A new Time Variant Wideband Propagation Channel Model is presented for a User Location Applications in Third Generation mobile environments. The model considers evolutionary angle of arrival (AOA) and evolutionary time of arrival (TOA), based on the real instantaneous relative user equipment and base station position. The channel model proposed in the paper is used also in a link level simulator (LLS) to estimate realistic delay and angle of arrival coherence time, that is, the time in which position and time delay and angle of arrival for the received signal remain almost constant. In order to increase the time integration period and consequently reduce the error in geographical positioning, the maximum coherence time has to be known in the Time Delay and Angle Estimating Process. The new wideband propagation channel model will provide the Delay and Angle Estimating process with realistic Coherence Time and Doppler Spread. The model also provides spatial correlation matrices for different diversity BS antenna schemes and compares them with experimental results.

1 Introduction

Wireless User Equipment Positioning. Classical radiolocation techniques are based on Time-Of-Arrival (TOA) estimation of the signal transmitted between a UE (User Equipment) and a BS (Base Station). The use of angle of arrival (AOA) information introduces a new measure, which is uncorrelated with time-of-arrival (according to most propagation models). The use of this measure allows to reduce variance in location positioning or alternatively a smaller number of BS involved in the process of locating a UE. The Position Computing Function (PCF) processes the delay and angle estimates and the covariance matrix to obtain the geometric coordinates and their statistical variances for the UE to be located [Vidal,01].

Delay and angle coherence time. The location accuracy using AOA or TOA depends on the mobility of the UE: as the time correlation function of the fast fading becomes narrower (corresponding to high speed mobile), more diversity can be obtained from the use of multiple channel observations. However, in order to obtain meaningful channel parameters, the number of observed channels should span a time period in which the position of the mobile has not changed significantly. That is, the parameters to be measured (angles or delays) should not have changed during the integration time. Time integration reduces dramatically the error in positioning [Jativa,01]. The maximum time of integration is determined by the coherence time of delay and angle.

Propagation Channel Models

The channel model presented in this work is based on published papers on realistic models for the statistical properties of the ray scattering process (See section 2), and a new time evolutionary process for the parameters of the different rays is presented in section 3. Section 4 present expectations for temporal and spatial correlation of the model, and finally in sections 5 and 6, simulation results and conclusions are respectively explained.

2 Ray model

In Propagation Channel Models for mobile radio environments, due to multipath propagation in the radio channel several replicas of the transmitted signal are received from different directions and/or with different delays. The basic equation for Multipath Model is then assumed as (1).
The time-variant channel response is composed by \( L \) impinging waves. Each wave is characterized by complex amplitude, delay and incidence azimuth: \( [\alpha_l,\tau_l,\phi_l] \). Based on [Pedersen 00] the number of impinging rays is modeled as a Poisson variable \( P_L(L) = \frac{\hat{L}^L}{L!} \exp(-\hat{L}) \), where \( \hat{L} \) represents the mean number of simultaneous rays. The expected power of the waves conditioned on their azimuth and delay (2) can be modeled in typical urban environments as a Laplatian distribution for the PAS (Power Azimuth Spectrum, \( P(\phi) \)) and as a one sided exponential decaying distribution for the PDS (Power Delay Spectrum \( P(\tau) \)). The AOA distribution can be modeled by a Gaussian function and the TOA for each ray (delay) distribution can be modeled by a one-sided exponential decaying function.

\[
P(\phi,\tau) = P(\phi)P(\tau) = E\left\{ \sum_{l=1}^{L} [\alpha_l]^2 \delta(\phi - \phi_l,\tau - \tau_l) \right\}
\]

with \( P_A(\phi) \propto \exp\left(-\frac{1}{2} \frac{[\phi]}{\sigma_A}\right) \) \( \phi \in [-180^\circ, 180^\circ] \); \( P_D(\tau) \propto \exp(-\tau / \sigma_D) \) \( \tau \) \( \sigma_A \) and \( \sigma_D \) are respectively the Delay Spread (DS) and the Azimuth Spread (AS).

In [Iwai,93] time variant conditions are introduced for a mobile model channel through a birth-death process to control each path. Two probability density functions model this process: One sided exponential decaying distribution for a temporal separation \( (t_{ol}) \) between generation of wave \( l \) and wave \( l+1 \) and also one sided exponential decaying distribution for the average lifespan time of each scattered wave \( (\Delta t) \). In (4) \( \Delta t \) is the average lifespan time of a scattered wave and \( \hat{L} \) the average number of simultaneous impinging rays:

\[
f_{t_{ol}-t_{ol-1}}(t) = \frac{\hat{L}}{\Delta t} \exp\left(-\frac{\hat{L} t}{\Delta t}\right) \]

\[
f_{\Delta t}(t) = \frac{1}{\Delta t} \exp\left(-\frac{t}{\Delta t}\right)
\]

3 Time evolutionary model

To generate a time evolutionary channel model that varies with the relative position between UE and BS, distributions (2), (3) and (4) will be used to generate initial conditions for each one of the paths.

\[
h(t) = \sum_{l=1}^{L} [\alpha_\phi(\phi_l(t))][\alpha_\tau(\tau_l(t))][\alpha_l(t_{ol},\Delta t)][\delta(\phi - \phi_l(t))][\delta(\tau - \tau_l(t))]
\]

For the time period to analyze applying (2), (3) and (4) the following parameters will be created for the paths:

- Birth Time of the path: \( t_{ol} \) (See 4)
- Lifespan of the path: \( \Delta t \) (See 4)
- AOA in time \( t_{ol} \) : \( \phi_l(t_{ol}) = \phi_{LOS}(t_{ol}) + \delta \phi_l \), where \( \delta \phi_l \) is zero mean Gaussian distributed.
- Azimuthal amplitude \( \alpha_\phi(\phi_l(t_{ol})) \) is computed applying (3).
• TOA in time \( t_{ol} \): \( \tau_{l}(t_{ol}) = \tau_{LOS}(t_{ol}) + \partial \tau_{l} \), where \( \partial \tau_{l} \) is one sided decaying exponential distributed.
• Delay amplitude \( \alpha_{\tau}(\tau_{l}(t_{ol})) \) is computed applying (3).

Initially a single coordinate system is used to position BS, UE and AOAs and TOAs for all the generated paths. From initial AOA \( \phi(t_{ol}) \) and initial TOA \( \tau_{l}(t_{ol}) \) the here called "Reflection Angle" \( \rho \) (Figure 1) between the end-fire direction of an antenna array placed at the BS and the \( l \)-th Scattering line can be computed. The "Reflection Angle" is used to rotate the coordinate system and to facilitate the calculus of temporal variations for the delay (TOA) and for the angle of arrival (AOA), reproducing realistic environment conditions. A different rotation transformation must be done for each path. The \( l \)-angle \( \phi_{l}(t) \) and \( l \)-delay \( \tau_{l}(t) \) temporal variation depends on the real geometric UE position. To compute the azimuth and delay evolution in the rotated domain, the temporal scattering point displacement will be represented by \( \Delta(t) \) (see figure 1).

\[
\Delta(t) = \frac{Y'(x'(t)) + X'(t) l'_{y}(t)}{l'_{y}(t) + Y'} \quad \text{where} \quad l'_{x}(t) = l'_{x}(t_{0}) + v'_{x}(t - t_{0}) \quad l'_{y}(t) = l'_{y}(t_{0}) + v'_{y}(t - t_{0})
\]  

(\( l'_{x}(t), l'_{y}(t) \)) and (\( v'_{x}(t), v'_{y}(t) \)) are respectively UE position and speed in the rotated domain. \((Y', X'(t)) \) represents the relative BS-Reflection point distance also in the rotated domain. From (6) the instantaneous AOA and TOA for the \( l \)-path is:

\[
\phi_{l}(t) = \tan^{-1}\left(\frac{Y'}{X'(t) - \Delta(t)} \right) + \rho - 180^\circ \\
\tau_{l}(t) = \sqrt{Y^2 + (X'(t) - \Delta(t))^2} + \sqrt{Y_y^2(t) + (l_y'^{(2)}(t) - \Delta(t))^2} / c
\]

Finally, following [Iwai,93] recommendations the amplitude \( \alpha_{\tau}(t_{ol}, \Delta t_{l}) \) is assumed to vary as a half-period sine wave during the lifespan time \( t_{ol} < t < t_{ol} + \Delta t_{l} \), to justify shadowing and dense scattering phenomena. The maximum value \( \alpha_{\tau}(t_{ol}, 0.5\Delta t_{l}) \) is assumed as a Gaussian distributed random variable. In figure 2, the flowchart for implementation of this time-varying channel model is shown.

3 Temporal and Spatial Theoretical Correlation of the model

The time variant behavior of the channel due to the motion can be estimated measuring the channel coherence time. This parameter can be defined as a measure of the expected time duration over which the channel’s response is essentially invariant. This parameter is directly connected with the well known "Doppler spread", this is the fading bandwidth of the channel. The Doppler Spread \( f_{d} \) and the Coherence Time \( T_c \) are reciprocally related. As a measure of the Coherence Time the autocorrelation function of the channel response will be computed: \( R(\Delta t) \). An ideal Time invariant channel results highly correlated for all values of \( \Delta t \). The theoretical spaced Time Correlation function of the channel [Steele,93], is estimated assuming that amplitudes vary slower than the Doppler frequency, and the Doppler angle \( \theta_{l} \) (angle between UE Velocity Vector and Steering Vector) is a random variable uniformly distributed in (-\( \pi \), +\( \pi \)].

With \( J_{0} \) the zero-order Bessel function of the first kind:

\[
\Phi_{b}(0, \Delta t) = \frac{L}{2 \pi \Delta D} \left\{ \sum_{l=1}^{L} |h_{l}|^2 e^{2 \pi \Delta D \cos(\theta_{l}) \Delta t} \right\} = \frac{1}{2 \pi} \int_{0}^{\infty} \int_{0}^{\infty} e^{-\tau / \Delta D} e^{2 \pi \Delta D \cos(\theta) \Delta t} d\tau d\theta = J_{0}(2\pi \Delta D \Delta t)
\]  

(8)
Figure 1: Scattering process for a single $l$-wave.

Stage 1: Path Generation

Start

YES

$\rho - \phi(t)$

NO

$\rho \Delta t$

Birth-Death Ray Process:
Generations along $N$ slots of: $L_{sd} \Delta t$

[Itai,93]

Initial TOA, AOA, Amplitudes,
$\tau_i(t_d), \phi_i(t_d), \alpha_i(t_d, \Delta t)$

Temporal evolution:
$\phi_i(t), \tau_i(t), \alpha_i(t_d, \Delta t)$

Stage 2: Channel Generation

For $n=1$, $N$ Slots
For $m=1$, $\Delta t$, $\phi_i(t_d)$

Generate $h(t)$

End

Time Coherence,
Doppler Spread,
Spatial Correlation
Analysis

Figure 2: Flowchart for implementation of this time-varying channel model.
The Fourier Transform of the function in (8) called the theoretic doppler Power Spectrum results the well known Jake’s model shown in (9) for $|f| \leq \frac{f_{source}}{c}$:

$$S_h(f) = \int_{-\infty}^{+\infty} \Phi_h(0,\Delta t) \exp\{-j2\pi \Delta t \} d\tau = \frac{K}{(1 - \left( \frac{f.c}{f_{source}} \right)^2)^{1/2}}$$

The spatial correlation function at the BS, between two sensors ($m$ and $n$) is defined as [Pedersen, 98]:

$$\rho_{mn}(D) = E\left[h_m(t)h_n^*(t)\right]^2$$

with $D = \frac{2\pi d}{\lambda}$, the normalized spatial distance between two sensors separated $d$ Mts. Assuming jointly Gaussian processes modeling the radio waves, the envelope autocorrelation coefficient for the two received complex baseband signals can also be computed as:

$$\rho_{mn}(D) = E\left|h_m(t)h_n^*(t)\right|^2 = \frac{1}{\sqrt{2}\sigma_A} \int_{-\pi}^{+\pi} e^{jD\sin(\phi)} \left( e^{-\sqrt{2} \frac{\phi - \phi_{LOS}}{\sigma_A}} \right) d\phi$$

Assuming the Laplacian distribution for the PAS (3):

$$E\left[e^{jD\sin(\phi)}\right] = \sum_{n=-\infty}^{+\infty} J_n(D) \left( e^{jn\phi_{LOS}} e^{-\sqrt{2} \frac{\pi + \phi_{LOS}}{\sigma_A}} - (-1)^n e^{jn\phi_{LOS}} e^{-\sqrt{2} \frac{-\pi - \phi_{LOS}}{\sigma_A}} \right)$$

Figure 3. presents the theoretical envelope autocorrelation (10.c) for different Azimuth Spread ($\sigma_A$). General conclusion from figure 3 is that the decorrelation increases when the distance between sensor increases, the azimuth Spread increases and the average AOA becomes more similar to the broadside AOA $\phi_{LOS} = 0^\circ$.
5. Simulation Results

In this section a NLOS (Non Line Of Sight) scenario will be presented using the proposed time-evolutionary model. The parameters used in the simulation are obtained from realistic models proposed in [Pedersen 00] and [Iwai 93].

**Parameters (TDD UTRA Up Link)**

- $T_c = 0.244 \, \mu s$. Chip Time
- $T_{slot} = 2560 \, T_c$. Slot period

**Mobile Position**

- BS is in (0,0)Km.
- MS in $t_0$ is in (1Km,1Km). and it moves with $v = (30,70) \, Km/h$ ; $|v| = 76 \, Km/h = 21 \, mts/seg$
- The channel is analyzed from $t_0 + 1000 \, Slots$ to $t_0 + 2000 \, Slots$

- $f_{source} = 2GHz$

**Azimuth and Delay Parameters**

- $\sigma_A = 5.8^\circ$. Azimuth Spread
- $\sigma_D = 0.52 \, \mu s = 2.1 \, T_c$. Delay spread

**Ray Appearance Process**

- $\hat{L} = 25$. Mean Number of Simultaneous Rays
- $E[\Delta t_l] = 20 \, mts/|v| = 0.95 \, sg = 1520 \, slots$. Average Lifespan length
- $E[t_{ol+1} - t_{ol}] = \Delta t / \hat{L} = 38 \, msg = 60.8 \, slots$. Average Temporal ray separation

In the simulation here presented, the time span to analyze is 1000 TDD-UTRA Slots duration. There have appeared a total of 38 paths along the complete period.

Figure 4 (Left) shows the AOA (º) evolution with the number of slots, for the 38 appeared paths. Continue line corresponds to the Line Of Sight LOS-AOA. Although the path correspondent to LOS has not been used to generate the impulse channel response in stage 2 (See simulator flowchart) in this graphic it is depicted to compare with the AOA of all the secondary paths. With a more detailed studio of one of the path AOA, a 0.001º/slot variation was observed for most of the paths. Figure 4 (Right) shows the TOA (Chip periods) evolution with the number of slots, for the 38 appeared paths. The LOS-TOA is the minimum one. This path varies at a rate of 0.00025 Chip period /slot. Figure 5 shows the mean AOA compared with the AOA obtained for the LOS path.

Figure 6 represents the superimposed impulse response channel $h(\tau,t)$ for a $t=1..1000$ consecutive slots period (left) estimated with a 25% rolloff pulse shaping. On the right The impulse response channel for TOA=31,5 chips is depicted. This TOA value corresponds approximately to the minimum received delay and it is the meaningful for location applications.

Figure 7 (Left) shows the theoretical and the estimated Spaced Time Correlation function for the estimated channel represented in Figure 6. The right graphic corresponds to the Doppler Spectrum function of the channel. Fourier Transform of the estimated Spaced Time Correlation function is depicted with the theoretical Doppler spectrum of equation (9). This theoretical spectrum is obtained for the worst hypothetical case; the densest scattering environment.

When comparing channel autocorrelation in figure 6 (right) for TOA=31 chips, with the Spaced Time Function of the channel represented in figure 7 (Left), the most important differences are produced by the different number of simultaneous paths impinging in the BS. For the Spaced Time Correlation function computing, all the paths impinging along the 1000 slots are used, for TOA=30,5...42 chips. The behavior for this function is more similar to the Jake's Autocorrelation in (8).

Spatial correlation results for this simulation are shown jointly with the theoretical ones in figure 3(left). The "*" represent the correlation obtained from simulation ($\phi_{LOS} = 45^\circ$ and $\sigma_A = 5.8^\circ$).
Figure 4. AOA (°) evolution with the number of slots, for the 38 appeared paths and TOA (Chip periods) evolution with the number of slots, for the 38 appeared paths.

Figure 5. Mean AOA (°) evolution with the number of slots, and time evolution of the LOS component.

Figure 6. Temporal Channel Impulse Response and Autocorrelation channel for Time Delay =31 Chips.
9 Conclusions
New features for the wideband propagation channel model have been presented and demonstrated with the object of applying UE Location techniques:

- The time evolutionary path channel is always computed depending on the relative position between UE and BS. Spatial wave appearance and spatial wave duration distributions have been extended to temporal wave appearance and temporal wave duration distributions. Temporal evolution expressions are obtained for the scattered wave TOA and AOA.
- Coherence time and Delay spread can now be computed and modeled respectively from the Spaced Time Correlation and the Doppler Spectrum functions of this realistic channel model.
- The influence of strict power control on this evolutionary parameters has also been analyzed and shown that it does not influence significantly the results.
- The TOA coherence time can be obtained from the variation that the LOS delay suffers along the time. Simulations of section 8 have produced a $25 \times 10^{-5}$ Chips/slots variation for this delay and UE speed. For location applications this parameter will be estimated from the first path impinging to the BS, this is, from the wave impinging with a minimum delay or TOA.
- The AOA coherence time (See Figure 5) is obtained from the mean AOA and presents for this simulation a $10^{-3}$ degrees /slots rate

In location applications, from the variation obtained with the model channel presented here, for TOA and AOA, the integration time will be chosen to guarantee stationary conditions.

References


