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Framework for Combined Optimization of DLC and Physical Layer in Mobile OFDM Systems

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Abstract—Wide-band mobile communication systems are based on the Orthogonal Frequency Division Multiplexing (OFDM) transmission technique for several reasons [1]. The objective of this paper is the design of flexible Data Link Control (DLC) protocols, which combine the information of the time variant radio channel (described by the channel transfer function) and the incoming data streams from different applications with both, constant and variable data rates. The goal is to fulfill the quality of service (QoS) requirements in terms of priority and throughput for all wireless terminals and to improve the average system throughput.

Keywords—combined optimization, scheduling policy, OFDM, quality of service

I. INTRODUCTION

Future wireless applications are expected to have highly heterogeneous and time-varying QoS requirements from the underlying layers. Hence, the DLC protocol layer and the physical (PHY) transmission layer must be very flexible. The OFDM transmission technique offers this flexibility in the PHY layer. The system parameters can be adjusted and adapted in the light of different service requirements.

This paper shows that flexible DLC protocols can be developed by combining the information from the time varying physical channel and the time varying incoming data streams from different applications. The radio channel behavior in a multi-path environment is described by the magnitude of the channel transfer function. An example of a frequency selective and time variant channel is shown in Fig.1. Due to the sub-carrier structure the OFDM systems show robust behavior in realistic radio channels.

Fig.2 shows the transmission chain between transmitter and receiver in a block diagram. A negotiation sub-layer between the DLC layer and the PHY layer can be introduced for the optimal exploitation of the physical resources to fulfil the QoS requirements.

Fig. 1. Example of a transfer function for a time varying and frequency selective physical channel

Fig. 2. Transmission chain for combined optimization of DLC and PHY layer

Flexibility of multiple access (MA) schemes plays an important role in all wireless mobile systems. The
OFDM transmission technique is robust in multipath propagation channels and offers simultaneously a large flexibility for the MA technique. The granularity for all considered MA schemes is a single subcarrier in each OFDM symbol. This situation is shown in Fig.3 for two different MA schemes, Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), respectively. In this paper, two wireless systems with different MA schemes are considered: OFDM-TDMA, which is described in section II, and OFDM-FDMA, which is discussed in section III.

Fig. 3. OFDM-TDMA and OFDM-FDMA depicted in the time-frequency plane

II. SCHEDULING POLICIES FOR OFDM-TDMA

A cellular radio network is considered with a single Access Point (AP) and several Wireless Terminals (WTs) in each cell (see Fig.4). All WTs communicate with the central AP, whose coverage defines the cell boundaries. The analyzed scheduling policies are based on a single cell environment. An OFDM transmission technique combined with a TDMA scheme and a pure downlink situation are assumed in this section. The used data traffic model is a video trace file according to the MPEG-4 standard [3]. Each of the video files has a specified priority class stamp with a certain dropping probability. Since the concepts of scheduling policies will become meaningful if the capacity of the wireless network is somehow limited compared to the offered load, the overload situation is investigated.

For guarantee of a limited packet error rate, a so-called link adaptation technique is applied. It means, in case of a poor radio link quality the PHY mode (according to the HIPERLAN/2 standard [2]) chosen for packet transmission can be adapted to a more robust one (see Fig.4).

A. Concepts for Scheduling Policies

For the OFDM-TDMA system, two different scheduling policies are analyzed compared with the reference scheduling policy, Round-Robin-OFDM-TDMA (RROT). As shown in Fig.5, in RROT, the AP does not take care of the QoS requirements of the WTs and also needs no channel state information.

In the first proposed policy (see Fig.6), named Priority-Oriented-OFDM-TDMA (POOT), the AP checks the QoS requirements of each WT and then labels the data packets with different priority class stamps. Each priority class is associated with a certain dropping probability. A pre-scheduling is performed according to the dropping probability of the WT. The packets are put into different priority queues after the pre-scheduling, and an absolute priority scheduling follows. In this way, the QoS requirements of the WTs can be fulfilled.

The second proposed policy, Throughput-Oriented-OFDM-TDMA (TOOT), has an additional pre-scheduling compared to the first policy, as illustrated in Fig.7.
In this policy, the first pre-scheduling is carried out according to the channel state. Data packets for that WT, which has a better link quality should get the preference. After this first pre-scheduling, the second pre-scheduling and an absolute priority scheduling are executed as in the POOT. In the TOOT, throughput for the whole system can be maximized, but the QoS requirements of the individual WT are no longer guaranteed.

B. Performance Evaluation and Comparison of the Policies

Two different environments are chosen for the computer simulations: office environment and large open space environment. Both environments are in a non line of sight (NLOS) condition with a cell size of 100m. The AP is placed in the middle of the cell. For each WT, a start point and an end point are randomly generated. WTs move directly towards the end point with a fixed velocity of 1m/s. If the end point is reached before the simulation is finished, the WT will remain stationary at the end point. For simulation of the CIRs, channel characteristics like path loss, slow fading and fast fading are taken into consideration. For link adaptation purpose, the channel state information is sampled in each MAC frame. This channel state information is assumed here as perfect. An overload situation is considered.

The simulation results in Fig.8 show that the average transmission bit rate of the whole system is only slightly better in the well-known reference model (RROT) compared to the new scheduling scheme POOT. The reason for this is the performance degradation of the non-privileged (e.g. WT with priority class 3) WT. But advantage of the POOT strategy is that it can fulfill the QoS requirements of the WTs simultaneously.

TOOT scheduling policy outperforms from an average transmission bit rate point of view the RROT strategy in almost the whole CIR range. Only in the case that the highest PHY mode can be used for all WTs, the performance of both strategies is more or less the same. But compared with the POOT strategy QoS requirements are not completely fulfilled in the TOOT case.

III. SCHEDULING POLICIES FOR OFDM-FDMA

In this section an OFDM transmission technique combined with FDMA multiple access scheme is considered compared to the previous section II. As given in Fig.1 the subcarrier quality is time and frequency dependent. Under the assumption that the quality of subcarriers is different for each WT and change over the time, probably more efficient scheduling policies can be found. By the means of signaling good subcarriers are assigned dynamically to the WT. The advantages of dynamic resource management for wireless networks was already used in [5], [6], [7]. The following results are based on [4].

A. System Model and Scheduling Approach

Consider the following scenario of a wireless network with an OFDM physical layer. The network is organized in cells. The focus is on a single cell, which contains $J$ WTs and one AP. The OFDM physical layer consists of a total of $S$ sub-carriers, $N$ per WT such that $S = N \cdot J$. For the data traffic $J$ constant bit rate streams, one stream per WT, are assumed. Further, only down-link traffic is considered.

The following is considered for the sub-carrier state behavior. A sub-carrier is either in a good state $G$ or in a bad state $B$. In state $G$ the AP can convey one symbol to the specific WT. Each symbol has the bit length $b$. In state $B$ transmission is not possible. Sub-carriers are assumed to be independent of each other as well as sub-carrier states towards different WTs. For each time in-
terval there is a certain probability that each sub–carrier will be in state $G$, denoted by $p_g$. Further, a term known as sub–carrier weight is introduced. This sub–carrier weight, which is time–v ariable, is defined to be the total number of WTs, which see the sub–carrier in the good state $G$ at that time instant. As already mentioned, time is divided into units of the length of the symbol time $T_s$. The AP is provided with state estimates of each sub–carrier before the transmission. Throughout this work the estimates are assumed to be perfect.

Sub–carrier assignments may be changed within one time unit. Therefore scheduling will take place on a per–symbol–time base. this work investigates if under these assumptions a dynamic scheduling policy will perform better for constant bit rate data traffic. For comparison a static assignment of sub–carriers being similar to traditional FDMA is used. The performance measure is the resultant throughput of each WT.

An additional constraint in the investigations is fairness between WTs. Since throughput is the performance measure and each sub–carrier may only transmit a fixed amount of information, fairness between WTs is achieved by assigning them the same amount of good sub–carrier over some time interval.

As dynamic scheduling policy, a priority based mechanism to assign the sub–carriers at the AP to WTs is investigated here. Each WT has one of $J$ priorities, which can be changed every time unit. The WT of class one will be assigned the $N$ best sub–carriers towards him out of the $S$ sub–carriers total in the cell. The AP assigns the $N$–best sub–carriers out of the remaining $S–N$ sub–carriers for a WT in class two. This scheme continues. The last class is assigned the remaining $N$ sub–carriers. For each time unit, the priorities rotate between the WTs. This assures fairness between the different WTs. This scheduling policy is referred to as simple Rotating Sub–carrier State Algorithm (simple RSSA). This policy will be later on extended to the advanced Rotating Sub–carrier State Algorithm (advanced RSSA).

The simple and advanced RSSA are compared with a static scheduling policy. Since sub–carrier assignments never change, this static policy is referred to as Static Sub–carrier Assignment (SSA).

**B. Analytical Results**

Throughput expressions for both the scheduling policies are to be obtained. For illustration purposes, $J$ is set to 3.

The SSA is analyzed first. Clearly, the throughput distribution per WT is equivalent to a binomial distribution where the $N$ sub–carriers are the $N$ repetitions and $p_g$ is equivalent to the probability $p$ for a certain outcome of each repetition. With this, the mean throughput is obtained:

$$D_{SSA} = N \cdot p_g \cdot \frac{b}{T_s} \quad (1)$$

In the case of the simple RSSA, the throughput per WT is the mean of all three throughput values achieved by the individual priority classes:

$$D_{simple \; RSSA} = \frac{D_{first} + D_{second} + D_{third}}{3} \quad (2)$$

Therefore, the single throughput values for the different priority classes are to be obtained.

Basically the binomial combination problem is encountered again. It has to be noted that for priority classes one and two, the probability that at least $N$ sub–carriers are in state $G$ are calculated By doing so the throughput achieved by the simple RSSA is reduced. However, the simplifications have only a light impact on the throughput results.

$$D_{first} = \left(1 - \sum_{i=0}^{N-1} \binom{3N - i}{i} \cdot p_g^i \cdot (1 - p_g)^{3N - i}\right) \cdot N \cdot \frac{b}{T_s} \quad (3)$$

$$D_{second} = \left(1 - \sum_{i=0}^{N-1} \binom{2N - i}{i} \cdot p_g^i \cdot (1 - p_g)^{2N - i}\right) \cdot N \cdot \frac{b}{T_s} \quad (4)$$

The throughput of the third priority class is given by Equation 1. In order to judge these throughput results, the theoretical upper limit for this scenario are considered. Any absolute throughput optimal scheduling policy has to utilize each sub–carrier that has at least the weight one. In order to obtain the throughput of such an unknown scheduling policy, the probability that a sub–carrier will have at least a weight one can be simply calculated and multiply the result by the number of fair assigned sub–carriers per WT and the symbol information length $b$.

$$D_{optimal \; Throughput} = \left(1 - (1 - p_g)^3\right) \cdot N \cdot \frac{b}{T_s} \quad (5)$$

**C. Comparison of the Policies**

In order to compare the policies, an example setting is discussed. $J$ and $N$ are respectively set to 3 and 4.
The symbol length, $b$, of the used modulation scheme is considered to be 8 bits. Furthermore, $p_g$ is assumed to be 0.9. Hence,

$$D_{\text{SSA}} = 3.6 \cdot \frac{b}{T_s} \text{ bits} = \frac{28.8}{T_s} \text{ bits}$$

$$D_{\text{simple RSSA}} = 3.8661 \cdot \frac{b}{T_s} = \frac{30.9288}{T_s} \text{ bits}$$

$$D_{\text{optimal Throughput}} = 3.996 \cdot \frac{b}{T_s} = \frac{31.968}{T_s} \text{ bits}$$

When the ratios of the throughput of each policy to the optimal throughput was compared among the different policies, it was found that in the case of the SSA, the ratio was equal to 90.1 percent and in the case of the simple RSSA, the ratio was equal to 96.7 percent.

D. Further Improvements and Comments

As seen from the above results, dynamic scheduling policies can outperform the static scheme in this scenario. However, the throughput may be increased furthermore. The key factor for the further increase is the distribution of sub-carrier weights between different priority classes. As seen in Equation 7, while priority class one and two almost achieve perfect throughput results, the last priority class obtains a throughput equivalent to the SSA throughput. This is due to the situation, that upper priority classes choose sub-carriers without respect to lower priority classes. By introducing a specific choosing function, this situation might be changed. The choosing function simply forces the AP to first pick low weight sub-carriers while assigning them to higher priority classes. By doing so, the amount of ‘heavy’ sub-carriers assigned to the lower priority classes is increased, specifically for the last priority class. This policy is referred to as the advanced RSSA. Unfortunately the choosing function cannot be easily analyzed. Instead, the algorithm for the stated scenario in section III.B was simulated. As result, the following throughput values were obtained.

$$D_{\text{advanced RSSA}} = 3.9933 \cdot \frac{b}{T_s} = \frac{31.946}{T_s} \text{ bits}$$

This corresponds to a ratio of 99.9 percent of the throughput achieved by the optimal scheduling policy.

Before proceeding with the conclusions it is important to state, that although results were presented here for the special case of $J = 3$, throughput results can only increase in case of the RSSA for more WTs in the cell. The reason for this is, that the choosing space for all priority classes is either increased (since more sub-carriers are available) or stays at least the same, an increase of which results in a higher probability to obtain $N$ good sub-carriers and therefore higher throughput. For the SSA case, throughput results will stay the same.

IV. Conclusions and Further Research

The focus of this paper has been directed towards the development of flexible scheduling policies with the background of the combined optimization between DLC layer and PHY layer. Two systems, OFDM-TDMA and OFDM-FDMA are independently analyzed. Simulation results show that tradeoffs between fairness, fulfilling of QoS requirements of the WTs and overall system throughput are sometimes meaningful. In systems where strict QoS is required, POOT is proven to be the better method than TOOT. In contrast TOOT outperforms POOT in the sense of system throughput. For the OFDM–FDMA system a more realistic channel scenario will be taken into consideration [8] for further research.

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References

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