EE-520: Project Report

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Downlink Resource Management for Packet Transmission in OFDM Wireless Communications Systems

1 Introduction

Multimedia services in wireless communication systems requires high data transmission rates. However, high transmission rates may result in severer frequency-selective fading and intersymbol interference (ISI) if the bandwidth of the transmitted signal is large compared to the coherence bandwidth of the channel. Orthogonal frequency-division multiplexing (OFDM) has been proposed to remove these kind of channel disturbance. In an OFDM, the signal is transformed into a number of components, each with a bandwidth narrower than the coherence bandwidth of the propagation channel. Each of the OFDM signal components is modulated onto a distinct subcarrier. With OFDM, the signal fading across the bandwidth of each subcarrier is uniformly distributed, and it is said to have transformed frequency-selective fading to flat fading. This feature makes OFDM an attractive multiple-access scheme for future multimedia wireless communication systems.

As the wireless access to the Internet becomes increasingly popular, the downlink (from the base station to the mobile users) may have to transport more traffic. However, supporting multimedia traffic, such as voice, video, and data, and making efficient use of the radio resource are very challenging tasks for the downlink OFDM wireless communication systems. This is due to the following: 1) the scarce radio resource and the limited base station transmission power; 2) the time-variant channel conditions resulting from the fading and user mobility; and 3) the diverse quality of service (QoS) requirements of multimedia users, in terms of delay, delay variance, throughput, and bit error rate. One of the promising approaches to efficiently support multimedia traffic in downlink OFDM systems is to employ a resource management scheme at the link layer which can dynamically allocate bandwidth to mobile users in accordance with the variation of traffic load and channel conditions. The resource management scheme should be efficient in utilizing the radio resources and be fair in scheduling services. By efficiency, it is meant that a user can get as much service as needed whenever there are available resources in the system. By fairness, it is meant that every user is guaranteed the agreed-upon service rate with QoS satisfaction, even though other users may be greedy in demanding bandwidth.

An ideal fair scheduling discipline is the well-known generalized processor sharing (GPS) [1]. The basic principle of GPS is to assign each user a fixed weight, instead of a fixed bandwidth, and to dynamically allocate bandwidth (or service rate) to all the users according to their weights and traffic load.With GPS, each user is guaranteed a minimum bandwidth proportional to its weight; in addition, if a user does not fully use its guaranteed bandwidth, the excess bandwidth can be distributed to other users in proportion to their weights. This results in perfect isolation of heterogeneous traffic flows and guaranteed bandwidth provision. The main drawback of GPS is that it is defined on virtual time and is not practically implementable. Several modified GPS fair scheduling schemes, such as packet GPS (PGPS), have been proposed for wireline packet networks and extended to wireless networks. These modified GPS scheduling schemes are based on a time-scheduling approach, which entails extensive computation for the virtual time of each packet . The time-scheduling approach is suitable for time division multiple access-based wireless networks and has been extended to code division multiple access (CDMA)-based wireless networks. Resource allocation schemes, which appropriately allocate power and transmission rates for each subcarrier, have been proposed to support multimedia traffic in single-user and multiuser OFDM systems[2]. In [3],a low-complexity power and subcarrier allocation algorithm is proposed. However, all these schemes assume persistent transmission and do not take fairness and burstiness of the traffic into account. Therefore, it is very important and challenging to develop an effective and efficient resource allocation scheme for multiuser packet-switched OFDM systems.

The effectiveness of the mechanisms used in the physical layer has a significant impact on the design and operation of upper layer protocols. For the OFDM system, its physical layer has the following properties.

1. Total bandwidth of the OFDM system is divided into many narrow bands such that information from different users can be transmitted in parallel. This feature enables the use of parallel-transmission-based scheduling schemes, for example, the GPS scheduling.

2. Different subcarriers of the same user experience different channel fading due to frequency selectivity, and channel fading experienced by different users are independent. These differences introduce the so-called multiuser diversity, the incorporation of which has been proven to offer significant capacity improvement.

3. Each subcarrier transmits at a fixed symbol rate. If the modulation scheme is fixed, all subcarriers have a fixed transmission bit rate.

These physical layer properties should be considered in developing resource management schemes at the link layer to determine the subcarrier and power allocation to a mobile user.

In this report, an optimal downlink resource management scheme is proposed for heterogeneous packet transmission in OFDM wireless communication systems. By making use of the physical layer properties of the OFDM system and the channel impulse response, the resource management scheme is developed by integrating power distribution, subcarrier allocation, and GPS scheduling. The scheme can:

1. achieve maximum system throughput
2. guarantee the required signal-to-noise ratio (SNR) for heterogeneous traffic
3. provide fairness to all the traffic admitted in the system
4. satisfy the total transmission power constraints.

To reduce the implementation complexity of the optimal resource management scheme, the overall optimization problem is decomposed into a hierarchy of two subproblems (scheduling and a combination of power and subcarrier allocation). Then, a distributed resource management scheme based on a simplified power and subcarrier allocation algorithm and a truncated GPS (TGPS) is introduced. Simulation results show that the proposed resource management scheme can achieve a much better performance in terms of system throughput and transmission delay than the conventional resource management scheme based on PGPS scheduling and can achieve similar fairness as GPS scheduling.

The remainder of this report is organized as follows. In Section 2, the OFDM system model is described. An optimal resource management problem by integrating power distribution, subcarrier allocation, and ideal GPS scheduling is formulated in Section 3. A TGPS and a simplified power and subcarrier allocation algorithm are presented in Section 4. Simulation results are given in Section 5 to demonstrate the performance of the proposed resource management scheme in terms of the system throughput and transmission delay under the homogeneous traffic. Conclusions and future work are given in Section 6.

2 System Model

Fig. 1 shows the structure of a downlink OFDM to support N users. At the base station transmitter, the serial data sequence from the scheduler, which is a sequence of samples occurring at interval T_s, is first serial-to-parallel (S/P) converted into M low-rate parallel streams to increase the symbol duration to $T = MT_s$. The low-rate streams can be represented by the symbols $b_m[k]$, where $m = 0, 1, ..., M-1$, k = 1, 2, ... Through scheduling, $b_m[k]$ for different m may come from the same user or from different users. $b_m[k]$ for some m may be equal to zero, which means no transmission on these subcarriers at the kth epoch. In order to eliminate interference between parallel data streams, each of the low-rate data streams is modulated onto a distinct subcarrier belonging to

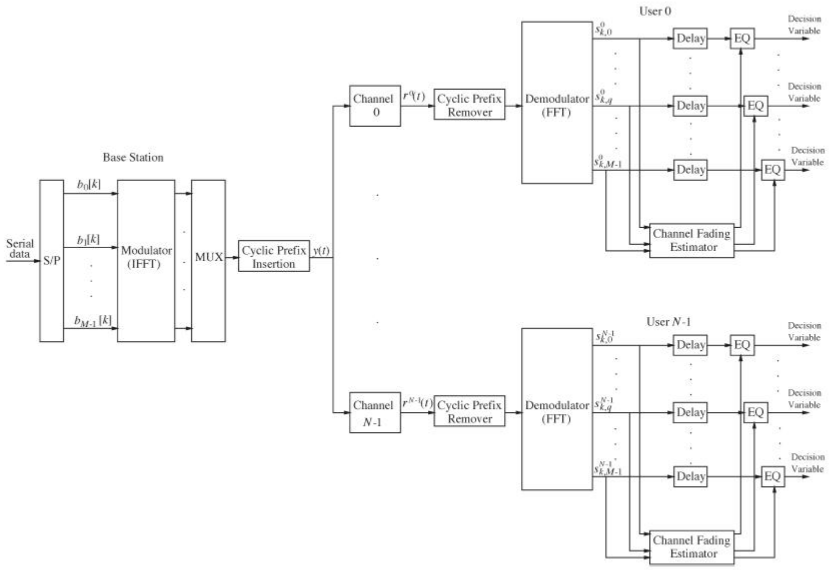

Figure 1: Transceiver structure of the OFDM system

an orthogonal set with subcarrier spacing $1/T$. The parallel streams are then multiplexed and a cyclic prefix is added to eliminate the effect of ISI.

It can be easily shown that OFDM downlink, a wideband multipath frequency-selective fading channel can be modeled as M separate narrowband flat fading channels (Fig. 2), each of which has a time-varying multiplicative complex channel fading gain $H^i_{k,q}$ [4]. This indicates that the OFDM system possesses the capability to support parallel transmission so that some parallel-transmission-based scheduling schemes, such as GPS scheduling, can be applied in OFDM downlinks. Moreover, parallel transmission in the frequency domain provides an opportunity to apply a more flexible resource allocation for the OFDM system. Since each subcarrier experiences flat fading, the channel gain can be defined as

$$\alpha^i_{k,q} = |H^i_{k,q}|^2, q = 0, 1, ...M - 1 \tag{1}$$

The frequency selectivity of the channel fading results in nonuniformly distributed channel gains among all subcarriers, i.e., for a given user i, $\alpha^i_{k,q}$ may be different for a different subcarrier index q. When the distance between two subcarriers is larger than the coherence bandwidth of the channel, the channel gains of these two subcarriers may be considered independent. Due to i.i.d. channel fading, multiuser diversity and subcarriers allocation should be analysed in order to maximize throughput. These properties can be used to form effective and efficient resource management.

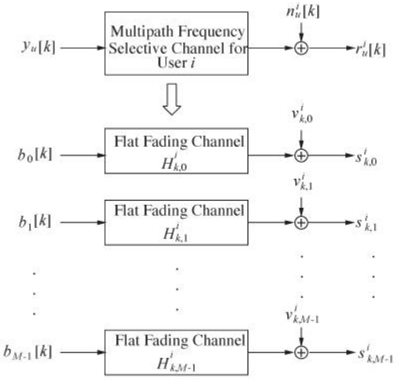

Figure 2: Equivalent channel model for user i

3 Optimal Resource Management

In this section, an optimal resource management scheme with ideal GPS scheduling to maximize OFDM system throughput while satisfying the total transmission power constraint and heterogeneous SNR requirements is developed. Since the discussion focuses on each OFDM symbol interval, in what follows, the symbol index k will also be used as the time index to denote the epoch corresponding to the symbol interval.

3.1 GPS Scheduling

GPS is ideal in the sense that it is designed in virtual time and hence not implementable. Consider N sessions sharing a network link with a total link transmission rate ψ. Each session i is associated with a positive weight η_i. Let $W_i(\tau,t)$ be the amount of session i traffic served during the interval $(\tau,t]$. Then, a GPS server is defined as a work-conserving service discipline for which

$$\frac{W_i(\tau,t)}{W_j(\tau,t)} \geq \frac{\eta_i}{\eta_j}, \qquad j = 0,1,....N-1 \tag{2}$$

for any session i that is continuously backlogged in the interval $(\tau,t]$. If both session i and session j are continuously backlogged in the interval $(\tau,t]$, then (2) holds with equality. It can be shown that in a GPS server, any backlogged session i is guaranteed a service rate R_i given by

$$R_i = \frac{\eta_i}{\sum_{j=0}^{N-1}\eta_j}\psi \tag{3}$$

In fact, R_i is the service rate of session i when all sessions are busy. Whenever fewer than N sessions are active, the system resources will be shared among those busy sessions, and hence each busy session will be served at a rate greater than its guaranteed service rate. GPS has a feature which imparts flexiblity to treat different class of services according to their QoS requirements.

3.2 Optimal Resource Management

In order to maximize the normalized system bandwidth utilization or the normalized throughput, defined as ψ_k/W, subject to following constraints

1. The total transmission power should be less than the target transmission power while satisfying all users' SNR requirements
2. No more than one user transmit in same carrier
3. The requirement of GPS scheduling should be satisfied.

It is very difficult to find optimal solution under the above constraints. To make above problem tractable, truncation of ideal GPS is proposed in next section.

4 Practically Implementable Scheduling and Resource Management Schemes

In this section, TGPS is proposed for feasiblity of resource management scheme [4].

4.1 TGPS Scheduling

When the target transmission power is taken into account, the number of effective subcarriers, defined as the number of subcarriers that can be actually supported by the system, is even less than M due to severe channel fading. Thus, at certain instants when the total number of backlogged sessions is larger than the number of effective subcarriers, some backlogged sessions cannot obtain the bandwidth which should be guaranteed with ideal GPS scheduling. A side effect of the quantization is that in the OFDM system, the minimal transmission unit is a symbol. Given the number of effective subcarriers at any epoch, number of carriers for an user is converted to an integer value by following relation with their predefined weight

$$M_i^k = [\frac{\eta_i}{\sum_{j\in\Lambda}\eta_j} M_{effective}^k], \qquad \forall i \in \Lambda \tag{4}$$

where Λ is set of all backlogged sessions. Total quantization error can be found which is total number of unallocated carriers. These subcarriers can be allocated to users according to their quantization error i.e. user with more quantization error will get subcarrier allocation first.

4.2 Power and Subcarrier Allocation Algorithm

The simplified power and subcarrier allocation algorithm is presented as follows

1. During any epoch k, the power and subcarrier allocation algorithm accepts the information $M_k^i, i \in$, the required number of subcarriers allocated to user i, from the TGPS scheduling.

2. The power and subcarrier allocation algorithm sorts the users in a nonincreasing order according to their SNR requirements.Then, the algorithm allocates the subcarriers to the users one by one.
3. At the jth step of subcarrier allocation, user with maximum SNR required got selected and M_k carriers with maximum channel gain out of unallocated carriers are allocated to above user.
4. Algorithm calculates power needed for each carrier.

4.3 Distributed Resource Management Scheme

1. Base station compares total transmission power with target transmission power. If it is less than target power, resource management scheme is complete.
2. Otherwise base station decreases effective number of carriers by 1 and keep doing it until target power requirement is not met.

4.4 Combining power and subcarrier allocation with resource management scheme - New Approach

In this algorithm, power and subcarrier allocation is done simultaneously with resource management scheme. Algorithm 2 is as follows:

1. During any epoch k,the power and subcarrier allocation algorithm sorts the users in a nonincreasing order according to their SNR requirements.Then, the algorithm allocates the subcarriers to the users one by one.
2. At the jth step of subcarrier allocation, user with maximum SNR required among unallocated users got selected and 1 carrier with maximum channel gain out of unallocated carriers are allocated to above user.
3. Base station compares total transmission power with target transmission power. If it is less than target power, repeat step 1 and 2.
4. Otherwise target transmission power and resource management requirement is complete.

5 Simulation Results and Discussions

Consider an OFDM system with 128 subcarrier and 800 kHZ bandwidth. Figure 3 and 4 show system throughput in case of two algorithms described in previous sections. New algorithm gives better performance compared to other algorithm i.e. system throughput is greater in case of new algorithm. When the target transmission power becomes large enough, each user will experience same capacity which is clear from graphs i.e. system throughput saturates for high target transmission power. Figure 5 and 6 demonstrates maximum and average transmission delay. Delay tends to zero if target transmission power is high.

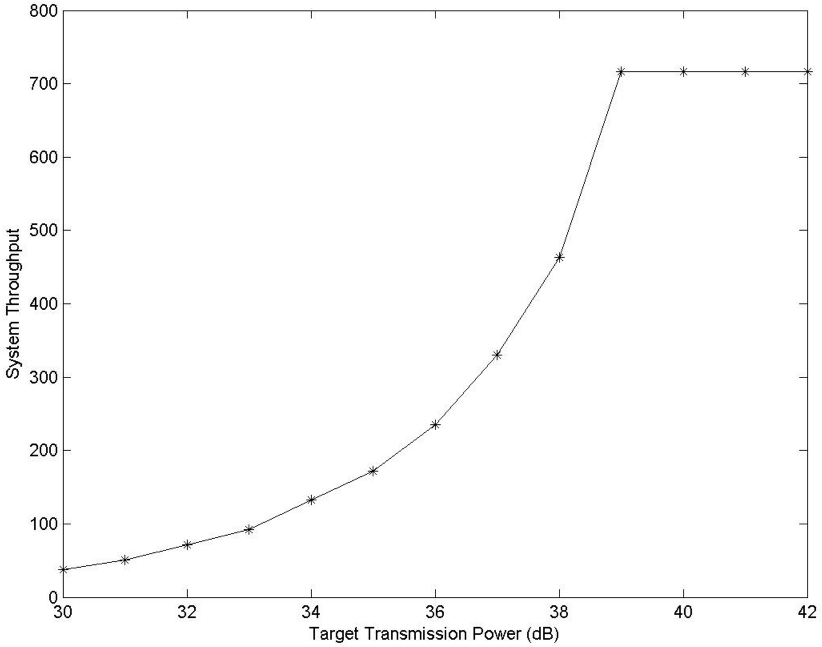

Figure 3: System Throughput for homogeneous case

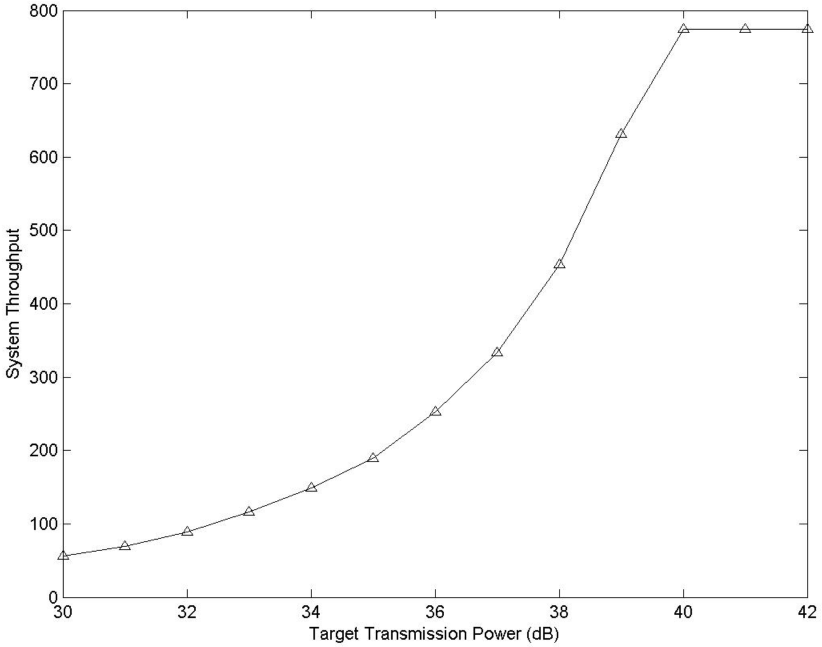

Figure 4: System Throughput for homogeneous case with new algorithm

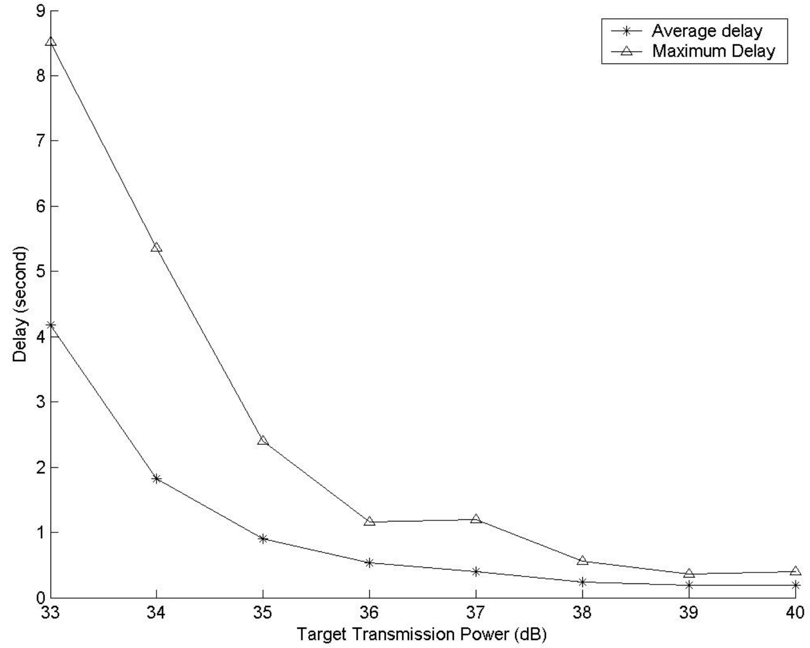

Figure 5: Average and Maximum Transmission Delay vs. Target Transmission Power with new algorithm

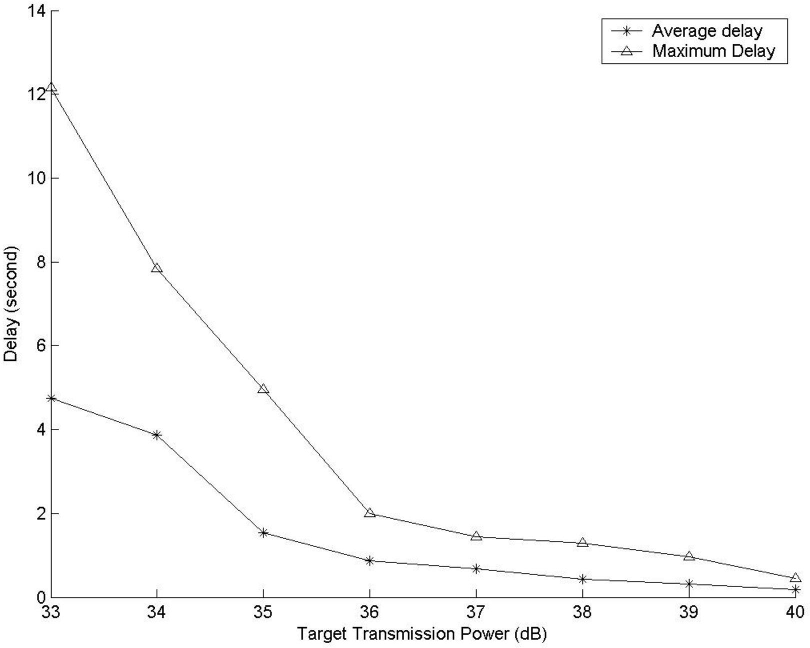

Figure 6: Average and Maximum Transmission Delay vs. Target Transmission Power

6 Conclusion and Future Work

A downlink resource management and power and subcarrier allocation scheme for packet transmission are combined to propose new algorithm in OFDM communication systems. Simulation shows that new algorithm is faster than other algorithm and imparts better system throughput. Delay tends to zero in both algorithms for high target transmission power. Average and maximum delay are less in case of new algorithm compared to old algorithm. Due to fixed number of sub-carriers, system throughput saturates at high values of target transmission power.

In simulation,rate of each user is determined by its channel condition only. If packet delay deadline is also considered, carriers allocation will also involve delay deadline parameter. Problem becomes more difficult because rate optimization constraint has increased. An optimal algorithm can be found such that packet drop rate is minimized and system throughput is maximized.

References

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