**WCDMA Simulator with Smart Antennas**

Hong Zhang

Communication laboratory

**Supervisor: Professor Seppo J. Halme**

**Instructor: M. Sc. Adrian Boukalov**
Outline

1. Background
2. Different approach in WCDMA system modelling
3. Spreading in WCDMA
4. RAKE Receiver and Multiuser Detection
5. Smart Antenna in WCDMA
6. Simulation Results
7. Conclusion
1. Background

The goal of 3G to provide a wide variety of communication services and high speed data access.

The increasing demand of high capacity

WCDMA
radio access technology for 3G

To provide high capacity

technique

Spreading
Smart antenna
RAKE receiver
Multiuser detection

tool

Simulation
2. Different approach in WCDMA system modelling (1)
2. Different approach in WCDMA system modelling (2):

Mobile radio channel

\[ h(t, \tau, \theta) = \sum_{j=0}^{N-1} \beta_j(t) \delta(\tau - \tau_j) \delta(\theta - \theta_j) \]

Multiple antennas in the receiver

Ray tracing model

The tapped delay line model

where \( \beta_j(t) \) is the complex amplitude, \( \tau_j \) is path delay and \( \theta_j \) is Direction Of Arrival, \( a(\theta - \theta_j) \) is the steering vector

GWSSUS: Gaussian Wide Sense Stationary Uncorrelated Scatters

DOA: Direction Of Arrival
2. Different approach in WCDMA system modelling (3):
the fundamental structure

Block diagram of the mobile transmitter for user k

Block diagram of the base station receiver
2. Different approach in WCDMA system modelling (4): Discrete time base band uplink model for asynchronous CDMA

- The received signal

\[
r = \sum_{i=0}^{L-1} \sum_{k=1}^{K} \sum_{m=1}^{M} \hat{c}_{k,m}(i) d_k(i) \begin{pmatrix} O_{INQ} \\ \hat{s}_{k,m}(i) \\ O_{(L-i-1)NQ} \end{pmatrix} + n = SCd + n
\]

- The output after matched filtering and correlating

\[
y = C^H S^H S C d + C^H S^H n
\]

Where \( \hat{s}_{k,m}(i) = \begin{pmatrix} O \hat{c}_{k,m} \\ \hat{s}_k(i) \\ O_M - \tau_{k,m} \end{pmatrix} \)

- \( d_k(i) \): the \( i^{th} \) data symbol transmitted by user \( k \)
- \( \hat{s}_k(i) \): the zero-padded spreading sequence for symbols generated by user \( k \)
- \( \hat{c}_{k,m}(i) \): the channel coefficients over the \( m^{th} \) multipath for the \( i^{th} \) symbol generated by user \( k \)
- \( L \): the total amount of the data symbol sent by every active user
- \( K \): the total amount of active users sending data to the BTS
- \( M \): the maximum delay spread normalised to sampling interval
- \( M \): the amount of resolvable multipath components per user data sequence
- \( C \): channel matrix
- \( S \): the matrix of received spreading waveform
- \( n \): Additive White Gaussian Noise
2. Different approach in WCDMA system modelling (5): Discrete time base band uplink model for asynchronous CDMA with smart antenna

- The phase difference of the received signal between adjacent antenna elements

\[ \phi = \frac{2 \pi d \cos \theta}{\lambda} \]

- The received signal

\[ \mathbf{r} = \mathbf{S} \psi \mathbf{C}_0 d + \mathbf{n} \]

- The output after matched filtering and correlating

\[ \mathbf{y} = \mathbf{C}_0^H \psi^H \mathbf{S}^H \mathbf{r} = \mathbf{C}_0^H \psi^H \mathbf{S}^H \mathbf{S} \psi \mathbf{C}_0 d + \mathbf{C}_0^H \psi^H \mathbf{S}^H \mathbf{n} \]

where \( \psi \) is the steering matrix
3. Spreading in WCDMA (1)

- **Pseudo Random (PN) sequence**: a bit stream of ‘1’s and ‘0’s occurring randomly, or almost randomly, with some unique properties.

\[
a_n = c_1 a_{n-1} + c_2 a_{n-1} + \ldots + c_r a_{n-r}
\]
3. Spreading in WCDMA (2): Spreading and scrambling at the uplink

**Spreading:** to multiply the input information bits by a PN code and get processing gain, the chip level signal’s bandwidth is much wider than that of input information bits. It maintains the orthogonality among different physical channels of each user.

**Scrambling:** to separate the signals from the different users. It doesn’t change the signal bandwidth. Each user has a unique scrambling code in the system.

- **Uplink spreading and modulation**

<table>
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<tr>
<th>WCDMA</th>
<th>Selecting codes</th>
<th>Suppressing interference</th>
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<tbody>
<tr>
<td>an interference limited system</td>
<td>high autocorrelation low cross correlation</td>
<td></td>
</tr>
</tbody>
</table>
3. Spreading in WCDMA (3) : Walsh-Hadamard code and Gold code

- Walsh-Hadamard code
  - Purpose: spreading
  - Generation: code tree

\[
\begin{align*}
C_{1,1} &= (1) \\
C_{2,1} &= (1, 1) \\
C_{2,2} &= (1, 1) \\
C_{4,1} &= (1, 1, 1, 1) \\
C_{4,2} &= (1, 1, -1, -1) \\
C_{4,3} &= (1, -1, 1, -1) \\
C_{4,4} &= (1, -1, -1, 1)
\end{align*}
\]

- Gold code
  - Purpose: scrambling
  - Generation: modulo-2 sum 2 m-sequences
4. RAKE Receiver and Multiuser Detection (1): RAKE receiver

RAKE receiver:
- to collect the signal energy from different multipath components and coherently combine the signal

Output: \[ y = C^H S^H r \]

SNR \( \uparrow \)

Optimal for single user system

- Combining methods
  - Selection Combining
  - Maximal Ratio Combining (MRC)
  - Equal Gain Combining (EGC)
4. RAKE Receiver and Multiuser Detection (2): Multiuser Detection

WCDMA
Multiple access

MAI

MUD
design and analysis the digital demodulation in the presence of MAI

Optimal Detector
High complex

Sub Optimal Detector

User 1 RAKE

User 2 RAKE

User K RAKE

Viterbi Algorithm

$d_1^\hat{}(i)$

$d_2^\hat{}(i)$

$\vdots$

$\vdots$

$d_K^\hat{}(i)$

LMMSE: Linear Minimum Mean Square Error
MUD: multiuser detection
MAI: multiple access interference
4. RAKE Receiver and Multiuser Detection (3): Multiuser Detection

**Decorrelating Detector**

\[ \hat{d}_{\text{Dec}} = \mathbf{R}^{-1} \mathbf{y} \] (synchronous)

\[ \hat{d}_{\text{Dec}} = [\mathbf{R}^T [1] z + \mathbf{R} [0] + \mathbf{R} [1] z']' \mathbf{y} \] (asynchronous)

**LMMSE**

\[ \hat{d}_{\text{Dec}} = (\mathbf{R} + \sigma^2 \mathbf{I})^{-1} \mathbf{y} \] (synchronous)

\[ \hat{d}_{\text{Dec}} = (\mathbf{R}^T [1] z + \mathbf{R} [0] + \mathbf{R} [1] z' + \sigma^2 \mathbf{I})^{-1} \mathbf{y} \] (asynchronous)

**Adaptive MMSE algorithm**

RLS algorithm with adaptive memory

\[ J(k) = \sum_{i=1}^{n} \lambda^{n-i} (|\xi(k)|^2) \]
5. Smart Antenna in WCDMA (1)

**Smart Antenna** consists of antenna array, combined with signal processing in space (or time) domain

### Broad-band beam-former structure

\[ y(t) = \sum_{n=1}^{B} w_n r_n(t) \]
5. Smart Antenna in WCDMA (2): Beamforming schemes

Conventional Beamforming
\[ w_c = \left( \frac{1}{B} \right) s \]

Statistically Optimum Beamforming
- MMSE: \[ w = R^{-1} p \]
- Max SNR: \[ R_n^{-1} R_s w = \lambda_{\text{max}} w \]
- LCMV: \[ w = R^{-1} c [c^H R^{-1} c]^{-1} g \]

Adaptive Beamforming
RLS algorithm with adaptive memory
\[
G(k) = \frac{\lambda^{-1} P(k-1) r(k)}{1 + \lambda^{-1} r^H(k) P(k-1) r(k)}
\]
\[
\zeta(k) = d(k) - \hat{w}^H(k-1) r(k)
\]
\[
w(k) = \hat{w}(k-1) + G(k) \zeta^*(k)
\]
\[
P(k) = \lambda^{-1} P(k-1) - \lambda^{-1} G(k) r^H(k) P(k-1)
\]
\[
\lambda(k) = \lambda(k-1) + \alpha \Re \{ \psi^H(k-1) r(k) \zeta^*(k) \} \frac{1}{\lambda}
\]
\[
S(k) = \lambda^{-1} [I - G(k) r^H(k)] S(k-1) [I - r(k) G^H(k)] + \hat{\lambda}^{-1} G(k) G^H(k) - \lambda^{-1} P(k)
\]
\[
\psi(k) = [I - G(k) r^H(k)] \psi^H(k-1) + S(k) r(k) \zeta^*(k)
\]

MMSE: minimize mean square error
LCMV: Linearly Constrained Minimum Variance
RLS: recursive least squares
6. Simulation (1)

- Simulation block diagram of transmitter in WCDMA uplink

![Simulation Diagram](image)
6. Simulation (2)

**Simulation block diagram of 2-D RAKE receiver in uplink WCDMA**

![Diagram of 2-D RAKE receiver in uplink WCDMA](image)
6. Simulation (3)

- Channel: ray tracing channel model
  The simulation area: the campus area of Dresden University of Technology.
6. Simulation Results (4)

- Assume all the users randomly access the channel, and the PN code of each user is acquired and synchronized perfectly in the base station.

- Assume the number of fingers in RAKE receiver equal to the number of multipath components.

- The channel parameters are updated symbol by symbol, i.e. channel varies with time.

The system performance of 1-D RAKE and conventional matched filter receiver for single user

System performance of 1-D RAKE receiver with Decorrelating Detector and linear MMSE

DD: Decorrelating Detector
LMMSE
SA: smart antenna for spatial processing
PG: Processing Gain
MUD: Multiuser Detection
6. Simulation Results

The system performance of 1-D RAKE with different Processing Gain:

- spreading by Walsh codes and scrambling by Gold codes
- spreading and scrambling by random codes

The system performance of 2-RAKE receiver with RLS algorithm with adaptive memory for spatial processing and MUD:

- 2 antenna elements
- 3 active users

Definitions:
- DD: Decorrelating Detector
- LMMSE
- SA: Smart antenna for spatial processing
- PG: Processing Gain
- MUD: Multiuser Detection

3 antenna elements
3 active users

Date: 10 January, 2002

Seminar of Master Thesis
7. Conclusion

• The simulation results have shown that spreading, RAKE receiver, multiuser detection and smart antenna are very important techniques to improve WCDMA system performance and increase system capacity.