Performance of an Indoor/Outdoor RSS Signature Cellular Handset Location Method in Manhattan

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Introduction

This paper presents handset location results in a live cellular network using a received signal strength (RSS) signature method that can locate handsets in the ultra-dense urban environment like Manhattan. Our results show that RSS location techniques are accurate for both outdoor and indoor users, surpassing the United States’ rigorous E911 guideline of location estimate errors of less than 100m 67% of the time and less than 300m 95% of the time \cite{1}. A unique indoor propagation model presented in this paper may enhance location-based services and (in the US) enhanced 911 safety service offered by cellular carriers.

Locating a handset in the complicated cellular radioscape is a difficult enough problem \cite{2}, but now that a majority of cellular calls are placed from indoor locations, it has become nearly impossible to locate users with conventional techniques (i.e. time-differencing schemes, array-based scanning, and integrated global-positioning system receivers). One location method that is immune to the rugged propagation environment of indoor and urban locations is the RSS signature method. This method takes advantage of a digital handset’s constant monitoring of power received from nearby base stations. These powers are normally reported to serving base stations as part of a \textit{network measurement report} (NMR) sent on the phone’s reverse control channel. The RSS recorded in an NMR or sequence of NMRs may be cross-correlated to a \textit{predicted signal-strength database} (PSD), allowing a computer to backsolve the most likely \textit{xy}-coordinates of a cellular handset \cite{4}.

The challenge for the RSS signature method in an ultra-dense urban environment is to generate an accurate PSD. This is especially important for areas where drive-test calibration measurements cannot be made, such as indoor areas and pedestrian pathways. To generate a more accurate PSD, a new indoor penetration model was developed for use in the trial. Location accuracy results showed encouraging performance improvements as compared to tests that did not contain the new indoor signal penetration model. We found that with this model, the majority of the location estimates are less than 50 m from the ground truth location.

Manhattan Test Area Information

All measurement were made inside a $2 \times 2$ km center measurement area which was enclosed by a $4 \times 4$ km test area in Manhattan. There were about 100 cell sectors inside the center measurement area and about 400 in the entire test area. The measurement campaign was performed on an live cellular network. RSS data was
measured on forward control channels, which are narrowband and have constant transmit power.

Data Collection

Outdoor drive-test collection for PSD calibration was performed along all streets in the test area. More than 50,000 RSS samples were collected by a commercial scanning receiver and grouped into 10m × 10m spatial bins. Thus, the RSS recorded in a PSD for each bin is a linear average of 3-8 instantaneous power measurements. Thorough indoor data collection was performed in 3 test area buildings to extract indoor penetration loss parameters; this data is used to form a generic penetration loss model. Further outdoor measurements of 10,170 data samples of live handset data were collected for testing purposes, as well as 2,326 indoor handset data samples in 21 test area buildings. For this last data, the field engineers simulated actual calling conditions, moving at slow speeds with the measurement handset held by their head.

Modified Indoor Modeling

Predicting the received signal strength for the indoor environment is critical for building an accurate PSD, especially for areas where no calibration measurement can be made. More accurate RF maps result in better location estimates.

From physics, we expect normal-incidence waves to have less penetration loss than grazing incidence waves. For algorithm simplicity, incident angles are divided into 8 uniformly-spaced octants as shown in Figure 1. Unique penetration loss values are calculated and assigned for each octant. Since different control channels originate from different base stations and propagate through a building exterior wall with dissimilar angles of incidence, the penetration loss for each control channel will vary. This effect is used for indoor signal strength prediction and adds diversity to the indoor signal strength to distinguish indoor areas from outdoor areas. The original indoor penetration model in [3] assumes that a line of sight exists or that the major mode of propagation is over-roof diffraction. This assumption simplified the incidence angle calculation by treating the bearing angle of the base station to the building wall as the principle angle-of-arrival. This assumption does not hold in the ultra-dense environment of Manhattan, where round-the-street-corner diffraction propagation dominates.

To model indoor penetration loss accurately in an environment like Manhattan, we modify the original octant model by considering streets as the major propagation path and introducing the concept of a pseudo-transmitter. For a building without Line of sight (LOS) to a real base station, the intersections around that building become the major source of radio wave diffraction and reflection. From the building perspective, the majority of the radio signal arrives from the intersection closest to the real transmitter. We call this intersection a pseudo-transmitter for that building, as shown in Figure 2. The pseudo-transmitter, instead of the real transmitter, is used to calculate the angles of incidence. The octant-dependent penetration loss values derived from measurements are 10 dB, 15 dB, 20 dB, 15 dB, and 10 dB for octant
Normal Incidence

Figure 1: Angles of incidence with respect to building surface (Thick line) are broken into uniform angle ranges called octants.

sector of 1, 2, 3, 4, and 5, respectively.

Location Performance

The location algorithm used to compile statistics in this study is described thoroughly in [4]; it uses relative signal strength and takes the movement of the cell phone into consideration, applying a Markov model in the location probability calculation. Six neighbors' info are reported in each network measurement report (NMR). A sequence of 30 NMRs are collected, filtered, and used together in estimating the location of the handset.

Location performance is reported by the percentages of calls located within error distances of 50m, 100m, 150m, 300m, and 500m. Table 1 shows the performance for indoor and outdoor handsets with and without indoor penetration loss modeling.

![Real Transmitter](image1.png)

![Pseudo Transmitter](image2.png)

Figure 2: Pseudo-transmitter case in ultra-dense urban environment.

Table 1: Location Performance for indoor/outdoor handset with/without modeling

<table>
<thead>
<tr>
<th>Error Statistics</th>
<th>Indoor Test Points</th>
<th>Outdoor Test Points</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1 PSD(^1)</td>
<td>Level 2 PSD(^2)</td>
</tr>
<tr>
<td>&lt;50m</td>
<td>25.3%</td>
<td>36.8%</td>
</tr>
<tr>
<td>&lt;100m</td>
<td>75.9%</td>
<td>77.0%</td>
</tr>
<tr>
<td>&lt;150m</td>
<td>92.0%</td>
<td>95.4%</td>
</tr>
<tr>
<td>&lt;300m</td>
<td>98.9%</td>
<td>100%</td>
</tr>
<tr>
<td>&lt;500m</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

\(^1\)Level 1 PSD: RF database calibrated with outdoor measurement

\(^2\)Level 2 PSD: Calibration with outdoor measurement and indoor modeling

For the indoor test points, the experimental results show 11.5% more calls are located within the 50 m error distance than without indoor modeling. In addition, indoor modeling improves location accuracies by 1.1%, 3.4%, 1.1% for 100 m, 150 m, 300 m error distance, respectively. The addition of the new penetration loss model clearly improves location estimates, particularly for 50 m indoor statistics.

The experiment also shows the indoor modeling helps improve outdoor location
performance. After applying indoor modeling the outdoor location accuracy improves, because it is less likely for an outdoor call to be mistakenly located to an indoor place. The modified indoor modeling improves the outdoor location accuracy by 0.6%, 1.6%, 2.8%, and 0.9% for 50 m, 100 m, 150 m, and 300 m statistics, respectively.

Conclusions and Suggestions

This trial demonstrated the effectiveness of RSS-based location performance in ultra-dense urban environments. 67% the outdoor location estimates are within 50 meters from ground truth and 67% of the indoor location estimates are within 80 meters from ground truth. Experiments also show that the modified indoor modeling improves location accuracy in both indoor and outdoor areas. The results suggest that a hybridization of the GPS assisted method and the RSS signature method may prove to be the most effective solution for locating handsets across a range of environments including rural, suburban, dense urban and indoors. The hybrid system will combine the high performance of GPS system in rural areas and the high performance of RSS system in urban and indoor environments.

References


