Dynamic Algorithms for Multiuser OFDM Wireless Cells

Kolloquium der Fakultät EIM

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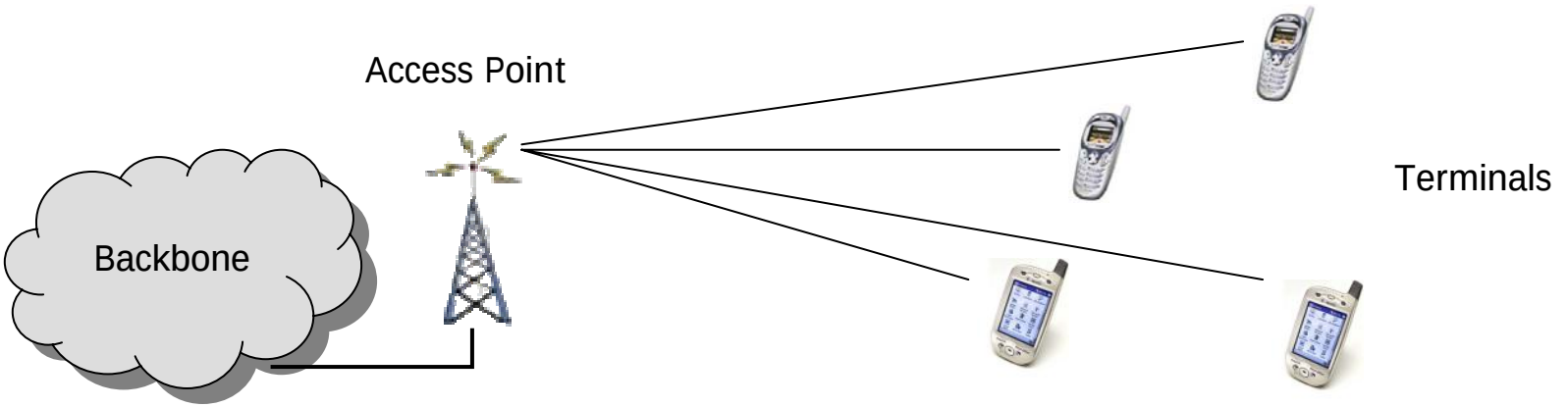
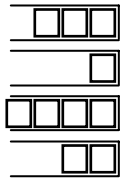
Basic Scenario



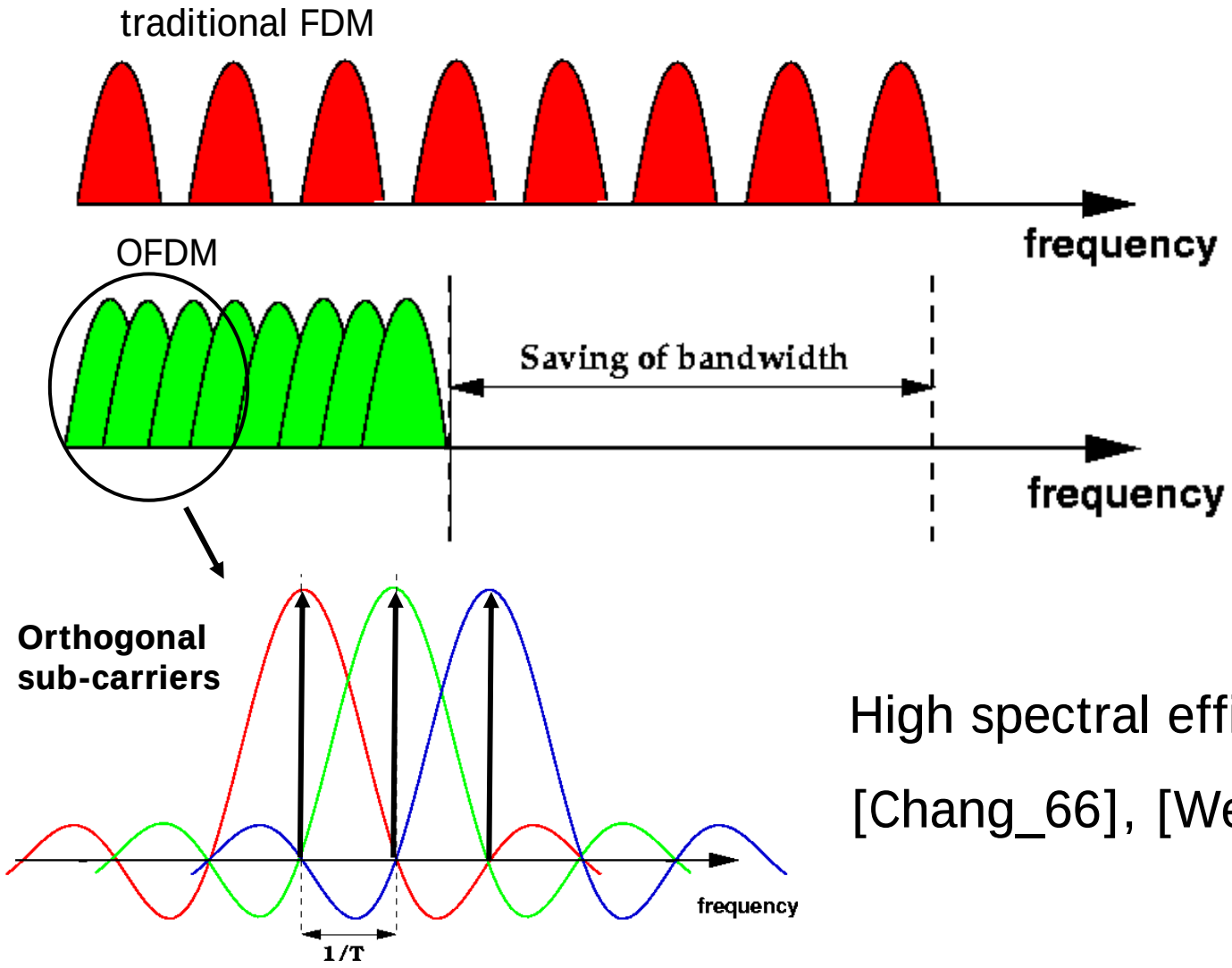


Data Queues at Access Point

Down-link

OFDM as transmission scheme!

Orthogonal Frequency Division Multiplexing

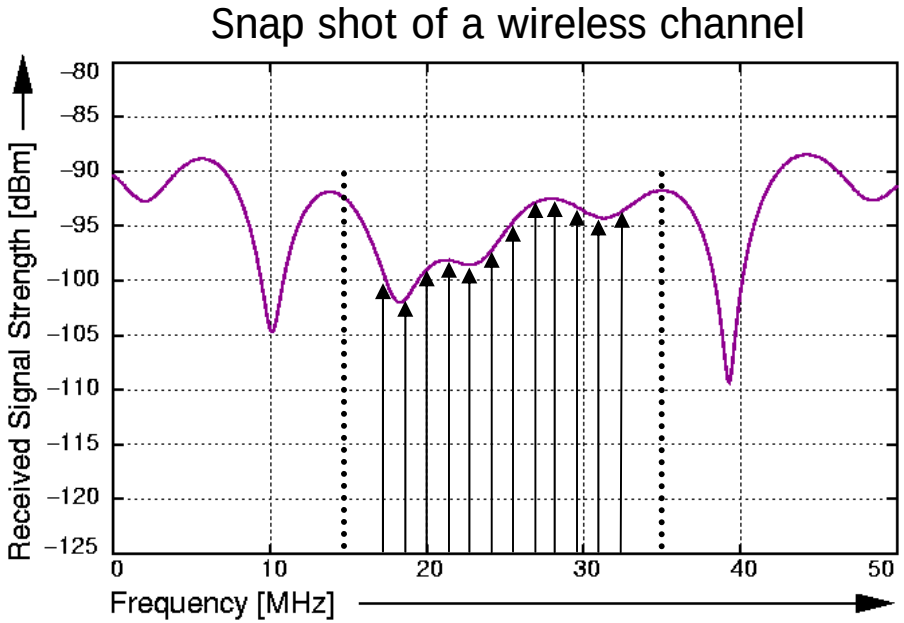


High spectral efficiency!

[Chang_66], [Wein_71]

Why OFDM? -> Wireless Channel Characteristics!

- Multi-path propagation ➔ frequency selective fading!

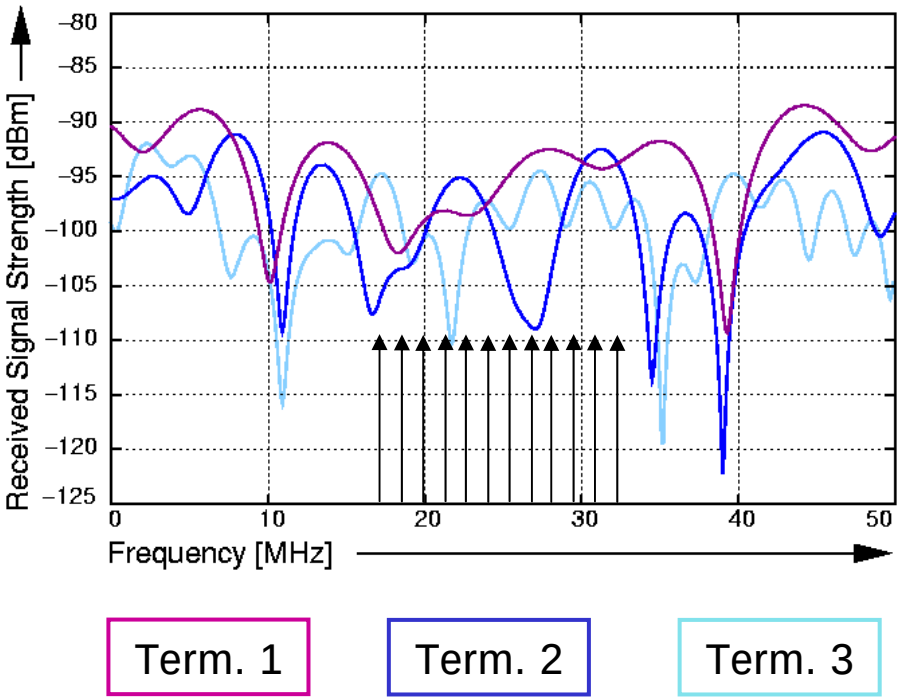


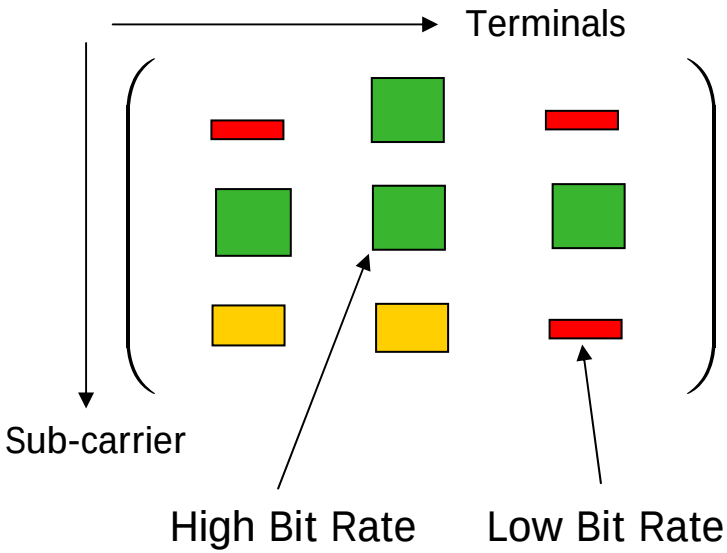
- Freq. sel. fading limits single-carrier systems
- OFDM overcomes this problem!
  - Implementations: DVB, 802.11a/g, 802.16 etc.
  - Candidate for future cellular systems (LTE)

Diversity in Multiuser OFDM Systems

- Signal-to-noise ratio (SNR) measures channel quality
- Adaptive modulation: Bit rate depends on the SNR

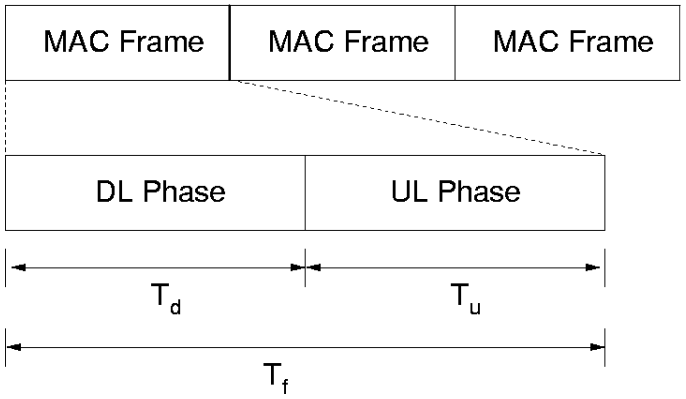
Multiple Terminals: Frequency and Multi-user Diversity





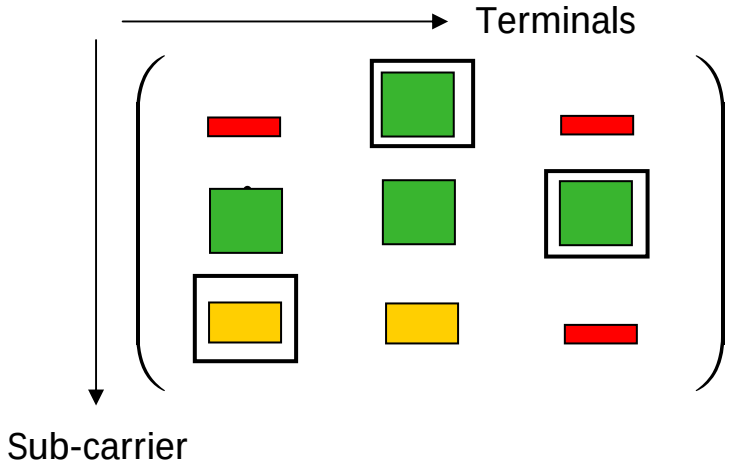
System Model & Dynamic OFDM

- Time slotted into frames
- Channel states constant during each frame
- Access point „knows“ current channel matrix
- Organization of the down-link transmissions?

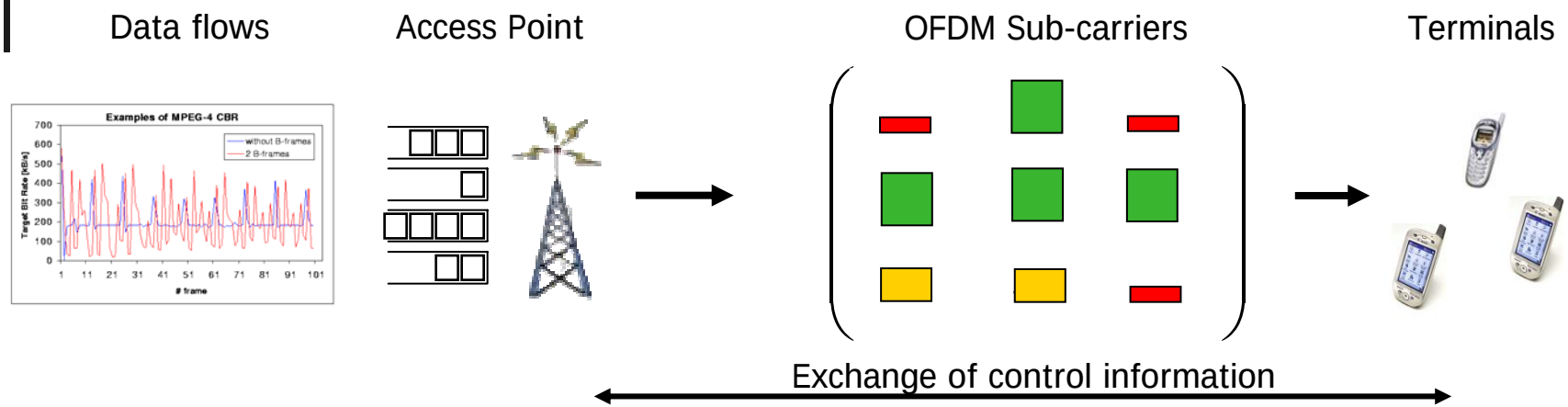


Dynamic OFDM:

Assign disjoint sets of sub-carriers to terminals depending on sub-carrier state matrix!



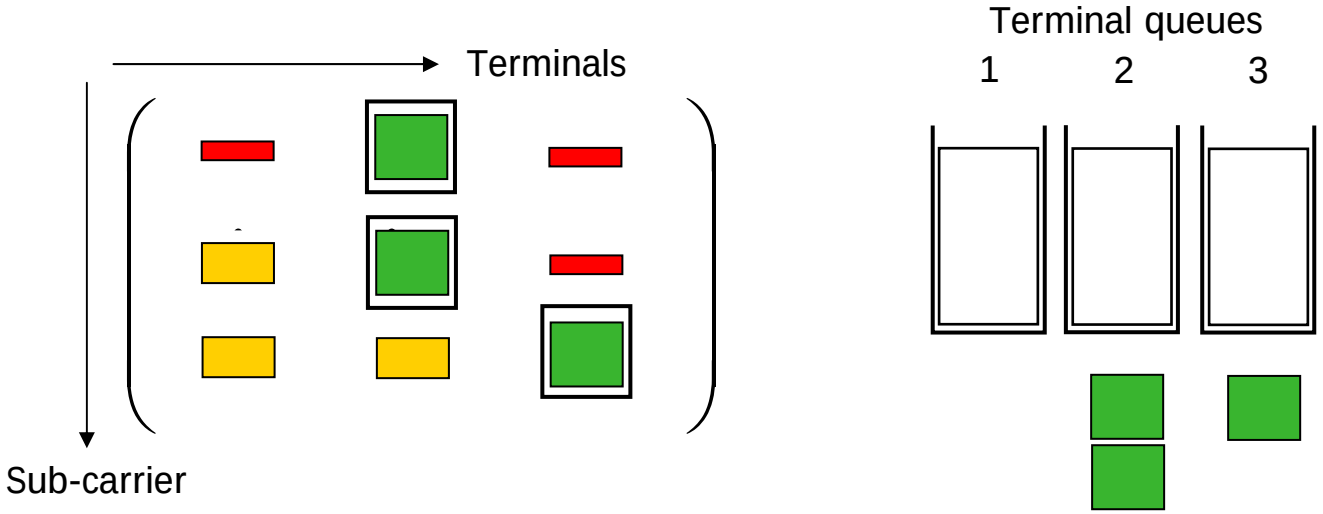
Dynamic OFDM Systems - Issues



- Resource assignment
  - Performance limits – How much dynamics?
  - Practical schemes – Heuristics, packet nature?
- Additional overhead
  - Signaling – Reduction of overhead?
  - Channel acquisition at the access point
- Application to example systems (IEEE 802.11)
  - Protocol modifications

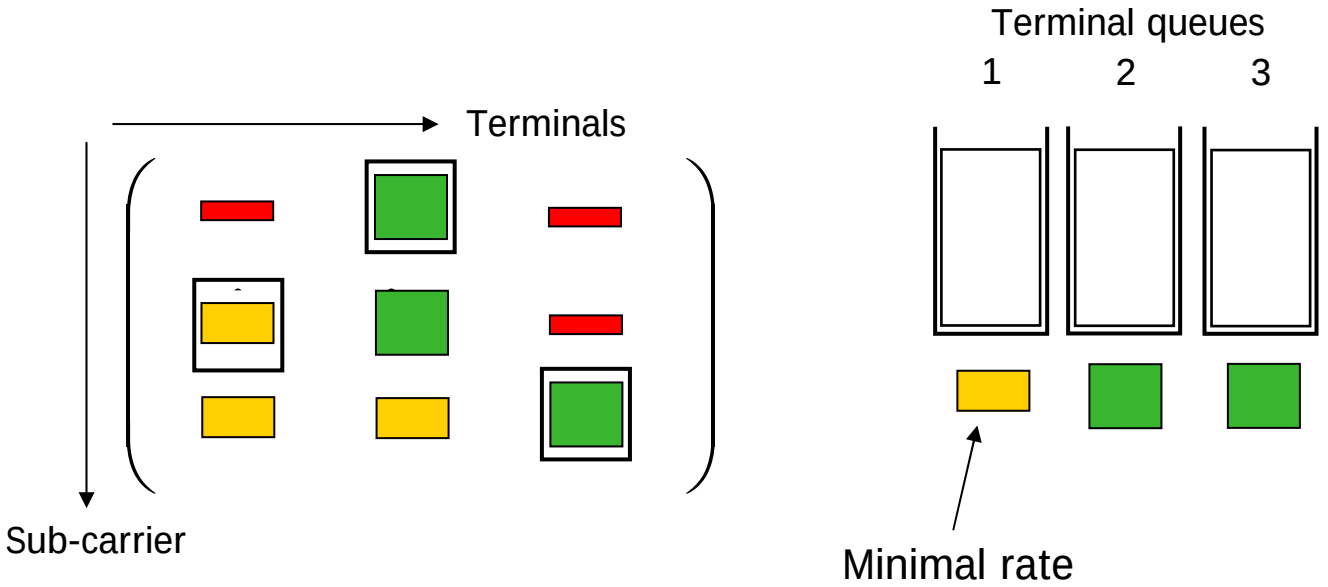
Performance Limits

- Assumption: 1 large file queued for each terminal
- Goal: Optimize the down-link throughput!
  - Integer constraint on the assignments
- Intuitive approach: „Maximize Sum Rate“ [Jang_03]
  - Each sub-carrier assigned to terminal with best rate



Performance Limits II

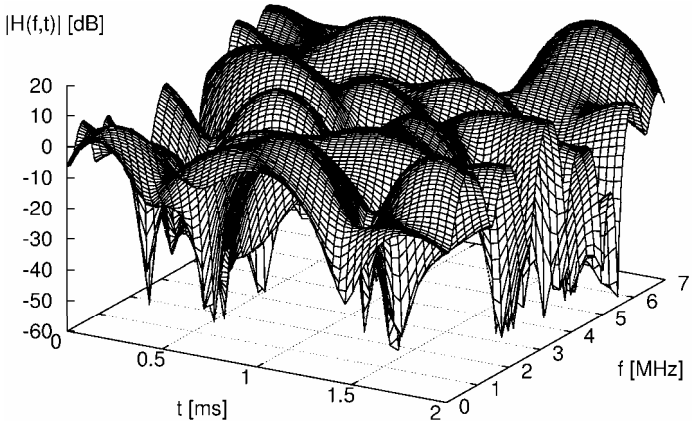
- Pure rate maximization leads to fairness problems
- Instead: Optimize „fairness-constrained“ throughput
  - Maximize the minimal throughput [Rhee_00]



- NP-hard optimization problem [Gross_06a]
- Practical instances are difficult [SNDlib]

Practical Assignment Algorithm - Relaxation

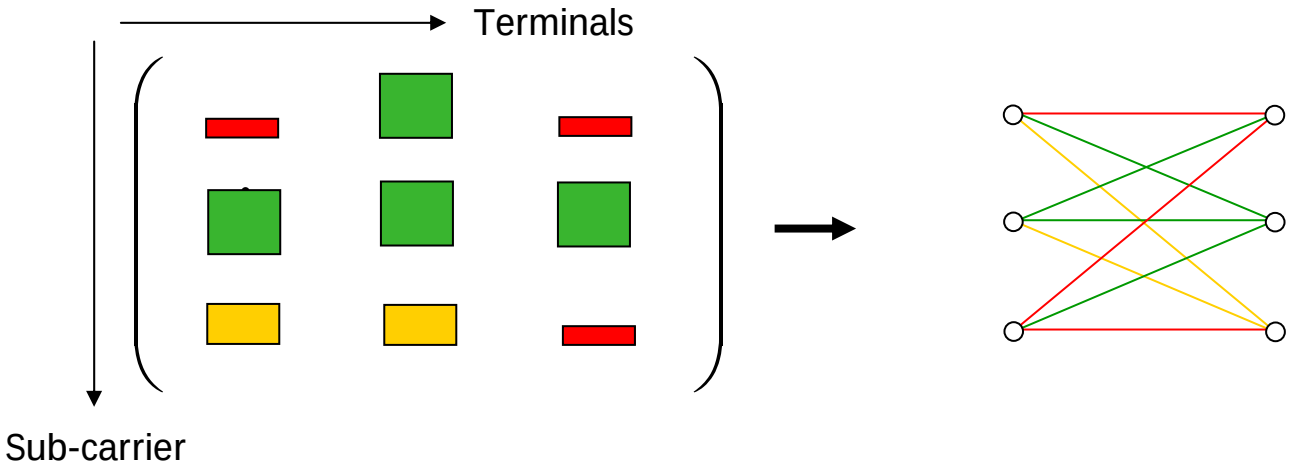
- Generate assignments within milliseconds!



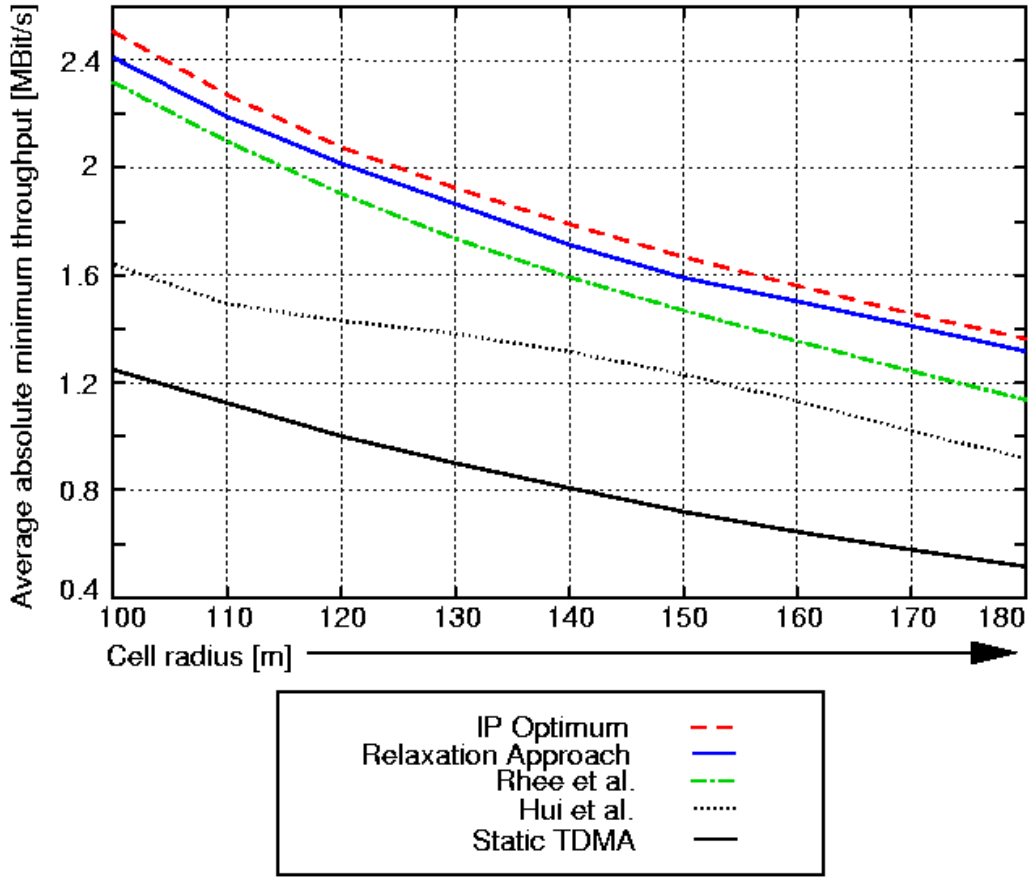
- Common approach in integer opt.: Relaxation
  - Solve the corresponding linear program
  - Problem: Obtain a feasible and good assignment from the LP (linear program) solution!
    - Static power distribution: Assign each sub-carrier to terminal with largest share
    - Dynamic power distribution: Initially assign each sub-carrier to terminal/modulation with largest share, afterwards check and modify regarding transmit power constraint

Practical Assignment Algorithm – Matching

- Achieved rate per terminal depends on:
  - Amount of sub-carriers received
  - Specific sub-carriers assigned
- Simplify the max-min problem by fixing the amount of sub-carriers assigned to each terminal
- Resulting problem is equivalent to bipartite weighted matching, optimal algorithms can be applied [Yin_00]



Example Results: Assignment Algorithms



Parameters:

- 8 terminals
- 1 m/s object mobility
- 16.25 MHz bandwidth
- 48 sub-carriers
- 5.2 GHz center freq.
- 10 s simulated time
- 2 ms frame length
- 10 mW transmit power
- static power distr.

Relaxation approach provides very good performance, also if power and sub-carriers are assigned dynamically!

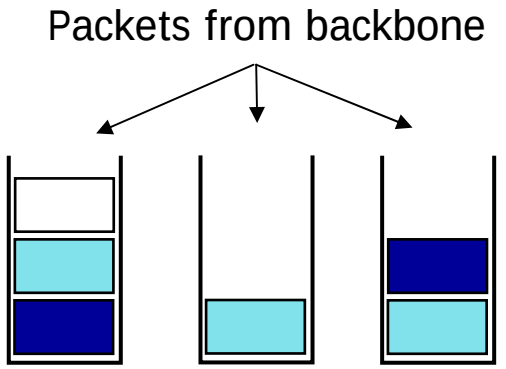
Further Aspects of Assignment Algorithms

- Usually queue states differ!

  Compute ratio between data queued for each terminal:

  ➔Relaxation with weights

  ➔Matching with adjusted sub-carrier amounts per terminal



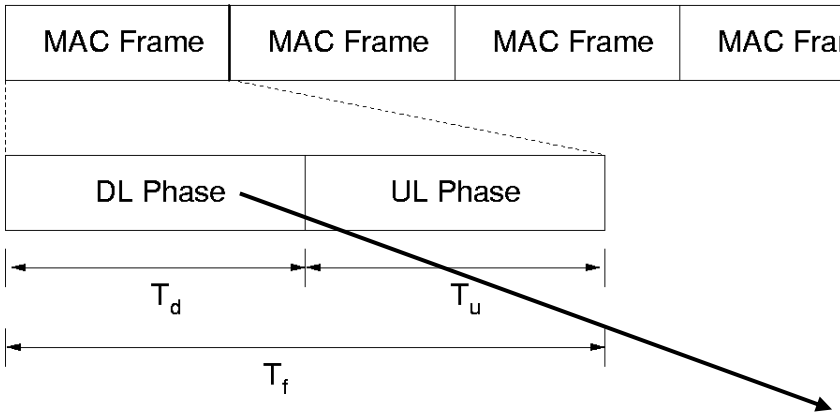
- More sophisticated models match packets to OFDM resources according to various scheduling policies for different flows (best-effort appl., real-time appl.)

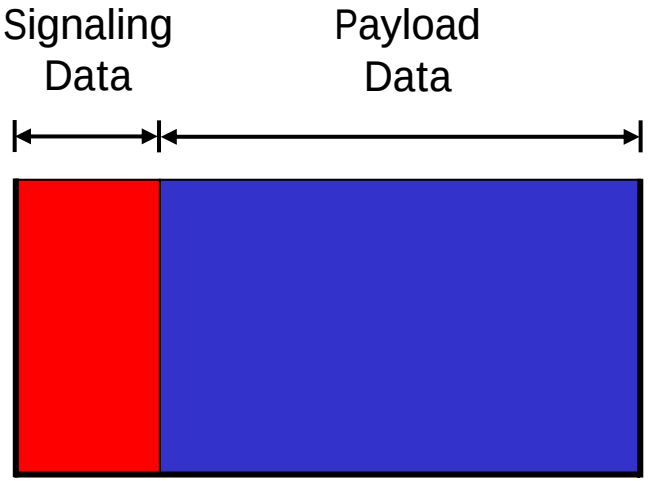
  ➔Currently a hot topic [Zhang_06], [Bohge_06], Relaxation approach seems well suited!

Signaling Cost

- Access point generates dynamic assignments

  ➔ How do terminals know about their assignments?





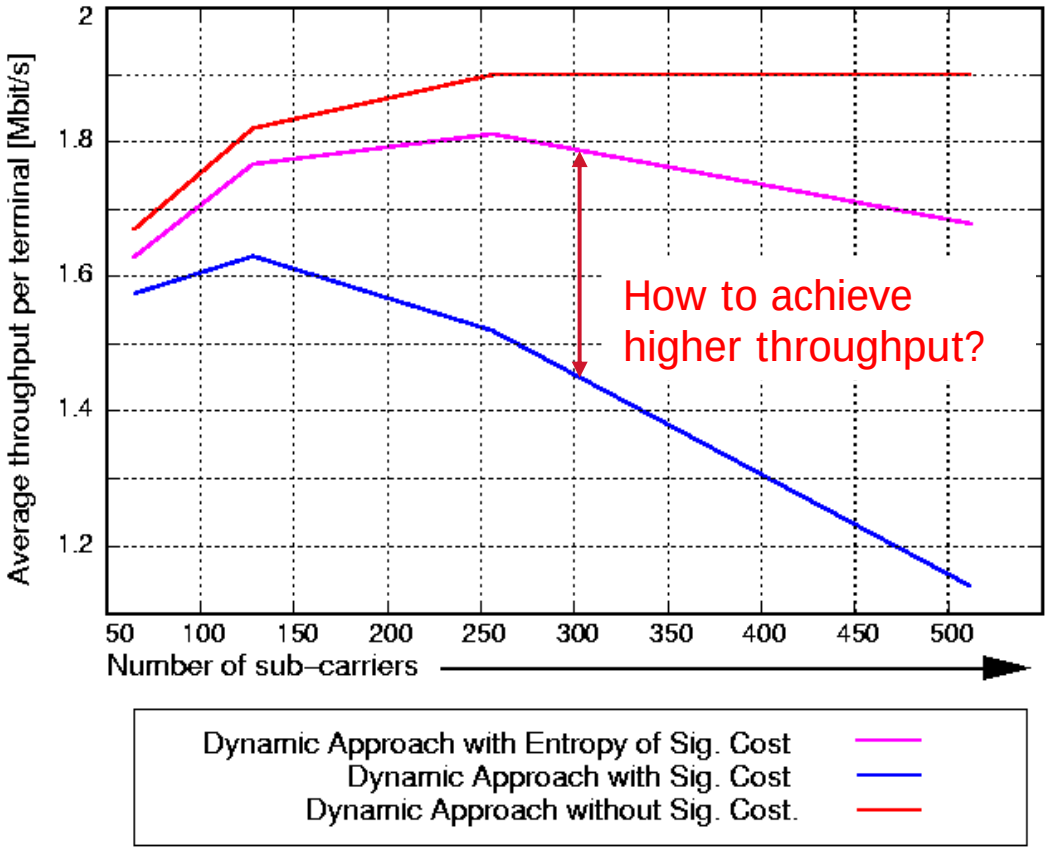
- <u>Problem:</u> Impact due to signaling cost?

Characterization of Signaling Cost

- Initially chosen signaling model:
  - Binary assignment representation
  - Signaling information broadcasted on all sub-carriers
  - Transmitted by robust modulation/coding combination
  - All assignments signaled per down-link frame

- Evaluation questions:
  1. What is the loss due to signaling?
  2. Is the signaling cost parameter dependent?

Example Results: Impact of Signaling Cost



Parameters:

- 8 terminals
- 1 m/s object mobility
- 100 m cell radius
- 16.25 MHz bandwidth
- 0.8 µs guard period
- 5.2 GHz center freq.
- 10 s simulated time
- 2 ms frame length
- 10 mW transmit power
- static power distr.
- 0.2 µs delay spread
- matching algorithm

- Quantitative and qualitative impact [Gross_04]!
- Imp. Param.: Sub-carrier number, bandwidth & frame length

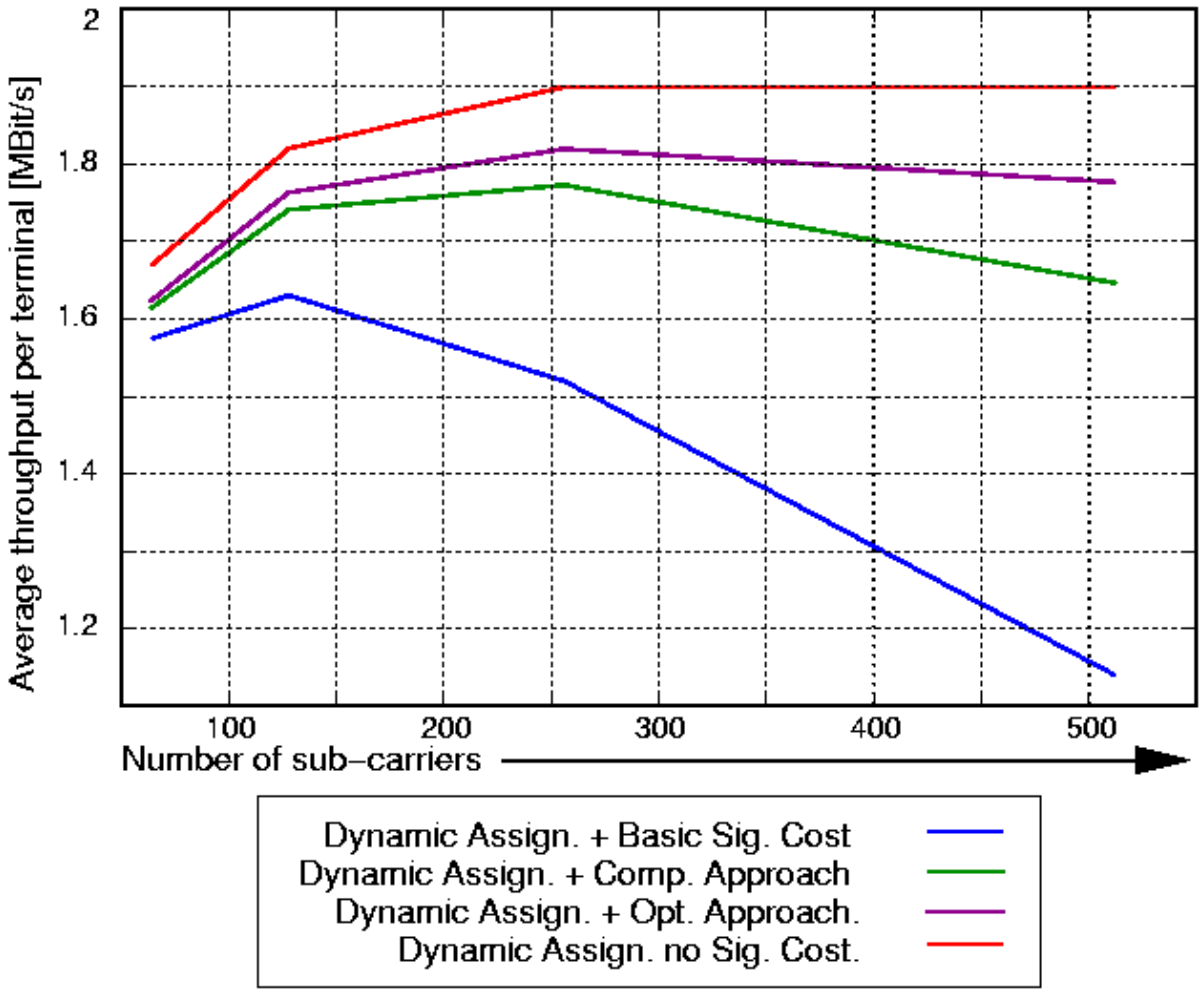
Advanced Signaling Approaches

- Entropy results indicate correlation of sub-carrier assignments (in time and frequency)

- Exploit correlation - two approaches investigated:
  - More complex assignment algorithms [Gross_06b]
    - Quadratic optimization model
    - Evaluation: Iterative sequence of integer programs
  - Compression of the signaling information
    - Evaluation: Choice of suitable compression algorithms

- Both schemes require additional computational resources

Example Results: Advanced Signaling Approaches



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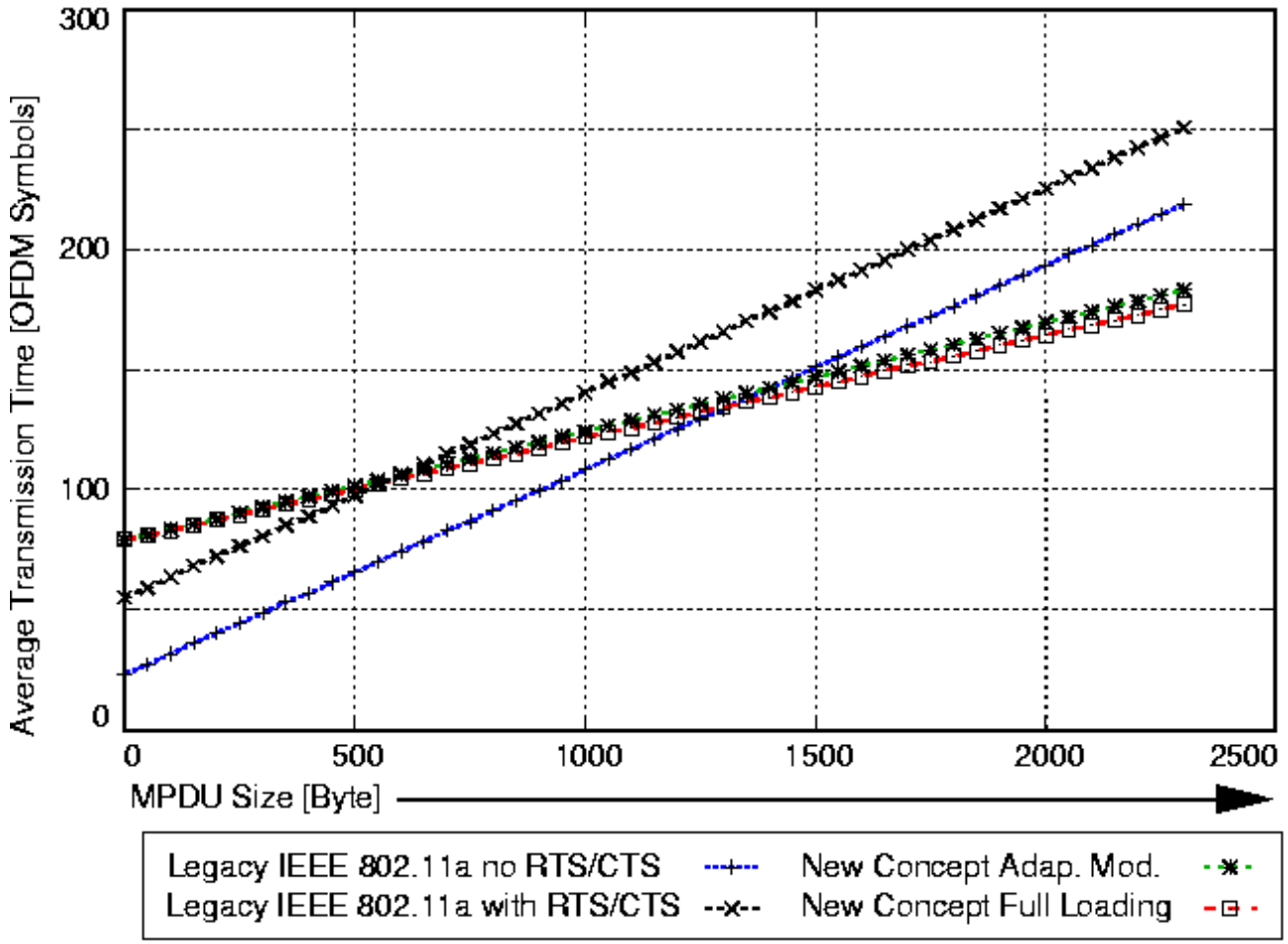
Protocol Modifications for IEEE 802.11 (a/g)

- How could IEEE 802.11 (a/g) networks benefit from dynamic OFDM assignments?

- Aspects of protocol modifications:
  - Acquisition of channel knowledge
  - Transmission of signaling information
  - Possible transmission delay due to assignment comp.
  - Compatibility to legacy systems

- In this talk: Only point-to-point dynamic schemes (adaptive modulation)

IEEE 802.11 (a/g) – Mod. Single-User DCF Mode



Parameters:

- 16 terminal positions
- 1 m/s object mobility
- 80 m cell radius
- 16.25 MHz bandwidth
- 48 sub-carriers
- 0.8 µs guard period
- 5.2 GHz center freq.
- 10 s simulated time
- 10 mW transmit power
- 0.2 µs delay spread

Pure transmission time comparison – no packet errors, no random channel access, no retransmissions

Conclusions

- Dynamic OFDM is a promising technology

- Meaningfull assignment problems can be difficult!
  - Relaxation approach best suboptimal technique

- Control overhead is required
  - Signaling cost has an quantitative and qualitative performance impact
  - Reduction of signaling cost possible

- Example results of dynamic OFDM for IEEE 802.11 (a/g) performs well for the point-to-point case

Some Currently Open Issues

- Table look-up for dynamic OFDM assignments
  - Diploma thesis at TKN
- Performance of multiuser dynamic OFDM in 802.11
  - Diploma thesis at TKN
- Assignment schemes for WiMax systems
- Dynamic OFDM schemes for multi-cell scenario
- Prototyp implementation of dynamic sub-carrier assignment schemes in OFDM transmission systems
  - Done here in Paderborn!

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