10 MHz distance	15 %	63 %	89 %	96 %
T-UMTS network in next band, i.e. 5 MHz distance	5 %	38 %	78 %	95 %

According to the results presented in Table III the influence of the T-UMTS interference on the SDMB coverage depends on the density of the terrestrial repeater network (and the configuration of the IMRs). For the transmitting power per sector values between 30 and 35 dBm have been selected. If 3 IMRs are deployed in the Monaco scenario (with different sectorisation as presented in Fig. 7) the coverage is rather independent of the T-UMTS interference. However for low IMR densities (only 1 or 2 IMRs are deployed over Monaco city center) the coverage is reduced significantly due to the interference of the T-UMTS network. The largest influence is given for the case without repeater deployment where a strong degradation of the SDMB coverage is observed.

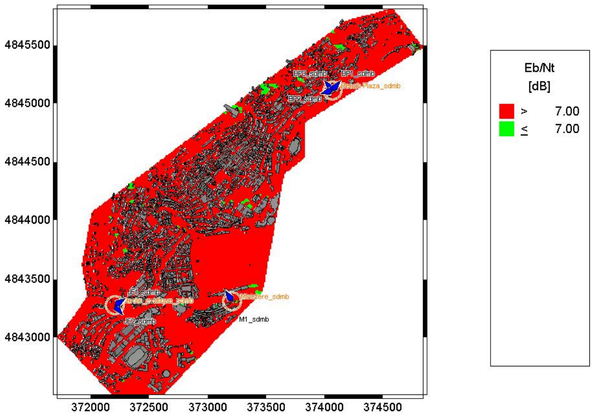

Fig. 7. Coverage in Monaco for hybrid (satellite plus IMR) network.

ACKNOWLEDGMENT

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