NEWCOM Dept1 Cluster3 Kick-Off

Advanced Signal Processing Algorithms and Mobility

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Overview

- pathwise channel modeling and estimation, N-way factor analysis etc
- EM algorithms for Kalman filtering based channel estimation and adaptive filtering  
  numerous versions of EM, SAGE, EM-ML combinations etc.  
  convergence analysis of adaptive EM versions  
  low complexity versions and ensuing performance degradation
- mobile terminal localization:  
  - reference scenario for performance evaluation  
  - Kalman filtering for mobility tracking
Overview (2)

• approximate MLSE techniques, sphere decoding etc putting into perspective different approximate techniques: sphere decoding, SIC in decreasing order of reliability etc

• single antenna interference cancellation (SAIC) and related techniques
MIMO Transmission

- multiple \((q)\) transmit and \((p)\) receive antennas
- MIMO: Multiple Input Multiple Output
Specular Wireless MIMO Channel Model

- time-varying channel: \( h(t, \tau) \)
  \[
  h(t, kT) = \sum_{i=1}^{N_P} A_i(t) e^{j2\pi f_i t} a_R(\phi_i) a_T^T(\theta_i) p(kT - \tau_i)
  \]
  
  \( h \) rank 1 in 3 dimensions; \( N_P \) pathwise contributions:
  
  - \( A_i \): complex attenuation
  - \( f_i \): Doppler shift
  - \( \theta_i \): angle of departure
  - \( \phi_i \): angle of arrival
  - \( \tau_i \): path delay
  - \( a(.) \): antenna array response, \( p(.) \) pulse shape (TX filter)
MIMO Channel Prediction

- \( h(t) = \text{vec}\{h(t,kT)\} = \sum_{i=1}^{N_P} h_i A_i(t) e^{j2\pi f_i t} \)
- \( N = N_T N_R N_\tau = \# \text{TX antennas} \times \# \text{RX antennas} \times \text{delay spread} \)
- \( f_i \in (-f_d, f_d) \Rightarrow \text{(fast fading) variation bandlimited } \Rightarrow \text{perfectly predictable!} \)
  : \( \infty \)th order prediction error variance:
  \( \sigma^2_{x,\infty} = e \int_{-\frac{1}{2}}^{\frac{1}{2}} \ln S_{xx}(f) df = 0 \) whenever spectrum bandlimited

- \( S_{hh}(f) \) can be doubly singular:
  1. if \( A_i(t) \equiv A_i \) and \( N_P \) finite: spectral support singularity: sinusoids!
  2. if \( I < M \): matrix singularity, limited source of randomness (limited diversity)
Subspace AR Channel Model

- $\mathbf{h}[k] = \mathbf{H} \mathbf{A}[k]$ sampling $t = kT$

- $\mathbf{A}[k]$ decorrelated stationary scalar processes

- channel distribution complex Gaussian

- if fast parameters $\mathbf{A}[k]$ not too predictable, then the estimation errors of the slow parameters $\mathbf{H}$ should be negligible (change with slow fading)

- spectrum: $S_{\mathbf{hh}}(f) = \mathbf{H} S_{\mathbf{AA}}(f) \mathbf{H}^H$ diag.

- components of $\mathbf{A}[k]$ conveniently modeled as AR processes, each spanning only a fraction of the Doppler spectrum
Separable Correlation Channel Model

- when $N_P \gg N$, dynamics of all paths get mixed up and get separable correlations [Visuri&Slock:SAM02]

- $S_{hh}(f) = R_\tau \otimes R_T \otimes R_R \ S_d(f)$

4D Kronecker model!

$R_\tau$: correlation matrix between delays, typically diagonal with power delay profile
$R_T$: TX side correlation matrix
$R_R$: RX side correlation matrix
$S_d(f)$: scalar common Doppler spectrum of all impulse response coefficients
EM-Kalman Filter Channel Estimation Perf

![Graph showing performance comparison of different methods: MSE adaptive Kalman via ML, MSE adaptive Kalman via EM, MSE Kalman filter]

- **Y-axis**: MSE (dB)
- **X-axis**: Discrete time
- **Legend**:
  - MSE adaptive Kalman via ML
  - MSE adaptive Kalman via EM
  - MSE Kalman filter
• multiple \((N_T)\) transmit and \((N_R)\) receive antennas
Specular Wireless MIMO Channel Model:

Slow Parameter Dynamics

- time-varying channel: $h(t, \tau)$

$$h(t, kT) = \sum_{i=1}^{N_P} A_i(t) e^{j2\pi f_i t} a_R(\phi_i) a_T^T(\theta_i) p(kT - \tau_i)$$

- fast fading parameters: $A_i$
- slow fading parameters: $f_i, \theta_i, \phi_i, \tau_i$
- dynamical models for slow fading parameters [EW2004]
- boils down to mobile trajectory tracking
Mobile Terminal Localization

- existing TDOA methods: based on delay of first path (=LOS assumed) of channel towards a number of base stations
- much more information in channel could be exploited
- for a NLOS path, e.g. Doppler frequency gives information on angle between speed vector and incoming ray, perhaps reflected off a major obstacle. A BS keeps track of major obstacles in its cell.
- mobile trajectory tracking
SAIC Techniques

1. creating a multichannel situation (subspaces) via
   • I and Q components for BPSK or GMSK modulations
   • oversampling to exploit excess bandwidth
   • exploiting unused codes in CDMA
   and performing linear spatiotemporal interference cancellation

2. exploiting partial symbol constellation knowledge: constant modulus

3. exploiting full symbol constellation knowledge: joint detection of signal of interest and interferer(s)

4. exploiting full channel encoding knowledge: joint decoding of signal of interest and interferer(s)
Downlink: SAIC at Mobile Terminal

- interference from a cochannel base station (BS) passes through a unique channel (if no beamforming is used at BS)
- a BS signal is a single user signal in a TDMA system (2/2.5G), while it is a superposition of user signals in a CDMA system (3G)
- interfering slots may not be synchronized
- frequency reuse factor is 1 in CDMA, hence more interfering BS than in TDMA (frequency reuse factor at least 3)