Allocating and assigning OFDM subcarriers to MPEG video transmissions – Does crossing layers really help?

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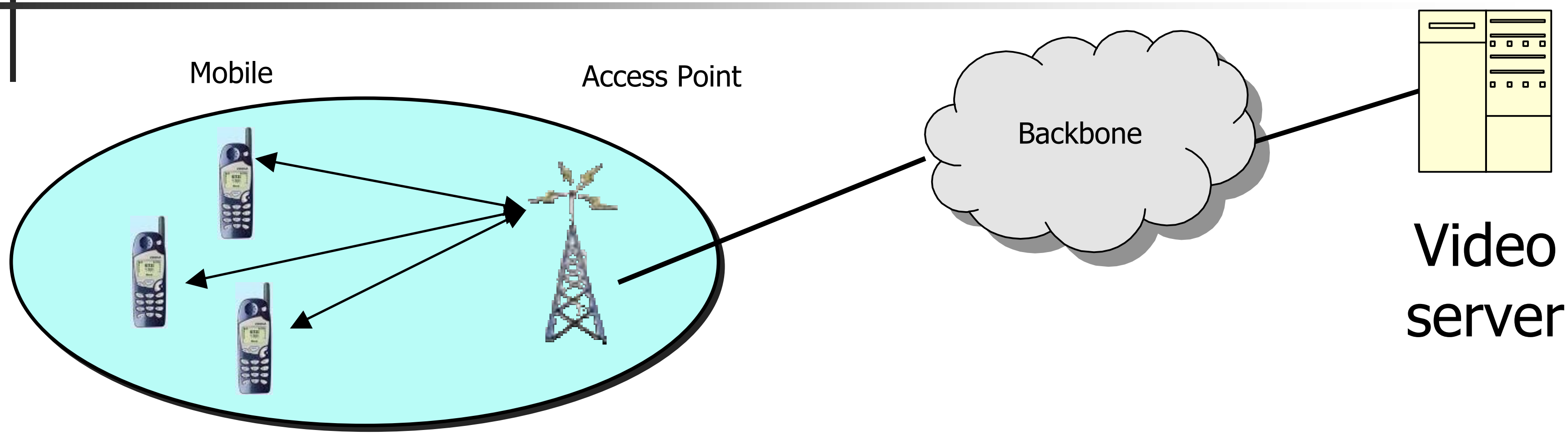
James Gross, Dr. Holger Karl, Jirka Klaue,
Prof. Dr.-Ing. Adam Wolisz

Telecommunication Networks Group
Technische Universität Berlin

Outline

- Motivation
- Flexibly mapping video transmissions to an ODFM system
- Evaluating video transmission quality
- Performance results
- Conclusions

Scenario



- Application scenario: Transmission of real-time MPEG-4 video-streams (downlink only)
  - Live events, video conferencing

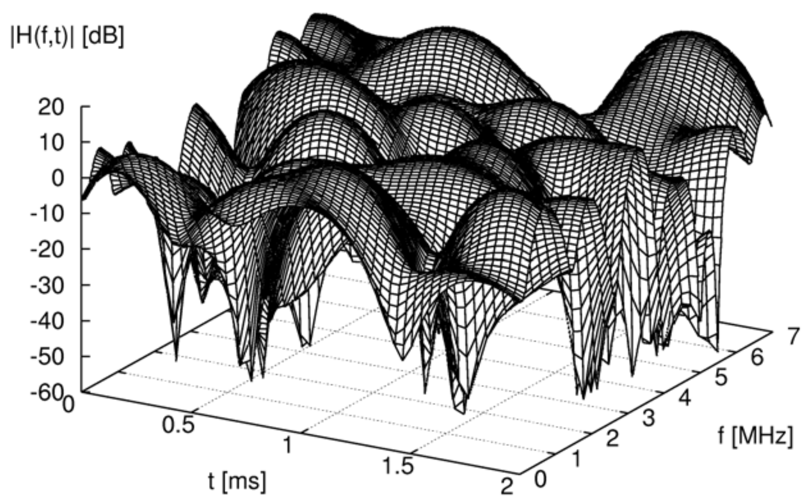
→ How many users can be served within the cell with good (acceptable) perceived video quality?

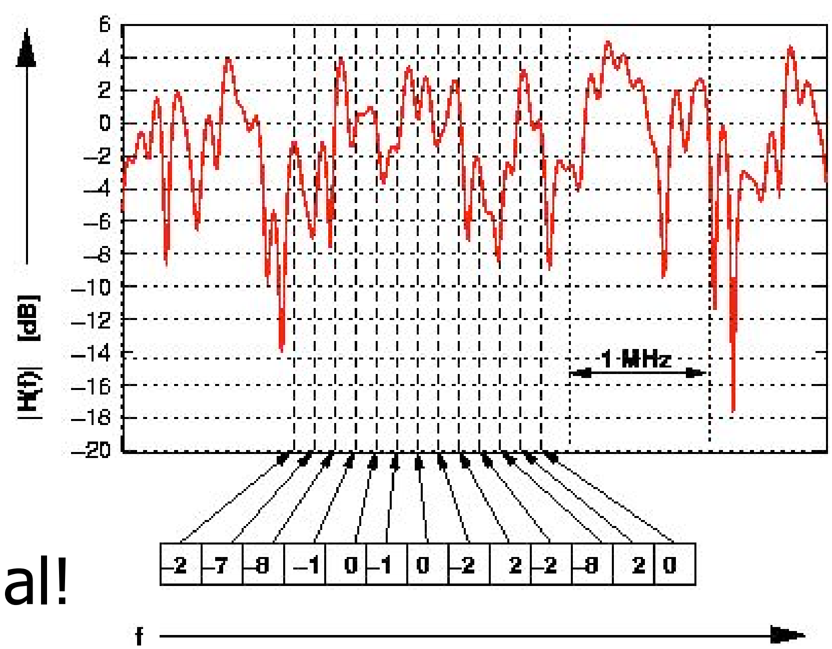
Problems & system approach

- What are quality impediments?
  - Time-variable nature of the wireless link
  - Dynamic nature of video transmissions, varying bandwidth
- Where to optimize?
  - Biggest problem in the wireless link & video
  - End-to-end optimization: too slow?
  - Link layer has/can obtain information about **both** application **and** channel characteristics
- What to optimize?
  - In access point`s link layer, assign wireless resources to flows such that many users will be happy

Resource: Time-varying wireless channels

- Attenuation determines quality of a channel
- Attenuation changes in time and frequency due to:
  - Path loss - deterministic
  - Shadowing & fading - stochastic





Different figures for each terminal!

Snapshots of wireless channels

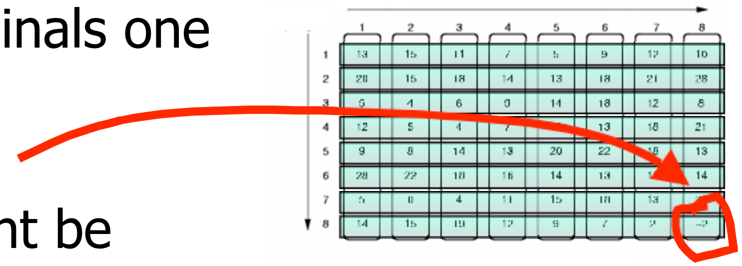
- Observation: Subcarrier gains are stable for a certain time span (coherence time)
- Access point can assume knowledge of “snapshots” of the current channel qualities to all terminals

Subcarrier →

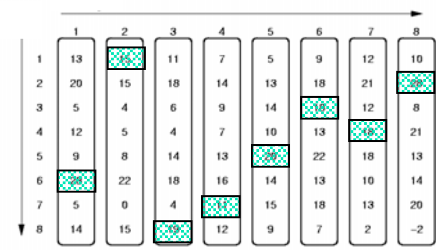
Receiver ↓	1	2	3	4	5	6	7	8
1	13	15	11	7	5	9	12	10
2	20	15	18	14	13	18	21	28
3	5	4	6	9	14	18	12	8
4	12	5	4	7	10	13	18	21
5	9	8	14	13	20	22	18	13
6	28	22	18	16	14	13	10	14
7	5	0	4	11	15	18	13	20
8	14	15	19	12	9	7	2	−2

How to multiplex channels based on snapshots?

- Time division multiplexing:
  - All subcarriers are given to terminals one at a time
  - Bad subcarriers are not utilized
  - However, these subcarriers might be good for other terminals !



- Frequency division multiplexing:
  - The set of all subcarriers is divided into **multiple subsets**, each of them supporting one terminal
  - Dynamically assigning subcarriers outperforms static schemes/TDM in terms of required power or cell capacity



- **Open question**: How to apply dynamic FDM subcarrier allocation/assignment to multi-media traffic?

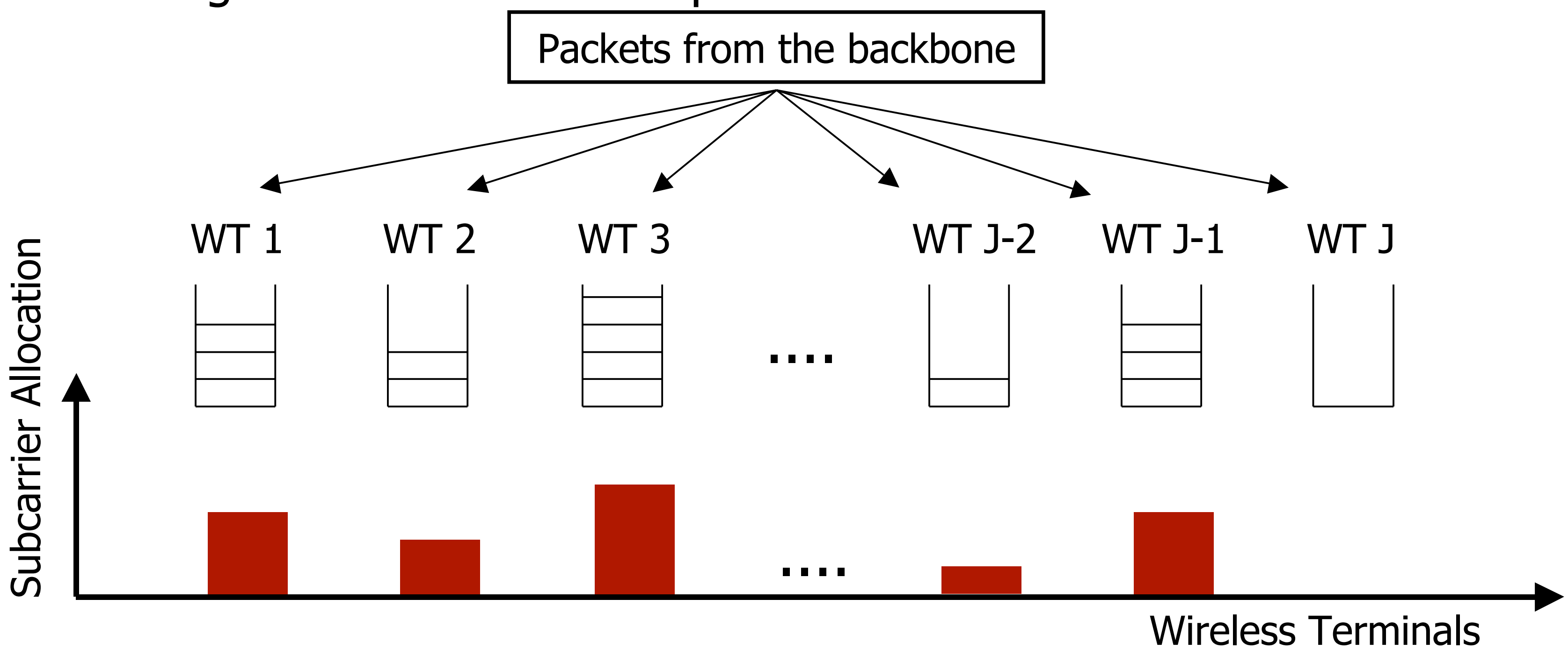
Optimization approach

- Basic issue
  - How to generate the subsets ?
- Two-step approach (Yin et al. 2000)
  - First: determine the **number** of subcarriers for each subset – called subcarrier **allocation**
  - Second: choose subcarriers according to the allocated number for each subset – called subcarrier **assignment**
- **Our concept**
  - Utilize data-traffic-related information for the allocation
  - Utilize channel-related information for the assignment

Allocation based on data traffic

- Observation: Terminals with bad states will build up their queues
  - Frames arrive faster than link can handle, retransmissions

➔ Approach 1: Allocate subcarriers to a terminal proportional to the length of this terminal's queue



Allocation based on *semantics* of data traffic

- Observation: Not all frames in an MPEG video are equally important (I, B, P frames)

- Approach 2: Allocate subcarriers based on *weighted* lengths of queues
  - The size of important packets is given a larger weight than lesser packets
  - Queue lengths is the sum of these weights
  - Described in forthcoming paper

- This talk: only approach 1!

- Additional option: Semantic-aware queue management, drop packets based on importance and queue lengths (not discussed here, results available as paper)

Assignment problem

- Given a certain subcarrier allocation:

How to choose which subcarriers are assigned to which terminal in order to maximize overall capacity ?

Subcarriers →

Receivers ↓

Receivers \ Subcarriers	1	2	3	4	5	6	7	8
1	13	**15**	11	7	5	9	12	10
2	20	15	18	14	13	18	21	**28**
3	5	4	6	9	14	**18**	12	8
4	12	5	4	7	10	13	**18**	21
5	9	8	14	13	**20**	22	18	13
6	**28**	22	18	16	14	13	10	14
7	5	0	4	**11**	15	18	13	20
8	14	15	**19**	12	9	7	2	−2

Optimal solution

- Assignment problem maps to a graph theoretical problem
  - Maximum weight bipartite matching problem

- An optimal algorithm for this problem exists – the Hungarian algorithm with complexity of $O(S^3)$
- Measured run times of the algorithm are too long compared to the coherence time of wireless channels

- In general, a faster assignment computation is better
  - Signaling and channel knowledge acquisition at the access point give constraints

Assignment: IP formulation

- More flexibility by formulating assignment as Integer Program
  - {1,...,J} : Set of wireless terminals,
  - {1,...,S} : Set of subcarriers
  - $g_{j,s}$: CNR of terminal j on subcarrier s
  - p_s : power assignment for subcarrier s
  - F(): Mapping of subcarrier SNR to applied modulation type
  - $c_{j,s}$:(= 0,1): Assignment of subcarrier s to terminal j
  - z_j: Subcarrier allocation for terminal j
- Basic formulation:

Maximize capacity

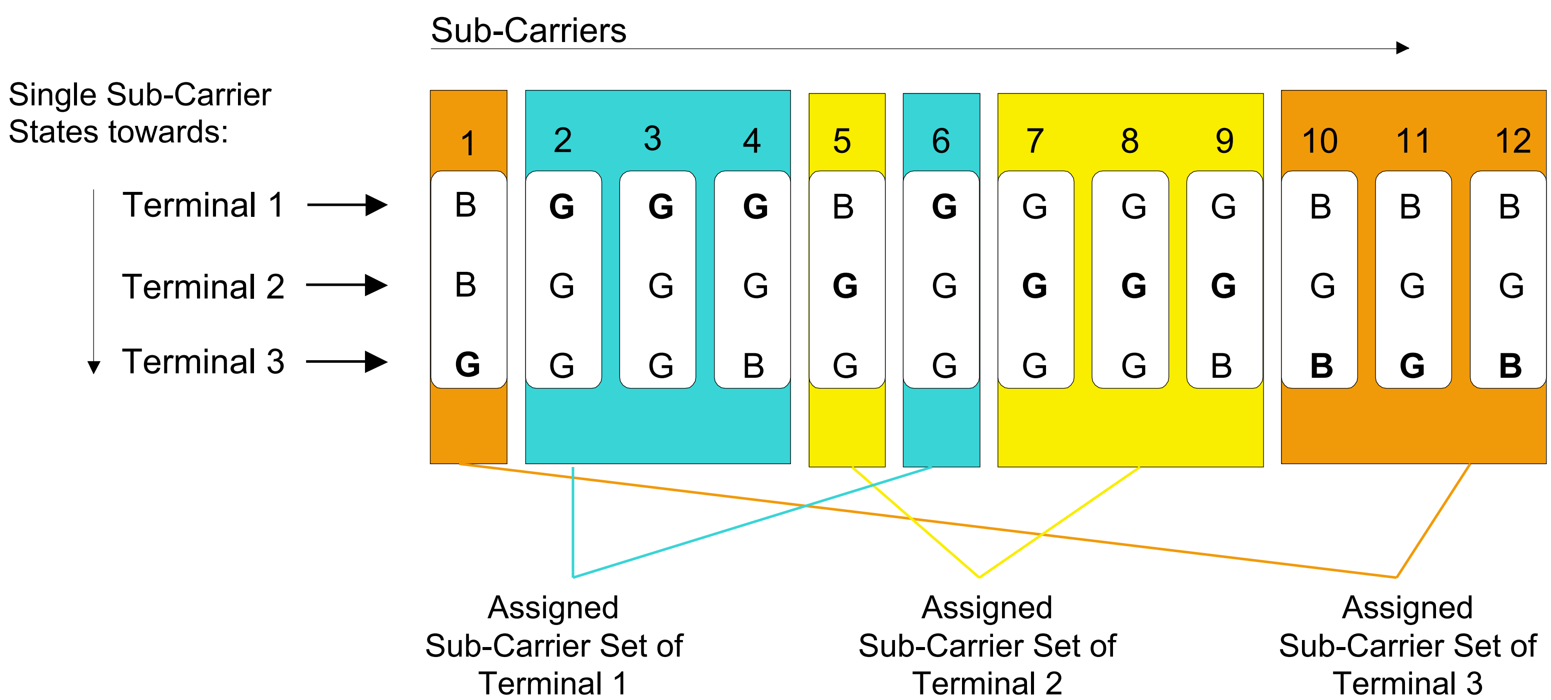
$$\max_{C=(c_{j,s})}\left(\sum_{\forall j,s} c_{j,s}\cdot F\left(p_s \cdot g_{j,s}\right)\right)$$

$$subject\ to: C = \left\{ \left(c_{j,s}\right) \middle| \begin{array}{l} \forall s : \sum_{\forall j} c_{j,s} = 1 \\ \forall j : \sum_{\forall s} c_{j,s} = z_j \end{array} \right\}$$

Each subcarrier only assigned once

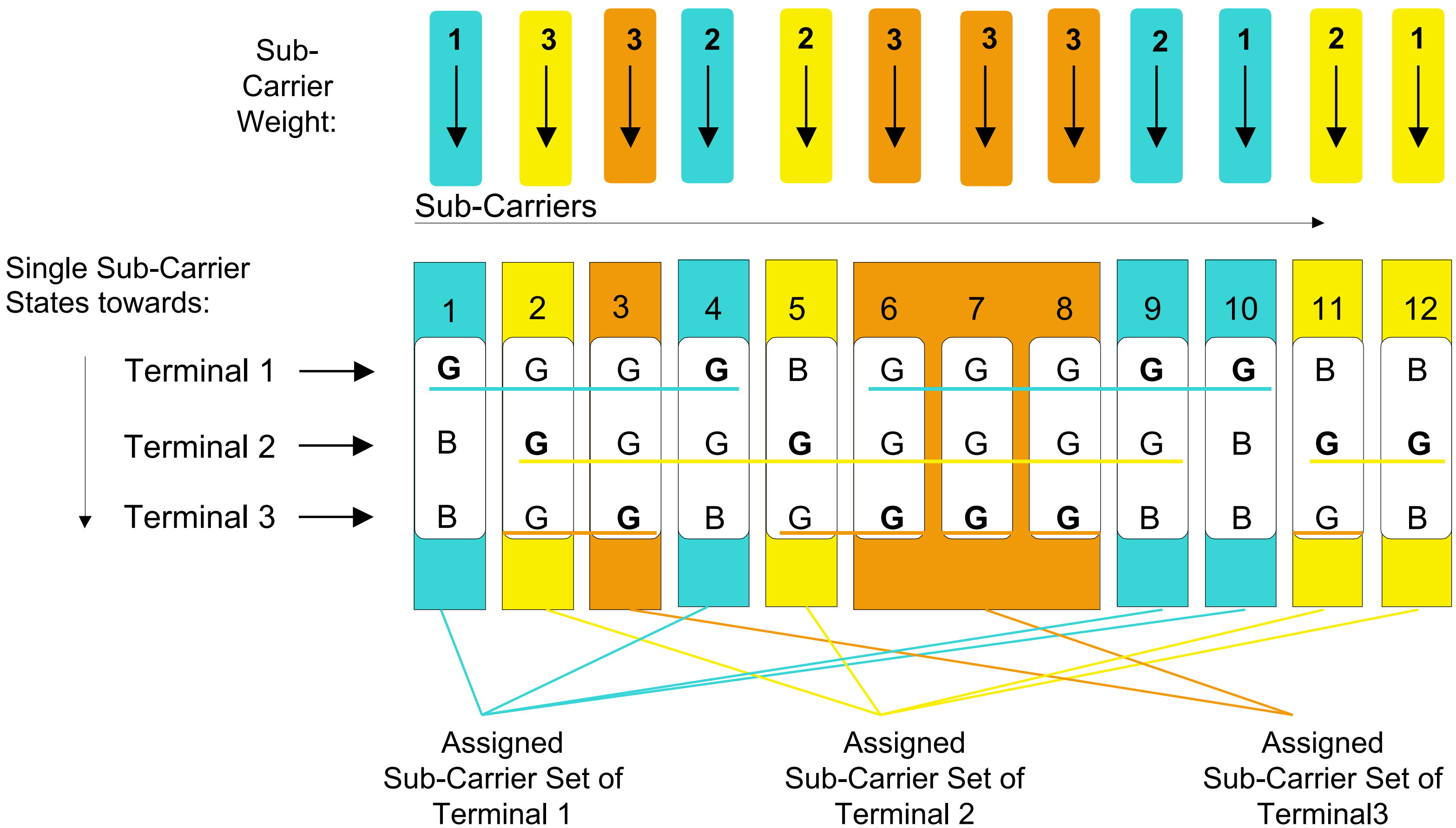
Assignment: Heuristic approach

- Example allocation decisions: Every terminal gets four subcarriers
- Simplification: subcarriers classified as „good“ or „bad“



Algorithm complexity: $O(J \cdot S \cdot \log(S))$

Assignment: Advanced heuristic



Summary mechanism

- Subcarriers can be allocated to terminals based on
  - Queue lengths of each terminal
  - Optionally: weighted by the type of video frames in a queue

- Subcarriers are assigned to terminals based on
  - Optimal (capacity-maximizing), but slow algorithms
  - Heuristics

→ What is the impact on **perceived** quality?

Assessing perceived quality – per frame

- User perceived quality is first estimated frame-by-frame
- Various methods:
  - Simple: e.g., Peak SNR of orginal vs. received video
  - Human Visual System (HVS)-based: e.g., Sarnoff JND
- Mapped to Mean Opinion Score (MOS)

MOS	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible, but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

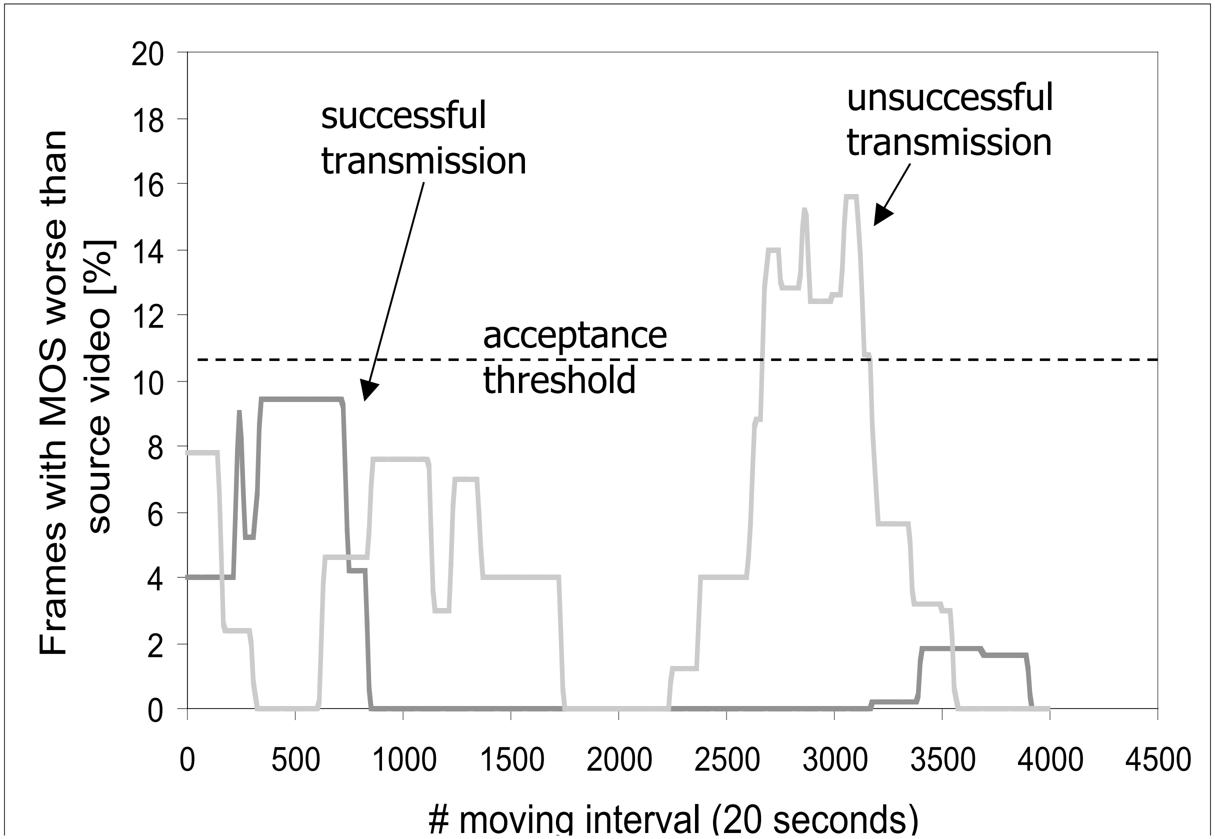
Subjective (user perceived) video quality
[ITU-R: BT.500-10]

Extending frame-wise metrics to videos

- Observations
  - Video quality is assessed frame-by-frame
  - Relative to the original (sent video)
- Potential problem
  - Averaging over long videos not a good indicator (many short deteriorations will be smoothed out)
  - ➔ How to assess a long video sequence?
- Solution
  - In every interval (10s – 20s), count frames with a worse MOS grade than original frames
  - Threshold for **maximum** percentage of worse frames (10% - 25%)

Metric example

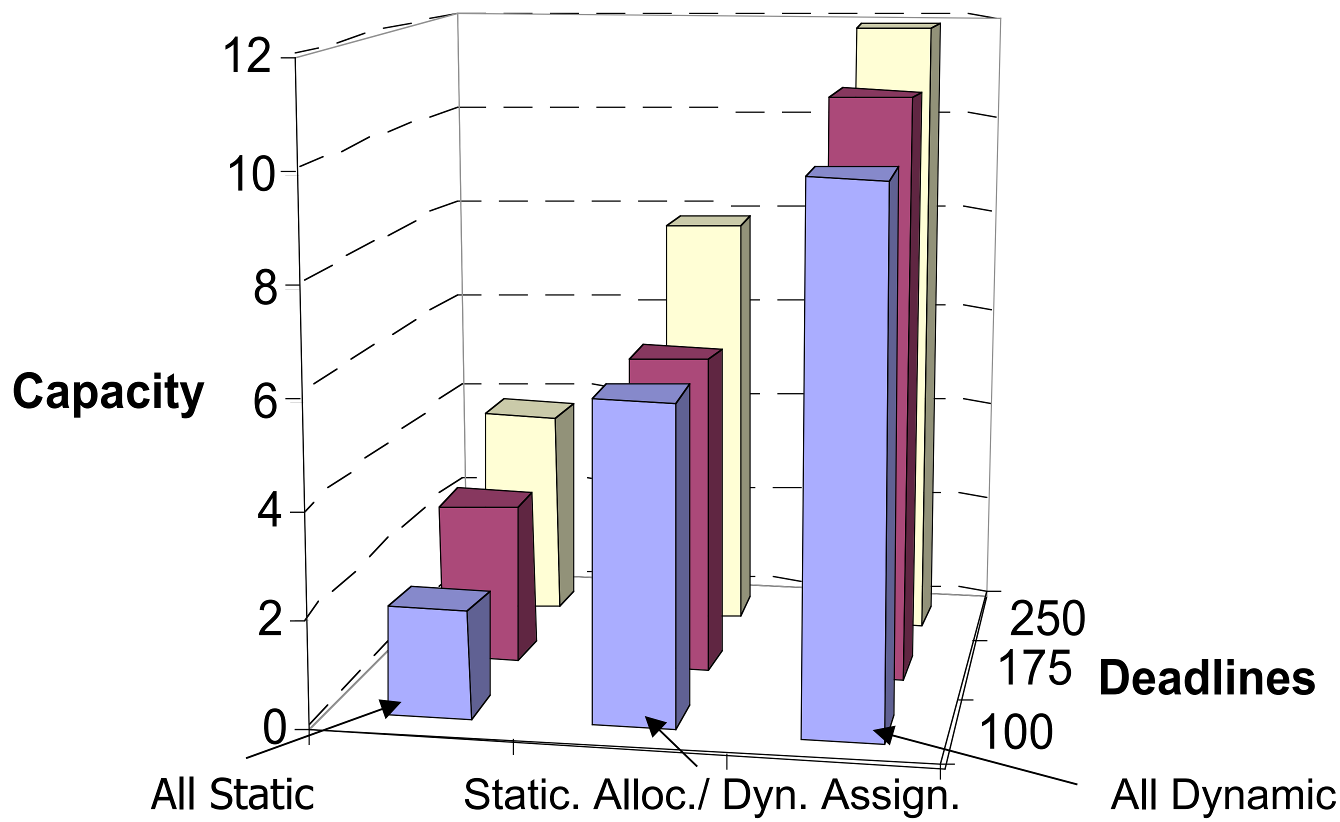
- Two 3 minute video clips (average MOS 3.8 and 3.9)
  - Small MOS difference, big quality difference!



Performance study – Parameters

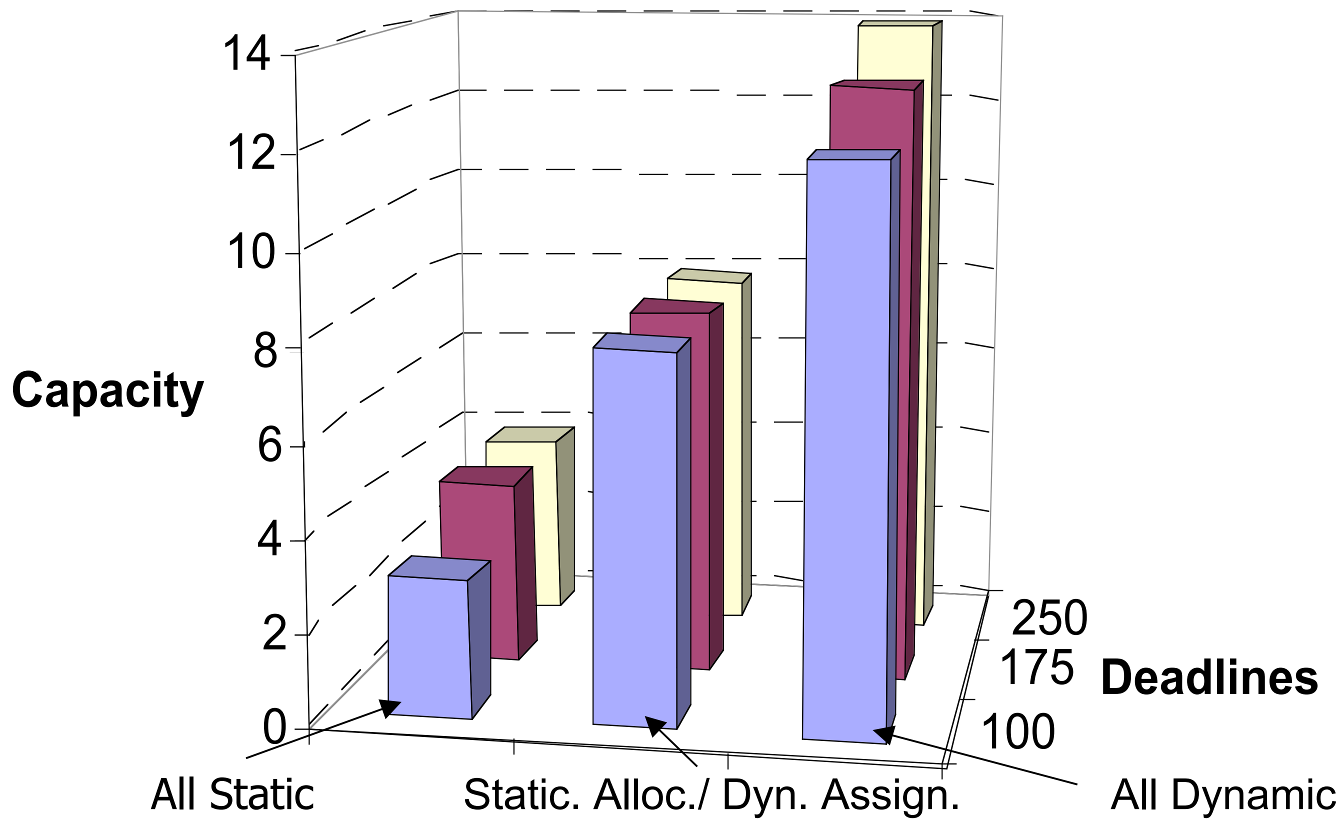
- System
  - 16.25 MHz system bandwidth, 48 subcarriers for data transmission, 4 μs symbol time
  - Adaptive modulation using BPSK, QPSK, 16QAM, 64QAM, 256QAM
  - Assignments change every 2ms
  - Per subcarrier the same transmit power (-7 dBm) is employed
- Scenario
  - Cell size of 200 meters (diameter), terminal speed: 1m/s, delay spread: 150 ns
- Load
  - 2 Types of MPEG-4 coded video sources (VBR): high motion video (950 kBit/s) and low motion video (723 kBit/s)
  - Three different deadlines per packet: 100 ms, 175 ms, 250 ms

Performance results – High motion video



100	2	6	10
175	3	6	11
250	4	8	12

Performance results – Low motion video



100	3	8	12
175	4	8	13
250	4	8	14

Conclusions

- Dynamic Resource Management can enhance the capacity of OFDM systems significantly
- Multiple different components contribute to this increase – possible to activate them separately
- Additionally including semantic queue management or weighted queue lengths for allocation can give further improvements
- Prerequisites: channel knowledge and a working signaling system
    - Results serve as upper limit on performance

Future work

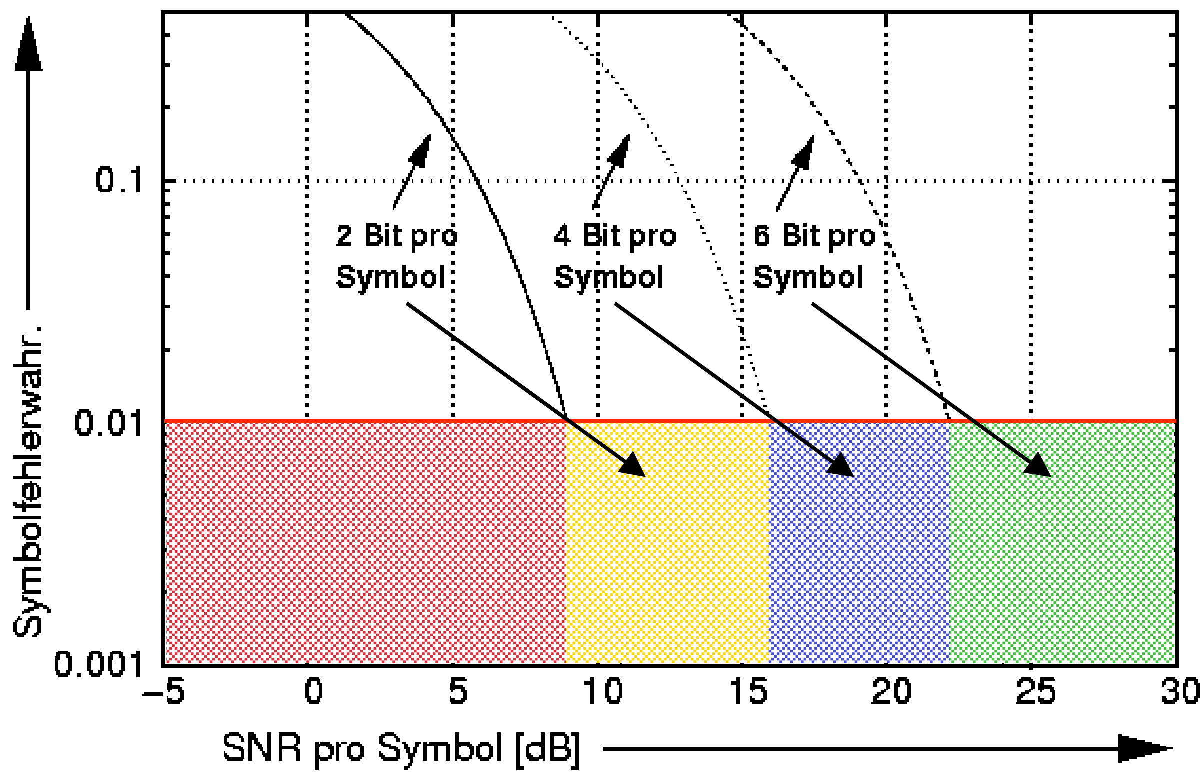
- Signaling
  - Given a working implementation, how does it affect the performance results
  - Optimization of the implementation (inband vs. out-of band)
- Channel Knowledge
  - What can realistically be expected at the access point ?
  - Impact on the performance results ?
- Computational Complexity
  - Subcarrier assignments and allocation takes time
  - How much? What is the impact on the system performance ?

THANKS! – QUESTIONS?

- Further material:
  - http://www.tkn.tu-berlin.de/publications
  - J. Gross, H. Karl, F. Fitzek, A. Wolisz „*Comparison of heuristic and optimal subcarrier assignment algorithms*", Proc. Of ICWN 2003
  - J. Gross, J. Klaue, H. Karl, A. Wolisz „*Subcarrier allocation for variable bit rate video streams in wireless OFDM system*", Proc. VTC Fall 2003
  - J. Klaue, J. Gross, H. Karl, A. Wolisz „*Semantic-aware Link Layer Scheduling of MPEG-4 Video Streams in Wireless Systems*", Proc. ASWN 2003

Adaptive Modulation Scheme

- Varying SNR results in a varying system performance when fixing the used modulation type
- Adapt the modulation type to actual channel quality



Assumptions

- Subcarrier SNR does not change significantly during T
- Access point „knows“ the most recent subcarrier SNRs
- Adaptive modulation system is present