MITIGATING ISI IN CELLULAR NETWORKS FOR A 3D SCATTERRED MODEL

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ABSTRACT*— Temporal behavior of a wireless scattered channel characterizes the response associated with timed behavior of the scattered components of a signal. One of the important features of the temporal characteristic is the propagation path delay (PPD). By using the directional antenna at Base Station (BS), a special case of 3D semi-ellipsoid—the illuminated scattered regions, is taken into consideration. By varying the azimuth and elevation angles, the PPD characteristics are changed. These characteristics can be further changed by varying the distance d between BS and Mobile Station (MS) and by varying the height of BS with respect to the axis of semi-ellipsoid covering the surrounding area of the MS. It is observed that certain values of these parameters can help in mitigating Inter-symbol Interference (ISI) effect, by about 7%. The ISI can also be affected by taking the special cases of dimensions a and b of the ellipsoid. These variations in characteristics of the PPD are useful in design perspectives of a communication system.*

Keywords-base station; directional antenna; inter-symbol interference; propagation path delay.

I. INTRODUCTION

Eliminating and mitigating ISI has always been desired for improving the signal quality at the receiving station. The desired solution can be found using different signal processing techniques at the receiver end of a communication system. Using spatial techniques for the elimination of ISI is a proposed method in this paper.

It is easy to visualize the cellular mobile channel of the macro-cell mobile communication system using 3D scattering model, which offers more precise spatial and temporal statistics. While using directional antenna at BS, it is essential to have reliable understanding of radio propagation characteristics of transmission path between BS and MS that leads to the design of effective signal processing techniques [1]. To derive the probability of Angle of arrival of multi-paths, a 3D Geometric model is proposed in [8] as seen from BS and MS simultaneously in azimuth and elevation planes. A 3D scattering ellipsoidal model is presented in [12] for deriving direction of arrival (DoA) and direction of departure (DoD). The uplink/downlink probability distribution of DoA and Time of Arrival (ToA) statistics are derived in [10] with the assumption that scatterers are uniformly distributed in a 3D semi-ellipsoid. The probability distribution as well as power spectral density of AoA with non zero elevation plane is derived theoretically in [11] using 3D scattering model, where the field measurements are compared with the theoretical results.

In this paper, we have proposed the use of directional antennas at BS in 3D scattering model to achieve optimal performance in terms of mitigating ISI in a mobile channel of a wireless system. A 3D scattering model is proposed for macro-cell environment which assumes uniform distributions of scattering objects around MS and is confined in a semi-ellipsoid.

II. SYSTEM MODEL

The proposed 3D scattering model is shown in Fig 1 and Fig 2, where dimensions of the Semi-ellipsoid are b and a. The angles made by the signal arrival in azimuth and elevation planes at MS are symbolized by ϕ_m and β_m respectively. The BS is employed with a height h_t with a directional antenna of beam-width α above the ground. The semi-ellipsoid, partially illuminated due to directional antenna at BS, won't allow all the scatterers present in the ellipsoid. The volume of the region, whose scatterers are illuminated, is represented as I_{Region}.

The height of BS antenna ht is assumed to be constant for all the results and measured from ground reference. The MS is located at 0 meters with respect to ground. The semi-ellipsoidal region is assumed to have uniformly distributed scatterers.

Let us consider the maximum beam-width angle extended at BS to be αmax = $\sin^{-1}\frac{a}{d}$. Where αmax is the angle at which we get the exact ellipsoid and I_{Region} has a maximum possible value. For α < αmax the threshold azimuth angles at which the two different portions of illuminated regions are separated are ϕ_{th1} and ϕ_{th2}; Reference Equations are expressed in (1) and (2).

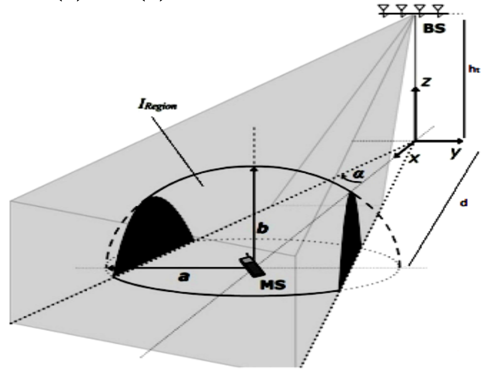

Figure 1. 3D scattering model showing semi-ellipsoid at MS.

$$\emptyset th1 = \begin{cases} \cos^{-1}\left\{\frac{d}{a\cos\alpha}\sin^2\alpha + \left(\frac{\cos\alpha}{a\cos\beta_m}\sqrt{(a\cos\beta_m)^2 - (d\sin\alpha)^2}\right)\right\} & ; lim_1 \\ \frac{\pi}{2} & ; lim_2 \end{cases} \quad \ldots\ldots\ldots (1)$$

$$\emptyset th2 = \begin{cases} \cos^{-1}\left\{\frac{d}{a\cos\alpha}\sin^2\alpha - \left(\frac{\cos\alpha}{a\cos\beta_m}\sqrt{(a\cos\beta_m)^2 - (d\sin\alpha)^2}\right)\right\} & ; lim_1 \\ \frac{\pi}{2} - \alpha & ; lim_2 \end{cases} \quad \ldots\ldots\ldots (2)$$

Where $lim_1 \rightarrow 0 < \beta_m < \cos^{-1}\frac{d\sin\alpha}{a}$

And $lim_2 \rightarrow \cos^{-1}\frac{d\sin\alpha}{a} < \beta_m < \frac{\pi}{2}$

The value of $\emptyset_{th1}$ at which $\beta = 0$ is $\emptyset_1$, whereas the value of $\emptyset_{th2}$ at which $\beta = 0$ is $\emptyset_2$. These angles are shown in Fig 2.

Now let us consider β_{thresh}, which is the threshold value of elevation angle at MS. The expression of β_{thresh} is in (3).

$$\beta_{thresh} = \begin{cases} \cot^{-1}\left\{\frac{ad\csc(\alpha+\phi_m)\sin\alpha}{b\sqrt{a^2 - d^2\csc^2(\alpha+\phi_m)\sin^2\alpha}}\right\} & ; lim_1 \\ 0 & ; \text{otherwise} \end{cases} \quad (3)$$

where $lim_1 \rightarrow |\phi_1| \leq \phi_m \leq |\phi_2|$. β_{thresh} is depicted in Fig 2. As we know that the illuminated ellipsoidal scattered region do not have the constant dimension a that's why r_m is taken instead of a constant value a. The expression of r_m is shown in (4).

$$r_m = \begin{cases} \sqrt{\frac{a^2b^2}{b^2\cos^2\beta_m + a^2\sin^2\beta_m}} & ; lim_1 \\ d\csc(\alpha+\phi_m)\sec\beta_m\sin\alpha & ; lim_2 \end{cases} \quad (4)$$

where It is interpreted that lim_1 is defined in two folds.

$lim_1 \rightarrow 0 < \beta_m < \beta_{thresh}$ or it can be defined as

$lim_1 \rightarrow \emptyset_{th1} < \emptyset_m < \emptyset_{th2}$

lim_2 can also be defined in two folds as:

$lim_2 \rightarrow \beta_{thresh} < \beta_m < \frac{\pi}{2}$, or it can be defined as

$lim_2 \rightarrow [-\emptyset_{th1} < \emptyset_m < \emptyset_{th1}$ and $\emptyset_{th2} < \emptyset_m < -\emptyset_{th2}]$

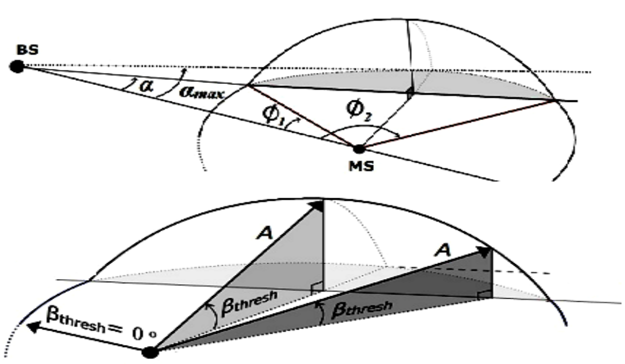

Figure 2. System model showing different angles of interest.

III. NUMERICAL RESULTS

Numerical results of this research paper have been described categorically in two folds. In first place, the radius b is considered to be less than the radius a (depicted as case A). Secondly, the radius b is considered to be greater than the radius a (depicted as case B). The above mentioned cases are elucidated for PPD characteristics at b>a and at b<a. These cases are explained below.

A. If b>a and 'd' increases [α = 5]

The ISI eliminating technique using spatial technique is presented here by considering a special case when the dimension b is greater than the dimension a of the semi-ellipsoid. If distance between the transmitter and receiver is very small, the PPD of the received signal is almost constant if scatterers are assumed to be uniformly distributed around MS. Fig 3 shows that the change in received PPD is almost constant if seen with respect to the azimuth and elevation angles assuming angle α to be less than αmax.

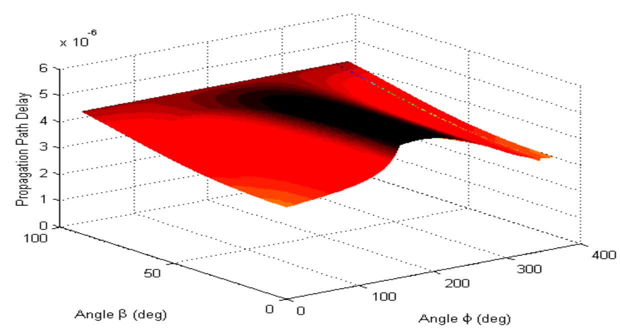

Figure 3. PPD (sec) characteristics for d=350, αmax =13.2°, b=100m and a=80m.

The distance d_{los} defined by the line of sight component of the signals received directly by the receiver is defined in (5).

$$d_{los} = \sqrt{d^2 + h_t^2} \quad (5)$$

We can define PPD, denoted by τ_{lim} as

$$\tau_{lim}(\emptyset_m, \beta_m) = \frac{r_m(\emptyset_m, \beta_m) + r_b(\emptyset_m, \beta_m)}{C}$$

Where c is velocity of light and $r_b(\emptyset_m, \beta_m)$ is the radius of illuminated signal originated at BS and it is defined in (6).

$$r_b(\emptyset_m, \beta_m) = \sqrt{r_m^2 + d_{los}^2 - 2r_m(d\cos\beta_m\cos\emptyset_m + h_t\sin\beta_m)}$$

(6)

The distance between BS and MS is assumed to be 350m provided αmax =13.2°. Lesser the distance between BS and MS, more planar is the graph and hence lower is the delay spread. Let us increase the distance between BS and MS such that angle α is less than αmax. Refer to Fig 4, from which it can be easily observed that the slope of the graph at lower and upper angles of azimuth angle, ϕ_m =180° decreases, which means the PPD is not constant for all angles of azimuth and elevation for larger values of distance d.

Fig 4 shows the effect of a larger physical distance between BS and MS. By increasing the distance between BS and MS, the value of αmax keep on decreasing. Fig 4 shows the PPD variations with respect to the angle of azimuth and elevation. The hump of the graph shows higher values at ϕ_m =180°, where the entire graph represents deviations at different values of azimuth and elevation angles. The different path delays at different angles of azimuth and elevation may cause ISI to happen as the delay spread increases with an increase in change among received PPD values.

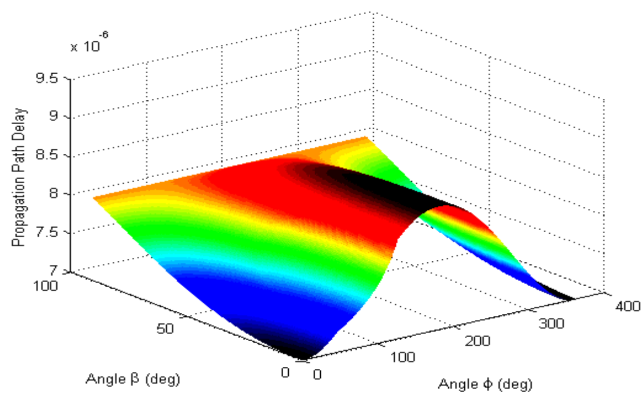

Figure 4. PPD (sec) characteristics for d=700, α_{max} =6.5°, b=100m and a=80m.

From Fig 5, it is observed that the effect of PPD is almost constant for a range of azimuth angle from β=0° to β=10°, or adding some tolerance it goes up to β =20°. To mitigate the effect of ISI, PPD from different paths must be kept constant at the MS receiver. For such a reason the DSP algorithm must be applied at MS receiver to accept only those signals which have almost constant PPD say from β = 0° to β = 10° keeping the change in angle ϕ_m very small.

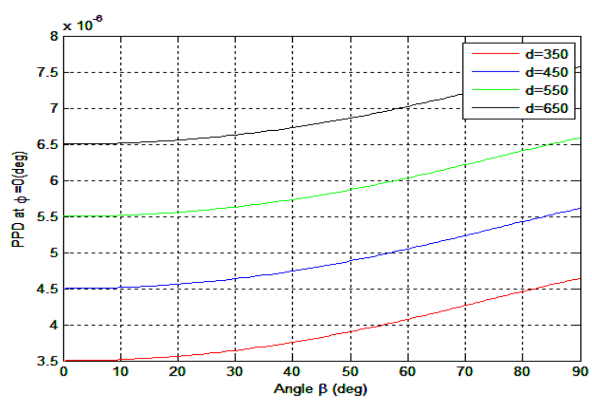

Figure 5. Effect of distance *d* on PPD (sec) characteristics.

Fig 6 and Fig 7 shows the characteristics of PPD assumed to be at constant distance and azimuth angle ϕ_m with respect to the elevation angle β. It is further observed that the PPD characteristics are almost constant near $\phi_m = 180^\circ$ for a high range of elevation angle β. It is interested to note that the Probability Density Function (PDF) of angle of arrival near $\phi_m = 0^\circ$ and $\phi_m = 180^\circ$ is relatively high [3, 4] that's why we are interested to receive the signals at $\phi_m = 0^\circ$ or for a range of azimuth angles from $\phi_m = 150^\circ$ to $\phi_m = 210^\circ$. From Fig 6 and Fig 7, a very small change in PPD is observed for the transition of angle ϕ_m near 0° and 180°.

B. If b<a, and 'd' Increases

If the dimensions of semi-ellipsoid is such that *b*<*a*, the characteristics of PPD with respect to azimuth and elevation angles are changed significantly. The PDF near $\phi_m = 0^\circ$ and $\phi_m = 180^\circ$ is greater than PDF between the mentioned angles [3, 4]. Unlike Fig 4, specifying elevation angle in the range from β=60° to β=90° for the whole range of azimuth angles ϕ_m the deviation in the received envelope of PPD plane decreases, which leads to a decrease in delay spread and hence ISI. This effect can be seen in Fig 8.

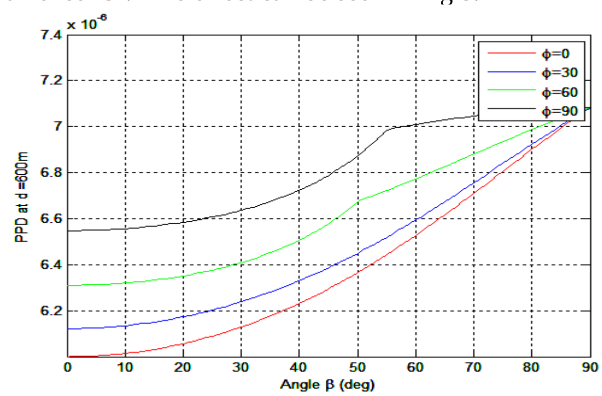

Figure 6. PPD (sec) characteristics for Φ=0° to Φ=90° for b>a.

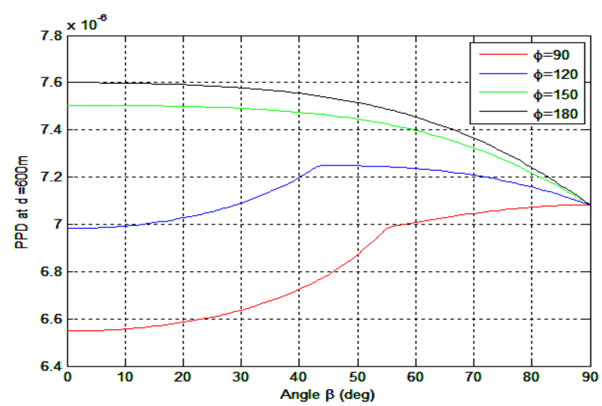

Figure 7. PPD (sec) characteristics for Φ=90° to Φ=180° for b>a.

Fig 9 and Fig 10 show the effect of decrease in the received envelope of PPD plane at the elevation angle ranging from β=60° to β=90° for the whole range of azimuth angle ϕ_m, which provides a simple solution in mitigating ISI.

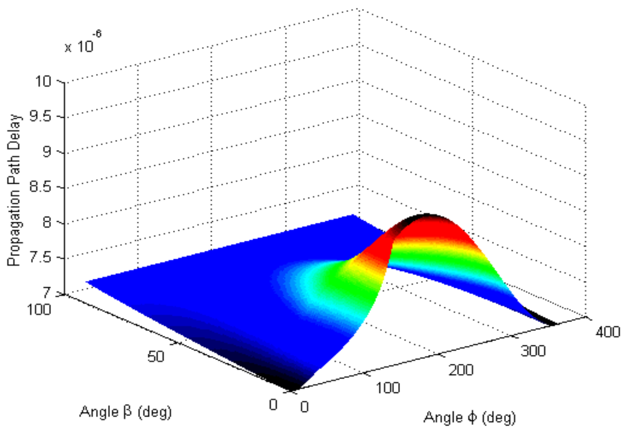

Figure 8. PPD (sec) characteristics for d=700, α_{max} =8.2°, b=30m and a=100m.

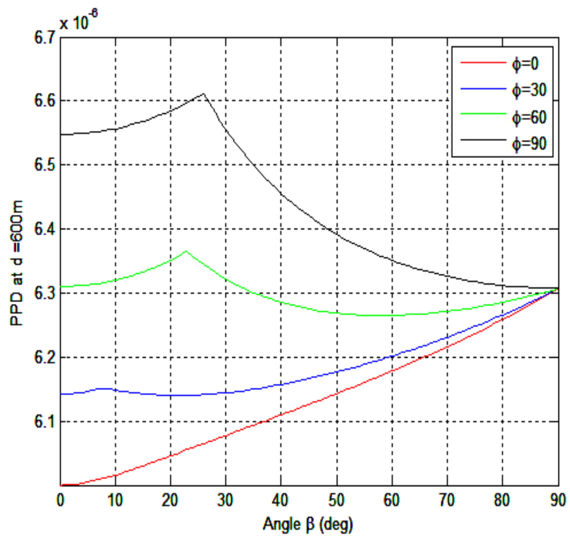

Figure 9. PPD (sec) characteristics for Φ=0° to Φ=90° for a>b.

IV. ALGORITHM EFFICIENCY

The algorithm if compared with the directivity of currently used receiving antenna at mobile station, provide 5-8% less ISI effect. The mobile stations are designed to provide less directivity in order to receive signals from every direction. This property enhances the effect of ISI as explained in previous section. Increasing directivity decreases the impact of ISI effect. Increasing directivity at certain angles of the receiving antennas, as suggested in previous sections, gives a satisfaction of using mobile station at any direction and at the same time decreasing ISI effect.

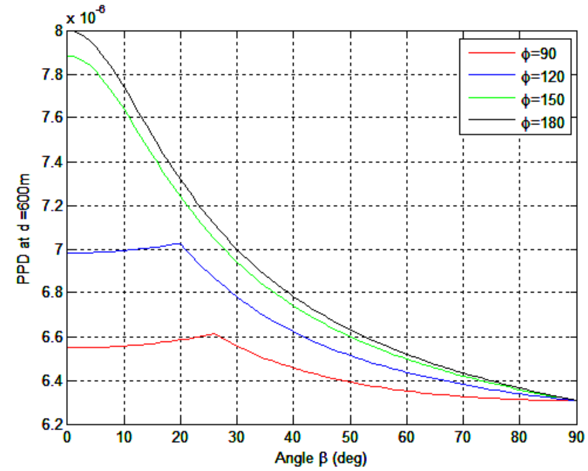

Figure 10. PPD (sec) characteristics for Φ=90° to Φ=180° for a>b.

V. CONCLUSIONS

A number of conclusions are derived from different observations. In very first place it is concluded that for *b*>*a*, provided the distance between BS and MS is small and taking the whole range of azimuth and elevation angles into consideration, the PPD spread is relatively very small which leads to a simple solution in mitigating ISI.

Secondly, it is concluded that at $\phi_m \approx 0^\circ$ and for *b*>*a*, the change in PPD is very small for the range of elevation angle from β=0° to β=10°. The PDF of received signal is greater at $\phi_m \approx 0^\circ$. The problem of mitigating ISI at $\phi_m \approx 0^\circ$ is that the change in PPD is significant for a small range of azimuth angles.

It is further analyzed that the condition *b*>*a*, provided the azimuth angle to fall in a range from $\phi_m = 150^\circ$ to $\phi_m = 210^\circ$, is a suitable option for mitigating the effect of ISI by decreasing the change in envelope of received PPD plane and hence the received symbol spread as:

- PDF of angle of arrival near $\phi_m = 180^\circ$ is greater,
- For larger values of angle of elevation β near $\phi_m = 180^\circ$, the change in PPD is relatively small, and
- Transition from $\phi_m = 180^\circ$ to any near-by angle, the change in PPD envelope plane is not very significant.

Moreover, it is also concluded that for *b*<*a* and applying DSP algorithms such that the received signal is accepted for the range of β=60 to β=90 and for the whole range of angle ϕ_m leads to a very small change in PPD, which is useful in mitigating the ISI effect as the received symbol spread at MS is decreased.

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