Physical Layer and Transceiver Algorithm Research

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FUTURA Workshop
12 August, 2002
University of Oulu, Oulu, Finland

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Introduction

■ FUTURA: Future Radio Access
  ➔ novel radio interfaces
  ➔ novel transceiver signal processing and algorithms needed.

■ Radio interface and algorithm research must go hand-in-hand
  ● reality check for radio interface designs
  ● feedback
  ● human resources shared between the topics.
Research Themes and Topics

① Receiver algorithms for WCDMA
   ● Equalizers for downlink terminals
   ● Interference cancellation and iterative decoding for uplink BTS
   ● Initial synchronization

② Receiver algorithms for interfered spread-spectrum
   ● Interference suppression under jamming
   ● Turbo decoding under jamming
   ● Decoding in non-Gaussian noise

③ Signal processing for adaptive radio links
   ● Modulation classification for adaptive radio links

④ Space-time coding and signal processing
   ● Fading channel simulation
   ● Space-time turbo coded modulation (STTuCM)
Theme #1: Receiver Algorithms for WCDMA

- **Objective**: Multiaccess interference resistant receiver algorithms for WCDMA.

- **Scope**: WCDMA uplink and downlink with main emphasis on FDD option.

- **Topics**:
  - Equalizers for downlink terminals
  - Interference cancellation (IC) and iterative decoding for uplink base stations
Multiple-Access Interference

- Multiple-access interference (MAI) is always present in WCDMA uplink:
  - asynchronous transmission $\Rightarrow$ no attempt to make user transmissions orthogonal.

- MAI in WCDMA downlink:
  - inter-cell interference
  - intra-cell interference
    - multipath propagation $\Rightarrow$ orthogonality between users lost.

- Different solutions for uplink and downlink:
  - **uplink**: centralized receivers $\Rightarrow$ multiuser (MU) detection (MUD)
  - **downlink**: decentralized receivers $\Rightarrow$ single-user (SU) detection (SUD)
MAI-Resistant Receiver Design Road-Map

- Ideal MUD receivers
- Linear MMSE equalizers
- Channel equalizers in WCDMA downlink

IC receivers
- improved solution
- IC + iterative decoding

suboptimal solutions

suboptimal

solution

solution
Channel Equalizers for WCDMA Terminals

- Traffic assumed to be asymmetric $\Rightarrow$ efficient use of downlink important.

- ‘Conventional’ MUD receivers not feasible in WCDMA / FDD downlink.
  - Long scrambling code (10 ms) causes problems in adaptation.
  - Multiuser detection is not usually feasible in terminals.

- Intra-cell interference suppressed with channel equalization.
  - Orthogonality between users restored (to some extent).
Channel Equalization

SNR = 4,0 dB
SNR = 7,3 dB
SNR = 8,0 dB

SINR = 2,5 dB
SINR = 4,0 dB
Channel Equalization: Main Issues Studied

- Efficient adaptation methods
  - Balance between performance and complexity
  - Implementation either chip-level or symbol-level

- Receiver structures for
  - 2 receive antennas
  - Soft handover
  - Transmit diversity

- Studies on fixed-point implementation

- Performance evaluations
  - Handover, STTD, HSDPA, etc
Example Results — Adaptive Equalizers

- 3-path channel
- no channel coding
- 60 km/h
- CPICH - 10% from base station transmission

**BER vs. $E_b/N_0$**

4 users with SF 8

**BER for changing number of users**

$E_b/N_0=12$ dB, different number of users with SF 64
Example Results — Adaptive Equalizers for HSDPA

- Data-rate bound for HSDPA
- Truncated ITU Vehicular A
- SINR-target corresponding 10% uncoded BER
- HSDPA user 50% and CPICH 10% from base station transmission

1-antenna receiver

2-antenna receiver
MUD and Iterative Decoding

- Iterative turbo decoding methods and MUD:
  - view transmission and multiuser channel as concatenated code
  - utilise error control code capabilities in interference suppression
  - inner code (channel) processing via MUD (e.g., IC)
  - outer code processing via channel decoding algorithms.

![Diagram of MUD and Iterative Decoding](image)
Iterative Detection and Decoding

- IC multiuser (MU) detection combined with single-user (SU) Viterbi or MAP channel decoding
- Viterbi applicable to hard decision interference cancellation with convolutional codes
- Soft (max-)log-MAP decoding for other codes
IC and Iterative Decoding: Example Results

SF = 16, Flat Rayleigh fading, 1/3 Conv.code (4,6,7), 48 Users
Two-Dimensional Code Acquisition

**Search strategies:**

- fix angle, sweep delay (FASD)
- fix delay sweep angle (FDSA)

\[ Q = mq \text{ cells} \]

\( q \) - delay cells
\( m \) - angular cells

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\[ FDSA \text{ (Fix Delay/Sweep Angle)} \]
\[ FASD \text{ (Fix Angle/Sweep Delay)} \]

\[ \sigma_{Tj}^2 : \text{Overall noise power in } j\text{th angular cell} \]
Performance Example

- Single path channels and multipath channels with delay and angular spreads
- Uniform and nonuniform spatial distribution of interference
- Static and dynamic (slow- and fast-fading) channels
- Different spatio-temporal search strategies were considered.
- Also adaptive detector structures were studied (e.g., adaptive integration time and threshold setting).
Summary and Conclusions

■ Channel equalizers
- are a viable option for WCDMA / FDD terminals
- suppress intra-cell interference.
- *For operator:* increases the network capacity
  - higher data rate (with same coverage)
  - larger coverage (with same high data rate service)
- *For user:* more reliable service
- Price: increased complexity of the receiver

■ Iterative detection and decoding
- offers significant performance gain in multiuser scenarios.
- Hard-decision multiuser processing suffices at low loads
  - limited to basic error control codes.
- Soft-decision processing offers better capacity
  - can be used with any codes.
Theme #2: Receiver Algorithms for Interfered Spread-Spectrum

- **Objective:** Receiver algorithms resistant to unknown interference for spread-spectrum (SS) systems.

- **Scope:** General jammed or interfered military or commercial spread-spectrum systems. Interference statistics unknown *a priori* to some extent.

- **Topics:**
  - Interference suppression under jamming
  - Turbo decoding under jamming
  - Decoding in non-Gaussian noise
Interfered Spread-Spectrum

- Spread Spectrum (SS) systems have inherent tolerance against interference
  - may not always be adequate
  - active interference suppression.

- Interference models:
  - statistics unknown \textit{a priori} to some extent
  - active jamming (military systems)
  - co-channel interference (frequency overlay)
  - non-Gaussian impulsive noise (adjacent channel interference).

- Decoding needs to know the noise and interference statistics
  - decoding under jamming or unknown interference.
Interference Suppression in DS/FH SS System

Fast convergence needed.
No synchronization to jamming.
FFT Constant Modulus Exciser (CME)

CME principle is used in frequency domain excision, i.e., CME detects interfered bins using recursive structure, where decision rule is based on the statistics of desired signal. Interfered frequency components are zeroed before IFFT.

Improved FFT notch filter.
Recursive Least Squares Interpolator

\[ r(n) + j(n) = s(n) \]

RLS weight update

\[ r(n) - s(n) = i(n) \]

\[ c_1, c_2 \]

\[ \Sigma \]
Performance Example: BPSK Jamming

- BER performance of coherent BPSK DS/FH system using IS device in stationary co-channel interference environment

![BER versus I/S graph]

- 25% rcBPSK
- $E_b/N_0 = 10$ dB

- 6 tap RLS interpolator
- FFT CME
Turbo Decoding Under Jamming

- Frequency Hopping Spread Spectrum (FH-SS) is used to overcome jamming on some radio channels.
- Turbo codes need a reliability estimate (SNR or SINR estimate) of the received bits. How sensitive?

Assumptions:
- BFSK modulation
- Gilbert-Elliott channel: two channel states correspond to jammed frequency hop and to non-jammed frequency hop.
- Jamming signal: AWGN.
The receiver mainly consists of two MAP algorithms and two jamming probability estimators.

The probability of a jammed hop for each hop is iteratively estimated between turbo iterations.

Both MAP and jamming estimators need SNR estimates for the good channel state and jammed state.
Turbo Decoding in Jammed FH SS — Example

- The system can operate even when 40% of the frequencies are jammed with white Gaussian noise.
- The system is not sensitive to SINR estimation errors.
Detection and Decoding in Man-Made Noise

- Decoding in man-made noise or external interference (EI)
- Interference+noise probability density function (PDF).
- Optimum detection approach to interference mitigation
  - detector = preprocessing stage to the decoder
  - exchange of soft information between detection and decoding.
- Algorithms:
  - type-based (type = histogram) detection
  - blind histogram estimation
  - parametric methods: minimax, EM algorithm, ML detection
  - decision feedback ⇒ iteratively improving PDF and covariance estimation.
Robust Decoder Performance

Comparison of robust decoders, AWGN noise

- optimal
- kernel
- minimax
- blind I
- type-based

Comparison of robust decoders, Laplacian noise

- optimal
- type-based
- kernel
- blind I
- minimax

Gaussian noise

Laplacian noise
Summary and Conclusions

- Receiver design and performance evaluation for jammed or interfered spread-spectrum systems.
- Active interference suppression (detection): preprocessor for decoder
  - Feedforward algorithms: FFT and RLS based
  - Feedback algorithms: type based
  - Robustness of turbo decoding.
- **Final goal**: adaptive, self-reconfigurable (preferably blind) receiver which automatically adapts to the interference conditions in the channel.
Theme #3: Signal Processing for Adaptive Radio Links

- **Objective**: Receiver algorithms to enable efficient link adaptation algorithms
- **Scope**: General adaptive radio links with particular emphasis on adaptive OFDM systems
- **Topics**: Modulation classification for adaptive radio links
Adaptive OFDM

- Channel quality estimation
- Appropriate modulation format selection
- Modulation mode detection

Structure of an adaptive radio link.
Modulation Classification

- Used modulation formats should be informed to the demodulator:
  - signaling transmission parameters $\Rightarrow$ loss of capacity
  - blind parameter detection $\Rightarrow$ capacity loss is avoided.

- Blind modulation mode classification: recognize the modulation format using observed symbols of the received signal.

- Modulation formats:
  - NoTx (no transmission)
  - BPSK, QPSK, 8PSK
  - 16QAM, 64QAM.
Modulation Classification

- **ML classifiers**
  - Good performance
  - High complexity

- **Statistical feature based classifiers**
  - Good performance only for PSK modulation classification
  - Low complexity

![Diagram showing modulation classification process]

1. Received signal
2. Sampling
3. Feature extraction
4. $r(t)$
5. Thresholds
6. $l(x \mid H_o)$
7. $l(x \mid H_5)$
8. Choose the largest
9. Report the modulation type
Summary and Conclusions

- Several low complexity classifiers with good performance exists for PSK modulations.

- Only a few ML modulation classifiers presented in the literature provide good performance for QAM modulations.

- The drawback of the ML classifiers is the fact they require high computational capacity.

- Further study needed.
Theme #4: Space-Time Coding and Signal Processing

■ **Objective**: Transmission techniques and receiver algorithms to enable efficient utilization of space-time radio channel.

■ **Scope**: Space-time signal design and receiver processing.

■ **Topics**:
  - Fading channel simulation
  - Space-time turbo coded modulation (STTuCM)
Fading Simulator

Small-scale wide-sense stationary uncorrelated scattering multiple-input–multiple-output (MIMO) multi-carrier fading channel simulator.

1. Uncorrelated white Gaussian noise generator
2. Time correlation shaping filtering
3. Space-frequency correlation transformation
4. Addition of direct component
5. Initial interpolation with lowpass filtering
6. Cubic interpolation to the channel sampling rate
Space-Time Turbo Coded Modulation

- A method to design space-time turbo coded modulations based on any space-time trellis code (STTrC).

Encoder:

- Symbol MAP 1
- sym/bit
- bit/sym
- $\pi_{O,E}$

Decoder:

- Symbol MAP 2
- bit/sym
- $\pi_{O,E}$

Puncture and/or Multiplex

Rec-STTrC

(Rec-) STTrC
Examples

- NonRec-STTrC & Rec-STTrC

Rec-STTrC & Rec-STTrC
Summary and Conclusions

- An efficient method to design space-time turbo coded modulations based on space-time trellis codes.
- Significant performance gains in several cases.
- Union bound analysis available.
- Distance spectrum insight on the STC design.

On-going and future work:
- design of new constituent codes based on distance spectrum
- design of the code matched interleaving.
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