MODELING AND CHARACTERIZATION OF CELLULAR MOBILE CHANNELS FOR 3-D RADIO PROPAGATION ENVIRONMENTS

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Brief Outline:

- **Introduction**
  - Basics of Multipath channels and Cellular Environments.
  - Scope and Significance of Research Topic.

- **Proposed Research Work**
  - **Part I**: Physical Modeling of cellular mobile channels in 3-D radio propagation environments.
  - **Part II**: Characterizations of the 3-D propagation channel for Doppler shift spectrum.
  - **Part III**: Performance analysis of handover procedures in 3-D cellular propagation environments.

- **Deliverables**
  - Research Publications in Journals.
  - Conference Proceedings.

- **Summary**
  - Conclusions and Future research directions.
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**Multipath Phenomenon.**

Multipath phenomenon causes:
- Spread in Spatial domain.
- Spread in Time domain.
It is necessary to have good understanding of mobile radio channel.

**Cellular Environments.**

- **Pico Cell.**
  - BS and MS antenna heights are approximately same.
  - Indoor (a floor or an entire building)

- **Micro Cell.**
  - BS antenna height $\leq$ Average roof top level.
  - Urban Areas.
  - Cell radius is only few dozen meters. (Small Area)

- **Macro Cell.**
  - Base station height $>>$ Average Rooftop level.
  - Cell Radius can be several Kilometers. (Large Area)
Cellular environments.

• Pico Cell.

• Micro Cell.

• Macro Cell.

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  ■ Conclusions and Future research directions.
Literature Survey, Notable 2-D Models.

- **2-D Circular Scatter Density Model.**
    - Propagation in 2-D space.
    - Macro-cell.
    - Uniform scatter density.
    - AoA and ToA seen from BS.

- **2-D Circular Scattering Model for downlink.**
    - Propagation in 2-D space.
    - Macro-cell.
    - Gaussian scatter density.
    - AoA and ToA seen from BS.

- **2-D Gaussian Scatter Density Model.**
    - Propagation in 2-D space.
    - Macro-cell.
    - Gaussian scatter density.
    - AoA and ToA seen from BS, rms delay spread, rms angular spread.

- **2-D hyperbolic Scatter Density Model.**
    - Propagation in 2-D space.
    - Macro-cell.
    - Hyperbolic scatter density.
    - AoA and ToA seen from BS, rms delay spread, rms angular spread.
Literature Survey, Notable 2-D Models.

- **2-D Elliptical Scatter Density Model.**
  - Property in 2-D space.
  - Pico- and Micro-cell.
  - Gaussian scatter density.
  - AoA and ToA seen from BS, rms delay spread, rms angular spread.

- **Generalized Eccentric Scattering Model.**
  - Property in 2-D space.
  - Macro-, Micro-, and Pico-cell.
  - Uniform scatter density.
  - AoA and seen from BS.

Spread of multipath components in elevation plane.

- **Outdoor propagation:**
  - The spread of multipath waves in elevation plane in outdoor environments is seen over angle of 20°. [7, 9].

- **Indoor propagation:**
  - In the indoor environment, a typical cluster of multipath waves in elevation plane extends over an angular sector of 9° with up to 5 clusters observed. [15]
Literature Survey, Notable 3-D Models.

Part I

• 3-D ellipsoidal model.
    ▪ Propagation in 3-D space.
    ▪ Pico-cell.
    ▪ Uniform scatter density.
    ▪ ToA seen from BS and MS.

• 3-D Macro-cellular Channel model.
    ▪ Propagation in 3-D space.
      ▪ Elevated BS.
      ▪ 2-D scattering region.
    ▪ Macro-cell.
    ▪ Uniform scatter density.
    ▪ AoA seen from BS.

Part I

• 3-D Hemispheroid Scattering Model.
    ▪ Propagation in 3-D space.
      ▪ Non-Elevated BS.
      ▪ 3-D scattering region.
      ▪ Hemi-spheroid with Same major and minor axes radii.
    ▪ Macro-cell. Uniform scatter density.
    ▪ ToA/AoA seen from BS.

• 3-D Semi-Spheroid Scattering Model.
    ▪ Propagation in 3-D space.
      ▪ Elevated BS with 3-D scattering region (i.e., Semi-spheroid)
    ▪ Macro-cell.
    ▪ Uniform scatter density.
    ▪ AoA seen from MS and BS.
Literature Survey.

- **Geometrically Based Single Bounce Macrocell Model.**

- Directional antenna at BS.
- Propagation in 2-D space.
- Macro-cell.
- Uniform scatter density.
- AoA seen from MS and BS.
- Doppler shift spectrum.

### Scattering Models Corresponding Cellular Environment Used Scatter Density Dimensions of Scattering Region. Elevated BS Directional antenna

<table>
<thead>
<tr>
<th>Scattering Models</th>
<th>Corresponding Cellular Environment</th>
<th>Used Scatter Density</th>
<th>Dimensions of Scattering Region.</th>
<th>Elevated BS</th>
<th>Directional antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lopez et al., 2005 [12]</td>
<td>Macrocell</td>
<td>Gaussian</td>
<td>2-D</td>
<td>at BS.</td>
<td></td>
</tr>
<tr>
<td>Petrus et al., 2002 [10]</td>
<td>Macrocell</td>
<td>Uniform</td>
<td>2-D</td>
<td>at BS.</td>
<td></td>
</tr>
<tr>
<td>Bilal et al., 2009 [20]</td>
<td>Macrocell</td>
<td>Uniform</td>
<td>2-D</td>
<td>at MS and BS</td>
<td></td>
</tr>
</tbody>
</table>
Problems Statement of Research Part I.

- For the case of 3-D propagation environments, no analysis is available in the literature which presents the effect of directional antenna on the spatio-temporal parameters of the radio channels.

- In literature [2, 3, 5, 11, 12, 13], the Gaussian distribution is proven as the most effective distribution to model the scattering objects. However, there is no such scattering model in literature which allows the propagation of multipath waves in 3-D environment.

- Nevertheless, there is a need of a generalized 3-D geometrical scattering model that can deduce to any 3-D or 2-D scattering model with an appropriate choice of a few parameters.

Scope of Research Part I.

Physical Modeling of cellular mobile channels in 3-D radio propagation environments.

- A comprehensive comparative analysis of 2-D and 3-D propagation models found in literature with uniform and Gaussian scatter densities is presented.

- A new geometrically based generalized 3-D scattering model is proposed which can be deduced to any 3-D or 2-D scattering model proposed in literature for macro-cell environment with an appropriate choice of a few parameters.

- An analysis is presented to measure the effect of directional antenna at BS on the angular and temporal statistics of land mobile radio cellular systems.

- A study to investigate and establish the realistic choice of distribution for the scattering objects around MS is presented. To serve this purpose, the analytical expressions are derived for both uniform and Gaussian scatter densities.
Common Assumptions

- The propagation between MS and BS antennas is assumed to take place via single scattering object (which is an isotropic obstacle) [1–24].

- Each scatterer is assumed to be an omnidirectional lossless reradiating element, which reflects some part of the incident wave directly towards the MS without any influence from the other scattering objects [1–24].

- All scattering objects are assigned equal scattering coefficients with uniform random phases.

- The antenna at elevated BS is assumed to be a flat-top directional antenna with equal gain within its beamwidth, $\alpha$, [10 - 12, 14].

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A Generalized 3-D Model for Macrocell Environment.

[Nawaz et al., IEEE Trans. on Veh. Technol.] [J01], [C01], [C02], [C03]
The directional antenna at elevated BS results in the **clipping** of scattering region.

Only the scattering objects in **illuminated** scattering region correspond to the arrival of multipath waves at the receiver.

The illuminated and eliminated scattering regions are labeled as; $R_1$, $R_2$, $R_3$, $R_4$, and $R_5$.

**Illuminated Region** ($I_{region}$) \(\rightarrow\) $R_1$, $R_2$, and $R_3$

**Eliminated Region** ($E_{region}$) \(\rightarrow\) $R_4$ and $R_5$
Further, on the basis of geometrical composition, the illuminated scattering regions (i.e., $R_1$, $R_2$, and $R_3$) are grouped into two partitions.

- $P_1 \rightarrow R_1 \& R_3 \rightarrow \begin{cases} \phi_1 \leq \phi_m \leq \phi_2 \\
0 \leq \beta_m \leq \beta_t \end{cases}$
  or
- $\beta_t < \beta_m \leq \frac{\pi}{2}$

- $P_2 \rightarrow R_2 \rightarrow \begin{cases} \phi_1 \leq \phi_m \leq \phi_2 \\
\phi_2 \leq \phi_m \leq -\phi_2 \end{cases}$

The separate among the said two partitions, threshold angles $\phi_1$, $\phi_2$, and $\beta_t$ are computed.

\[
\beta_t = \cot^{-1} \left( \frac{\sin \alpha \cdot \sin \phi_m \cdot \sin \alpha_0}{\sqrt{\alpha^2 - \sin^2 \phi_m \sin^2 \alpha_0}} \right), \quad \phi_1 \leq |\phi_m| \leq \phi_2 \\
\text{otherwise.}
\]

\[
\phi_1 = \arccos \left( \frac{\sin \alpha \cdot \sin \phi_m \cdot \sin \alpha_0}{\alpha \cos \beta_m - \cos \alpha} \sqrt{1 - \sin^2 \phi_m \sin^2 \alpha_0} \right) - \alpha, \quad 0 \leq \beta_m < \arccos \left( \frac{\sin \alpha_0}{\alpha} \right)
\]

\[
\arccos \left( \frac{\sin \alpha \cdot \sin \phi_m \cdot \sin \alpha_0}{\alpha \cos \beta_m - \cos \alpha} \sqrt{1 - \sin^2 \phi_m \sin^2 \alpha_0} \right) - \alpha, \quad 0 \leq \beta_m \leq \pi/2
\]
A Generalized 3-D Model for Macrocell Environment.  

\[
\begin{align*}
 r_m(\phi_m, \beta_m, \alpha) &= \frac{d \csc(\alpha + \phi_m) \sec \beta_m \sin \alpha}{\sqrt{a^2 + b^2 \cos^2 \beta_m + a^2 \sin^2 \beta_m}}, P_1 \\
 V &= \frac{V_{sphero}d}{2} - 2V_1 \\
 V &= \frac{2\pi bd \sin \alpha}{3n} (a^2 + d \sin \alpha(a - d \sin \alpha)) \\

\end{align*}
\]

Derivations … PDF of AoA Observed at MS.

\[
p(r_m, \phi_m, \beta_m) = \frac{f(x_m, y_m, z_m)}{\int f(x_m, y_m, z_m) \, dx_m} \\
J(x_m, y_m, z_m) = \begin{vmatrix}
\cos \beta_m \sin \phi_m & r_m \cos \beta_m \cos \phi_m & -r_m \sin \beta_m \sin \phi_m \\
\cos \beta_m \cos \phi_m & -r_m \cos \beta_m \sin \phi_m & -r_m \sin \beta_m \cos \phi_m \\
\sin \beta_m & r_m \cos \beta_m & 0 \\
\end{vmatrix}^{-1} \\
p(\phi_m, \beta_m) = \begin{cases}
\frac{a d^2 \csc^2(\alpha + \phi_m) \sec^2 \beta_m \sin^2 \alpha}{2\pi b(a^2 + d \sin \alpha(a - d \sin \alpha))}, & P_1 \\
\frac{a \cos \beta_m \csc \alpha \left(a^2 \csc^2 \beta_m + a^2 \sin^2 \beta_m\right)^{3/2}}{2\pi bd(a^2 + d \sin \alpha(a - d \sin \alpha))}, & P_2.
\end{cases}
\]
Simulation Results.

- Joint PDF of AoA at MS.
- Marginal PDFs of azimuth and elevation AoA at MS.
- Marginal PDFs of azimuth and elevation AoA at BS.
- Joint PDF of azimuth AoA and ToA at MS and BS.
- Joint PDF of Elevation AoA and ToA at MS and BS.

Joint PDF of AoA Observed at MS.

\[ p(\phi_m, \beta_m) = \begin{cases} \frac{a^2 \cos^2(\alpha + \rho_m) \sec^2 \beta_m \sin^2 \alpha}{2 \sin(a^2 + d \sin \alpha (\alpha - d \sin \alpha))} \times \frac{a^2 \beta_m \cos \alpha (\frac{a^2 \cos \beta_m + b^2 \sin^2 \beta_m}{2a^2 + b^2 \sin \alpha (\alpha - d \sin \alpha)})^{3/2}}{2 \pi b(a^2 + d \sin \alpha (\alpha - d \sin \alpha))}, & P_1 \\
\frac{1}{P_2} & P_2 \end{cases} \]

Joint pdf of the AoA seen at the MS (\(h_t = 100 \text{ m}, d = 800 \text{ m}, a = 100 \text{ m}, b = 50 \text{ m}, \text{ and } \alpha = 2^\circ\)).
Marginal PDF of Azimuth AoA Observed at MS.

\[ p(\theta_m) = \frac{\beta_m}{\sigma_m^2} \int_{-\beta_m}^{\beta_m} p(\phi_m, \beta_m) \, d\beta_m + \int_{-\beta_m}^{\beta_m} p(\phi_m, \beta_m) \, d\beta_m. \]

\[ p(\phi_m) = \frac{1}{2\pi \beta_m} \left( \frac{\pi}{\beta_m} \right) \exp \left( -\frac{\beta_m^2}{2\sigma_m^2} \right) \times \left\{ \begin{array}{l} \frac{\beta_m}{\sigma_m^2} + d \sin \alpha (\alpha - d \sin \alpha) \\ \frac{\beta_m}{\sigma_m^2} \sin^2 \alpha + a^2 \csc \alpha \\ \frac{1}{\alpha} \sqrt{a^2 + b^2 - (b^2 - a^2) \cos(2\beta_m)} \end{array} \right\} \]

Marginal pdf of the AoA in the azimuth plane ($\theta_m = 100$ m, $d = 800$ m, $a = 100$ m, $b = 50$ m, and $\alpha = 2^\circ$).

Marginal PDF of Elevation AoA Observed at MS.

\[ p(\beta_n) = \int_{-\beta_n}^{\beta_n} p(\phi_n, \beta_n) \, d\phi_n + \int_{-\beta_n}^{\beta_n} p(\phi_n, \beta_n) \, d\phi_n. \]

\[ p(\phi_n) = \frac{1}{2\pi \beta_n} \left( \frac{\pi}{\beta_n} \right) \exp \left( -\frac{\beta_n^2}{2\sigma_n^2} \right) \times \left\{ \begin{array}{l} \frac{\beta_n}{\sigma_n^2} \sin^2 \alpha \\ \frac{2}{\beta_n} \cos(\alpha - \beta_n) - 1 \cos(\alpha - \beta_n) \\ \frac{2}{\beta_n} \sin \beta_n \csc \alpha \sin \alpha \\ \frac{2}{\beta_n} \sec \beta_n \csc \alpha \sin \alpha \\ \frac{2}{\beta_n} \tan \beta_n \csc \alpha \sin \alpha \\ \frac{2}{\beta_n} \csc \beta_n \csc \alpha \sin \alpha \\ \frac{2}{\beta_n} \csc \beta_n \csc \alpha \sin \alpha \end{array} \right\} \]

Marginal pdf of the AoA in the elevation plane for proposed model ($\theta_n = 100$ m, $d = 800$ m, $a = 100$ m, and $b = 50$ m).
Statistics Observed at BS.

PDF of Azimuth and Elevation AoA observed at BS.

\[ p(\phi_0, \beta_0) = \begin{cases} 
\frac{a \cos \alpha \sec^2 \beta_0 (\rho_0^2 - \rho_{\min}^2)}{2 \pi \beta_0 \sin(\alpha - \phi_0) \sin(\beta_0 - \beta_{\min})}, & -\alpha \leq \phi_0 \leq \alpha \text{ and} \\
0, & \beta_{\min} \leq \beta_0 \leq \beta_{\max} \text{ otherwise.}
\end{cases} \]

Marginal pdf of the AoA in the azimuth plane seen at the BS \( \theta_T = 100 \) m, \( \phi = 500 \) m, \( \alpha = 100 \) m, and \( b = 50 \) m.

Marginal pdf of the AoA in the elevation plane seen at the BS \( \phi = 800 \) m, \( \alpha = 100 \) m, \( b = 50 \) m, and \( b_0 = 100 \) and 50 m.
Derivations...

\[ \rho_{12} = \begin{cases} 1 & \left( a^2 + b^2 \tan^2 \beta_b \right) \left( a^2 \tan \beta_b + b^2 \cos \phi_b \right) \\ -b \sqrt{a^2 - d^2} (b^2 + a^2 \tan^2 \beta_b) + a^2 (2bd \cos \phi_b \tan \beta_b - h_t^2) + b^2 d^2 \cos^2 \phi_b \end{cases} \]

\[ \rho_{12} = \begin{cases} 1 & \left( a^2 + b^2 \tan^2 \beta_b \right) \left( a^2 \tan \beta_b + b^2 d \cos \phi_b \right) \\ +b \sqrt{a^2 - d^2} (b^2 + a^2 \tan^2 \beta_b) + a^2 (2bd \cos \phi_b \tan \beta_b - h_t^2) + b^2 d^2 \cos^2 \phi_b \end{cases} \]

\[ \phi_b \geq \phi_0 \text{ or } \beta_b \geq \arctan \left( \frac{h_t}{\sqrt{a^2 - d^2}} \right) \]

\[ \frac{h_t}{\tan \beta_b} \]

\[ p(\phi_m, \beta_m) = \begin{cases} \frac{a^2 \csc^3 (\alpha + h_m) \sin^2 \beta_m \sin^2 \varphi}{2 \pi b (a^2 + d \sin \alpha (\alpha - d \sin \alpha))} & ; P_1 \\ \frac{\cos \beta_m \csc \alpha \left( \frac{a^2 \beta_m \sin^2 \beta_m + b^2 \sin^2 \beta_m}{2 a bd (a^2 + d \sin \alpha (\alpha - d \sin \alpha))} \right)^{3/2} & ; P_2 \end{cases} \]

Joint and Marginal PDFs of ToA.

\[ p(\tau, \phi_m, \beta_m) = \frac{1}{8 \pi^3 (\cos \beta_m \cos \phi_m - \tau + h_t \sin \beta_m)^4} \]

\[ \times \left( \frac{\sqrt{d^2 - r^2}}{d r} \right)^2 \]

\[ \times \left( r^2 + d^2 - 2 \tau (d \cos \beta_m \cos \phi_m + h_t \sin \beta_m) \right) \]

\[ \times \cos \beta_m \]
### A Generalized 3-D Model for Macrocell Environment

**[Nawaz et al., IEEE Trans. on Veh. Technol.] [J01], [C01], [C02], [C03]**

<table>
<thead>
<tr>
<th>Scattering Models</th>
<th>Targeted Environment</th>
<th>Elevated BS</th>
<th>Directional Antenna at BS</th>
<th>Modeling of Scattering Region</th>
<th>Substitutions to obtain the statistics of other models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed.</td>
<td>Macrocell</td>
<td>Yes.</td>
<td>Yes.</td>
<td>3D semi-spheroid (i.e., different major and minor axes), centered at MS.</td>
<td>$\alpha = \alpha_{\text{max}}$.</td>
</tr>
<tr>
<td>Janaowary [9]</td>
<td>Macrocell</td>
<td>Yes.</td>
<td>No.</td>
<td>3D semi-spheroid (i.e., different major and minor axes), centered at MS.</td>
<td>$\alpha = \alpha_{\text{max}}$, $b_1 = 0$, and $b = 0$.</td>
</tr>
<tr>
<td>Oktlak et al. [8]</td>
<td>Not specified.</td>
<td>No.</td>
<td>No.</td>
<td>3D hemispheroid (i.e., same major and minor axes), centered at MS.</td>
<td>$\alpha = \alpha_{\text{max}}$, $V = A_x$, and $b = 0$.</td>
</tr>
<tr>
<td>Baltzis et al [7]</td>
<td>Macrocell</td>
<td>Yes.</td>
<td>No.</td>
<td>2D circular disc, centered at MS.</td>
<td>$h_1 = 0$, $\beta_{\text{rad}} = 0$, and $V = A_x$.</td>
</tr>
<tr>
<td>Petros et al. [10]</td>
<td>Macrocell</td>
<td>No.</td>
<td>Yes.</td>
<td>2D circular disc, centered at MS.</td>
<td>$\alpha = \alpha_{\text{max}}$, $h_1 = 0$, $\beta_{\text{rad}} = 0$, and $V = A_x$.</td>
</tr>
<tr>
<td>Etel et al. [1]</td>
<td>Macrocell/Microwave</td>
<td>No.</td>
<td>No.</td>
<td>2D circular disc, centered at MS / 2D elliptical disc with focus at MS and BS.</td>
<td>$\alpha = \alpha_{\text{max}}$, $h_1 = 0$, $\beta_{\text{rad}} = 0$, and $V = A_x$.</td>
</tr>
<tr>
<td>Khan et al. [5]</td>
<td>Macrocell/Microwave</td>
<td>No.</td>
<td>No.</td>
<td>2D circular elliptical disc (for macrocell $a = b$, i.e., circular disc centered at MS).</td>
<td>$\alpha = \alpha_{\text{max}}$, $h_1 = 0$, $\beta_{\text{rad}} = 0$, and $V = A_x$.</td>
</tr>
</tbody>
</table>
PDF of Azimuth AoA Observed at MS for Gaussian SDF

\[
p(\phi_m) = \begin{cases} 
\frac{64\pi^2 \alpha}{3E} \cos^2 \beta_m \left( \frac{\sin \alpha \pi}{\sqrt{\sigma_\alpha^2 \cos \beta_m}} \right) \\
\frac{64\pi^2 \alpha}{3E} \cos^2 \beta_m \left( \frac{\alpha + \phi_m}{\sqrt{\sigma_\alpha^2 \cos \beta_m}} \right) 
\end{cases} : F_1 \\
\frac{\sigma_\alpha^2 \alpha^2}{3E} \left( \frac{\alpha + \phi_m}{\sqrt{\sigma_\alpha^2 \cos \beta_m}} \right)^{3/2} : F_2
\]

Marginal PDF of azimuth AoA seen at MS, \( \sigma_\alpha = 50, \alpha = 15, d = 800m, \) and \( h = 100m \)

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PDF of Azimuth AoA Observed at BS for Gaussian SDF

\[
p(\phi_b) = \frac{\sigma_\alpha \pi \alpha \left( 2\sigma_\alpha^2 - \alpha^2 + \alpha^2 \cos(2\phi_b) \right) \exp \left( \frac{-\alpha^2 \cos^2 \phi_b}{\sigma_\alpha^2} \right)}{2 \sigma_\alpha \sec \phi_b}
\]

Marginal PDF of azimuth AoA seen at BS for different values of beam-width \( \alpha \) along with measurement values provided in [24], \( \sigma_\alpha = 230, \alpha = 15, d = 1.5km, \) and \( h = 100m \)
A Generalized 3-D Model is proposed, which can be deduced to other 2-D and 3-D scattering models in literature.

- Elevated BS employing a directional antenna is considered.
- 3-D scattering region (flexible for different major and minor axes).
- Closed form expressions for Spatio-temporal characteristics of up and down radio links are derived.
- Results are obtained for Both uniform and Gaussian scatter densities.
- Comparison of AoA observed at BS with measured data set is provided.
- A comprehensive analysis on the basis of obtained theoretical results is presented.

Brief Outline:

- **Introduction**
  - Basics of Multipath channels and Cellular Environments.
  - Scope and Significance of Research Topic.

- **Proposed Research Work**
  - **Part I:** Physical Modeling of cellular mobile channels in 3-D radio propagation environments.
  - **Part II:** Characterizations of the 3-D propagation channel for Doppler shift spectrum.
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- **Deliverables**
  - Research Publications in Journals.
  - Conference Proceedings.

- **Summary**
  - Conclusions and Future research directions.
Characterizations of The 3-D Propagation Channel for Doppler Spectrum.

Part II

Mobility is considered

Literature Survey.

<table>
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<tr>
<th>Scattering Models</th>
<th>Corresponding Cellular Environment</th>
<th>Used Scatter Density</th>
<th>Used dimensions to model scatterers.</th>
<th>Elevated BS</th>
<th>Considered Directional antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrus et al. [10]</td>
<td>Macrocell</td>
<td>Uniform</td>
<td>2-D</td>
<td>No.</td>
<td>at BS.</td>
</tr>
<tr>
<td>Lotter et al. [11]</td>
<td>Pico-,micro, and Macrocell</td>
<td>Gaussian</td>
<td>2-D</td>
<td>No.</td>
<td>at BS.</td>
</tr>
<tr>
<td>Lopez et al. [12]</td>
<td>Macrocell</td>
<td>Gaussian</td>
<td>2-D</td>
<td>No.</td>
<td>at BS.</td>
</tr>
<tr>
<td>Castellon et al. [13]</td>
<td>Macrocell</td>
<td>Gaussian</td>
<td>2-D</td>
<td>No.</td>
<td>at BS.</td>
</tr>
<tr>
<td>Iqbal et al. [14]</td>
<td>Macrocell</td>
<td>Uniform / Gaussian</td>
<td>2-D</td>
<td>No.</td>
<td>at MS and BS</td>
</tr>
<tr>
<td>Shouxing [22]</td>
<td>Macrocell</td>
<td>Uniform</td>
<td>3-D / 2-D</td>
<td>Yes.</td>
<td>No.</td>
</tr>
</tbody>
</table>
Problems statement.

- For the case of 2-D models, both for uniform and Gaussian scatter distributions the effect of directional antenna at BS on the Doppler shift characteristics are comprehensively presented in the literature. However, such study for 3-D propagation models is missing in the literature.

Scope of Research Part II.

Characterization of the 3-D Propagation Channel for Doppler Spectrum

- A **generalized 3-D analytical model** is proposed which employs a directional antenna at elevated BS and considers the mobility of MS.
- The **effect of directional antenna** on statistic distributions of power, Doppler spectrum, and Angle-of-Arrival (AoA) for 3-D radio propagation environment is intensively analyzed.
- An analytical relationship of **joint and marginal Probability Density Function** (PDF) of azimuth and elevation AoA with Doppler shift is derived.
- A study to gauge the **impact of direction of MS's motion and velocity** on the characteristics of Doppler shift distribution for uniform and Gaussian scatter densities is presented.
- **Comparative analyses** of the proposed Doppler characteristics with those provided in literature for both 2-D and 3-D propagation models with uniform and Gaussian scatter densities are presented.
Model.

\[ f_m = \frac{v}{c} f_c \]

\[ f_{DS} = f_m \cos \theta_m \cos \beta_m \]

\[ \phi_m = \phi_b - \cos^{-1} \left( \frac{\gamma}{\cos \beta_m} \right) \]

\[ \gamma = \cos \theta_m \cos \beta_m \]

Part II

Derivations ...

\[ l_{\text{hm}}(\alpha, \phi_m, \beta_m) = r_{m, \text{max}} \]

\[ + \sqrt{r_{m, \text{max}}^2 + P_{\text{LoS}}^2 - 2r_{m, \text{max}}(d \cos \beta_m \cos \phi_m + h_t \sin \beta_m)} \]

\[ p(l, \phi_m, \beta_m) = \frac{p(r_m, \phi_m, \beta_m)}{|J(l, \phi_m, \beta_m)|} \]

\[ p(r_m, \phi_m, \beta_m) = f(x_m, y_m, z_m) r_m^2 \cos \beta_m \]

\[ J(l, \phi_m, \beta_m) = \left| \frac{\partial r_m}{\partial l} \right|^{-1} = \frac{2(d \cos \beta_m \cos \phi_m - l + h_t \sin \beta_m)^2}{P_{\text{LoS}}^2 + l^2 - 2l(d \cos \beta_m \cos \phi_m + h_t \sin \beta_m)} \]

\[ p(l, \phi_m, \beta_m) = \left\{ \begin{array}{c} f(x_m, y_m, z_m) \left( P_{\text{LoS}}^2 - l^2 \right) \\ x \cos \beta_m \cos ^4 (d \cos \beta_m \cos \phi_m - l + h_t \sin \beta_m) \end{array} \right\} \]
Derivations ...

\[ p_r = p_\alpha \left( \frac{l_p}{l_{\text{LoS}}} \right)^{-\eta} \]

\[
p(r, \phi_m, \beta_m) = \left. \frac{p(l_p, \phi_m, \beta_m)}{J(l_p, \phi_m, \beta_m)} \right|_{l_p = l_{\text{LoS}}/(p_\alpha)}^{-1/n}
\]

\[
p(r, \phi_m, \beta_m) = \left\{ \begin{array}{l}
p_{\text{LoS}} \left( \left( \frac{p_\alpha}{p_0} \right)^{-2/n} - 1 \right)^2 f(x_m, y_m, z_m) \\
8np_\alpha \sec \beta_m \left( \frac{p_\alpha}{p_0} \right)^{\frac{2+\eta}{n}} \\
4 \left( l_{\text{LoS}} + l_{\text{LoS}} \left( \frac{p_\alpha}{p_0} \right)^{-2/n} - 2 \left( \frac{p_\alpha}{p_0} \right)^{-1/n} (d \cos \beta_m \cos \phi_m + h_t \sin \beta_m) \right) \\
(d \cos \beta_m \cos \phi_m - l_{\text{LoS}} \left( \frac{p_\alpha}{p_0} \right)^{-1/n} + h_t \sin \beta_m)^4 \end{array} \right\}
\]

Model.

\[
p(r, \gamma, \beta_m) = \left. \frac{p(r, \phi_m, \beta_m)}{J(r, \phi_m, \beta_m)} \right|_{\phi_m = \phi_0 - \cos^{-1}(\gamma \cos \beta_m)}
\]

\[
p(r, \gamma, \beta_m) = \sum_{i=1}^{2} \left\{ \left( \frac{l_{\text{LoS}}(\xi^2 - 1)^2 \xi^{\eta+1} f(x_m, y_m, z_m)}{8np_\alpha \sqrt{1 - \gamma^2 \sec^2 \beta_m}} \right) \right. \\
\times \left. \left( (l_{\text{LoS}} + l_{\text{LoS}}(\xi^2 - 2(\cos \beta_m \cos \phi_i + h_t \sin \beta_m))) \right) \right. \\
\left. (d \cos \beta_m \cos \phi_i - \xi l_{\text{LoS}} + h_t \sin \beta_m)^4 \right\}
\]

\[
\xi = \left( \frac{p_\alpha}{p_0} \right)^{-1/n}
\]

\[
\phi_i = \begin{cases} 
\phi_0 + \cos^{-1}(\gamma \sec \beta_m), & i = 1 \\
\phi_0 - \cos^{-1}(\gamma \sec \beta_m), & i = 2
\end{cases}
\]
Derivations ...

\[ p(p_r, \gamma) = \cos^{-1}(\gamma) \]

\[ p(\gamma) = \int_0^{\beta_m} p(p_r, \gamma, \beta_m) d\beta_m \]

\[ p(\gamma) = \int_0^{p_o} p(p_r, \gamma) dp_r \]

\[ p_u = p_o \quad p_t = p_o \left( \frac{h_{\text{im}}}{h_{\text{LOS}}} \right)^{-\alpha} \]

Effect of Direction Antenna on Distribution Characteristics of Doppler Spectrum.

The PDF of Doppler shift (\( \gamma \)) for different beam-widths (\( \alpha \)) of directional antenna,\( (d = 800\text{m}, a = 100\text{m}, b = 30\text{m}, h_1 = 150\text{m}, \phi_e = 90^\circ, \alpha = 2, \text{and } p_0 = 1\text{ W}) \)

\[ \gamma = f_{\text{DS}} / f_{\text{m}} \]

\[ \alpha \text{ [degrees]} \]

\[ \log_{10}[p(\gamma)] \]

\[ 0.5 \quad 0 \quad 0.5 \quad 1 \quad -0.5 \quad -1 \quad 2 \quad 4 \quad 6 \quad 8 \]
Effect of Direction of MS’s Motion on Distribution Characteristics of Doppler Spectrum.

The distribution of normalized Doppler spread in correspondence with direction of MS’s motion, \((d = 800\text{m}, a = 100\text{m}, b = 30\text{m}, h = 150\text{m}, \phi = \phi_{\text{max}}, \alpha = 2, p_s = 1\text{ W})\)

Effect of Scatterers in Elevation plane on the distribution characteristics of Doppler Spectrum.

The PDF of normalized Doppler shift in correspondence with the ratio between radii of scattering-region’s major and minor axes (i.e., \(a/b\)) and for the cases of directional and omnidirectional antennas, \((d = 800\text{m}, a = 100\text{m}, b = 30\text{m}, h = 150\text{m}, \alpha = \alpha_{\text{max}}, p_s = 1\text{ W}, \phi_{\phi} = 90^\circ)\)
Brief Outline:

- **Introduction**
  - Basics of Multipath channels and Cellular Environments.
  - Scope and Significance of Research Topic.

- **Proposed Research Work**
  - **Part I**: Physical Modeling of cellular mobile channels in 3-D radio propagation environments.
  - **Part II**: Characterizations of the 3-D propagation channel for Doppler shift spectrum.
  - **Part III**: Performance analysis of handover procedures in 3-D cellular propagation environments.

- **Deliverables**
  - Research Publications in Journals.
  - Conference Proceedings.

- **Summary**
  - Conclusions and Future research directions.

**Handoff Scenario.**

Part III

![Handoff Scenario Diagram]
Literature Survey.

- Influence of velocity on the Handover.
    - Geometrically based analysis.
    - Influence of Velocity on the HO.
    - Direction of MS’s motion is assumed fixed as moving directly towards the target BS.

- Geometrically-based analysis of HO performance.
  - [Qureshi et al., 2010, Proc. of IEEE Int. Conf. Wireless Commun.] [26]
    - Geometrically based analysis.
    - Impact of propagation environment, direction and velocity of MS’s motion on the HO.

Scope of Research Part III:

Performance Analysis of Handoff Procedures in Cellular Environments

- A geometrically based comprehensive analysis for the performance of handoff procedures in cellular networks is presented.

- A study is presented to analyze the effects of propagation environments on the performance of Handoff process.

- An analysis is presented to measure the impact of direction and velocity of MS's motion on the performance of handoff margin in cellular networks.

- Relationship for the ratio between the length of overlapping region and radius of cell, \( \delta_{HO} = d_{HO}/r_c \), required to achieve a certain handoff margin is proposed.
Performance analysis of handover procedures in 3-D cellular propagation environments. [C04]

\[ p_{r,i}(d_i) = K_1 - K_2 \log_{10}(d_i) \]

\[ p_{a,i}(d, w) = \frac{1}{d_{i0}} \int_{d_{i0}}^d p_{r,i}(x) dx \]

\[ p_{a,i}(d_i) \leq p_{th} \leq \max(iP_{th}) \]

\[ \tau_{	ext{HARQ}} = \frac{1}{v}(g - m) \]

\[ m = \sec \theta_{HO} \left( \frac{d}{2} - d_1 \cos \Psi_1 \right) \]

\[ g = -d_1 \cos(\theta_{HO} + \Psi_1) + \sqrt{r_2^2 + r_3^2 + d_1^2 \cos^2(\theta_{HO} + \Psi_1)} \]
Part III

Performance analysis of handover procedures in 3-D cellular propagation environments. [C04]

\[ \tau_{\text{marg}} = \frac{1}{v} (g - m) \]

\[ m = \frac{-d_1^2 + d_2^2}{2(d_2 \cos(\Psi_2 - \theta_{10}) + d_1 \cos(\Psi_1 + \theta_{10}))} \]

\[ g = \frac{1}{10^{2\alpha/K_2} - 1} \left( 10^{2\alpha/K_2} d_2 \cos(\Psi_2 - \theta_{10}) + d_1 \cos(\alpha_1 + \theta_{10}) \right. \]
\[ \left. -\frac{1}{2} \left( -4 \left( 10^{2\alpha/K_2} - 1 \right) (10^{2\alpha/K_2} d_2^2 - d_1^2) + 4 \left( 10^{2\alpha/K_2} d_2 \cos(\Psi_2 - \theta_{10}) \right)^2 \right)^{1/2} \right) \]

\[ \delta_{\text{HO}} = \frac{2 v \tau_{\text{marg}} \cos(\theta_{\text{HO}})}{d_{\text{BS}} + v \tau_{\text{marg}} \cos(\theta_{\text{HO}})} \quad \text{for } \Psi_1 = 0^\circ \text{ and } \theta_{\text{HO}} = 0^\circ \]
Part III

Performance analysis of handover procedures in 3-D cellular propagation environments. [C04]

The handoff margin, $\tau_{\text{mag}}$, in correspondence with velocity, $v$, of MS for different angles of MS's motion, $\theta_{\text{HO}}$ by using the residual power ratio, $(\eta_1 = 6\,\text{dB}, d_{BS} = 1000\,\text{m}, d_1 = 100\,\text{m}, K_2 = 40\,\text{dB}, \Psi_1 = 40^\circ$, and $r_e = 700\,\text{m}$).

(a) Shown on linear scale (along Y-axis). (b) Shown in logarithmic scale (along Y-axis).

Part III

Performance analysis of handover procedures in 3-D cellular propagation environments. [C04]

The handoff time margin $\tau_{\text{mag}}$ in correspondence with velocity $v$ of MS for different values of residual power ratio, $(\theta_{\text{HO}} = 45^\circ, d_{BS} = 1000\,\text{m}, d_1 = 100\,\text{m}, K_2 = 40\,\text{dB}, \Psi_1 = 40^\circ$, and $r_e = 700\,\text{m}$).

(a) Shown on linear scale (along Y-axis). (b) Shown on logarithmic scale (along Y-axis).
Performance analysis of handover procedures in 3-D cellular propagation environments. [C04]

Part III

Brief Outline:

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- Deliverables
  - Research Publications in Journals.
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- Summary
  - Conclusions and Future research directions.

The effect of $K_3$ on handoff margin $\tau_{\text{margin}}$ in correspondence with velocity $v$ of MS for different values $K_3$, ($\theta_{\text{HE}} = 45^\circ$, $d_{\text{RS}} = 1000\,\text{m}$, $d_d = 100\,\text{m}$, $q_2 = 2dB$, $\Psi_1 = 40^\circ$, and $r_v = 700\,\text{m}$). (a) Shown on linear scale (along Y-axis), (b) Shown on logarithmic scale (along Y-axis).
**Related Publications**

**Journal:**


**Conference Proceedings:**


**Other Expected Publications:**

**Journal:**

- [J03] Syed Junaid Nawaz and Noor M. Khan, "Impact of propagation environment, velocity, and direction of mobile motion on the performance of Handover schemes", to submit.

**Conference Proceedings:**

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**Summary**

**Physical Modeling of Cellular Mobile Channels in 3-D Radio Propagation Environments.**
- A comprehensive comparative analysis of 2-D and 3-D propagation models found in literature.
- A new geometrically based generalized 3-D scattering model is proposed which can be deduced to any 3-D or 2-D scattering model proposed in literature for macro-cell environment with an appropriate choice of a few parameters.
- An analysis is presented to measure the effect of directional antenna at BS on the angular and temporal statistics.
- A study to investigate and establish the realistic choice of distribution for the scattering objects around MS is presented. To serve this purpose, the analytical expressions are derived for both uniform and Gaussian SDFs.

**Characterization of the 3-D Propagation Channel for Doppler Spectrum.**
- A generalized 3-D analytical model is proposed which employs a directional antenna at elevated BS and considers the mobility of MS.
- The effect of directional antenna on statistic distributions of power, Doppler spectrum, and Angle-of-Arrival (AoA) for 3-D radio propagation environment is intensively analyzed.
- Relationships of joint and marginal PDFs of azimuth and elevation AoA with Doppler shift are derived.
- A study to gauge the impact of direction of MS's motion and velocity of MS on the characteristics of Doppler shift distribution for uniform and Gaussian scatter densities is presented.
- Comparative analyses of the proposed Doppler characteristics with those provided in literature for both 2-D and 3-D propagation models with uniform and Gaussian scatter densities are presented.

**Performance Analysis of Handoff Procedures in Cellular Environments.**
- Author provides a geometrically based analysis for the performance of handoff procedures in cellular networks.
- A study is presented to analyze the effects of propagation environments on the performance of Hando process.
- An analysis is presented to measure the impact of direction and velocity of MS's motion on the performance of handoff margin in cellular networks.
Thank You.

References.

References.


References.


References.
