SIMULATION AND MEASUREMENT OF THE SATELLITE TO INDOOR PROPAGATION CHANNEL AT L- AND S-BAND

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ABSTRACT

The satellite to indoor propagation channel in L- and S-band is becoming of significant importance because future satellite broadcast and navigation systems (as e.g. S-DMB and Galileo) are aiming at optimum performance in all kind of environments, i.e. even in indoor scenarios.

In the framework of the EU FP6 project MAESTRO, Fraunhofer IIS has carried out measurements of the satellite to indoor coverage for the geostationary Worldspace-Afristar satellite for different types of buildings in Athens and Erlangen. The satellite to indoor propagation channel depends on several parameters as building layout and materials. Wave propagation models are mandatory for analysing the various influences in detail. For the accurate simulation a ray-optical model which considers 3D building vector data has been implemented by AWE Communications.

1. INTRODUCTION

Indoor reception of satellite signals is becoming of more and more interest, since nowadays larger available electrical powers on satellite platforms are feasible, resulting in higher system link budget margins. Furthermore, the indoor scenarios are of special relevance for the attractiveness of new Mobile Satellite Services (MSS) services in order to provide ubiquitous coverage over all environments.

An example is the Satellite Digital Multimedia Broadcast (S-DMB) system which has been studied in the framework of the MAESTRO project [1]. The S-DMB system aims to provide multimedia services (e.g. MobileTV) with high availability in a cost effective way. Key to this concept is a hybrid network architecture comprising a geo-stationary satellite and complementary terrestrial repeaters.. While the indoor coverage in urban/suburban areas will be ensured by the deployment of repeaters the indoor coverage in rural areas will be limited to the reception of the satellite signal.

The Land Mobile Satellite (LMS) channel has motivated numerous experimental campaigns in L and S-bands [2]. The results of these campaigns have enabled to get a better knowledge of the physical signal impairments encountered in such channels [3]. However, there is a lack of similar information and knowledge for the satellite to indoor channel. Some measurements are presented in [4] about satellite propagation into buildings in the U.S., carried out with a satellite emulator on a mobile tower. Another measurement campaign (in the context of Galileo) is reported in [5], where measurements are performed on different floors but limited to a single building.

Also, a lot of research work has been carried out on modelling the radio channel into buildings for terrestrial networks. In [6-9] such investigations were performed for different types of buildings by utilising both measurement campaigns and experimental data. Due to geometrical reasons, i.e. basically the difference in elevation angle, the results available for terrestrial networks can not be applied directly to satellite scenarios, but parts of the work can be reused, e.g. the classification of buildings and materials.

This paper is organised as follows: After this introduction, the principles of the satellite to indoor channel will be described. In the following chapter the results from the measurement campaigns carried out by Fraunhofer IIS are presented [10]. Finally, the ray tracing tool [11-12] from AWE Communications, which allows the simulation of the satellite to indoor channel, is shown together with example results and comparisons to the measurement data.

2. THE SATELLITE TO INDOOR CHNANNEL

The satellite to indoor propagation channel depends strongly on the layout and the material properties, i.e. the construction materials used for walls, windows, and ceilings of the building where the receiver is located. Therefore it is important to first categorise the buildings into relevant types and to define typical material properties for each of the defined categories. A possible classification could be the distinction according to [6]:

- residential houses with 1-2 storeys,
- multi-storey residential buildings (e.g. apartment blocks),
- office buildings,
- commercial buildings as factories, stations, airports.

Besides the building materials also the location inside the building has strong influence (e.g. floor level). According to geometrical evaluations, different coverage zones can be distinguished (as presented in Fig. 1) for most building types and constellations. In rooms oriented towards the satellite (south front rooms on Northern hemisphere for geo-stationary satellites) zone A describes the region reached with single wall/window penetration. The remaining part (zone B) of such rooms is reached by additionally reflected contributions or paths with additional ceiling penetration. Rooms not directly oriented towards the satellite can be attributed to zone C. In this case additional walls must be penetrated, resulting in high signal attenuation.

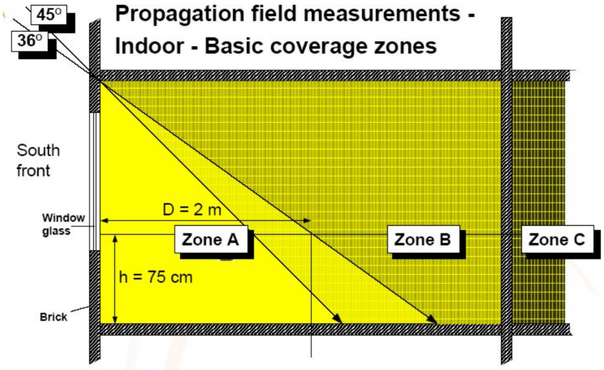

Figure 1. Zones of indoor coverage

Other important parameters influencing the satellite to indoor propagation are given by the satellite elevation angle and the orientation of the building towards the satellite (azimut angle).

Besides the varying attenuation of the direct satellite signal depending on the penetration loss, multipath contributions are introduced by the building walls (e.g. reflection on the floor) leading to Rice or Rayleigh fading distributions depending on the location of the receiver inside the building. Generally, the short distances between the obstacles inside the building imply only a short delay of echoes and consequently a small delay spread. Measurements reported in [5] confirm that nearly all echoes arrive within 100 ns at the receiving antenna.

3. MEASUREMENTS

The Fraunhofer Institute IIS has carried out in the context of MAESTRO two measurement campaigns of the satellite to indoor channel for different types of buildings in Athens and Erlangen. In this paper the basic concept and results of these campaigns are reported, further details can be found in [10].

3.1. Measurement Concept

The geo-stationary Afristar satellite at 21° East which is owned by Worldspace has been chosen for the measurements. The physical channel of the Worldspace digital radio system implements a QPSK modulation scheme at a symbol rate of 1.84 Msymbols/s with roll-off factor 0.4, resulting in an active band width of 2.5 MHz. The centre frequency of the circular polarised satellite signal is 1478.224 MHz (L-band).

Since the main service area of the west beam of Afristar satellite is Africa, the equivalent transmit power over Europe is rather low (48 dBW). Due to a lack of high power geo-stationary satellites over Europe operating in L-band or S-band, a measurement method was developed to carry out high dynamic measurements with the weak signals (i.e. C/N < 0 dB) from existing satellites received by omni-directional dipole antennas. By correlating the received indoor IF signal with a re-modulated error-free reference sequence, the processing gain ensures reliable results even at low C/N values. Further details concerning the hardware set-up are given in [10].

The measured *absolute* C/N is then normalised with an outdoor reference recording with free LOS to the satellite. As a consequence, the *relative* C/N represents the building penetration loss (BPL)**,** which can be determined with a dynamic range of 35 dB. For each measurement route the antenna was moved on a wooden cart, without influencing persons, and a value was taken every 27.6 ms (e.g. 650 values along 4 m route). Due to the evaluation of the building penetration loss, the polarisation loss of the receiving antenna is not taken into account in the measurement results. An additional loss of 3 dB to the free space loss has to be considered in the system link budget in case of circular polarised satellite signals and linear receive antennas.

3.2. Measurement Scenarios

The measurements have been performed in six buildings, three in Athens (at 46° elevation) and three further buildings in Erlangen (at 32° elevation). Table 1 gives an overview of the different measurement environments and Fig. 2 presents views for two of the measured buildings.

Figure 2. Two of the measured buildings in Athens A1 (left) and Erlangen E1 (right)

Table 1. Overview of considered buildings for the measurements in Athens (A) and Erlangen (E)

Site	Building	Windows	Rooms
A1	Residential building in suburban area made of reinforced concrete with bricks between columns.	Normal glass, aluminium frames	Two rooms on 2nd floor: Salon without window, dining room with one window ➔ sat. azimut 30°
A2	Residential building in urban area made of reinforced concrete with bricks between columns.	Normal glass, wooden frames	Two rooms on 1st floor: Room #1 Room #2 ➔ sat. azimut 30°
A3	Hotel in urban area, made of reinforced concrete and bricks between columns.	Normal glass, aluminium frames	Two rooms on 2nd and 5th floor both with windows ➔ sat. azimut 30°
E1	Residential building built 1967, with 36 cm outer brick walls.	Normal glass	Two rooms: Salon and adjoining room, both with windows ➔ sat. azimut 10°
E2	New residential building, built 2002, with 36 cm outer brick walls.	Thermal isolating glass, aluminium window frames	Two rooms: Kitchen (sat. azimut 20°), Salon (70°)
E3	Typical residential house with 36 cm outer brick walls, built around 1965, renovated 1994 (with pitched roof).	Normal glass, wooden frames	Two rooms+corridor on 1st floor: Salon with window (sat. azimut 40°), kitchen no LOS to satellite (130°), corridor with 2nd wall penetration

3.3. Measurement Results

For each measurement route the statistics concerning the building penetration loss have been evaluated, i.e. mean value, standard deviation, and cumulative density function. Based on the CDF the probabilities for the BPL being smaller than 10 dB and 16 dB (system link budget margins for two reference network configurations) along the route have been derived.

The results for building E1 are given in Table 2 (the corresponding routes are indicated in Fig. 3), while the detailed results for the other buildings can be found under [10].

Table 2. Summary of measurement results for site E1

Measurement route, dist. wall	Mean BPL [dB]	Std. Dev. [dB]	P < 10 dB [%]	P < 16 dB [%]
Salon (331) 0m	-2.9	2.8	98	100
Salon (323) 0.5m	-10.0	4.3	60	90
Salon (324) 1.0m	-8.7	3.4	70	97
Salon (325) 1.5m	-12.8	3.7	25	83
Salon (328) 2.0m	-19.0	5.3	0	35
Ad.room (348) 0m	-5.4	3.0	93	98
Ad. room (342)	-14.5	4.8	14	69

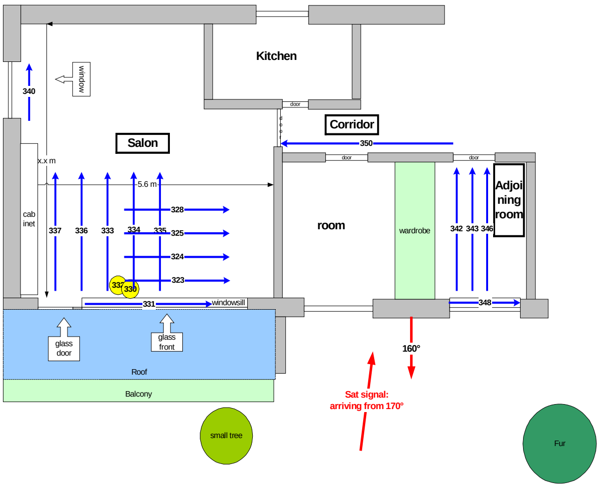

Figure 3. Layout of building E1 (see Fig. 2)

The measurements confirm the different zones of signal penetration depending on the location inside the building with respect to the satellite (as already indicated in Fig. 1). The Fig. 4 visualises this effect with a measurement route moving from the outer wall towards the inner of the building (for site E1).

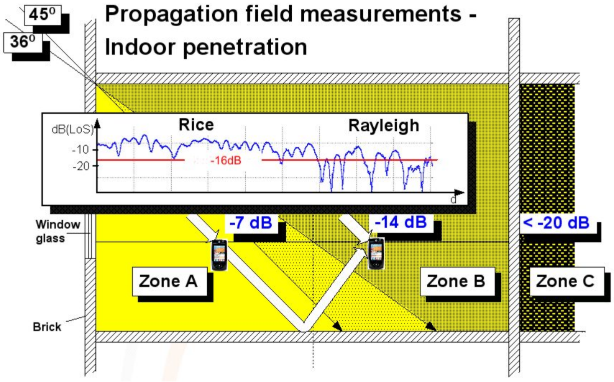

Figure 4. Measured zones of indoor coverage

3.4. Measurement Conclusions

The satellite to indoor measurements in Athens and Erlangen with a real geo-stationary satellite show that with reasonable system link budget margins between 10 and 16 dB, direct satellite indoor reception in future satellite systems could be possible, at least when the user cooperates by positioning the receiving antenna behind an appropriate southern wall or window.

In all sites in Erlangen and Athens, a steep characteristic of around 10 % per dB in the CDF was observed between the thresholds of 10 dB and 16 dB. This means that a slightly higher system link margin between these two values increases significantly the percentage of indoor locations with satellite reception.

According to the measurements a strong influence is given by the material used for the windows. Normal glass according to [13] has a thickness-dependent attenuation of only 1 to 3.5 dB in L-band. These values are confirmed by the measurements on the windowsill for sites A1 and E1. In contrary, the new thermal isolating glass as used in the building E2 has been measured to an average attenuation of 15 dB.

In general, the attenuation of the signal increases with higher distance from the southern wall. However on upper floors directly under the roof construction (site E3), a low mean attenuation between 9 and 14 dB over the complete room was observed (but here no aluminium foil is installed for thermal isolation).

In rooms not directed to the satellite (zone C), the reception with feasible satellite link margins seems to be impossible due to attenuations larger than 20 dB.

The recorded small-scale fading due to multipath propagation (zones B and C) can be overcome by utilising antenna diversity, especially as the measured coherence lengths are in the order of half the wave length [10].

4. SIMULATION MODEL

Due to the high amount of parameters influencing the satellite to indoor propagation channel, wave propagation models are an appropriate method for analysing the various effects in detail, as measurement campaigns are obviously impractical. However, measurements are necessary to validate the results of the simulation.

4.1. Ray-optical Model

For the accurate simulation of the satellite to indoor propagation channel a ray-optical model for the coverage prediction in terrestrial networks has been upgraded to consider satellite transmitters. Valid rays between transmitter and receiver are determined according to a ray tracing technique using the principles of geometrical optics. To calculate the path loss of each ray the free space loss is superposed to the loss due to penetration, reflection, or diffraction. Accordingly, the ray-optical model allows a site-specific prediction of the satellite to indoor radio channel for each point inside the corresponding building.

4.2. Building Database

The basis for any wave propagation model is a database which describes the propagation environment. The ray-optical model is based on 3D vector data of buildings. The penetration of the electromagnetic waves into the buildings is basically influenced by the building layout, i.e. by the interior building structure. According to this, the 3D-vector data includes 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).

4.3. Penetration Loss of Materials

Usually the buildings have a wide variety of walls and obstacles which form the internal and external structure. According to the magnitude of the penetration loss for electromagnetic waves hard partitions and soft partitions can be distinguished [14]. While hard partitions are formed as bearing parts of the building structure (e.g. walls made out of reinforced concrete or brick, thickness > 10 cm) soft partitions may be moved and therefore show lower losses (e.g. plasterboard or plywood, thickness < 10 cm). In order to get a more accurate modelling of wave propagation, a detailed description of the electrical properties for all building elements is necessary. However, in most cases the partitions are made out of several layers and are not homogeneous. Nevertheless, a lot of researchers have collected databases for a great amount of different materials [13]. While the physical behaviour is described by the permittivity and conductivity, the resulting partition losses as given in Table 3 are of more interest from a practical point of view.

Table 3. Partition losses and properties of different typical construction materials (for 1800 MHz)

Material Type	Thickness [cm]	Permittivity (relative)	Conductivity [S/m]	Loss [dB]
Concrete	20	6.0	0.07	11.04
Brick	15	4.3	0.04	5.87
Plywood	10	1.8	0.03	3.83
Glass	1	8.0	0.01	2.31

The total loss experienced by electromagnetic waves when penetrating walls can be divided into two independent parts. The first part refers to the penetration of the wall surface and shows no explicit frequency dependence, whereas the second part belongs to the in depth penetration of the wall material. The magnitude of the latter depends on the wavelength and leads to higher losses with increasing frequency. Therefore slightly higher penetration losses are observed when moving from frequencies in L-band to S-band.

4.4. Comparison to Measurements

In order to compare the measurements with the results generated by the ray-optical model implemented in the radio planning tool the layout of building E1 has been redrawn in the planning tool and appropriate material properties for walls, windows, and the roof have been defined. Fig. 5 shows a sketch of the modelled building from the South (to be compared with the layout of the building as given in Fig. 3) together with some penetrating rays from the satellite direction. Besides the directly penetrating rays also the reflected paths (at the floor and the surrounding walls) are of prime importance for the accurate modelling of the satellite to indoor scenario. For this purpose the ray tracing model used for the simulations has considered multiple reflections and an arbitrary number of transmissions.

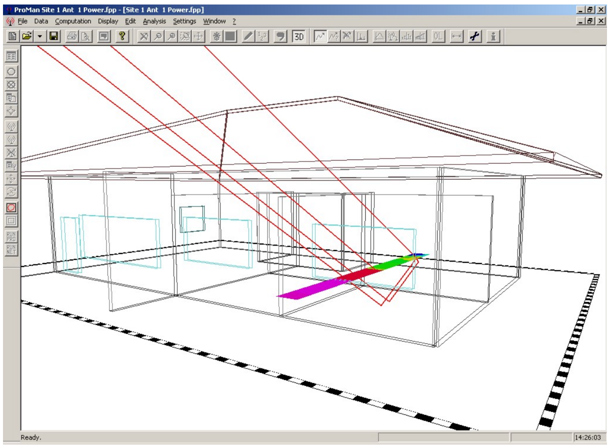

Figure 5. Layout of building E1 as considered in the radio planning tool and visualised ray paths

Fig. 6 and Fig. 7 compare the predicted building penetration loss (i.e. indoor field strength level minus the outdoor level in LOS to satellite) for the two measurement routes 334 and 343 in building E1 (see Fig. 3). Both routes are perpendicular to the southern wall, i.e. they move from the outer windows towards the inner of the building. Route 334 was taken in the salon and route 343 in the adjoining room. While the measurements (given in blue) include the fast fading due to the random superposition of the impinging contributions, i.e. constructive and destructive interference, the ray tracing tool predicts the mean signal level (or mean BPL) as the different contributions are here superposed according to their power (given in red).

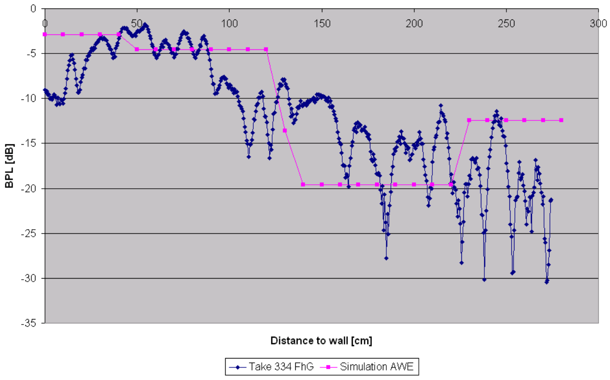

Figure 6. Comparison between prediction and measurement for route 334

As indicated in the previous chapters different zones of coverage can be distinguished. First there is a region with direct window penetration and subsequent low attenuation. From a certain distance on the direct ray has to penetrate additional walls with higher penetration loss, which leads to a strong decrease in the predicted field strength level (see Fig. 6 and Fig. 7). On this level neither the direct nor the reflected rays are passing through the window. The following reduction of the BPL for the simulated curves is given due to the ground reflection which passes from a certain distance on through the window. This reduction of BPL can be also observed in the measurement route 343 (see Fig. 7). Concerning the mean run of the BPL curve there is a fair agreement between prediction and measurements for both routes.

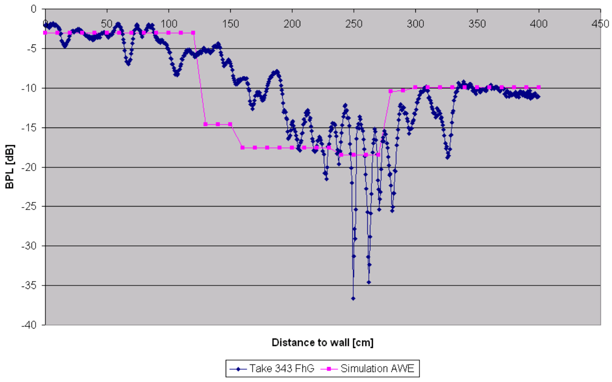

Figure 7. Comparison between prediction and measurement for route 343

5. CONCLUSIONS

This paper presents measurements and simulation results for the satellite to indoor propagation channel, which is becoming of significant importance for future satellite systems.

The measurements of the satellite to indoor coverage have been carried out by Fraunhofer IIS for the geostationary Worldspace-Afristar satellite for different types of buildings in Athens and Erlangen. Both the measurements and the simulation results, which have been generated by using the ray tracing model included in the radio planning tool of AWE Communications, show different zones of indoor coverage. In rooms oriented towards the satellite a zone with direct wall/window penetration and another zone reached by additionally reflected paths only can be distinguished. Depending on the available link budget margin and the given material properties the indoor reception of satellite services could be achieved in both zones, which is rather difficult for rooms not directed to the satellite as in this case additional walls have to be penetrated.

6. REFERENCES

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