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OPTIMAL AVERAGE NUMBER OF DATA BLOCK TRANSMISSIONS FOR THE ARQ MECHANISM IN THE IEEE 802.16 OFDMA SYSTEM

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ABSTRACT

In this paper for the IEEE 802.16 OFDMA system we propose the fast algorithm to find the optimal average number of data block transmissions that minimizes the total downlink and uplink transmission power subject to satisfying QoS requirements. We show that the optimal average number of data block transmissions in the IEEE 802.16 OFDMA system is almost independent of the coding and modulation scheme used, propagation channel model, and data block size. In the IEEE 802.16 OFDMA system the optimal average number of data block transmissions is very close to 1.18.

I. INTRODUCTION

The IEEE standards 802.16 [1] and 802.16e [2] specify the requirements to the physical (PHY) and medium access control (MAC) layers of the fixed and mobile broadband wireless access. The standards include such data transmission technologies as quality-of-service (QoS) mechanisms, adaptive coding and modulation, power control, selective and hybrid automatic repeat request (ARQ), orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA). This gives a lot of opportunities to optimize the IEEE 802.16 system performance.

While optimizing the performance of the modern communication systems it is reasonable to use the adaptive transmission approach [3], [4] and the cross-layer optimization approach [5].

An important optimization problem is the minimization of the total downlink and uplink transmission power subject to satisfying QoS requirements for all users of the system. The minimization of the total transmission power results in the reducing the inter-sector interference, thus improving the receiving conditions and increasing the system capacity.

The minimization of the total transmission power is performed in [6], [7]. The authors of these papers do not consider the ARQ mechanism. Papers [8], [9] show that the total radiated energy and the system spectral efficiency are strongly determined by the average number of data block transmissions, when the ARQ mechanism is used. Hence, the average number of data block transmissions shall be one of the adaptation parameters while minimizing the total transmission power in the system using the ARQ mechanism.

In [10] we solved the total transmission power minimization problem subject to satisfying the QoS requirements for the given average number of data block transmissions. In [10], the average number of data block transmissions is determined by the QoS requirement for the maximum average data block transmission delay.

In this paper for the IEEE 802.16 OFDMA system we find the optimal average number of data block transmissions that minimizes the total downlink and uplink transmission power subject to satisfying the QoS requirements. Our algorithm requires the optimization over only one variable. Thus, we propose a very fast solution to the optimization problem.

Using our algorithm we calculate the optimal average number of data block transmissions for numerous coding and modulation schemes and coding block sizes of the IEEE 802.16 OFDMA, for several propagation channels, and for different numbers of coding blocks containing one data block. We show that the optimal average number of data block transmissions in the IEEE 802.16 OFDMA system is almost independent of these parameters. Hence, we recommend setting the optimal average number of data block transmissions to 1.18 in the IEEE 802.16 OFDMA system.

The rest of this paper is organized as follows. In Section II we describe the IEEE 802.16 OFDMA system considered. In Section III we formulate the total transmission power minimization problem. We optimize the average number of data block transmissions in Section IV. In Section V we analyze the optimal values of average number of data block transmissions in the IEEE 802.16 OFDMA system. We conclude in Section VI.

II. IEEE 802.16 OFDMA SYSTEM DESCRIPTION

We consider a cellular IEEE 802.16 OFDMA network. It comprises some sectors and some users. The sectors transmit data to the users in the downlink and the users transmit data to the sectors in the uplink. The sectors in the downlink and the users in the uplink have the maximum transmission power constraints. Each user may have several downlink service flows and several uplink service flows. A service flow is a flow of data packets from a service. Different service flows may have different traffic arrival rates.

The network uses the OFDM technology, the OFDMA multiple access, and the time division duplex. Each sector uses frames for the downlink and uplink data transmission. A frame comprises a downlink subframe and an uplink subframe. The frame boundary between the downlink and uplink subframes may be adaptively adjusted. In the time

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domain, the frame comprises OFDM symbols. In the frequency domain, the frame comprises subcarriers.

We consider the frequency diversity frame structure, that is, “partial usage of subchannels (PUSC)” and the “full usage of subchannels (FUSC)” permutation schemes of the IEEE 802.16 OFDMA. The subcarriers assigned to a particular user are pseudo-randomly interleaved within the whole OFDM signal bandwidth before transmission. In this case, even only a part of the subcarriers is allocated to the user, its receiving conditions are characterized by the receiving conditions averaged over the OFDM symbol.

Data blocks of a service flow shall be transmitted with the required QoS. The set of the QoS requirements includes the maximum data block reception error probability and the maximum average data block transmission delay.

A scheduler selects a set of the downlink and uplink service flows and a set of the data blocks for each selected service flow for transmission in the current frame. These data blocks are converted into data packets at the MAC layer using the fragmentation and packing operations. Also, ARQ mechanism is used. Coding and modulation scheme and transmission power are selected for the set of the data packets of a particular service flow at the PHY layer. For the ARQ mechanism of a particular service flow the average number of data block transmissions is selected. Before transmission, the set of the data packets is converted to the set of the coding blocks.

The following adaptation parameters are available in the IEEE 802.16 OFDMA network considered: frame boundary position, coding and modulation schemes, transmission power values, and average number of data block transmissions.

III. TOTAL TRANSMISSION POWER MINIMIZATION PROBLEM FORMULATION

In this section we formulate the total transmission power minimization problem in the IEEE 802.16 OFDMA system.

Let us consider the downlink. The average transmission power of the downlink service flow j of the user i can be written as

$$P_{i,j}^{DL} = p_{i,j}^{DL} \cdot b_{i,j}^{DL} \Big/ \left[T^{DL} \cdot B\left(q_{i,j}^{DL}\right) \right], \quad (1)$$

where $p_{i,j}^{DL}$ is the transmission power per subcarrier value selected for the downlink service flow j of the user i, $q_{i,j}^{DL}$ is the coding and modulation scheme selected for the downlink service flow j of the user i, $b_{i,j}^{DL} \Big/ \left[T^{DL} \cdot B\left(q_{i,j}^{DL}\right) \right]$ is the average number of subcarriers used by the downlink service flow j of the user i, $b_{i,j}^{DL}$ is the average amount of data of the downlink service flow j of the user i that shall be transmitted in the current frame, T^{DL} is the number of the OFDM symbols in the downlink subframe, $B\left(q_{i,j}^{DL}\right)$ is the amount of data that can be transmitted on one subcarrier in one OFDM symbol when the coding and modulation scheme $q_{i,j}^{DL}$ is used.

The average amount of data $b_{i,j}^{DL}$ is given by

$$b_{i,j}^{DL} = \left(1 + \alpha_{i,j}^{DL}\right)\left(\lambda_{i,j}^{DL} \cdot t_{frame}\right) L_{i,j}^{DL}, \quad (2)$$

where $\alpha_{i,j}^{DL}$ is the average fraction of the transmission overhead for the service flow j of the user i, $\lambda_{i,j}^{DL}$ is the average traffic arrival rate for the service flow j of the user i, t_{frame} is the frame duration, and $L_{i,j}^{DL}$ is the average number of data block transmissions for the service flow j of the user i.

The total power transmitted by all downlink service flows of all users can be found as

$$P^{DL} = \sum_{i=1}^{m} \sum_{j=1}^{c_i^{DL}} P_{i,j}^{DL}, \quad (3)$$

where m is the number of users, c_i^{DL} is the number of the downlink service flows of the user i.

The total power transmitted by all uplink service flows of all users is

$$P^{UL} = \sum_{i=1}^{m} \sum_{j=1}^{c_i^{UL}} P_{i,j}^{UL}, \quad (4)$$

where $P_{i,j}^{UL}$ is the average transmission power of the uplink service flow j of the user i, which is found similar to $P_{i,j}^{DL}$, c_i^{UL} is the number of the uplink service flows of the user i.

The total transmission power minimization problem is formulated as follows. Find

$$\left\{t, \mathbf{q}^{DL}, \mathbf{p}^{DL}, \mathbf{L}^{DL}, \mathbf{q}^{UL}, \mathbf{p}^{UL}, \mathbf{L}^{UL}\right\} = \arg\min\left(P^{DL} + P^{UL}\right), \quad (5)$$

subject to satisfying the QoS requirements for all downlink and uplink service flows of all users.

In (5), t is the position of the frame boundary between the downlink and uplink subframes, $\mathbf{q}^{DL}$ is the set of the coding and modulation schemes $q_{i,j}^{DL}$, $\mathbf{p}^{DL}$ is the set of the transmission power values $p_{i,j}^{DL}$, $\mathbf{L}^{DL}$ is the set of the average numbers of data block transmissions $L_{i,j}^{DL}$; $\mathbf{q}^{UL}$, $\mathbf{p}^{UL}$, and $\mathbf{L}^{UL}$ have the same meaning as in the downlink.

In [10] we solved the optimization problem (5) for the given sets of the average numbers of data block transmissions $\mathbf{L}^{DL}$ and $\mathbf{L}^{UL}$. In this paper we find the optimal average numbers of data block transmissions $\mathbf{L}^{DL}$ and $\mathbf{L}^{UL}$ that minimize the total transmission power.

IV. OPTIMIZATION OF THE AVERAGE NUMBER OF DATA BLOCK TRANSMISSIONS

Let us note that for the given position of the frame boundary t the optimization problem (5) can be divided into several optimization sub-problems

$$\min_{\mathbf{q}^{DL},\mathbf{p}^{DL},\mathbf{L}^{DL},\mathbf{q}^{UL},\mathbf{p}^{UL},\mathbf{L}^{UL}} \left(P^{DL}+P^{UL}\right)= = \sum_{i=1}^{m}\sum_{j=1}^{c_i^{DL}} \min_{q_{i,j}^{DL},p_{i,j}^{DL},L_{i,j}^{DL}} P_{i,j}^{DL} + \sum_{i=1}^{m}\sum_{j=1}^{c_i^{UL}} \min_{q_{i,j}^{UL},p_{i,j}^{UL},L_{i,j}^{UL}} P_{i,j}^{UL}. \quad (6)$$

Consequently, to solve the optimization problem (5) we shall solve the optimization sub-problems

$$\left\{q_{i,j}^{DL}, p_{i,j}^{DL}, L_{i,j}^{DL}\right\} = \arg\min P_{i,j}^{DL}, \quad (7)$$

$$\left\{q_{i,j}^{UL}, p_{i,j}^{UL}, L_{i,j}^{UL}\right\} = \arg\min P_{i,j}^{UL}. \quad (8)$$

The solutions to the optimization sub-problems (7) and (8) are similar. We describe the solution to the optimization sub-problem (7).

The number of the available coding and modulation schemes is not very large in the IEEE 802.16 OFDMA system. Hence, the minimization of (7) over the coding and modulation scheme $q_{i,j}^{DL}$ can be performed using the full enumeration. For the given coding and modulation scheme $q_{i,j}^{DL}$ let us find the values of $p_{i,j}^{DL}$ and $L_{i,j}^{DL}$ that minimizes $P_{i,j}^{DL}$.

Let us note that

$$P_{i,j}^{DL} \sim p_{i,j}^{DL} \cdot b_{i,j}^{DL}. \quad (9)$$

Consequently,

$$P_{i,j}^{DL} \sim p_{i,j}^{DL} \cdot L_{i,j}^{DL}. \quad (10)$$

Let us note also that

$$p_{i,j}^{DL} \sim z_{i,j}^{DL}, \quad (11)$$

where $z_{i,j}^{DL}$ is the signal to interference plus noise ratio (SINR) of the service flow j of the user i.

We use two assumptions to find the average number of data block transmissions $L_{i,j}^{DL}$. First, we assume that the maximum number of data block transmissions is unlimited. Second, we assume that the data block reception error probability is the same for all transmissions. Under these assumptions the average number of data block transmissions is

$$L_{i,j}^{DL} = 1\Big/\left[1-\beta_{SDU}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)\right], \quad (12)$$

where $\beta_{SDU}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)$ is the reception error probability of the data blocks of the service flow j of the user i, when the coding and modulation scheme $q_{i,j}^{DL}$ is used and the SINR is $z_{i,j}^{DL}$.

Using equations (11) and (12) we evaluate equation (10) as

$$P_{i,j}^{DL} \sim z_{i,j}^{DL}\Big/\left[1-\beta_{SDU}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)\right]. \quad (13)$$

A data block is received without errors if all coding blocks containing this data block are received without errors. Hence, the data block reception error probability can be written as

$$\beta_{SDU}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right) = 1-\left[1-\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)\right]^{n}, \quad (14)$$

where n is the number of coding blocks containing the data block, $\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)$ is the reception error probability of the coding block for the coding and modulation scheme $q_{i,j}^{DL}$ and the SINR $z_{i,j}^{DL}$.

Consequently, for the given coding and modulation scheme the optimization sub-problem (7) can be formulated as

$$z_{i,j}^{DL,opt} = \arg\min_{z_{i,j}^{DL}}\left\{z_{i,j}^{DL}\Big/\left[1-\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)\right]^{n}\right\}, \quad (15)$$

which can be easily solved numerically if the function $\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)$ is known. The function $\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)$ can be obtained, for example, using link level simulation.

When the solution to (15), that is, $z_{i,j}^{DL,opt}$ is known, the optimum average number of the data block transmissions can be found from

$$L_{i,j}^{DL,opt} = \left[1-\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL,opt}\right)\right]^{-n}. \quad (16)$$

The optimal value of the transmission power $p_{i,j}^{DL,opt}$ is the value corresponding to the optimal value of the SINR $z_{i,j}^{DL,opt}$.

The optimization of (15) should be performed on condition that the QoS requirements are satisfied for the service flow j of the user i. The set of the QoS requirements includes the maximum data block reception error probability and the maximum average data block transmission delay. As we assume the unlimited maximum number of data block transmissions, the residual data block reception error probability is zero. Consequently, the optimization of (15) should be performed on condition that $L_{i,j}^{DL} \le L_{i,j}^{DL,max}$, where the maximum average number of data block transmissions $L_{i,j}^{DL,max}$ is determined by the maximum average data block transmission delay.

V. Numerical Value of the Optimal Average Number of Data Block Transmissions

Using link level simulation we obtained the functions $\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)$. We obtained these functions for the following 19 coding and modulation schemes and coding block sizes of the IEEE 802.16 OFDMA:

- QPSK, convolutional coding with the coding rate of $1/2$, coding block sizes of 6, 12, 18, 24, 30, and 36 bytes,
- QPSK, convolutional coding with the coding rate of $3/4$, coding block sizes of 9, 18, 27, and 36 bytes,
- 16-QAM, convolutional coding with the coding rate of $1/2$, coding block sizes of 12, 24, and 36 bytes,
- 16-QAM, convolutional coding with the coding rate of $3/4$, coding block sizes of 18 and 36 bytes,

- 64-QAM, convolutional coding with the coding rate of $1/2$, coding block sizes of 18 and 36 bytes,
- 64-QAM, convolutional coding with the coding rate of $2/3$, coding block size of 24 bytes,
- 64-QAM, convolutional coding with the coding rate of $3/4$, coding block size of 27 bytes.

We obtained the functions $\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)$ for the following 4 propagation channel models:

- SUI-1 [11],
- SUI-5 [11],
- Indoor A [12], and
- Vehicular B [12].

Hence, we obtained 76 functions $\beta_{FEC}\left(q_{i,j}^{DL}, z_{i,j}^{DL}\right)$. For each of these functions we solved the optimization problem (15), that is, we found the optimal average number of data block transmissions. We analyzed the dependence of the optimal average number of data block transmissions $L_{i,j}^{DL,opt}$ on the coding and modulation scheme, the coding block size, the propagation channel model, and the number n of the coding blocks containing one data block.

Fig. 1 shows the optimal average number of data block transmissions $L_{i,j}^{DL,opt}$ for different coding and modulation schemes, coding block sizes, and propagation channel models. In Fig. 1, the number n of the coding blocks containing one data block is equal to 50. The horizontal curve represents the average value of the optimal number of data block transmissions, which is equal to 1.186 in this case. The optimal average number of data block transmissions $L_{i,j}^{DL,opt}$ has very low dependence on the coding and modulation scheme, the coding block size, and the propagation channel model.

Fig. 2 shows the optimal average number of data block transmissions $L_{i,j}^{DL,opt}$ as a function of the number n of the coding blocks containing one data block. In Fig. 2 the optimal average number of data block transmissions $L_{i,j}^{DL,opt}$ is averaged over all coding and modulation schemes, coding block sizes, and propagation channel models. For $n=1$ the optimal average number of data block transmissions is equal to 1.2 and for $n=1000$ it is equal to 1.18. Consequently, the optimal average number of data block transmissions $L_{i,j}^{DL,opt}$ has very low dependence on the number n of the coding blocks containing one data block.

We recommend setting the optimal average number of data block transmissions to 1.18 in the IEEE 802.16 OFDMA system. As this value is very close to one transmission, the QoS requirement for the maximum average data block transmission delay will be satisfied in most cases.

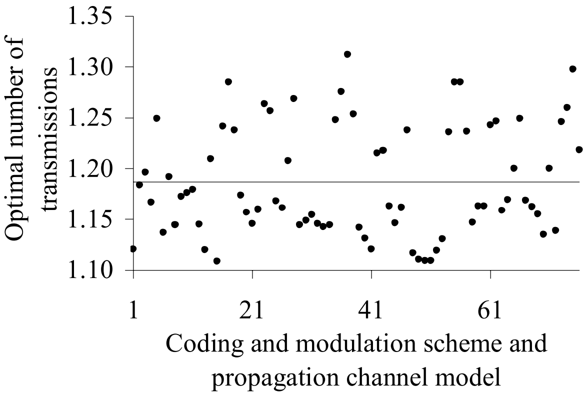

Figure 1. The optimal average number of data block transmissions for different coding and modulation schemes, coding block sizes, and propagation channel models.

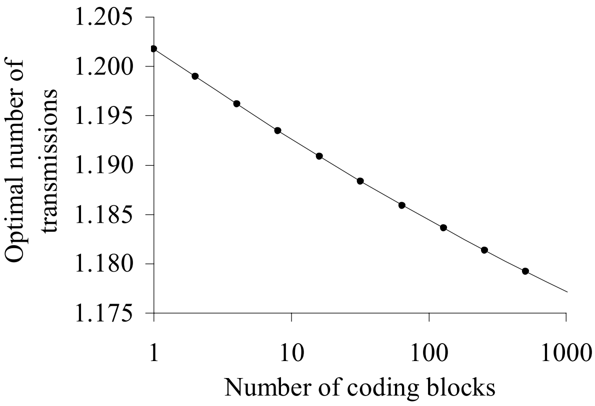

Figure 2. The optimal average number of data block transmissions as a function of the number of coding blocks containing one data block.

VI. CONCLUSIONS

In this paper we found the optimal average number of data block transmissions that minimizes the total downlink and uplink transmission power subject to satisfying QoS requirements for the IEEE 802.16 OFDMA system. Our algorithm requires the optimization over only one variable. Thus, we proposed a very fast solution to the optimization problem.

Using our algorithm we calculated the optimal average number of data block transmissions for numerous coding and modulation schemes and coding block sizes of the IEEE 802.16 OFDMA, for several propagation channel models, and for different numbers of coding blocks containing one data block. We showed that the optimal average number of data block transmissions in the IEEE 802.16 OFDMA system is almost independent of these parameters. Hence, we recommend setting the optimal average number of data block transmissions to 1.18 in the IEEE 802.16 OFDMA system.

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