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Subcarrier allocation for variable bit rate video streams in wireless OFDM systems

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***Abstract*— Wireless OFDM systems have attractive means for adapting wireless transmission to a given situation: one possibility is to assign a varying number of subcarriers to wireless terminals for downlink communication. Deciding *how many* and *which* subcarriers to assign to a given terminal is a difficult problem. This paper concentrates on deciding how many: we use the relative length of a terminal's queue in an access point to determine this number. Applying this scheme to the transmission of homogeneous MPEG-4 videos, we obtain a significant capacity increase compared to non-adaptive subcarrier allocation schemes.**[1]

I. INTRODUCTION

Wireless **O**rthogonal **F**requency **D**ivision **M**ultiplexing (*OFDM*) systems can support the simultaneous downlink transmission of data to different terminals by assigning different sets of subcarriers to multiple terminals in an FDM downlink scheme. Among others, two factors determine the resulting bit rate per terminal: the size of the set, that is the number of *allocated* subcarriers, and the choice of subcarriers in this set, that is choosing subcarriers to be *assigned*.

It is well known that in principle by dynamically assigning subcarriers to terminals, data transmissions can be improved in terms of spent transmission power [1] or transmitted amount of data [2]. This is due to exploiting varying subcarrier channel gains for different subcarriers as well as for different terminals (multi-user diversity). Nonlinear optimization approaches are used in the studies mentioned above in order to determine subcarrier allocation and assignments. Due to their high computational complexity, also heuristic schemes have been suggested. For the task of subcarrier *assignment*, multiple schemes have been investigated [3], [4], [5], [2]. We focus here on the problem of *allocating* subcarriers to terminals.

Allocating subcarriers to terminals has to be done before the assignment. Various factors like subcarrier channel gains or desired bit rates of terminals influence the amount of allocated subcarriers per terminal. In a heavily loaded system with multiple terminals and varying bit rates per terminal as well as varying channel gains per terminal, a proper allocation is crucial for the successful transmission of data streams, i.e., for an acceptable performance recognized at the application layer.

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For the allocation of subcarriers, several schemes have been presented. Yin et al. [6] suggest to consider only each terminal's average channel to noise ratio over all subcarriers. Subcarrier allocation for each terminal is then executed by considering the rate requirement, the average channel to noise ratio, and an overall power requirement. A similar scheme has been suggested in [3]. However, considering only the average channel to noise ratio does not account for the ability of dynamic assignment algorithms to assign subcarriers with a better channel gain than the average one. In addition to this, the access point in running systems mostly has no information about the rate requirement of streams, which might change from time to time and also might differ significantly from its average for certain time intervals.

In this work we study a different approach to subcarrier allocation. We suggest a scheme of distributing subcarriers purely depending on the length of the terminal's data queue — the fuller the queue, the more subcarriers are allocated (each terminal's data streams are queued separately). Thus, channel variations, coding constraints, spent transmission power, and desired bit rate do not have to be considered for the allocation task. In addition, such a scheme provides a control mechanism for average channel gain imbalances between different terminals.

We claim that this strictly load-oriented allocation scheme is particularly beneficial for applications with real-time constraints: A full queue indicates that a lot of data is present, which likely has to be transmitted to meet the deadlines. Evidently, this is only an approximation to the true deadlines, but it is one that is simple and efficient to evaluate. We will use variable bit rate encoded video streams of the same rate for each terminal to test our claim, and use the perceived quality of the received video stream as a figure of merit to compare various allocation schemes.

The remaining paper is organized as follows: in Section II we present our system model. Then, in Section III the subcarrier allocation mechanism is described in detail, while in Section IV the performance of the scheme is evaluated. Finally, we conclude our investigation in Section V.

II. SYSTEM MODEL

In a single cell, an access point and multiple wireless terminals are located. We only consider the downlink transmission direction. For data transmission a certain bandwidth is provided, where OFDM is employed as transmission scheme, splitting the bandwidth into S subcarriers. Due to mobility of the terminals and the multipath propagation environment, the subcarrier gains vary constantly over time and over frequency. This phenomenon, called fading, causes channel gain variations of adjacent subcarriers regarding the same wireless terminal. We assume channel gains of subcarriers regarding different wireless terminals to behave statistically independent. In addition to fading all channel gains of one terminal also vary due to path loss and shadowing.

At the access point subcarriers are assigned dynamically to terminals depending on the channel gains for a certain time span. As dynamic assignment algorithm we choose an algorithm from [4]: Provided the number of subcarriers, i.e. the subcarrier allocation, to be assigned to each terminal this algorithm determines in a fast and nearly optimal way which subcarrier should be assigned to which terminal in order to increase bit rates for all terminals. These assignments are valid for the length of one downlink phase. In addition to such an adaptive assignment scheme we also consider an adaptive modulation scheme to be used per subcarrier. This modulation adaption is performed rather simple: from a set of possible modulation schemes always the one is chosen which provides the highest rate while still yielding a lower symbol error rate than P_{S}.

As precondition for both, the adaptive modulation as well as the dynamic subcarrier management, we assume that the access point knows the channel gains of each subcarrier for the next downlink phase. Also we assume that the dynamic assignments can be signaled to the terminals without any loss or cost in the system.

As a model application, we consider the streaming of video, e.g., video broadcasting, from a remote server over the wireless access to the mobile terminals. Each terminal receives a variable bit rate stream of data packets. These packets are transmitted from the source via the wired backbone and the access point to each terminal. At the access point the packets are queued and are transmitted at some point in time. Each terminal has a separate queue at the access point and only receives a single stream.

We are interested in supporting in this cell as many terminals with video streams as possible; as transmitted streams we chose MPEG-4 encoded video streams. As a limiting factor each transmitted video stream has to be received by the corresponding terminal such that the resulting video quality is still acceptable. We defined a minimum acceptable quality of a transmitted video based on mean opinion score (MOS) as explained in Section IV-B. A video stream is required to reach at least 80% of good frames in every possible period to be acceptable. Our actual performance metric is the number of acceptable video streams, equivalent to the number of wireless terminals/ users that can be supported in a wireless cell, also referred to as capacity of the cell.

III. Subcarrier Assignment and Allocation

As stated we apply a heuristic, dynamic subcarrier *assignment* algorithm [4]. The scheme works as follows: for a given downlink phase different terminals are assigned different priorities. The subcarriers are then distributed by the algorithm by assigning to each terminal sorted by priority its allocated number of subcarriers which have the best quality (in terms of SNR, CNR or even bit rates) regarding this terminal from the yet not assigned subcarriers. For the next downlink phase the priorities are then shifted, such that each terminal's priority is constantly changed and therefore its order in the selection process varies from downlink phase to downlink phase.

This assignment scheme is based on knowledge or estimated knowledge of the subcarrier qualities regarding all terminals. Also it is based on an already performed subcarrier allocation.

To *allocate* subcarriers for terminals, multiple variables such as subcarrier channel gains, amount of data to be transmitted, available power, coding scheme, and so on could be considered. However, this requires some preconditions like the knowledge of average bit rates of a stream, which may not be available at the access point.

Instead of this, we suggest the following method to allocate subcarriers to terminals. The amount of data in the queue of each terminal should influence the number of subcarriers allocated to each terminal. The precise allocation algorithm works as follows: First, each terminal which has some data in its queue receives one subcarrier. Then, in a second step the remaining subcarriers are distributed according to the ratio of each terminal's data in the queue versus the overall data in all queues. More precisely denote the queue size of terminal j by $d_j(t)$. Then terminal j will be allocated the amount of subcarriers $s_j(t)$ given in Equation 1. J_a denotes the overall number of terminals for which data is actually stored in their queues at the access point. S denotes the total number of subcarriers available in the system.

$$s_j(t) = 1 + (S - J_a) \cdot \left\lfloor \frac{d_j(t)}{\sum_{\forall j} d_j(t)} + 0.5 \right\rfloor \tag{1}$$

Thus, even if some terminal recently suffered from its overall bad subcarrier channel gains due to path loss or shadowing for example, its queue will simply build up, which will in turn result in more subcarriers being assigned to this terminal for the next downlink phase; eventually, the queue length is reduced, the backlog is removed.

IV. Performance Analysis

A. Comparison Schemes

The performance study has been performed through simulation. The load-adaptive subcarrier allocation scheme is compared against two other schemes. The first comparison scheme uses the same dynamic subcarrier assignment algorithm; however, due to the same average bit rate of each stream per terminal, the same number of subcarriers are allocated to each wireless terminal for each downlink phase. Therefore, this scheme can not benefit from the stochastic variations of variable bit rate video streams. The second scheme also allocates the same number of subcarriers to each terminal but in contrast to the other two schemes a static subcarrier assignment algorithm is used. Each terminal receives a block of subcarriers, these assignment are never changed again. Note that the fourth possible combination, a static subcarrier assignment and a variable subcarrier allocation, has no practical relevance.

B. Performance Metric

Describing the human quality impression by a subjective quality metric is usually done with a "mean opinion score" (MOS), on a scale from 5 (best) to 1 (worst) as defined by ITU [7]. We approximate the MOS for every frame in the received (possibly distorted) video and compare it with the MOS values of the undistorted frames of the undistorted encoded video. It must be noted that not only the overall percentage of frames with a worse MOS value influences the user impression, but also the distribution of bad phases. To address this fact, we calculate the percentage of worse frames within a window sliding over the whole duration of the video. Only if the percentage of frames with a worse MOS is small in *each* interval, the video quality is rated as good. This method is explained in detail in [8].

C. Scenario Parameters

For the simulation, we consider a system with $S = 48$ subcarriers, equivalent to IEEE 802.11a [9]. The OFDM symbol duration is $4\ \mu\text{s}$, where $0.8\ \mu\text{s}$ belong to the guard interval. Subcarrier assignments are always valid for a frame time of $2\ \text{ms}$, while a downlink phase lasts half of this assignment time. Data is transmitted on each subcarrier with an adaptive modulation scheme, where five modulation types are available (BPSK, QPSK, 16-QAM, 64-QAM and 256-QAM). The modulation types are chosen such that always the highest rate scheme is used which still provides a symbol error rate of $P_\text{S} \leq 0.01$. The cell radius is set to $100\ \text{m}$. We assume a uniform distribution of the transmission power over the subcarriers, resulting in a transmit power of $-7\ \text{dBm}$ per subcarrier. The noise power is assumed to equal $-117\ \text{dBm}$ per subcarrier. The channel gains vary due to path loss, shadowing and fading. The path loss is determined by taking the distance between access point and terminal into account, where the used mobility model generates for each terminal a source and destination point and terminals then move with a certain speed from the source to the destination. The path loss reference loss was set to $10 \log(K) = 46.7$ and the path loss exponent was chosen to equal $\alpha = 2.4$. Shadowing was assumed to be log-normal distributed with zero mean and a standard deviation of $\sigma = 5.8\ \text{dB}$. Changes of the shadowing factor took place every second and were not modeled to be correlated. In contrast, the fading *was* assumed to be correlated. The correlational behavior in time was characterized by a Jakes-like power spectral density, while the correlational behavior in frequency was characterized by an exponential power delay profile. The maximum speed in the environment was chosen to be $1\ \text{m/s}$, the delay spread was assumed to equal $\Delta\sigma = 0.15\ \mu\text{s}$. Therefore this set up represents a transmission scenario like a large exposition or airport hall crowded with people.

As video source we chose an MPEG-4 video coded with an average bit rate of $723\ \text{kbit/s}$. The video file (Figure 1) has a frame rate of 25 Hz and a length of 3 minutes; during this time terminals roamed through the cell and subcarrier gains varied constantly (resulting in 90000 channel gain values per subcarrier per terminal, correlated in time as well as in frequency). Each terminal received the same video stream, however they are randomly time-shifted at the beginning so that different parts of the video stream arrived at different times at the access point for different terminals.

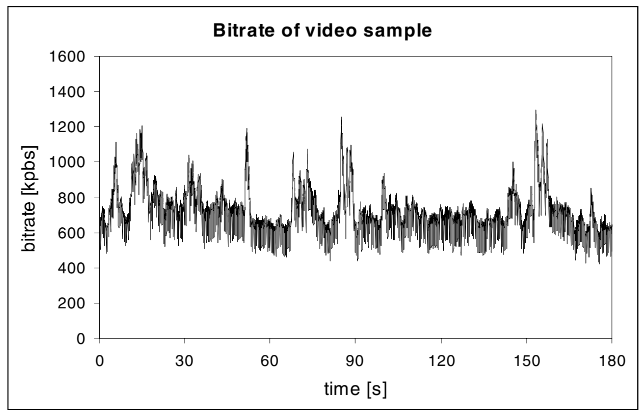

Fig. 1. Time-varying bit rate of the encoded video source used for the simulations

As maximum end-to-end delay for the transmitted video stream we considered a time span of $400\ \text{ms}$. From this time length we assumed the backbone forwarding of the packets of each stream to consume three different values up to a maximum of $300\ \text{ms}$. The remaining time span served as transmission deadlines for the packets in the queue of each terminal. We considered three different deadlines: $100\ \text{ms}$, $175\ \text{ms}$ and $250\ \text{ms}$.

In order to battle bit errors, block codes are employed to correct a certain number of bits per packet. If the packet is still erroneous after applying the error correction, a simple retransmission mechanism sends the packet again from the access point to the terminal during one of the following downlink phases. Therefore, video quality degradation can only be caused by receiving outdated packets or not receiving these packets at all (if a packet is not transmitted successfully at the end of its deadline, it is dropped without being transmitted).

D. Results

In Figure 2 we show the capacity results — the number of supportable terminals — for the different simulation

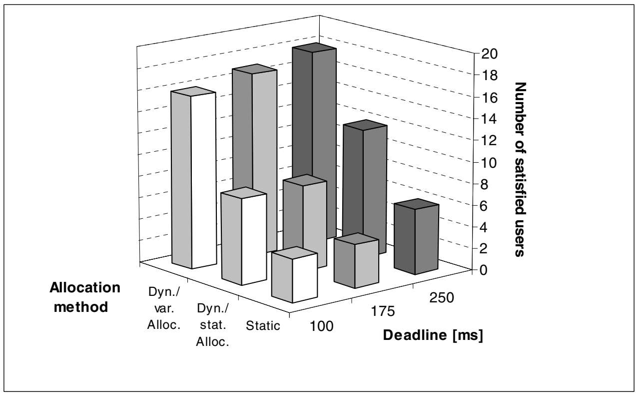

Fig. 2. Comparison of static and variable subcarrier allocation scheme with static and dynamic subcarrier assignments

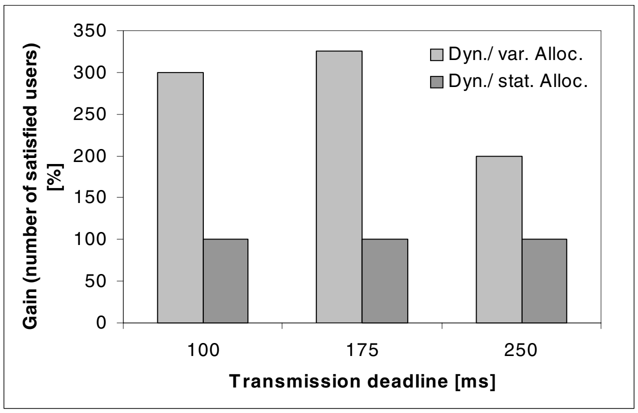

Fig. 3. Capacity gain of the variable and static subcarrier allocation scheme combined with dynamic subcarrier assignment compared to the static allocation and assignment scheme for different deadlines

settings. In the static case (no dynamic allocation, no dynamic assignment of subcarriers) a cell might support up to 6 terminals. Purely switching to a dynamic assignment scheme with still fixed subcarrier allocation already results in up to 12 terminals which can be supported. The suggested subcarrier allocation scheme in combination with the dynamic subcarrier assignment algorithm is able to support up to 18 terminals in the cell.

All three combinations obviously benefit from a longer remaining end-to-end delay in absolute terms, the capacity results are higher the longer the deadline is. Figure 3 shows the increase of the dynamic combinations compared to the static scheme. Here it is clearly seen that for short deadlines the dynamic subcarrier allocation improves the situation. Keeping the allocation method fixed and purely switching the assignment method from static to dynamic always yields a capacity increase of 100%, not depending on the deadlines. However, changing the allocation method to the one proposed here yields an additional capacity increase which is higher for shorter deadlines and is up to an additional 200%.

V. Conclusions

We presented a new subcarrier allocation method for parallel transmission of data streams to different terminals in an OFDM-FDM system. The subcarrier allocation determines the number of subcarriers each terminal should receive by a dynamic assignment algorithm for the next transmission phase, i.e. downlink phase. The method is based on allocating subcarriers for terminals depending on the actual queue size of each terminal relative to the overall data queued at the access point. In contrast to other methods, channel gain information as well as any stream specific knowledge is not included in the allocation of subcarriers.

Although rather simple the method responds intuitively to changes in the transmission situation regarding wireless channel qualities or queue sizes. In the case of a severe quality degradation of most channels for one terminal, its queue simply increases, leading to a higher number of subcarriers allocated to this terminal for the next downlink phases. Similarly, a burst of data arriving at the access point for one terminal will lead to a higher number of subcarriers allocated to this terminal for the next downlink phases. As a consequence the suggested variable subcarrier allocation method can take advantage of the statistical variations in data streams without explicitly provided information of the streams at the access point.

Applying this method to the transmission of MPEG-4 coded video streams and using the number of supportable terminals as a figure of merit, the dynamic allocation scheme behaves well compared to static allocation methods. For a given remaining deadline of the data arriving at the access point, the dynamic allocation scheme achieves a capacity improvement of up to 300 $\%$ over static allocation methods.

As future work we consider multiple areas. First of all, strong assumptions have been made regarding the overhead of dynamic subcarrier allocation and assignments. In reality each terminal has to be informed prior to the actual downlink transmission which subcarrier it has been assigned by the access point. This task has to be performed by a signaling system, which definitely consumes some system resources. One open issue is by how much the performance gain is reduced if this overhead is taken into account.

As second open issue we will consider the channel knowledge. In this work it is assumed that the access point knows prior to each downlink phase all subcarrier gains regarding each wireless terminal. However, this information can not be present at the access point at that time. More likely the access point will have to assign subcarriers based on outdated subcarrier gain information. This it likely to also reduce the performance of dynamic subcarrier management.

As third issue we are interested in linking semantic knowledge of data packets to the subcarrier allocation and assignment process: For video transmission not all packets have the same semantic importance regarding the perceived quality at the application layer. Considering this, the subcarrier allocation could also take this information into account instead of purely considering the amount of data in each queue. We hope that such a method leads to an additional increase in capacity.

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