Overview of Activities Carried out within SatNex on Land Mobile Satellite and Satellite-to-Indoor Channel Modeling

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Abstract—This paper presents the activities carried out within SatNex on land mobile satellite and satellite-to-indoor channel modeling. SatNex is an EU Network of Excellence.

I. INTRODUCTION

This paper reports on some of the activities carried out within SatNex on land mobile satellite, LMSS, and satellite-to-indoor channel modeling. SatNex is an EU Network of Excellence dealing with satellite communications. Channel modeling and propagation activities have been centralized within Joint Activity 2310. The work has been further subdivided into Focused Topics:

- FT-2311: Mobile/indoor multipath.
- FT-2312: Atmospheric effects.
- FT-2313: Wireless Optics.
- FT-2314: Satellite navigation channel.

Here we report on the work carried out within FT-2311. The organizations participating in this FT are ESA, ICCS, DLR, UVIGO, BME and UniS.

II. CONCLUDED AND ON-GOING WORK

The main achievement of the JA as a whole has been the common writing of a book, first written in the form of an ebook, published by Shaker Verlag, Aachen, 2008 and entitled "Influence of the Variability of the Propagation Channel on Mobile, Fixed Multimedia and Optical Satellite Communications" [1] where a review of the most relevant issues on satellite propagation have been performed including the most recent advances contributed by FT members.

Several research activities are on-going which can be summarized in the following headings, corresponding to the four Specific Research Activities (SRAs) in which the common work is organized:

- SRA 01 - Development of physical-statistical propagation LMS channel models.
- SRA 02 - Diversity techniques including MIMO.
- SRA 03 - In-cabin propagation modeling.
- SRA 04 - Satellite-to-Indoor studies.

Any work to be considered as a part of SatNex has to be performed in collaboration between personnel of at least two participating organizations. Common work is encouraged by funding personnel exchanges.

Regarding SRA 01, work is mainly dealing with the development of a "virtual city" and a "virtual roadside tree" scenario [2]. The received signal at the terminal can be assumed to be composed of the direct signal, subjected to shadowing, and diffuse multipath. These two components can be modeled using a deterministic approach. Deterministic models can be applied either to specific scenarios or to generic ones, created from statistical distributions describing their most significant features: heights, widths, depths, densities, etc. Progress has been achieved in the modeling of rough surface scattering for quantifying the amount of multipath power generated on building faces. Similarly, physical tree attenuation and scattering modeling is being used to model both the direct (coherent) signal and the (incoherent) diffuse multipath. This approach can also be used in coordination with Markov based statistical models.

One of the main contributions to the multipath power in an urban environment is the scattered power by the façades of the buildings [2]. The façades are assumed to be rough surfaces with square protruding plates with homogeneous dielectric constants as shown in Fig. 1. Physical optics (PO) is an appropriate method to study such a complex shape of the façade since it will allow a discrete meshing of the scattering...
surface. It moreover provides information relative to the depolarization effects of the surface (Fig. 2).

Another approach [3] followed within SRA 01 is a novel statistical analysis for Ku/Ka-band LMS channels whose fading state(s) can be modeled by the Ricean distribution with a relatively high $K$-factor. A novel analytical relationship between the Ricean $K$-factor and the rain fading effects has been developed whereby an analytical statistical prediction model for the distribution of the Ricean $K$-factor was derived. The proposed model is flexible as it can be applied on a global scale, and incorporates the impact of several critical operational, climatic, and geometrical parameters of an LMS channel on its multipath behavior (Fig. 3).

Amongst the features of this second approach, the following can be highlighted:

- It allows the combination of tropospheric and local environment propagation effects for Mobile Satellite Services above 10 GHz.
- An analytical model for the calculation of CDF of Ricean parameter is available.
- It is applicable to mobile satellite systems above 10 GHz in tropical regions.

In SRA 02, Diversity Techniques Including MIMO, a number of developments have been carried out to produce statistical and deterministic models taking diversity into consideration. A relevant issue has been the accounting of polarization effects as an important dimension in land mobile satellite MIMO systems. Measurements and modeling results have been obtained, also suitable in the evaluation of capacity gains and the testing of space-time codes.

The aim of the SRA is to produce a realistic physical-statistical model for (1) the investigation of polarization behavior in SatCom links; (2) to investigate MIMO behavior if the channels are distinguished by polarization only (not space); (3) to determine the role of 3D polarization in satellite environment; (4) to study propagation-related phenomena in SIMO satellite downlinks; (5) to determine the effect of depolarization in SISO and SIMO-MIMO/space-diversity and in polarization diversity situations, and (6) to elaborate an electromagnetic tool for an approximate simulation of polarization behavior.

Amongst the achievements in this SRA ([4], [5], [6], [10]), the following can be highlighted:

- A software tool was developed based on the Finite-Difference Time-Domain scheme for solving the Maxwell equations to be applied to physically small satellite to indoor propagation scenarios. It has been demonstrated that full-wave electromagnetic methods are capable of reproducing the small-scale signal variations and accurately predict the spatial characteristics of the received signals what other methods, like the ray tracing can only do in a limited manner.
- Propagation effects, influencing the application MIMO and user cooperation were investigated. The conclusion was drawn that in MIMO polarization diversity is the simplest to be realized, while in satellite diversity problems arise not yet fully solved. Cooperative diversity would be of most advantage in joint satellite/terrestrial networks.
- A new model was developed for the effect of depolarization on Rayleigh channels.
- Modeling aspects have been analyzed particularly with regard to depolarization in different environments, Markov chains and polarization multiplexing.
- Extensive simulation was carried out in SIMO downlink.

Main results on capacity are listed below.

- Capacities are achieved, varying between 3 and 8 b/s/Hz.
- The capacity decreases gradually with an increase in the elevation angle at all the frequencies. From 20 to 80 degrees the variation becomes 2 b/s/Hz for $M_R = 2$ and 1.9 b/s/Hz for $M_R = 4$, with $MR$ being the number of branches.
- Higher capacity values are achieved for low and medium elevation angles.
- In a heavy shadowing scenario, the capacity drops significantly in comparison with the light shadowing.
case. It reduces, in average, 1.4 b/s/Hz and 1.7 b/s/Hz when $M_R = 2$ and $M_R = 4$ respectively. The capacity becomes comparable when we have two elements and a light shadowing case with four elements and a heavy shadowing case.

- The depolarization causes a capacity reduction which, in case of two elements, drops 1 b/s/Hz, whereas in four element case, the capacity reduces 1.05 b/s/Hz.

In-aircraft cabin systems (SRA 03) can be made possible by means of satellite feeder links. The in-cabin propagation channel has been studied within SatNex as an extension of the satellite link [7], [8].

The first goal of this work was to perform a narrowband measurement campaign and provide an adequate channel characterization of the propagation characteristics for personal wireless communications systems such as GSM, UMTS and WLANs. An empirical in-cabin path loss model has been developed together with a statistical characterization of the multipath environment. Results correspond to the aisle as well as the passenger seats. The insertion loss caused by the seat backrests was also defined and quantified. Additionally, entry loss measurements were conducted to evaluate the outdoor-to-indoor attenuation introduced by the body of the aircraft at different seats along its length.

Continuous wave (CW) measurements were performed inside a Boeing 737-400 aircraft at three different frequency bands: (i) 1.8 GHz representative of GSM services, (ii) 2.1 GHz for UMTS services and (iii) 2.45 GHz for WLAN and Bluetooth services. Additional measurements were conducted in an Airbus A340-300 to extract path loss models and statistical results inside a larger aircraft and compare them with those from the Boeing aircraft.

A model to predict the path loss inside the aircraft cabin can be formulated using the following relationship:

$$\overline{PL}(d) = FSL(d_0) + 10n \log_{10} \left( \frac{d}{d_0} \right) \text{ (dB)} \quad (1)$$

where $\overline{PL}(d)$ is the average path loss value (dB) at a distance $d$ (m) from the transmitter to the receiver. $PL_{FS}(d_0)$ is the free-space path loss (dB) at a reference distance $d_0$, and $n$ is the path loss exponent (decay rate) that characterizes how fast path loss increases with increasing transmitter-receiver separation. This model is quite standard in indoor propagation studies and corresponds, in linear units, to a power law of exponent $n$ with the inverse of the path length. What needs to be worked out is the adequate model parameter, $n$, for the specific case of in-cabin propagation, where wave-guide effects may be present.

For the aisle paths, the path loss parameter (decay rate) $n$ was found to be 2.1 at 1.8 GHz, 2.2 at 2.1 GHz and 2.3 at 2.45 GHz. A comparison between the measured and the model results is presented in Fig. 4 for the three bands.

For the seat paths, the loss exponent was found to be between 2.0 and 3.1 at 1.8 GHz, 2.5 and 3.4 at 2.1 GHz and between 2.5 and 3.9 at 2.45 GHz. From the ensemble study of all 150 seats, the average path loss factor, $n$, was found to be 2.6, 3.1, and 3.2 at 1.8, 2.1 and 2.45 GHz, respectively. A comparison between the measurements and the model at all the seats is presented in Fig. 5 at the frequency of 2.45 GHz.

In the second part of this research, a comparison between the above measurements and simple electromagnetic modeling results based on the application of Physical Optics (PO) techniques was performed. Physical Optics uses the concept of (equivalent) surface currents over the surface of an object or an aperture. The currents result from the overall tangential part of the incident electric and magnetic field intensity vectors. The resulting reradiated field is obtained by integrating the surface currents densities over the scattering object surface or, alternatively, aperture. In addition, wall scattering effects can also be taken into account.

The principle for the calculation of the received field strength originating at an aperture is outlined in Fig. 6. The figure can be interpreted as a point source (antenna) followed by a concatenation of two apertures, each corresponding to planes where the field strength is calculated. These apertures can be taken to be along the cabin length and have the same shape as its cross-section. The apertures have to be tightly sampled in a regular mesh with a sub-lambda step. Here, for the tests carried out at 2.1 GHz, the step size was 2 cm.
The field was calculated over subsequent apertures formed by the space of the cabin above the seats, by seat backrests and by the walls, ceiling and the floor of the cabin. The field over the aperture in each row of seats is reradiated onward to obtain the field over the next aperture. Fig. 7 shows an example of obtained path loss maps. A similar technique was also used for the outdoor-to-indoor paths.

The Satellite-to-Indoor (SRA 04) channel at S-Band has recently attracted attention from researchers as it can be used in satellite broadcast applications. In this respect, measured entry loss data and a wideband model have been developed. Moreover, contributions have also been carried out at Ku-Band where experimental work has been performed. Fig. 8 illustrates the evolution of the entry loss with the elevation angle extracted from the measurements at S-Band [9].

In a different experimental work [11] carried out at Ku-Band measurement data was derived using a geostationary satellite transponder as a transmitter and a VSAT dish as a receiver. Two wideband FM-TV signals were measured: one horizontally polarized at 10.8 GHz (Channel 1) and another vertically polarized at 11.1 GHz (Channel 2). The utilized measurement setup is shown in Fig. 9.

The indoor room environment plays a major role in the way signal propagates inside the building. In order to extract a deterministic tool describing how penetration loss is affected by entry loss, a regression model can be used. This can be accomplished by expressing penetration loss as a suitable mathematical function of entry distance (\( PL = f(d) \)). The three different models are based on logarithmic, linear and exponential functions respectively. In each case, the respective mathematical equation and regression coefficient of the model have been calculated. In Fig. 10, regression results are presented for the horizontal polarization signal at room window. Similar models are used for all other windows for both signals.

Noting from Fig. 10, it seems that exponential regression model gives results which are much closer to the measured penetration loss values and it could be used as a deterministic tool to describe how entry distance affects building penetration loss involved. It should be noticed that penetration loss due to an external window (the mean value measured at 105 cm) is a very important parameter which depends on the building material. For the present case where room and corridor windows are the same, potential difference in regression model function is due to the area around each window.

From the above experiment several conclusions can be derived:
- Building penetration loss was measured between 9.2 dB and 22.8 dB for room area, while it ranged from 7.8 dB to 21 dB for corridor environment.
- Another factor involved is window area indoors which can be expressed via a mathematical function of entry distance.
- An exponential regression model was found to be the most appropriate according to obtained results.

### III. SUMMARY

In this paper we have summarized the concluded and ongoing work on land mobile satellite and satellite to indoor channel modeling carried out in the frame of the EU SatNex Network of Excellence. For more details the interested readers are referred to the papers listed in the references and several others to be published in this conference.
REFERENCES


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**Fig. 2.** On the left, magnitude of received field, cross-polar component. On the right, magnitude of received field, co-polar component. elevation 20°, 40°, 60° and 80° (from the top)

**Fig. 7.** Example of PO results (path loss in dB) for all rows.

**Fig. 8.** Entry loss values for all buildings as a function of the elevation angle.