A Recursive Street Canyon Model for Low Height Terminal System

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Abstract—A novel recursive street canyon model is proposed for propagation in low height terminal system. This model combines a street canyon method and a recursive method together, describing the path loss of all street types (LOS, NLOS1, NLOSn) with a unified expression. Related parameters in the expression, such as recursive distance, street intersection number, street intersection orientation, street intersection separating distances, are achieved by a simplified ray tracing platform which considers only one ray along each street. Compared with present street canyon model and recursive model, this proposed model not only has a much simpler expression but also shows a higher prediction precision.

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1. INTRODUCTION
The concept of relaying and multi-hop [1, 2] brings the research on propagation models between low height terminals. Usually, in simulating such relaying link with low height transmitter, it’s better to differentiate line-of-sight (LOS) and non-line-of-sight (NLOS). Further, for NLOS, it can be classified as one-corner type (NLOS1), two-corner type (NLOS2) and n-corner type (NLOSn, n > 2), with NLOS1 and NLOS2 are the most concern. In [3], street canyon models are proposed for both LOS and NLOS but with different expressions. What’s more, this NLOS model and also some other physical models in [4] considers actually only the NLOS1 case. The recursive model in [5, 6] can trace any street type with arbitrary crossings but shows an over estimation in case of a big number of corners.

This paper combines the idea of street canyon method and that of recursive method, putting forward a recursive street canyon model. This model has a simple but unified expression and is suitable for all street types. It’s easy to use in simulation and in reality.

2. STREET CANYON METHOD
In [3], both LOS and NLOS are considered as propagating in street canyons when transmitter and receiver are both below roof-top level. Different models are proposed for LOS and NLOS. The LOS is modelled by two bounds, a lower one and an upper one, each is represented by a dual-slope.

\[ L_{LOS,l} = -6 + 20 \log_{10} \left( \frac{4\pi}{\lambda} \right) + \begin{cases} 20 \log_{10}(d) & d \leq d_b \\ 20 \log_{10}(d_b) + 40 \log_{10}(d/d_b) & d > d_b \end{cases} \]

\[ L_{LOS,u} = 14 + 20 \log_{10} \left( \frac{4\pi}{\lambda} \right) + \begin{cases} 20 \log_{10}(d_b) + 25 \log_{10}(d/d_b) & d \leq d_b \\ 20 \log_{10}(d_b) + 40 \log_{10}(d/d_b) & d > d_b \end{cases} \]

\[ d_b = 4h_t h_r/\lambda \]

where \( L_{LOS,l} \) and \( L_{LOS,u} \) are the lower and upper bound path loss, \( d \) is the distance from transmitter [m], \( d_b \) is the breakpoint distance, \( h_t \) and \( h_r \) are transmitter and receiver height, and \( \lambda \) is the wavelength. The NLOS is modelled by a sum of reflection and diffraction components.

\[ L_{NLOS} = -10 \log_{10} \left( 10^{-L_r/10} + 10^{-L_d/10} \right) \]

\[ L_r = 20 \log_{10} \left( \frac{4\pi}{\lambda} \right) + 20 \log_{10}(d_1 + d_2) + \frac{d_1 d_2}{w_1 w_2} \frac{3.86}{\theta^{3.5}} \]

\[ L_d = -29 + 20 \log_{10} \left( \frac{4\pi}{\lambda} \right) + 10 \log_{10}(d_1 d_2 (d_1 + d_2)) \]

\[ + \frac{18\theta}{\pi} + \frac{40}{\pi} \left( \tan^{-1}\left( \frac{d_1}{w_1} \right) + \tan^{-1}\left( \frac{d_2}{w_2} \right) \right) \]
where \( L_r \) and \( L_d \) are the reflection and diffraction component, \( w_1 \) and \( w_2 \) are the LOS and NLOS street width, \( \theta \), \( d_1 \) and \( d_2 \) are the orientation [arc] and separating distances at the street crossing, \( d_1 + d_2 \) means a recursive distance from the transmitter.

Comparing expression (4)–(6) with (1)–(3), we can simply say that for street canyon method, NLOS considers an extra component relative to LOS. This extra component relates to the street orientation, separating distances and street widths.

3. RECURSIVE METHOD

In [5, 6], a computer efficient ray tracing platform is performed which considers only one single ray propagating along each street, as shown in Figure 1. An illusory distance is achieved by the following recursive expression

\[
d_n = \sum_{j=0}^{n-1} r_j + \sum_{i=0}^{n-2} r_i \sum_{j=i+1}^{n-1} r_j \sum_{k=i+1}^{n-2} q_k + \sum_{i=0}^{n-3} r_i \sum_{j=i+1}^{n-2} r_j \sum_{k=i+1}^{n-1} r_k \sum_{h=i}^{n-2} q_h \sum_{l=j}^{n-1} q_l + \cdots
\]

\[
d_r = \sum_{j=0}^{n-1} r_j
\]

where \( d_n \) is the illusory distance of the \( n \)th node, \( d_r \) is the recursive distance of the \( n \)th node, \( r_j \) is the physical distance at the \( j \)th node, \( q_j \) is a function for the street orientation \( \theta_j \). A dual-slope model is built based on the illusory distance and the recursive distance.

\[
L = 20 \log \left( \frac{4\pi}{\lambda} \right) + \begin{cases} 
20 \log_{10}(d_n) & d_r \leq d_b \\
20 \log_{10}(d_n d_r/d_b) & d_r > d_b 
\end{cases}
\]

From formula (7)–(9), we can see that this recursive model has an over estimation at large distances with multiple crossings, because the illusory distance increases exponentially with the recursive distance and the crossing number. Approximately, for zero street crossing, namely LOS, the path loss exponent will be about 4; for one street crossing, namely NLOS1, the path loss exponent will be about 6; for two street crossings, namely NLOS2, the path loss exponent will be about 8; and for \( n \) street crossings, namely NLOS\( n \), the path loss exponent will be about 2(\( n + 2 \)).

4. PROPOSED MODEL

The proposed model tries to combine the idea of above street canyon method and recursive method but avoid their disadvantages. It has the following characteristics:

(1) It is a dual-slope model.
(2) It has a unified expression for LOS and all types of NLOS streets.
(3) For LOS, only recursive distance from transmitter is considered.
For NLOS1, an extra path loss relative to LOS is considered. This extra path loss is a function of the crossing orientation and separating distances.

For NLOS2, a weighted extra path loss relative to NLOS1 is considered.

Similarly, for NLOSn, a weighted extra path loss relative to NLOSn-1 is considered.

The weighted value decreases with the crossing number.

This proposed model is expressed as

$$L = c_1 + 20 \log \left( \frac{4\pi}{\lambda} \right) + \sum_{j=1}^{n-1} W_j \cdot L_{\text{extra}}(r_{j-1}, r_j, \theta_j)$$

$$L_{\text{extra}}(r_{j-1}, r_j, \theta_j) = c_2 \log_{10} r_{j-1} + c_3 \log_{10} r_j + c_4 \log_{10} \theta_j$$

$$W_j = \begin{cases} 0 & j \leq 0 \\ 1 & j = 1 \\ c_5 e^{-j} & j > 1 \end{cases}$$

where $L$ is the predicted path loss, $L_{\text{extra}}(r_{j-1}, r_j, \theta_j)$ is the extra path loss [dB] at the $j$th street crossing with orientation $\theta_j$ [arc] and separating distances $r_{j-1}$, $r_j$, $W_j$ is the weighting function, $n_1$, $n_2$ are path loss exponents, and $c_1$, $c_2$, $c_3$, $c_4$, $c_5$ are constants.

According to formula (10), for LOS, NLOS1 and NLOS2 streets, the path loss can be simplified as

$$L_{\text{LOS}} = c_1 + 20 \log \left( \frac{4\pi}{\lambda} \right) + \begin{cases} 10n_1 \log_{10}(d_r) & d_r \leq d_b \\ 10n_1 \log_{10}(d_b) + 10n_2 \log_{10}(d_r/d_b) & d_r > d_b \end{cases}$$

$$L_{\text{NLOS}1} = L_{\text{LOS}} + L_{\text{extra}}(r_0, r_1, \theta_1)$$

$$L_{\text{NLOS}2} = L_{\text{NLOS}1} + W_2 \cdot L_{\text{extra}}(r_1, r_2, \theta_2)$$

That is, the path loss of the $n$th crossing is a recursive expression based on the former $n-1$ crossings. Each former crossing can be regarded as the source of a following crossing.

5. PERFORMANCE

Here, we evaluate the performance of this proposed model and compare it with the street canyon model in [3] and the recursive model in [5]. The main street types, LOS, NLOS1 and NLOS2 are evaluated separately.

The measurement was taken in the Kingsland region of London city, with transmitter and receiver height are both 1.5 meters above the ground and the frequency is 2.1 GHz. Figure 2 shows the Geographic Information System (GIS) data with recorded measurement points. The street types of these points are got by a simplified ray tracing platform. For this scenario, the calculated

Figure 2: The GIS data with recorded measurement points.
parameters for the proposed model are the following: \( n_1 = 2.3, \ n_2 = 4, \ c_1 = 1.9, \ c_2 = 5.9, \ c_3 = 2.2, \ c_4 = 9.9, \ c_5 = 5.1. \)

Table 1 shows the error statistics with above three models compared with measurement results. From this table we can see that the proposed model has much better performance than the other

<table>
<thead>
<tr>
<th>Model</th>
<th>LOS</th>
<th>NLOS1</th>
<th>NLOS2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>std</td>
<td>mean</td>
</tr>
<tr>
<td>Proposed</td>
<td>-0.8</td>
<td>5.0</td>
<td>-0.2</td>
</tr>
<tr>
<td>Street Canyon in [3]</td>
<td>--</td>
<td>--</td>
<td>-13.8</td>
</tr>
<tr>
<td>Recursive in [5]</td>
<td>-8.0</td>
<td>5.1</td>
<td>-2.2</td>
</tr>
</tbody>
</table>

From this table we can see that the proposed model has much better performance than the other two models for all street types. The mean error is within ±1 dB and the standard deviation error is within 5 dB. Combining all points, Figure 3 shows the plots of predicted path loss with measured results according to the travelling process. From this figure, the proposed model can match the measurement very well. The calculated mean error is -0.3 dB and the standard deviation error is 4.4 dB.

![Figure 3: Comparison of predicted path loss with measured results.](image)

6. CONCLUSION

In this paper, we proposed a novel recursive street canyon model which combines the idea of street canyon method and recursive method. This model has a simple and unified expression and can describe any street type. By simulation, the proposed model shows much higher prediction accuracy than present street canyon model and recursive model, with the mean error is within ±1 dB and the standard deviation error is within 5 dB.

REFERENCES