Lecture 12: Summary
Advanced Digital Communications (EQ2410)[1]

Ming Xiao
CommTh/EES/KTH

Monday, Mar. 7, 2016
15:00-17:00, B23

[1]Textbook: U. Madhow, *Fundamentals of Digital Communications*, 2008

Ming Xiao
CommTh/EES/KTH

Overview

Lecture 12

1. Summary
2. Standards
3. Final Exam
4. Course Evaluation

Summary
– Equalization

Maximum likelihood sequence estimation (MLSE)

- Optimal equalizer minimizing the sequence error probability
- Viterbi algorithm, complexity $\sim M^L$ (channel memory L, symbol alphabet size M)
- Performance analysis: union bound

Linear equalization

- Suboptimal linear equalization with mild complexity
- Design rules: minimum mean squared error (MMSE) and zero forcing (ZF)
- Performance analysis: averaging over the interfering symbols

Decision-feedback equalization

- Suboptimal nonlinear equalization with further reduced complexity
- Use decisions for previous symbols to "subtract" interference; linear equalization on the reduced model for interference from "future" symbols.
- Performance analysis: potentially complicated, approximation of the BER, full analysis in simple cases.

Summary
– Channel Coding

Turbo codes

- Parallel concatenated convolutional codes and iterative decoding between the respective component decoders.
- Optimal a-posteriori probability symbol-by-symbol decoding for convolutional codes.
- Performance analysis: union bound and density evolution (not discussed in the lecture but similar to LDPC codes)

LDPC codes

- Linear block codes with sparse check matrix, can be represented by Tanner graph
- Iterative decoding between variable-node decoders and check-node decoders on the Tanner graph (belief propagation, Gallager's Algorithm A)
- Performance prediction based on density evolution.

Summary
– Channel Coding

Bandwidth efficient coding

- Bit-interleaved coded modulation (BICM)
  - Interleaver between channel code and modulator (spread burst errors, enable iterative decoding)
  - Depending on the components, iterative decoding/detection or separate decoding and detection
- Trellis coded modulation
  - Combine convolutional coding with modulation, set partitioning of the constellation
  - Performance analysis: union bound, evaluation of the minimum Euclidean distance between two sequences

Summary
– Wireless Channels

Channel Modeling

- Statistical models for channel coefficients
- Slowly varying vs. time-variant channels
  $\rightarrow$ coherence time / Doppler spread
- Frequency selective vs. frequency flat channels
  $\rightarrow$ coherence bandwidth / delay spread

Fading channels and diversity

- Performance analysis for fading channels
  - Error probability conditioned on fading realization
  - Average error probability averaged over the distribution of the fading coefficients
- Outage probability, outage capacity
- Receive diversity (MRC, selection combining, equal gain combining, rake receiver for CDMA...)
- Transmit diversity (Alamouti's code, transmit beam forming,...)

Summary
– Wireless Channels

Multicarrier systems

- OFDM based on I-DFT and DFT, cyclic prefix, implementation
- Channel capacity for parallel channels
- Optimal power allocation for parallel channels, waterfilling

Spread spectrum techniques

- Direct sequence spread spectrum
  - Design of spreading codes, auto-/cross-correlation proterties
  - Rake receiver (frequency diversity at the receiver)
  - CDMA and multi-user detection (similar techniques as for equalization!)
- Frequency-hop spread spectrum techniques
  - Frequency diversity
  - Randomize multiple access

Summary
– Wireless Channels

Multi-antenna systems

- Channel characteristics
- Multiple-input/multiple-output (MIMO) systems
  - Channel capacity for MIMO channels: singular value decomposition, power allocation for parallel channels, waterfilling
  - Spatial multiplexing to achieve high rates (receiver processing to CDMA)
- Transmit diversity (space time coding, transmit beamforming)

Standards
– GSM (2G)

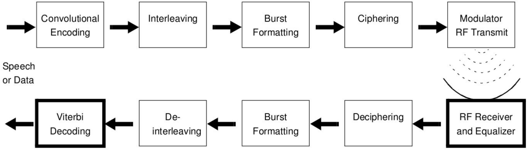


Figure 7. Block diagram of a typical GSM data communication system

- Main applications: speech transmission, short messages
- Frequency planed cellular network; TDMA; frequency division duplex (FDD)
- Modulation: Gaussian minimum shift keying
- Channel coding: convolutional codes
- Channel equalization: soft-output Viterbi algorithm
- Diversity through frequency hopping (for example for slow users)
- Data service (EDGE/GPRS): 8-PSK modulation, up to 177 kbps

Standards
– UMTS (3G)

- WCDMA: DS CDMA using BPSK/QPSK, 5 MHz channels
- Down-link rates up to 2 Mbps
- Equalization with Rake receiver (frequency diversity)
- Channel coding with convolutional and Turbo codes
- Power control
  (near/far problem)

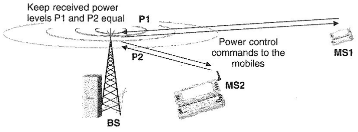
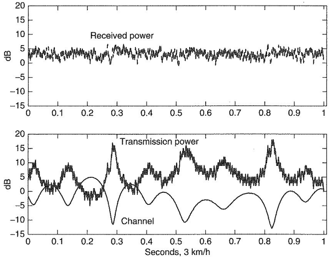


Figure 3.8. Closed-loop power control in CDMA

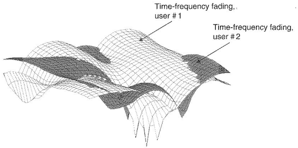


HSPA (3.5 G, 14 Mbps downlink, 5.7 Mbps uplink)

- Higher-order modulation, 16-QAM
- Channel-dependent scheduling (user with best channel is served)
- Hybrid ARQ (automatic repeat request) with soft combining.
- HSPA Evolution: MIMO (spatial multiplexing, MIMO precoding)

Standards
– LTE (4G)

- MIMO OFDM; QPSK, 16QAM and 64QAM; peak data rates 100 Mbps/50 Mbps
  5-20 MHz channels.



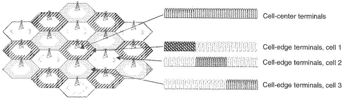


Figure 14.2 *Example of inter-cell interference coordination.*

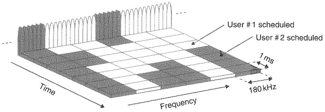


Figure 14.1 *Downlink channel-dependent scheduling in time and frequency domains.*

- MIMO techniques
  - Beamforming
  - Space Frequency Block Coding
  - Spatial multiplexing
- Hybrid ARQ (automatic repeat request) with soft combining.
- Channel dependent scheduling and rate adaptation
- Inter-cell interference coordination

Standards
– LTE (4G)

Chase combining:

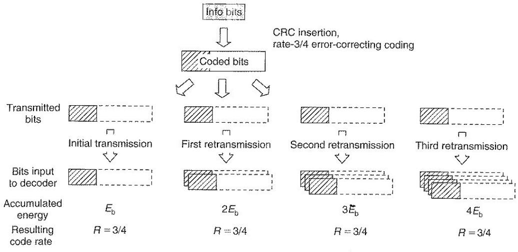


Figure 7.5 *Example of Chase combining.*

Soft combining:

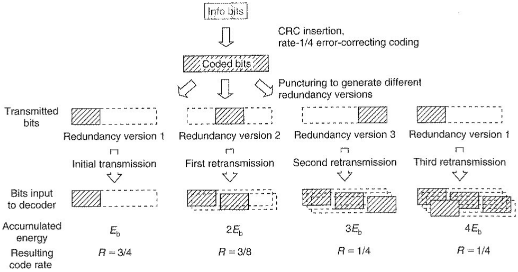


Figure 7.6 *Example of incremental redundancy.*

Standards
– 5G

- Major deployment time: around 2020. Test (Ericsson, Huawei) 2015-2016.
- Data rate: up-to 10 GigaBPS.
- Low delay: 10 times lower than 4G, down to 1ms.
- Energy-efficiency: 100 times higher than 4G
- Main technologies: (1) Massive MIMO.
- (2) Wireless caching
- (3) Coding, spatial coupling
- (4) Millimeter Wave communications
- (5) SCMA (sparse coded multi-access).
- (6) Machine-type communications, connecting hundreds of thousands of sensors.

Final Exam

Date and time (**Please check KTH social for updates!**)

- 1. Exam: Thursday, March 24, 14:00-19:00, rooms E51
- Re-exam: Thursday, June 6, 8:00-13:00, room E32

Format

- Written exam (5 h) with 5 problems
- Each problem can give a maximum of 5 points; a maximum of 25 points can be achieved in the exam.
- The homework projects give extra credit on the mandatory exam.

Pass criterion

- More than 11 (eleven) credits have to be obtained (including the bonus from the homework projects).
- 4 (four) out of 5 (five) exam problems have to be passed with 2 (two) or more credits.

Allowed aids on exam

- Handbooks (mathematical handbooks, e.g. Beta)
- Collection of signal processing formulas (Swedish version)
- The textbook (Proakis/Madhow) and handouts
- Lecture slides
- Calculator

Course Evaluation

- Link to the course evaluation:

  `https://www.kth.se/social/course/EQ2410/survey/`
- Login with your KTH social ID.
- Note
  - Course evaluation surveys are an important tool for teachers to get constructive feedback on the course design. Conclusions drawn from course evaluation surveys are used to improve the quality of teaching. Course evaluation surveys are also an important part of the teacher's documentation.
  - This survey is anonymous. That is, we will receive the collection of all submitted answers, but we will not be able to map the answers to the individuals.