Mobilkommunikation - Mobile Communications

Lecture 11: 3G and 4G

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2G cellular system: GSM circuit switched

- architecture
- radio interface
  - TDMA frames
  - logical channels
- protocol stack
- localization and calling
- handover
- security

Universal Mobile Telecommunication System (UMTS, 3G)

- Code Division Multiple Access (CDMA)

Higher data rates for 3G evolution and 4G

- Adaptive Modulation
- Channel-Dependent Scheduling
- Hybrid ARQ

Direct sequence CDMA

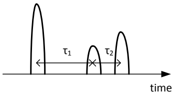
UMTS radio access network

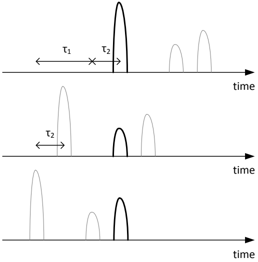
- based on an evolved GSM core
- Orthogonal Variable Spreading Factor (OVSF)
  - channel bandwidth: 5 MHz
  - chipping sequences for spreading
  - constant chipping rate: 3.84 million chips per second
  - different spreading factors in the range from 4 to 512
  - lower spreading factor
    - less robustness
    - higher data rate
  - modulation: QPSK
  - coding: 1/2 or 1/3 FEC
  - sophisticated power control
    - target: same signal to interference ratio for all mobile stations

Rake receiver

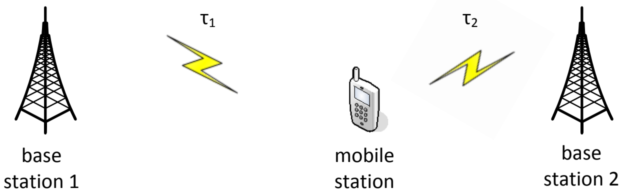
Time dispersion, e.g., due to multi-path propagation

- the autocorrelation function of a good code has a single peak
  - the receiver synchronizes with the sender, i.e., it finds the peak
- time shifted copies of the signal are linearly superposed
  - the correlation function of the superposed signals and the code has several time-shifted peaks
  - the receiver has n Rake fingers to synchronize to the n strongest peaks; the results of all n fingers are combined





Soft handover



Rake receiver can tune to the signals of two base stations

- using the same code
- signals need not be fully synchronized at the receiver

Frequency reuse

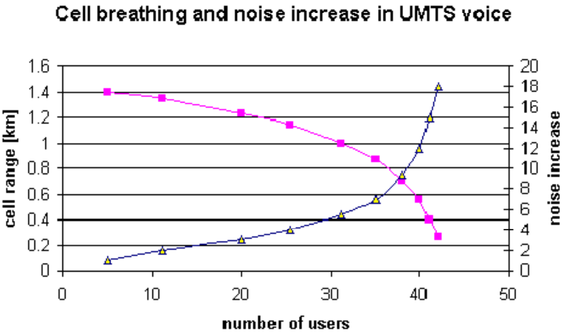
One cell frequency reuse

- enables soft handover
- requires efficient power control
- makes controlling system load harder

GSM versus UMTS

- TDMA
  - frequency planning
  - time-slot assignment
- CDMA
  - one cell reuse
  - interference reduces capacity
  - power planning

Cell breathing



Source: Schiller, Mobile Communications

- interference from other users adds to the noise
- users at the border of the cell have weak signals that may be drowned in noise so that they cannot communicate
- cell size decreases with increasing number of users
- cell breathing makes network planning difficult

Towards higher data rates

- higher signal power
  - but causes also higher interference
  - not useful in band-width limited regime
- wider bandwidth
  - CDMA, now OFDM
- MIMO
  - antenna diversity (combining)
  - beam forming (less interference)
  - spatial multiplex
- higher order modulation

- Shannon's law

$$C = B \log_2 \left(1 + \frac{S}{N}\right)$$

- $S/N =$ signal-to-noise ratio
- $B =$ bandwidth [Hz]
- $C =$ max data rate [b/s]

modulation	symbols	bits/symbol
BPSK	2	1
QPSK	4	2
16QAM	16	4
64QAM	64	6

Towards higher data rates

The maximum rate is shared among all users belonging to a cell

- higher data rates allow accommodating more users
- smaller cells can also accommodate more users by utilizing spatial multiplexing

Radio channels are subject of rapid and significant variations of channel conditions due to

- fading and shadowing
- distance dependent path loss
- interference

A number of options exist how these variations can be dealt with

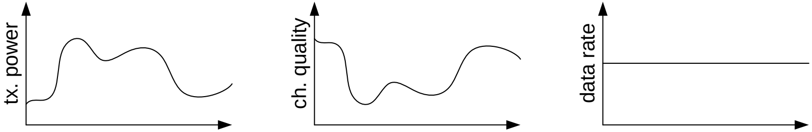
- adaptive modulation: power versus rate control
- channel-dependent scheduling
- hybrid ARQ with soft combining

Link adaptation: dynamic power control

- real time constant bit rate data, e.g. voice
- highly variable channel
- the achievable data rate depends on the channel SNR according to Shannon's law

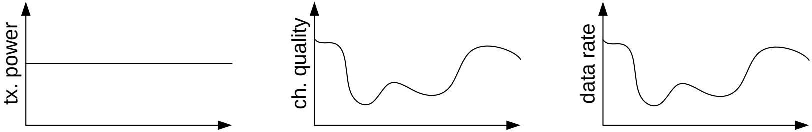
$$C = B \log_2 \left(1 + \frac{S}{N}\right)$$

- adjust the transmit power dynamically to achieve a constant SNR at the receiver



Link adaptation: dynamic rate control

- non real time constant or variable bit rate data, e.g. WWW
- target is simply to achieve a data rate as high as possible
- the data rate and the amount of redundancy is adjusted to the channel SNR using different modulation and coding schemes (MCS)
- the transmitter can always use (near) optimal transmit power



Channel-dependent scheduling

Transmissions to multiple users often occur in parallel, e.g.

- high speed downlink packet access (HSDPA) uses a combination of TDM and CDM
- long term evolution (LTE) systems use a combination of TDM and FDM

Instantaneous radio conditions

- vary quickly and
- vary independently for each user

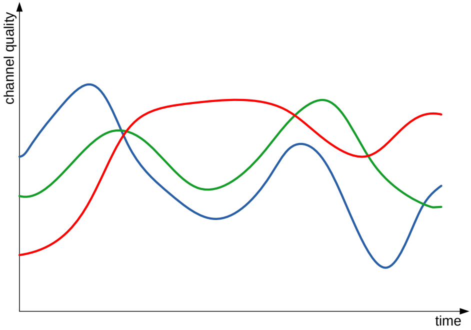
Channel-dependent scheduling

- at any time transmit to the mobile station that sees the best instantaneous channel conditions
- also referred to as opportunistic scheduling

$\Rightarrow$ fading is beneficial and is exploited

Multi-user diversity

Channel-dependent scheduling exploits multi-user diversity



Using channel-dependent scheduling the effective channel variations as seen by the base station become smoother with increasing number of mobile stations.

Channel-dependent scheduling

- assigns the channel to the station $k = \arg\max_i R_i$
  - R_i is the instantaneous data rate achievable by station i
- is beneficial for overall system throughput
- can, however, cause fairness and quality of service issues
  - stations that see a bad channel are not assigned the channel
  - stations may see a bad channel for quite long durations, e.g. due to the distance or due to shadowing

Round robin scheduling

- assigns the channel to each station in a round robin fashion
- gives each station a fair share of the radio resources
- not generally fair regarding the quality of service
  - stations with bad channel conditions receive less data
  - achieving the same data rate by all stations requires allocating the channel to stations with bad conditions for longer periods

Proportional fair scheduling

Target

- use fast variations of channel quality for channel-dependent scheduling while
- limiting the adverse effects of long-term differences in channel quality

Proportional fair scheduling

- assign the resources to the user with the relatively best channel conditions
- assigns the channel to station $k = \arg\max_i \frac{R_i}{\overline{R}_i}$
  - R_i is the instantaneous data rate achievable by station i
  - $\overline{R}_i$ is the average data rate of station i, e.g. averaged over 1 s

Many more sophisticated scheduling algorithms and proprietary (secret) implementations in base stations.

Acquiring channel state information

Channel state information

- downlink
  - reference signals are broadcast on the downlink
  - mobile stations generate measurement reports for the BTS
- uplink
  - more difficult since no reference signal exists

Ideally channel-dependent scheduling has information about the instantaneous channel conditions

- measurement data reflects, however, only the past
- predictions of future channel conditions are better in case of slow fading (low mobility)

Note that we always assumed greedy stations. If a station is not backlogged it cannot contribute to multi-user diversity.

Hybrid ARQ

Forward error correction (FEC)

- introduces redundancy by adding parity bits to the information bits
- parity bits can be used by the decoder to fix bit errors (up to a certain degree)

Automatic repeat request (ARQ)

- uses cyclic redundancy checks (CRC) to detect bit errors
- requests retransmissions of erroneous packets using ACK/NAK

Hybrid automatic repeat request (HARQ)

- uses FEC to correct a subset of errors
- relies on CRC to detect remaining errors
- uses ARQ to request retransmissions

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HARQ with soft combining

If an error remains after FEC and is detected by CRC a HARQ implementation

- discards the erroneous packet
- requests retransmission of the packet

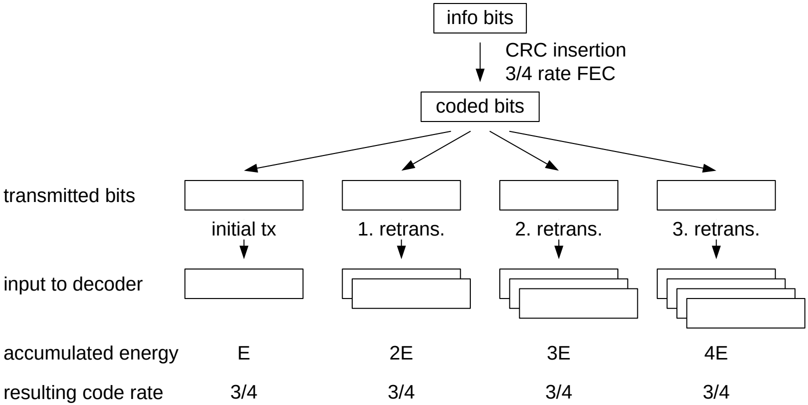
Instead HARQ with soft combining

- stores the erroneous packet in a buffer and
- later combines it with the retransmission to
- obtain an estimate that is more reliable than its parts

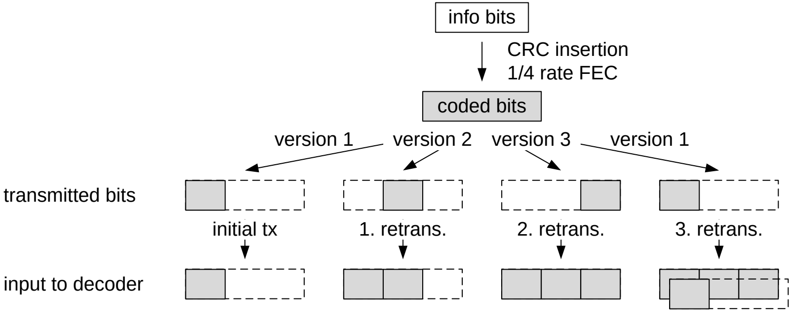
Implementation options

- Chase combining: the retransmission consists of exactly the same coded bits as the original
- Incremental redundancy: the same information bits are retransmitted using multiple different sets of coded bits

Chase combining



Incremental redundancy



accumulated energy	E	2E	3E	4E
resulting code rate	3/4	3/8	1/4	1/4

Literature

- Jochen Schiller, Mobile Communications, Second Edition, Addison-Wesley, 2003.
- Vijay Garg, Wireless Communications & Networking, Morgan Kaufmann, 2007.
- Erik Dahlman, Stefan Parkvall, John Sköld, Per Beming, 3G Evolution: HSPA and LTE for Mobile Broadband, Elsevier Academic Press, 2nd edition, 2008.