A Direction-Specific Land Use Based Path Loss Model for Suburban/Rural Areas

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Introduction

Fast and accurate path loss prediction is a prerequisite for effective planning and optimization of cellular radio networks [1]. Ray optical algorithms often achieve very high prediction accuracy, see [2], but consume much computation time. However, semi-empirical prediction models suffer from inherent low prediction quality but require reasonable computational effort.

In this paper we propose a new ***Di**rection-specific **La**nd use based **P**ath loss model (DiLaP)* that benefits from both approaches by utilizing the particular radio wave propagation characteristics of all land use segments that lay on the direct path between receiver and transmitter. It is intended for application to suburban/rural areas. According to common path loss models, e.g. see [3], this model defines a distance dependent signal attenuation according to specific land use properties. Moreover, it is not restricted to only one land use segment but considers all segments - with different sizes and attenuation properties - that are passed by the straight ray from receiver to transmitter. Smart direction-specific evaluation from receiver to transmitter causes a strong influence of land use segments that are located nearby the receiver and reduces the impact of segments far away, which comes close to reality. After introducing the new model we discuss its specific characteristics and compare it to Erceg‘s widely-used path loss model [4] by verification based on WiMAX measurement data. In doing so, DiLaP prediction leads to mean squared errors of less than 6 dB while area-wide computation of a 6.25 km^2 scenario at 2.5 m resolution only takes a few seconds. Hence, we suggest to integrate our smart direction-specific approach into existing semi-empirical models.

Path Loss Model

According to [5], the path loss $L_0(r)$ from transmitter point t to receiver point r equals the ratio of emitted power P_t to received power $P_0(r)$. On a logarithmic scale this interrelationship is generally described as

$$L_0^{\mathrm{dB}}(r) = c_0 + c_f + G_f + \gamma 10 \log_{10} d(r) \ , \tag{1}$$

where $d(r)$ denotes the distance from t to r, c_0 is a base loss and $c_f = 20\log_{10}(4\pi/\lambda_t)$ the frequency dependent loss at wavelength λ_t. For line-of-sight and non-line-of-sight the fast fading component G_f is modelled as a Rice- and Rayleigh-distributed random variable, respectively. The path loss coefficient γ depends on the considered land use type and ranges typically from 2 (free space) to 3.5 (urban). Most empirical

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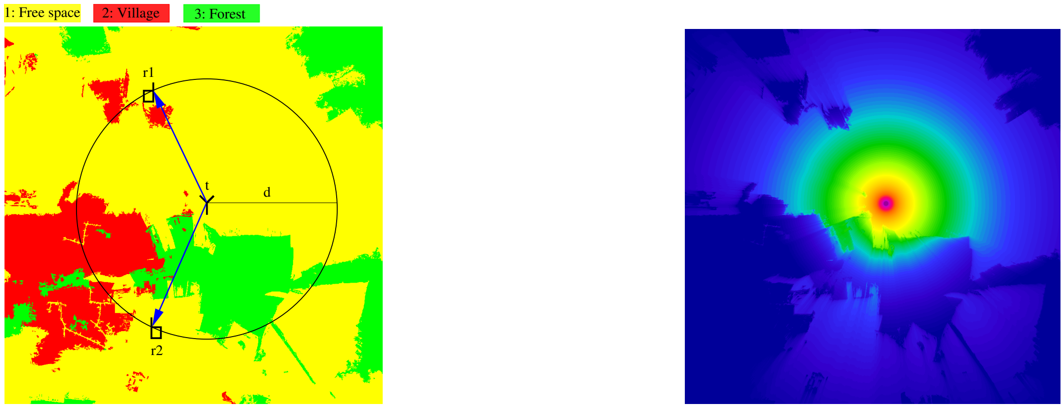


(a) Suburban/rural area containing three land use classes.

(b) DiLaP prediction.

Figure 1: Exemplary direction-specific land use based path loss prediction.

models could be embedded in the form above. For instance, Erceg‘s widely used model, see [4, 6], defines - when all stochastical components are neglected - the path loss coefficient as

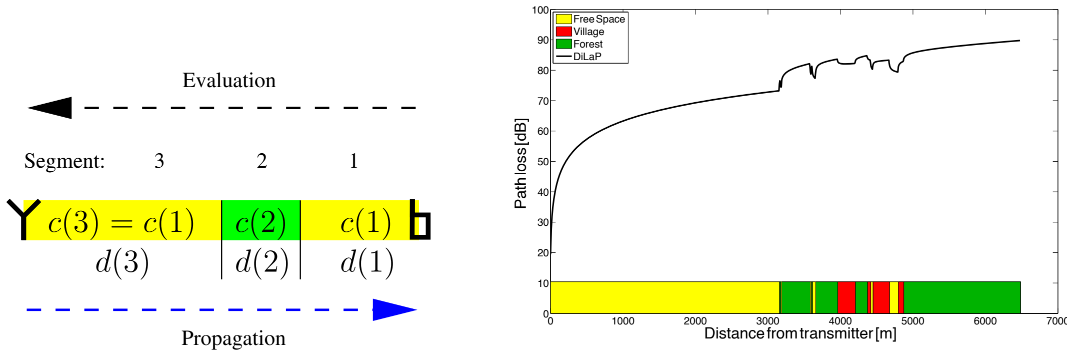
$$\gamma = a - bh_b + c/h_b$$

for transmitter height h_b, $10 \leq h_b \leq 80$ [m], and parameters a, b, c chosen from a given table according to the predominant terrain type. Hence, all receiver points at the same distance from the transmitter gain identical path losses. Obviously, this often contradicts reality. As depicted in Figure 1 (a), in a typical suburban/rural area, the two receivers $r1$ and $r2$ will experience different signal attenuation due to differing land use segments on their individual path to transmitter t - even if they are located at the same distance d from the transmitter.

To overcome this drawback, we propose the following ***Di**rection-specific **La**nd use based **P**ath loss model (DiLaP)*. It considers all $i = 1, \ldots, n(r)$ segments of conjoined differing land use classes $c(i) \in \mathcal{C} = \{1 \text{ (free space)}, 2 \text{ (village)}, 3 \text{ (forest)}\}$ on the direct path from receiver r to transmitter t according to

$$\begin{aligned} L^{\text{dB}}_{\text{DiLaP}}(r) = {} & c_0 + c_f + G_f + \gamma_{c(1)} \, 10 \log_{10} \left(d(1)\right) \\ & + \sum_{i=2}^{n(r)} \left[\gamma_{c(i)} \, 10 \log_{10} \left(\sum_{j=1}^{i} d(j) \right) - \gamma_{c(i)} \, 10 \log_{10} \left(\sum_{j=1}^{i-1} d(j) \right) \right] \end{aligned} \tag{2}$$

where $d(i)$ [m] denotes the length of segment i, $c(i)$ its land use class, and the parameters c_0, c_f, G_f are defined in the same way as for the general path loss model (1). Each land use class $c \in \mathcal{C}$ consequently corresponds to an individual path loss coefficient $\gamma_c \in \{\gamma_1, \gamma_2, \gamma_3\}$ that has to be predetermined for computation of (2). Note that the set of considered land use classes is not necessarily limited to the three ones used but this choice leads to satisfying results. Figure 2 (a) illustrates the idea behind formula (2), particularly the logical evaluation direction that is reversely aligned to the physical propagation direction. Path loss at the receiver is modelled as additive superposition of the segments‘ path losses in between. For instance, path loss contribution of segment 2 in Figure 2 (a) is calculated as the path loss



(a) Path evaluation principle.

(b) Exemplary path loss prediction.

Figure 2: DiLaP path loss prediction.

with respect to the corresponding land use class $c(2)$ and distance $d(1)+d(2)$ to the receiver. The result is then revised by substracting the land use specific influence of antecedent segment 1 using the same land use class $c(2)$ but distance $d(1)$. Therefore, the impact of segment 2 on the overall path loss relies on its land use type and length but particularly depends on its distance to the receiver. Hence, the impact of segments that are located far away from the receiver is significantly smaller than the impact of segments nearby. This effect becomes more obvious when model (2) is rewritten as

$$L_{\mathrm{DiLaP}}^{\mathrm{dB}}(r) = c_0 + c_f + G_f + \gamma_{c(1)}\, 10\log_{10}\left(d(1)\right) + \sum_{i=2}^{n(r)} \gamma_{c(i)}\, 10\log_{10}\left(1 + \frac{d(i)}{\sum_{j=1}^{i-1} d(j)}\right).$$

Figure 2 (b) illustrates the properties of path loss prediction using (2) for an exemplary ray that starts at the transmitter in a certain direction and treats all intersected points successively as receiver point.

Implementation and Comparison

As input for the DiLaP prediction procedure we initially generate the land use information for the considered prediction area by an automatic classification approach based on satellite image data, which is not addressed in this work. The attained land use classification of a typical suburban/rural area with a resolution of 6.25 m^2 per pixel is depicted in Figure 1 (a). Furthermore, we determine the model parameters using a least-squares estimation approach that operates on provided measurement data. Table 1 gives the estimated values for provided WiMAX measurements at 5.8 GHz from a measurement campaign in Regensburg, Germany. Using these parameters, Figure 1 (b) shows the area-wide DiLaP prediction for the scenario depicted in Figure 1 (a).

Even though DiLaP does not exploit any additional information like antenna height, comparison of prediction´s mean-squared error from Table 1 indicates its advantage over Erceg‘s path loss model. Particularly, the smart direction-specific evaluation enables the new model to notably reflect the path loss characteristics on the underlying measuring track, see Figure 3. According to Table 1, the runtime on a single

Model	DiLaP	Erceg‘s
Parameter	$c_0 = 3.2, \gamma_1 = 2.0$	Terrain type
	$\gamma_2 = 2.2, \gamma_3 = 2.3$	C
MSE [dB]	4.97	6.86
Runt. CPU	8640 msec	53 msec
Runt. CBEA	1300 msec	–

Table 1: Models‘ parameters and verification results.

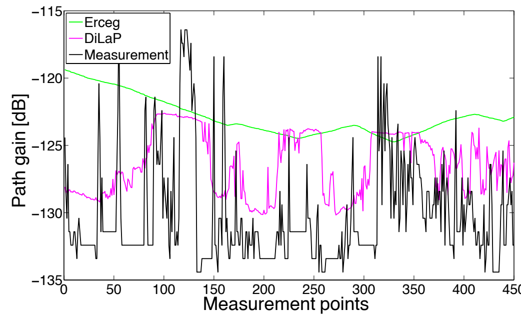


Figure 3: Prediction‘s characteristics.

core CPU of about 8 seconds can significantly be reduced by implementing DiLaP on a *Cell Broadband Engine Architecture (CBEA)* instead.

Conclusions

The proposed ***Di**rection-specific **La**nd use based **P**ath loss model (DiLaP)* provides fast and accurate path loss prediction for suburban/rural areas. Land use information for the scenario under consideration is generated by automatic classification of cost-saving satellite image data. WiMAX measurement based verification of DiLaP certifies excellent prediction results and notable advantages over Erceg‘s widely-used path loss model. Therefore, we suggest to integrate our smart direction-specific approach into existing semi-empirical models.

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