Parametric Channel Modelling for Wireless Systems

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Outline

▷ Introduction
   ◦ Background & Motivation
   ◦ Channel Model Classification
   ◦ Parametric Channel Modelling

▷ Research Contributions
   ◦ Statistical Properties of Parametric Channel Models
   ◦ Mobile Station Mobility in Parametric Channel Models

▷ Conclusions
Wireless Systems

▶ Evolution of wireless systems
Introduction

- The **channel** is the physical medium that connects the transmitter and receiver.

- A **wireless propagation channel** is the environment surrounding a transmitter and receiver.
Wireless Propagation Scenarios

Examples of real-world wireless propagation channels:

- Satellite
- Rural (macrocell)
- Urban (microcell)
- Indoor (picocell)
Challenges in Channel Modelling

- **New** real-world wireless propagation channels:

- New communication technologies must work in real-world wireless channels.
Classification

MIMO Channel Models can be classified as follows:†

Analytical Channel Models

- **Analytical Models** characterize the impulse response in an analytical/mathematical manner without explicitly accounting for wave propagation.

\[
H = \begin{pmatrix}
  h_{11} & h_{12} & \ldots & h_{1N_T} \\
  h_{21} & h_{22} & \ldots & h_{2N_T} \\
  \vdots & \vdots & \ddots & \vdots \\
  h_{N_{R1}} & h_{N_{R2}} & \ldots & h_{N_{RN_T}}
\end{pmatrix}
\]

- **i.i.d model**, i.e. all elements of MIMO channel matrix are uncorrelated and have equal variance.

- **Gauss Markov Model**

\[
h_l = \alpha h_{l-1} + w_l \quad \quad [\alpha = J_0(2\pi f_D T_s)]
\]
Physical Channel Models

Physical Channel Models characterize the channel impulse response on the basis of electromagnetic wave propagation.
Physical Channel Models

- **Deterministic Models** characterize the channel impulse response in a completely deterministic manner (e.g., using stored measurement data or Ray Tracing technique).
Physical Channel Models

▷ Electromagnetic Models characterize the channel impulse response using the actual wave field in the propagation environment.

\[ F(x) = \sum_{p} a_p e^{i k \cdot x \cdot y_p} \quad F(x) = \sum_{n=-\infty}^{\infty} i^n x_n J_n(k|x|) e^{i n \varphi(x)} \]

▷ Allows investigation of fundamental limits that space imposes on the wireless channel.
Physical Channel Models

- **Geometry-based Stochastic Models** characterize the impulse response by laws of wave propagation applied to specific TX, RX and scatterer geometries.

Fig. 2. Waves arriving with delay $\tau$ at the BS will arise from the scatterers located on the ellipse $r_B + r_m = c\tau \pm \mu$. 
Physical Channel Models

- **Parametric Models** (non-geometrical) characterize the impulse response by using **physical parameters** without assuming underlying scatterer geometry.

- A stronger condensation of channel information is achieved by parameterization.

- Parametric channel modelling approach adopted by 3GPP-3GPP2 for 3G cellular systems.
The **Spatial Channel Model (SCM)** was developed by 3GPP-3GPP2 to be a common reference for evaluating different MIMO concepts in outdoor environments at a center frequency of 2GHz.
3GPP-3GPP2 SCM

▶ Generation of **channel impulse response** in SCM:

1. Choose scenario
   - Suburban macro
   - Urban macro
   - Urban micro

2. Determine user parameters
   - Angle spread $\sigma_{AS}$
   - Lognormal shadowing $\sigma_{LN}$
   - Delay spread $\sigma_{DS}$
   - Pathloss
   - Orientation, Speed Vector $\theta_{BS} \theta_{MS} \Omega_{MS}$
   - Antenna gains

3. Generate channel coefficients
   - Far scattering cluster (urban macro)
   - Urban canyon (urban macro)
   - Polarization
   - LOS (urban micro)

Options
Research Questions

▷ What are the desired temporal and statistical properties of a reference channel model for MIMO systems in an urban macro-cell environment?

▷ How many subpaths are sufficient to accurately capture the statistical properties of the MIMO wireless channel?

▷ How can you modify the 3GPP/3GPP2 model to include MS mobility for beamforming applications?
Conclusions

▷ Parametric channel modelling is a versatile technique for characterization of real-world wireless propagation channels.

▷ Current work:
  ◇ Deriving analytical expressions for properties of parametric channel models.
  ◇ Parametric channel models for wireless ad hoc networks.
Thank you for your attention
Statistical Properties of a Parametric Channel Model for Multiple Antenna Systems

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Outline

▷ Introduction
  ◇ MIMO Channel Models
  ◇ Motivation

▷ Reference Channel Model
  ◇ Statistical Properties

▷ Parametric Channel Model

▷ Results
  ◇ Temporal and Spatial Properties

▷ Conclusions
Introduction

MIMO Channel Models can be classified as follows:†

Parametric Channel Model

- Parametric channel models use important physical parameters such as phases, delays, doppler frequency, angle of departure (AOD), angle of arrival (AOA) and angle spread to provide a description of the MIMO channel.

- Each path consists of (unresolvable) $S$ subpaths that all have the same delay, but different angles of arrival and departures distributed around the mean angles.

- How many subpaths are sufficient to accurately capture the statistical properties of the MIMO wireless channel?
We consider a MIMO system in an **urban macro-cell environment**.
The channel impulse response between MS antenna \( m \) and BS antenna \( n \) for user \( k \)'s path \( l \) can be written as

\[
h_{k,l}^{m,n}(t) = (h_I)_{k,l}^{m,n}(t) + j(h_Q)_{k,l}^{m,n}(t)
\]

For isotropic scattering, the temporal correlation properties are summarized below:

\[
\begin{align*}
R_{h_I h_I}(\tau) &= E[h_I(t)h_I(t + \tau)] = J_0(2\pi f_D \tau) \\
R_{h_Q h_Q}(\tau) &= E[h_Q(t)h_Q(t + \tau)] = J_0(2\pi f_D \tau) \\
R_{h_I h_Q}(\tau) &= E[h_I(t)h_Q(t + \tau)] = 0 \\
R_{h h}(\tau) &= E[h(t)h^*(t + \tau)] = J_0(2\pi f_D \tau) \\
R_{|h|^2|h|^2}(\tau) &= 4 + 4J_0^2(2\pi f_D \tau)
\end{align*}
\]
The **Level Crossing rate** is defined as the rate at which the fading envelope crosses a specified threshold in the positive slope

\[ L_{|h|} = \sqrt{2\pi} f_D \rho e^{-\rho^2} \]

The **Average Fade Duration** is the average duration of time that the fading envelope remains below a specified threshold.

\[ T_{|h|} = \frac{e^{\rho^2} - 1}{\rho \sqrt{2\pi} f_D} \]
Reference Channel Model

▷ We assume that the angular distribution of the subpaths at the MS can be modelled by a Uniform PDF over \([-\pi, \pi]\).

▷ Measurements have shown that the angular distribution of the subpaths at the BS can be modelled by a Gaussian PDF.†

◊ For urban macro-cellular environment, median angular spread: 5° – 20°.

Reference Channel Model

The spatial envelope correlation coefficient $\rho_s$, between the $p$th and $q$th antenna elements for a ULA, is given by

$$\rho_s(p, q) = |R_s(p, q)|^2 = |\Re\{R_s(p, q)\} + j\Im\{R_s(p, q)\}|^2$$

Spatial Correlation at BS

$$\Re\{R_s(p, q)\} = J_0(z_{pq}) + 2C_g \sum_{v=1}^{\infty} J_{2v}(z_{pq}) \cos(2v \theta_{AOD}) e^{-2v^2 \sigma_{AOD}^2} \Re\left\{ \text{erf}\left( \frac{\pi + j 2v \sigma_{AOD}^2}{\sqrt{2} \sigma_{AOD}} \right) \right\}$$

$$\Im\{R_s(p, q)\} = 2C_g \sum_{v=0}^{\infty} J_{2v+1}(z_{pq}) \sin[(2v + 1) \theta_{AOD}] e^{-\frac{(2v+1)^2 \sigma_{AOD}^2}{2}} \Re\left\{ \text{erf}\left( \frac{\pi + j (2v + 1) \sigma_{AOD}^2}{\sqrt{2} \sigma_{AOD}} \right) \right\}$$

Spatial Correlation at MS

$$\Re\{R_s(p, q)\} = J_0(z_{pq}) + 2 \sum_{v=1}^{\infty} J_{2v}(z_{pq}) \cos(2v \theta_{AOA}) \text{sinc}(2v \Delta)$$

$$\Im\{R_s(p, q)\} = 2 \sum_{v=0}^{\infty} J_{2v+1}(z_{pq}) \sin[(2v + 1) \theta_{AOA}] \text{sinc}[(2v + 1) \Delta]$$
The channel impulse response can be written as

\[ h_{k,l}^{(m,n)}(t) = \sqrt{\frac{\Omega_{k,l}}{S}} \left\{ \sum_{s=1}^{S} \exp[j(\phi_{k,l}^{(s)} + 2\pi f_D t \cos \theta_{k,l,\text{AOA}}^{(s)})] \right. \\
\left. \quad \times \exp[-j\kappa d_M (m-1) \sin \theta_{k,l,\text{AOA}}^{(s)}] \right. \\
\left. \quad \times \exp[-j\kappa d_B (n-1) \sin \theta_{k,l,\text{AOD}}^{(s)}] \right\} \delta(t - \tau_{k,l}) \]

**Temporal Parameters**
- \( K = \) users;
- \( L = \) multipaths;
- \( S = \) sub-paths/path;
- \( \Omega_{k,l} = \) mean path power;
- \( \tau_{k,l} = \) propagation delay;
- \( \phi_{k,l}^{(s)} = \) random phase;
- \( f_D = \) Doppler frequency;

**Spatial Parameters**
- \( N = \) No. of antennas;
- \( d = \) inter-element distance;
- \( \kappa = \frac{2\pi}{\lambda}; \)
- \( \theta_{k,l,\text{AOD}}^{(s)} = \theta_{k,\text{AOD}} + \vartheta_{k,l,\text{AOD}}^{(s)} \)
- \( \theta_{k,l,\text{AOA}}^{(s)} = \theta_{k,\text{AOA}} + \vartheta_{k,l,\text{AOA}}^{(s)} \)
- \( \theta_{k,\text{AOA}} = \) Mean Angle of Arrival;
- \( \theta_{k,\text{AOD}} = \) Mean Angle of Departure;
# Parametric Channel Model

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Parameter</th>
<th>Value or Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General</strong></td>
<td>Carrier frequency</td>
<td>$f_c = 2$ GHz</td>
</tr>
<tr>
<td></td>
<td>Number of channel samples</td>
<td>$T = 20000$</td>
</tr>
<tr>
<td></td>
<td>Samples/wavelength</td>
<td>8</td>
</tr>
<tr>
<td><strong>Temporal</strong></td>
<td>MS velocity</td>
<td>$v = 60$ km/hr</td>
</tr>
<tr>
<td></td>
<td>Number of paths</td>
<td>$L = 1$</td>
</tr>
<tr>
<td></td>
<td>Number of subpaths</td>
<td>$S = 25$</td>
</tr>
<tr>
<td><strong>Antennas</strong></td>
<td>Antenna geometry</td>
<td>ULA</td>
</tr>
<tr>
<td></td>
<td>Number of antennas</td>
<td>$N_B = 2$, $N_M = 2$</td>
</tr>
<tr>
<td></td>
<td>BS Inter-element distance</td>
<td>$d_B = 5\lambda$</td>
</tr>
<tr>
<td></td>
<td>MS Inter-element distance</td>
<td>$d_M = 0.5\lambda$</td>
</tr>
<tr>
<td><strong>Spatial</strong></td>
<td>Mean Angle of Arrival</td>
<td>$\theta_{AOA} = 60^\circ$</td>
</tr>
<tr>
<td></td>
<td>pdf in Angle of Arrival</td>
<td>Uniform $[-\pi, \pi]$</td>
</tr>
<tr>
<td></td>
<td>Mean Angle of Departure</td>
<td>$\theta_{AOD} = 0^\circ$</td>
</tr>
<tr>
<td></td>
<td>pdf in Angle of Departure</td>
<td>Gaussian</td>
</tr>
<tr>
<td></td>
<td>BS Angle spread</td>
<td>$\sigma_{AOD} = 5^\circ, 10^\circ, 20^\circ$</td>
</tr>
</tbody>
</table>
Results – Temporal Correlations

Autocorrelations

Cross-correlation

For \( S = 25 \), simulation results agree with reference results for \( 0 \leq f_D \tau \leq 3 \).
Results – LCR & AFD

MS velocity $v = 60 \text{ km/hr} \ (f_D = 111.11 \text{ Hz})$

For $S = 25$, simulation results deviate from reference results only for very low threshold values.
Results — MS Spatial Correlation

Spatial Correlation Coefficient vs. distance $d_M/\lambda$

![Graph showing the spatial correlation coefficient vs. normalised inter-element distance $d_M/\lambda$. The graph compares the reference model and simulation results.](image)
Results – BS Spatial Correlation

Spatial Correlation Coefficient vs. distance $d_B/\lambda$

Mean AOD = 0°

Mean AOD = 60°
Conclusions

▷ In this paper, we have analysed the **statistical properties of a parametric channel model** for MIMO systems in an urban macrocell environment.

▷ The proposed channel model can accurately represent the **temporal correlations** for time delays $0 \leq f_D \tau \leq 3$ and **spatial correlations** at MS and BS for inter-element spacings $0 \leq d/\lambda \leq 3$.

▷ The obtained results have shown that $S = 25$ **subpaths** is sufficient to capture the important statistical properties of MIMO wireless channel.
A Parametric Channel Model for Smart Antennas Incorporating Mobile Station Mobility

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Outline

▷ Introduction
  ◇ Motivation
  ◇ Spatial Channel Model

▷ Proposed Channel Model
  ◇ Parameterization
  ◇ Mobile Station Mobility Model

▷ Results
  ◇ Temporal and Spatial Properties

▷ Conclusions
Introduction

▷ **Smart or adaptive antennas systems** can improve the performance of wireless systems by mitigating Multiple Access Interference (MAI).

▷ The performance of a smart antenna cannot be realistically evaluated without simulating **Mobile Station (MS) mobility**.
Spatial Channel Model (SCM)

- SCM is a channel model adopted by Third Generation Partnership Project (3GPP) and Third Generation Partnership Project Two (3GPP2) for 3G Cellular systems.

- Each path is characterized by its delay and mean angles and consists of several subpaths that all have the same delay, but different angles of arrival and departures distributed around the mean angles.

- Mainly established for evaluation of transmit diversity and Multiple Input Multiple Output systems.
Typical propagation scenario for suburban and urban macro-cellular environment.

- Dominant reflector
- Subpaths
- Local scattering structures around the MS
- Angular dispersion of received signal at the BS, characterized by angle spread $\sigma_{AOA}$
- Mean AOA $\theta_k$
BS is equipped with a **Uniform Linear Array (ULA)** of $N$ omni-directional antenna elements. (at 2 GHz frequency, 8 element ULA $\approx 0.5$ m).
The channel impulse response can be written as

\[
h_{k,l,n}(t) = \sqrt{\frac{\Omega_{k,l}}{S}} \sum_{s=1}^{S} \exp \left[ j(\phi_{k,l}^{(s)} + 2\pi f_D t \cos \Psi_{k,l}^{(s)}) \right] \\
\times \exp \left[ -jKd(n-1)\sin(\theta_{k,l}^{(s)}) \right] \delta(t - \tau_{k,l})
\]

**Temporal Parameters**

- \( K \) = users;
- \( L \) = multipaths;
- \( S \) = sub-paths/path;
- \( \Omega_{k,l} \) = mean path power;
- \( \tau_{k,l} \) = propagation delay;
- \( \phi_{k,l}^{(s)} \) = random phase;
- \( f_D \) = Doppler frequency;

**Spatial Parameters**

- \( N \) = BS antennas;
- \( d \) = inter-element distance;
- \( K = 2\pi/\lambda \);
- \( \Psi_{k,l}^{(s)} \) = Angle of Departure (AOD);
- \( \theta_{k,l}^{(s)} = \theta_k(t) + \psi_{k,l}^{(s)} \)
- \( \theta_k(t) \) = Angle of Arrival (AOA);
- \( \sigma_{AOA} \) = angle spread;
MS Mobility Model

▷ **AOA Initialisation**: Desired user’s AOA = $-60^\circ$, Interferer’s AOA = uniformly distributed over the azimuth range.

▷ **AOA Evolution**: A ‘drop’ is defined as the simulation time required by the desired user to traverse the entire azimuth range $[-60^\circ, 60^\circ]$ with mean AOA change $\Delta\theta = 0.01^\circ$ per snapshot.
## Simulation Assumptions

<table>
<thead>
<tr>
<th><strong>Temporal Parameter</strong></th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier frequency ( f_c )</td>
<td>( f_c = 2 \text{ GHz} \ (\lambda/2 = 7.5 \text{ cm}) )</td>
</tr>
<tr>
<td>No. of subpaths ( S )</td>
<td>( S = 25 )</td>
</tr>
<tr>
<td>Doppler frequency ( f_D )</td>
<td>( f_D = 100 \text{ Hz} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Spatial Parameter</strong></th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of BS antenna elements</td>
<td>( N = 1 - 8 )</td>
</tr>
<tr>
<td>Element pattern</td>
<td>Omnidirectional</td>
</tr>
<tr>
<td>Antenna geometry</td>
<td>Uniform linear array</td>
</tr>
<tr>
<td>Inter-element distance</td>
<td>( d = \lambda/2 )</td>
</tr>
<tr>
<td>Angle of Arrival</td>
<td>(-60^\circ \leq \theta \leq 60^\circ )</td>
</tr>
<tr>
<td>PDF in AOD</td>
<td>Uniform</td>
</tr>
<tr>
<td>PDF in AOA</td>
<td>Gaussian</td>
</tr>
<tr>
<td>Angle spread ( \sigma_{\text{AOA}} )</td>
<td>( 0^\circ - 20^\circ )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Mobility Parameter</strong></th>
<th><strong>Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>User mobility</td>
<td>( 0.01^\circ ) per snapshot</td>
</tr>
</tbody>
</table>
Results – Smart Antenna Simulations

Smart Antenna Simulation Using Proposed Channel Model†

\[ N = 8 \text{ ULA antenna} \]
\[ M = 64, N_c = 256 \] (IS-95 CDMA Parameters)
\[ L = 2, 3 \text{ paths/user} \] (uniform PDP’s)
\[ K = 5, 20 \text{ users} \]

In this paper, we have proposed a channel model for smart antennas which includes a thorough framework for MS mobility.

A mathematical formulation of the channel model has been presented, along with the simulation results.

The simulation results have shown that the model can accurately characterise different smart antenna channel aspects, while maintaining low complexity for system level simulations.
Thank you for your attention