Physical-statistical analysis of land mobile-satellite channel

C. Tzaras, B.G. Evans and S.R. Saunders

The authors describe a time-series propagation model in mobile-satellite channels which considers 3D path profiles. Based on the Fresnel-Kirchhoff theory, the prediction is produced by considering statistical distributions for the building profile, leading to time-series which have both first- and second-order statistics similar to real outdoor measurements.

Introduction: In propagation channel modelling, *empirical* [1] or *semi-empirical* [2] models, are commonly characterised by simple input data, but are usually restricted by short parameter ranges and also suffer from a classification problem. At the other extreme, *deterministic* approaches [3] have yielded excellent results but are impractical, since the input data and computational requirements of such methods are prohibitive.

The present work combines these two approaches by integrating the statistical accuracy, ease-of-use of empirical models with the physical insight and wide parameter range of deterministic models. It avoids the sharp transitions in two-state based models such as [2] or the need to add a large number of states to approximate a continuous transition from LOS to shadowing [4], providing continuous in level predictions.

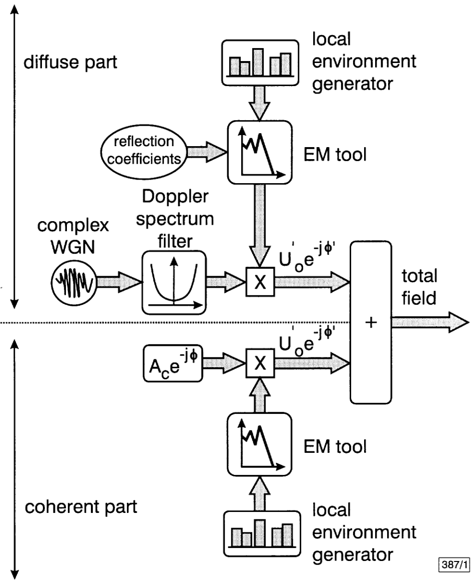

Fig. 1 *Physical-statistical model structure*

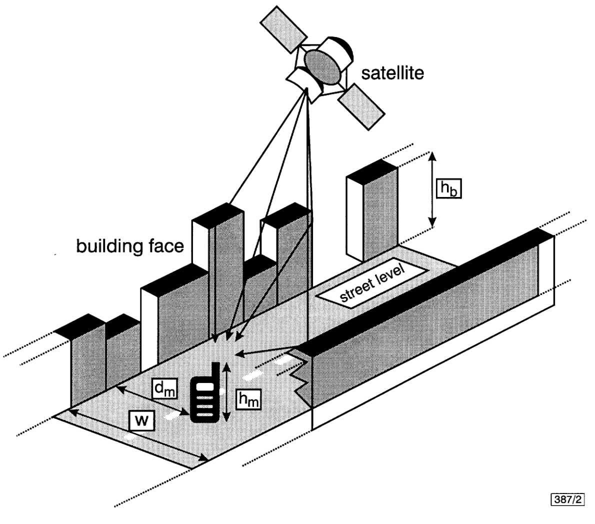

Fig. 2 *Path geometry for mobile satellite channel*

Model structure: The total narrowband fading signal is decomposed into a coherent part, associated with the direct path between the satellite and mobile, and a diffuse part, arising from a large number of multipath components of differing phases as shown in Fig. 1. A three-dimensional (3D) deterministic-type physical mechanism is used for both parts of the model. In the diffuse part, the final outcome is estimated by considering the Fresnel reflection coefficients for both the ground and the building reflections. To avoid the need for analytical input data, the dimensions and positions of the buildings in the proposed work are obtained from a random generator database with parameters that have been measured in real environments (e.g. mean and standard deviation of building heights).

Analysis: The path geometry is illustrated in Fig. 2. A mobile user is situated on a long straight street with a direct ray from the satellite impinging on the mobile from an arbitrary direction. The received power from the direct path is given by

$$u_0(P)=u_{00}(P)\left[1-\frac{i}{2}\sum_{m=1}^{N}\left(\int_{-\infty}^{v_{x2_m}}e^{-\frac{i\pi}{2}v_x^2}dv_x\cdot\int_{v_{y1_m}}^{v_{y2_m}}e^{-\frac{i\pi}{2}v_y^2}dv_y\right)\right] \tag{1}$$

where

$$\begin{cases} v_{x1}=-\infty \qquad v_{x2}=\sqrt{\dfrac{2(d_1+d_2)}{\lambda d_1 d_2}}(x_{22}-x_m) \\ v_{yi}=\sqrt{\dfrac{2(d_1+d_2)}{\lambda d_1 d_2}}(y_{2i}-y_m) \qquad i=1,2 \end{cases}$$

$$x_m=\frac{d_2x_1+d_1x_3}{d_1+d_2} \qquad y_m=\frac{d_2y_1+d_1y_3}{d_1+d_2} \tag{2}$$

and the other parameters are: ϕ, θ: satellite elevation and azimuth angle, respectively; w: street width; d_1: satellite - building face distance; $d_2 \equiv d_M$: mobile - building face distance; $x_3 \equiv h_M$: mobile antenna height; $x_{22} \equiv h_B$ building height; y_{21}, y_{22}: left, right edge position of a building; y_3: mobile position along the street. (Note that all the distance measurements are in metres.) Using image theory, the reflected field from the opposite buildings is also evaluated through eqn. 1 with $d_2 = 2w - d_M$, whereas for the ground-reflected field $x_3 = -h_M$, and the other parameters remain the same. Finally, if R denotes the direct satellite-mobile distance, then simple trigonometry yields:

$$\begin{aligned} y_{sat}&=\frac{R\cos\phi}{\sqrt{1+\tan^2\theta}} \\ x_{sat}&=R\sin\phi+h_m \\ d_1&=\sqrt{R^2\cos^2\phi-y_{sat}^2}-d_2 \end{aligned} \tag{3}$$

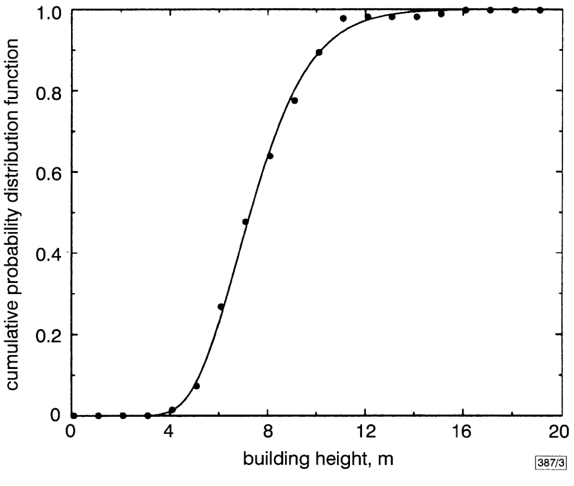

Fig. 3 *Experimental CDF and best-fit lognormal CDF for city of Guildford*

● data
——— lognormal

Building height statistics: The present model uses the statistics of building heights in typical built-up areas as input data. A suitable form was sought by comparing with geographical data for the city of

Guildford, United Kingdom. The probability density function that was selected to fit the data was the log-normal distribution with unknown parameters: mean value μ and standard deviation σ_B. As can be noted from Fig. 3, it was found to be a good fit to the geographical data values with parameters $\mu = 7.3$m, $\sigma_B = 0.26$.

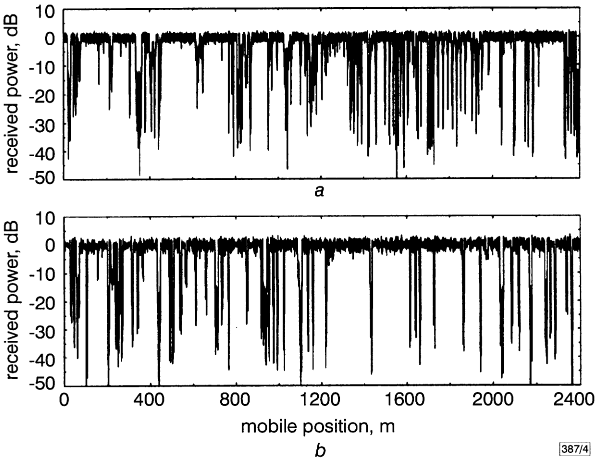

Fig. 4 *Comparison of theoretical output with real outdoor measurement data from satellite*

a Netherlands suburban measurement set
b Physical-statistical simulation results

Example calculations: Fig. 4 illustrates measured [5] and simulated data for a suburban environment at 18.6GHz with the same sampling interval and with 90° azimuth angle and 35° elevation angle. The other model parameters were: $w = 16$m, $d_M = 9.5$m, open area = 35%, $\mu = 7.3$m and $\sigma_B = 0.26$. For the opposite building and ground reflection, the conductivity was set to 0.2S/m, 1.7S/m and the relative permittivity was set to 4.1, 12, respectively. Owing to a non-identical environment, a perfect agreement should not be expected between the measurements and the model predictions. However, it is clear that the physical-statistical model has the same statistical behaviour as the measurements and could have the same output if the input statistical parameters of the model represented the particular environment of the measurements.

Conclusions: The model presented here allows mobile-satellite propagation predictions to be assigned from objective input data with very modest computational effort and allows for deterministic, as well as first- and second-order, statistical predictions, such as the level crossing rate, over a very wide frequency range using a single model. Derived estimations are assigned parameters which are directly related to the physical environment, varying both with azimuth and elevation angles.

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