An Improved 3D Ray Launching Method for 
Wireless Propagation Prediction*

Greg Durgin, Neal Patwari, Theodore S. Rappaport 
Mobile and Portable Radio Research Group
Bradley Department of Electrical Engineering
Virginia Polytechnic Institute and State University
840 Pointe West Commons, University City Blvd., Blacksburg, VA 24061

Indexing Terms: Ray Tracing, Radio Wave Propagation

Abstract

3D ray tracing produces accurate, deterministic channel models for wireless system design. Increasing a ray tracing algorithm’s ability to identify correct propagation paths reduces the kinematic errors of a simulation. This paper presents a new 3D ray tracing technique that reduces kinematic errors associated with ray launching algorithms.

*This work is sponsored by the NSF Presidential Faculty Fellowship under grant No. NCR-9253598 and the MPRG Industrial Affiliates Program.
1 Introduction

Ray launching techniques shoot rays from a transmitter location which are then reflected, diffracted, and scattered through a computerized environment. Launched rays that pass arbitrarily close to a receiver location are used to predict the actual propagation paths. Rays may be launched from the vertices of a geodesic sphere to provide unbiased 3D coverage and localized uniformity [1].

2 The Reception Sphere

A common method to interpret the traced ray information is the reception sphere model. A sphere, centered on a candidate receiver location and sized according to the angular separation of the incoming rays, collects the rays that contribute to the overall electric field. Figure 1 shows the ideal impingement of geodesic-launched rays onto a spherical wavefront. The minimum radius for a reception sphere to guarantee the collection of at least one ray from a wavefront is $\frac{1}{\sqrt{3}}$ the distance between adjacent rays. This radius sweeps out a circular area across the wavefront where sometimes two rays fall within the sphere, registering additional field at the particular receiver location [2]. For a randomly placed receiver, these double count errors occur with a probability of $\frac{2\pi}{3\sqrt{3}} - 1$ or 20.9% of the time.

The angles of arrival and the path lengths of two rays from the same wavefront are identical. Since their amplitudes and phases are equal, they add coherently to register twice as much electric field – a +6 dB power error per wavefront. Assuming random location of a receiver across a single wavefront, a measurement with reception spheres will increase the mean power by at least 63% and introduce ±122% of additional standard deviation error. Even higher deviations have been shown in [3].
3 Distributed Wavefronts

The method of distributed wavefronts remedies the double count problem inherent with the reception sphere model, while maintaining the speed and simplicity of ray launching. Instead of counting hit-or-miss rays, the contribution of nearby rays are weighted as a function of proximity to the receiver. Thus, the total electric field at any receiver point \( \vec{r} \) is determined by a weighted sum of fields across each multipath wavefront:

\[
\vec{E}(\vec{r}) = \sum_{i=1}^{N} \vec{E}_i \cdot f(x_i)
\]

(1)

The vector \( \vec{E}_i \) is the field associated with the \( i \)th ray. The weighting function is \( f(x_i) \), where \( x_i \) is the normalized distance between the \( i \)th ray and the receiver location. A ray makes a non-zero contribution to the total field only if the receiver point is at a distance closer than the ray’s nearest neighbor. The radially symmetric weighting function in Table 1 is designed to produce a very accurate field result for the case of a uniform spherical wave. If all of the rays on Figure 1’s geodesic wavefront pattern have the same field vector \( \vec{E}_o \), then the weighted sum of nearby ray fields at any point on this wavefront will also be \( \vec{E}_o \).

This tabulated function weights field contributions based on the arc length from the receiver point to a nearby ray, shown as \( d \) in Figure 2. Equations for the total distance traveled by the ray, \( R \), and the normalized distance along a wavefront, \( x \), are given by (2) and (3).

\[
R = \sqrt{L^2 + t^2 + 2Lt \cos \theta}
\]

(2)

\[
x = \frac{d}{\alpha R} = \frac{1}{\alpha} \tan^{-1} \left[ \frac{t \sin \theta}{L + t \cos \theta} \right]
\]

(3)

The normalized distance \( x \) is a ratio of the distance \( d \) to the arc length between a ray and its nearest neighbor, as described by the geodesic ray launching geometry. It allows the distributed wavefront method to use the same weighting function given by Table 1 in the range \( 0 \leq x \leq 1 \) regardless of the angular separation between rays.
4 Results and Measurements

Both reception sphere and distributed wavefront techniques were tested in a simple theoretical environment. The 3D scene, shown in Figure 3, consisted of a flat plane with a single box-like building. All surfaces were assigned arbitrary reflection coefficients of -3 dB. The geometrical optics fields of a 900 MHz transmitter were modeled and a receiver line was placed on the far side of the building. Among the receivers was a group that received specular reflections from one side of the building, increasing the mean power level.

Figure 4 shows the received power along the line. For clarity, a small averaging window of one meter was applied to mitigate the erratic wave interference pattern. It is seen that the reception sphere method artificially inflates the mean power along the 80 meter track and produces non-physical fluctuations absent in the distributed wavefront method. These fluctuations worsen for reception spheres in the region of increased illumination.

5 Conclusions

Geodesic spheres and distributed wavefront methods increase the accuracy of 3D ray tracing for propagation prediction by eliminating the kinematic errors of double-counting while maintaining simplicity and speed. The distributed wavefront method corrects the deviations in the reception sphere model. Unlike the reception sphere model, this new technique can model phasor-summed fields and produce accurate fading profiles. The method also lends itself to modeling non-uniform, astigmatic wavefronts and discrete 3D antenna patterns.

References


Figure 1: Reception sphere double counts on a uniform, geodesic wavefront.
Figure 2: Side view of geometry for a distributed wavefront.
Figure 3: A receiver line is place in a simple environment to compare ray tracing algorithms.
Figure 4: Power along a receiver line using reception sphere and distributed wavefront methods (0 dBm transmit power at 900 MHz). For clarity, an averaging window of 1 meter was applied to the raw power predictions.
Table 1: Tabulated values for a distributed wavefront weighting function.

<table>
<thead>
<tr>
<th>$x$</th>
<th>$f(x)$</th>
<th>$x$</th>
<th>$f(x)$</th>
<th>$x$</th>
<th>$f(x)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.000</td>
<td>1.000000</td>
<td>0.350</td>
<td>0.755992</td>
<td>0.700</td>
<td>0.143627</td>
</tr>
<tr>
<td>0.025</td>
<td>0.997451</td>
<td>0.375</td>
<td>0.714609</td>
<td>0.725</td>
<td>0.114993</td>
</tr>
<tr>
<td>0.050</td>
<td>0.994310</td>
<td>0.400</td>
<td>0.670687</td>
<td>0.750</td>
<td>0.090079</td>
</tr>
<tr>
<td>0.075</td>
<td>0.989887</td>
<td>0.425</td>
<td>0.624725</td>
<td>0.775</td>
<td>0.068779</td>
</tr>
<tr>
<td>0.100</td>
<td>0.983723</td>
<td>0.450</td>
<td>0.577259</td>
<td>0.800</td>
<td>0.051053</td>
</tr>
<tr>
<td>0.125</td>
<td>0.975419</td>
<td>0.475</td>
<td>0.528856</td>
<td>0.825</td>
<td>0.036723</td>
</tr>
<tr>
<td>0.150</td>
<td>0.964567</td>
<td>0.500</td>
<td>0.480105</td>
<td>0.850</td>
<td>0.025471</td>
</tr>
<tr>
<td>0.175</td>
<td>0.950793</td>
<td>0.525</td>
<td>0.431592</td>
<td>0.875</td>
<td>0.016905</td>
</tr>
<tr>
<td>0.200</td>
<td>0.933756</td>
<td>0.550</td>
<td>0.383894</td>
<td>0.900</td>
<td>0.010621</td>
</tr>
<tr>
<td>0.225</td>
<td>0.913197</td>
<td>0.575</td>
<td>0.337574</td>
<td>0.925</td>
<td>0.006190</td>
</tr>
<tr>
<td>0.250</td>
<td>0.888966</td>
<td>0.600</td>
<td>0.293157</td>
<td>0.950</td>
<td>0.003215</td>
</tr>
<tr>
<td>0.275</td>
<td>0.861056</td>
<td>0.625</td>
<td>0.251151</td>
<td>0.975</td>
<td>0.001356</td>
</tr>
<tr>
<td>0.300</td>
<td>0.829511</td>
<td>0.650</td>
<td>0.211982</td>
<td>1.000</td>
<td>0.000000</td>
</tr>
<tr>
<td>0.325</td>
<td>0.794412</td>
<td>0.675</td>
<td>0.176035</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>