TOA-DOA Statistics of “Double-Bounced”
Multipaths Suffering Propagation Loss in Uplink
Cellular Fading-Channel Geometric Modeling

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Abstract—In the “geometric” modeling of radiowave wireless-communication channels, the transmitted signal’s each propagation path is typically idealized as bouncing off exactly one scatterer before reaching the receiver, without accounting for the multipath’s power loss due to propagation. This paper’s Monte Carlo simulations investigate how the distribution functions of the uplink multipath’s time-of-arrival (TOA) and azimuth direction-of-arrival (DOA) would be influenced by accounting for the multipath’s propagation power loss and by using a “double-bounced” model wherein each propagation path successively bounces off exactly two scatterers before reaching the receiver.

I. Geometric Modeling of a Radiowave Fading-Channel

“Geometric model” refers to an abstractized simplification of the spatial geometry relating the transmitter and the scatterers and the receiver — in order to statistically characterize a wireless fading-channel’s received multipaths’ fading statistics, e.g., the distribution of the uplink and downlink multipaths’ arrival angle and delay that are considered in this paper.

This idealized geometry is necessarily site-unspecific but can be widely applicable to a generic category of propagation-channels such as all “bad urban” or the “rural” scenarios. This contrasts with site-specific computer simulations based on electromagnetic ray-shooting and ray-tracing, which are necessarily tailored to only one particular setting, e.g., a specific street corner in a specific city under a specific weather. Despite geometric modeling’s idealized approximations, its wide applicability fundamentally simplifies the engineer’s system-design of mass-marketable products for a wide subclass of propagation channels.

Geometric models also attempt to integrally embed the channel’s various measurable metrics into the propagation channels’ idealized geometry, such that the geometric parameters would affect these various fading metrics in an inter-connected manner to conceptually reveal the channel’s underlying fading dynamics. This contrasts with non-geometric Monte Carlo models (e.g., [9]) that separately impose on the channel’s each fading metric an ad hoc a priori statistics not motivated by any underlying geometric inter-connection among the model’s measurable spatial and temporal behavior. An ad hoc collection of a priori imposed statistics might be useful for curve-fitting purposes, but would yield little general analytical insight into an entire class of fading-channels’ underlying propagation mechanism, would offer little conceptual framework for generalization, and could hardly facilitate much meaningful generalization into categorically different propagation settings.

Monte Carlo simulations of the TOA-DOA distribution from “single-bounce” “geometrical” models of the land-mobile cellular fading channel have been available in [2], [6] and [7], both with the scatterers elliptically centered upon the mobile and the basestation. A similar Monte Carlo investigation is available in Newhall/MILCOM02 for a ground-based mobile and an airborne basestation. The “double-bounced” model has been mentioned in [4] but little simulation result or insights are therein presented. This work investigates how geometrically modeling the transmitted signal’s each propagation as undergoing two successive bounces off two different scatterers (instead of each propagation path experiencing only one single bounce off one scatterer) would change the distribution of the uplink multipaths’ TOA-DOA statistics in a land-mobile cellular wireless communication system. [3] has investigated how path loss in a “single-bounce” geometric model influences the Doppler spectrum, but not for the distribution of the DOA and TOA and not for “double-bounced” geometric models. This work will also investigate how accounting for propagation path loss in the uplink multipaths’ power would affect the azimuth arrival angle’s and the arrival excess delay’s distribution.

II. Simulation Model

Subsequent simulation studies will make these geometric modeling assumptions:

1For example, a common non-geometric approach involves ad hoc modeling of the temporal fading statistics in a way unrelated with additional ad hoc modeling for the spatial fading statistics. One or more of these ad hoc statistics might be partially based on unrelated “geometric” considerations. These separate and “geometrically” un-integrated statistics are then forcibly welded together to describe the channel’s spatial-temporal fading statistics. In contrast, the fully “geometric” approach here has all spatial and temporal statistics of the transmitted signal’s random field produced by the propagation channel’s geometry.
The scatterers’ spatial distribution according to Lee’s Model [1].

Geometry among the mobile transmitter, a scatterer, and the base-station receiver in the “single-bounce” case.

Geometry among the mobile transmitter, a scatterer, and the base-station receiver in the “double-bounce” case.

Each propagation path, between the mobile transmitter (MS) and the base-station receiver (BS), reflects off a to-be-specified number of scatter(s) (1 or 2).

Each scatterer acts as an omnidirectional lossless retransmitter, independently of other scatterers.

Complex-phase effects in the receiving-antenna’s vector-summation of the arriving-multipaths may be overlooked. That is, all arriving multipaths arriving at each receiving-antenna are assumed to be temporally in-phase among themselves.

All antennas are omnidirectional; and polarizational effects may be overlooked.

The scatterers are spatially distributed according to Lee’s model [1] in Figure 1, wherein the scatterers are uniformly distributed within small circular discs, which in turn are spaced evenly on a ring centered at the mobile transmitter. To be more precise: 250 scatterers are uniformly distributed within each of $N = 8$ circular discs of radius $r = 1$ meter. These $N$ clusters are angularly evenly spaced on a circular ring centering at the mobile station. That circular ring has a radius of $R = 6$ meters. Each multipath’s power is inverse proportional to the $\alpha = 2$ power of the distance it has traveled. The mobile station (MS) is located at $(0, 0)$; and the base-station (BS) is located at $(10, 0)$ meters.

In the “single-bounce” case of Figure 2, the propagation delay $\tau$, from the mobile transmitter reflecting off a scatterer and arriving at the base-station, equals $\frac{r_s}{c}$, where $c$ denotes light speed. In the “double-bounce” case of Figure 3, the propagation delay $\tau$, from the mobile transmitter reflecting off two scatterers consecutively and arriving at the base-station, equals $\frac{r_s + r_m}{c}$.

III. “Double-Bounce” Versus “Single-Bounce” Geometric Modeling

A. Time of Arrival

Figure 4 shows the TOA’s different distributions under the “single-bounce” model and the “double-bounce” model.
model.

The “single-bounce” TOA distribution a disjoint series of arrivals, separated by gaps with no arrivals. These gaps arise from the spatial discreteness in Lee’s model’s region of support. The high spike at approximately 33ns \(\left(=\frac{33\text{ns}}{10\text{m}}\right)\) corresponds to the direct path between the mobile and the basestation. The distribution is high in this TOA vicinity because a change in the scatterer location in Region A will change little the multipath distance. For example, scatterers at \((5, 0)\) and \((7, 0)\) in Region A both correspond to a multipath distance of 10m. The maximum TOA corresponds to the scatterer located on the left side of Region E at \((-7, 0)\), giving a \(\tau = \frac{2m_{17}m}{2m_{17}m} = 80\text{ns}\).

In contrast, the “double-bounce” TOA distribution is nonzero over a much longer range of durations, because the two scatterers in a double-bounced multipath can be located in two different regions of support around the ring. Each local peak in this distribution corresponds to multipaths with their two scatterers belonging to separate discs, e.g., one in Region A and the other in Region B.

B. Azimuth Direction-of-Arrival

The DOA distribution is identical for the “single-bounce” and the “double-bounce” models when there is assumed no propagation power loss, because the DOA distribution would then depend only on the last scatterer’s spatial location and all multipaths are weighted equally in computing the DOA distribution.

C. Joint TOA-DOA

Figure 5 shows the TOA-DOA joint distribution for the “single-bounce” case, and Figure 6 for the “double-bounce” case. In Figure 5, the eight peaks correspond to the eight discs in Lee’s model.

IV. Influence of the Multipath’s Propagation Loss on the TOA-DOA Statistics

A multipath’s amplitude attenuates as the multipath travels over more distance and the curved wavefront has a wider area, resulting in less signal power per unit area of the multipath’s wavefront. The lower-power multipaths makes weaker contribution to the TOA and DOA distributions than the stronger multipaths.

A. Time of Arrival

Denote the multipath by \(d\) the multipath’s propagation path length, the multipath’s amplitude may be modeled as:

\[
\text{Amplitude} \propto d^{-\alpha}
\]

where \(\alpha\) refers to the propagation-loss coefficient. Figure 7 shows how the TOA distribution drops off faster at the right, with a larger \(\alpha\).

B. Azimuth Direction-of-Arrival

Figure 8 shows that as \(\alpha\) increases, the DOA concentrates more at the center 0°, as contributions from the region of support closest to the basestation (i.e., Region A) rises as \(\alpha\) increases.

References

Fig. 8. PDF of AOA (variable = α)