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Re:	IEEE 802.16m-07/040, “Call for Contributions on Project 802.16m System Description Document (SDD)”
Abstract	This contribution proposes a section/sub-section to describe a scheme of energy efficient radio resource allocation for wireless multiuser multimedia communications in the Table of Contents (ToC) of IEEE 802.16m SDD to further improve the bandwidth and power efficiency of current IEEE 802.16 system.
Purpose	Propose to have a section/subsection “Adaptive radio resource allocation” in TGm SDD ToC.
Notice	
Release	
Patent Policy	

Adaptive Radio Resource Allocation for Wireless Multiuser Multimedia Communications in Project 802.16m SDD

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I. Introduction

As the demand for higher data rate multi-media wireless communications increases, it also becomes more and more important that one takes into account the energy-efficiency factor in designing an anti-fading transmission scheme. Resource allocation such as power control has long been regarded as one of an effective way to dynamically reduce power expense and co-channel interferences in wireless networks. The power control constantly adjusts the transmitted power so as to maintain the received link quality.

In multiuser systems using static time-division multiple access (TDMA) or frequency-division multiple access (FDMA) as multi-access schemes, each user is allocated a predetermined time slot or frequency band to apply OFDM transmission. As a result, these unused subcarriers within the allocated time slot or frequency band of a user are wasted and are not used by other users. Nevertheless, the subcarriers which appear in deep fade to one user may not be in deep fade for other uses. The probability of the subcarriers are in deep fade for all users is extremely minor because the channel fading coefficients for different users are mutually independent. Hence, a key issue in multi-user OFDM is the allocation of the OFDM subcarriers and power allocation among users. In [1], the authors proposed an adaptive multiuser subcarrier allocation scheme based on the instantaneous channel information to minimize the overall transmit power.

Zhu et al. [2] proposed a method to solve the problems about who should help whom and how to cooperate over a multiuser Orthogonal Frequency Division Multiplexing (OFDM) network. Although their algorithm leads to optimal performance, the associated computing complexity is relatively high for a mobile device. Water-filling-like algorithms for optimal power allocation with prescribed error tolerance for various systems have been proposed [2]-[6]. These algorithms are basically greedy (exhaustive) searches. The suboptimal subcarriers allocations algorithm in [5] assumed that power distribution across all subcarriers is equal. However it is not reasonable and not close to the optimal solution. In [7], the authors had proposed a simple iterative power allocation algorithm to obtain the optimal solution for mono-rate requirement.

This contribution is concerned with efficient subcarrier, power and rate assignments that fulfill multi-user multi-media requirements with minimum total transmitted power. We generalize the conventional problem setting by defining virtual orthogonal channels (VOCs), and present very efficient iterative algorithms that is guaranteed to yield the near-optimal solution.

The rest of this contribution is organized as follows. The ensuing section describes potential operation scenarios for downlink radio resource allocation needs and gives an abstract problem statement. In Section III, we propose our efficient radio resource allocation algorithms based on dynamic programming method. Our algorithm can obtain a near-optimal resource allocation solution for multiple rate applications. We provide some numerical performance of our proposed algorithm in Section IV. Then, some concluding remarks are given in Section V. Finally, proposed sections/subsections in the table of content (ToC) for IEEE 802.16m SDD are described in the last section.

II. System Model and Problem Formulation

A. System Model

A base station in a cellular system needs to transmits multiple data streams to mobile stations simultaneously. To eliminate or suppress mutual interference, these data streams are often transmitted through channels that are orthogonal in time, frequency, code or hybrid domains. For example, the IEEE 802.16e adapts an OFDMA scheme so that a user data stream can be allocated in a fixed number of orthogonal subcarriers and time slots. Multiple orthogonal channels are also available in the 3G-Cdma2000 system via Walsh-Hardamard coding. If multiple antennas are installed at one side or both sides of the link and if the channel state is known to both sides, the resulting multiple-input multiple-output (MIMO) channel can be decomposed into parallel orthogonal channels (eigen channels). Hence, without loss of generality, we shall consider a general scenario under which *N* virtual orthogonal channels (VOCs) are available for multirate downlink transmission and the instantaneous channel conditions of all VOCs are available to the transmitter(s). Therefore, the number of VOCs includes the number of the orthogonal subcarriers, time-slots which are unused or any other forms of orthogonal channels like the number of eigen-channels in a MIMO wireless link [9].

It is assumed that each VOC is independently and frequency non-selectively Rayleigh-faded and the bandwidth of the *i*th channel is W_i during a fixed transmission interval. The candidate data types might include voice, image, video, data, etc., each has a distinct rate requirement, and the number of the requested data types is given by

$d = \sum_{j-1}^{K_d} n_j$,where K_d is the number of active destination terminals and n_j is the number of the *j*th user's request data types. For convenience, the same data type, like voices, from different users will be regarded as different types.

The maximum transmission rate (capacity) C_{ij} offered by the *i*th channel to serve the *j*th data type with transmitted power p_{ij} is given by

$$C_{ij} = W_i \log_2\left(1 + \frac{p_{ij} h_{ij}}{\sigma_{ij}^2}\right), 1 \le i \le N, 1 \le j \le d ,$$

where h_{ij} and σ_{ij}^2 denote the channel gain and noise power of the *i*th VOC which serves the *j*th data type. For simplicity, it is assumed that the noise power (σ_{ij}^2) and bandwidths(W_i) are the same for all VOCs and are given by (σ^2, W). Further, each channel's gain-to-noise ratio (GNR) $\frac{h_{ij}}{\sigma^2}$ is known to the base station and the normalized capacity (rate) r_{ij} for the *i*th channel to serve the *j*th data type is

$$r_{ij} = \frac{C_{ij}}{W \log_2 e} = \ln\left(1 + \frac{h_{ij} p_{ij}}{\sigma^2}\right) = \ln(1 + a_{ij} p_{ij}) \text{ where } a_{ij} = \frac{h_{ij}}{\sigma^2}.$$

B. Problem Formulation

Given the multiple rate requirements and channel state information (i.e., a_i's), one would like to find the channel assignment and power allocation that minimize the total transmitted power. We first define the $N \times d$ channel assignment matrix $\mathrm{A}_{\mathrm{N\times d}} = \lfloor \mathrm{A}_{\mathrm{ij}} \rfloor$ by $A_{ij} = 1$ if the *i*th VOC is used to transmit the *j*th data type; otherwise, $A_{ij} = 0$. Assuming a VOC can only serve one data type at a given time interval, then A_{ij} is either 1 or

0 and a legitimate channel assignment matrix $\mathrm{A}_{\mathrm{N \times d}}$ must satisfy $\sum_{j=1}^{d} A_{ij} \le 1, \sum_{i=1}^{N} A_{ij} \ge 1, 1 \le i \le N, 1 \le j \le d$

In downlink multi-user OFDM systems, all signals are transmitted in the same time slot from the same base station, hence only the total transmitter power will be considered. Mathematically, the problem of concern is given by the following equation which is similar to the problem in [1]

$$\min_{\mathrm{P,A}} \sum_{i=1}^{N} \sum_{j=1}^{d} p_{ij} \text{ , s.t. } \sum_{i=1}^{N} A_{ij} r_{ij} = R_j$$

where A is the channel assignment matrix defined above and P denotes the power allocation matrix whose (*i; j*)th entry P_{ij} represents the *i*th VOC's transmitted power for sending the *j*th data type and r_{ij} is the corresponding transmission rate. R_j is the required rate of the *j*th data type.

III. Dynamic Programming Based Resource Allocation Algorithm

A. Dynamic programming formulation

For introducing the dynamic programming optimization algorithm to simplify searching the assignment matrix $\mathrm{A}_{\mathrm{N \times d}}$, we must modify the problem formulation into the dynamic programming format.

First, for the initial problem of each data type subset, in opposition to the intuitional idea that each data type subset is initialized as an empty subset and VOCs are assigned at each stage, we propose an innovative thought which all VOCs are initialized to each data type and VOCs are deleted at each stage.

Second, due to the assumption that each VOC can serve only one data type, which data type should be served by this VOC has to be determined stage by stage. Additionally, to save the cost of memory and reduce the computational complexity, only the state with the minimum sum of all data types' transmitted power is survived at each stage. Therefore, the data type corresponding to the state with the minimum power will keep the VOC which is allocated at this stage and the VOC will be removed from all other data type subsets.

Third, the order of VOC to be determined also affects the performance of DP algorithm much. By the intuition, the VOC with better channel response needs to be allocated carefully to avoid large performance loss from the optimal solution. For this reason, we choose the maximum channel response of the VOC to each data type to stand for this VOC and the order of VOC to be allocated depends on this maximum value. This method is shown as the following formula,

$$\underset{i}{Sort}\left[\max_{j}\left(a_{ij}\right)\right], 1 \le i \le N, 1 \le j \le d$$

Finally, the stage by stage searching trellis with the DP format is illustrated below

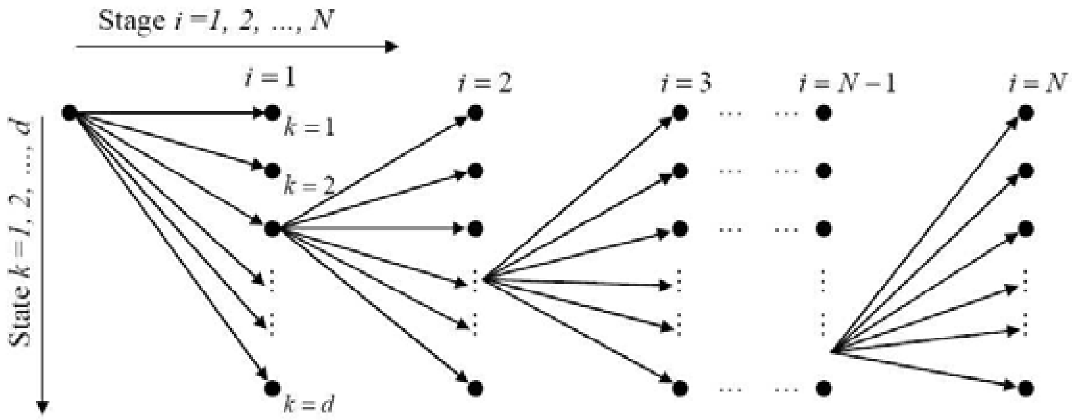

Figure 1. The problem formulation modified to DP format

B. A dynamic programming approach

To apply the DP technique to solve the optimization problem stage by stage, we have to define the following subsets and functions,

C_t^r **:** the survived VOC's subset vector at the t stage, where $C_t^r = \left(C_t^r(1), \cdots, C_t^r(d)\right)$

$C_t^r(j)$ **:** the survived VOC's subset of the j th data type at the t stage,

$g(R, C)$**:** the total consuming power computed by the iterative optimization algorithm in [7] with the require normalize rate R and the VOC's subset C

$f_k\left(C_t^r(j)\right)$**:** a function that describes the subset by which the state is updated,

where $f_k\left(C_t^r(j)\right) = \begin{cases} C_{t-1}^r(j), \ j = k \\ C_{t-1}^r(j) \setminus t, \ j \neq k \end{cases}$

The VOC's subset of each data type is initialized as $C_0^r(j) = \{i \mid 1 \le i \le N\}, 1 \le j \le d$ **.**

Then the cost formula is given by $J_t\left(C_t^r\right) = \min_{k, 1 \le k \le d} \left\{ \sum_{j=1}^{d} g\left(R_j, f_k\left(C_k^r(j)\right)\right) \right\}, 1 \le t \le N$

and the VOC's subset of each data type are updated each stage to implement DP method to solve the problem of searching a near optimal channel assignment matrix $A_{N \times d}$ and this algorithm will be referred as *DPRA* algorithm in the following section.

IV. Simulation Results and Discussion

As we describe above, the solution provided by *DPRA* approach is not always optimal. The following simulated results show the performance of *DPRA* method. To avoid the sum of the normalized rates increases with the number of data types, we define *the normalized sum rate* $= \sum_{j=1}^{d} R_j$. Various numbers of data types with the same normalized sum rate are simulated and the normalized rate of each data type is randomly assigned. For simplicity, the normalized noise power (σ^2) is assumed to be *0.01*. The results are the average of the *100000* simulated times.

From Fig. 2, the simulated results have shown the probability of *DPRA* algorithm achieving the optimal solution. Compared 64 VOCs with 128 VOCs, since the number of better VOCs in each data type subset increases and fewer VOCs are better in more than one data type subset, the correct probability of the decision at each stage by *DPRA* method will raise. On the opposite, if the number of data types increases, it means selections at each stage become more, so the probability of reaching the optimal solution should degrade as the results.

Except for the probability of achieving the optimal solution, the average performance loss is a useful evaluation to a sub-optimal algorithm, so Fig. 3 illustrates the average performance loss from the optimal solution by *DPRA* approach. With fewer VOCs, a wrong decision will introduce more performance loss than it with more VOCs. Additionally, the probability of achieving the optimum with fewer VOCs is lower than more VOCs, so the average performance with fewer VOCs is obviously worst than it with more VOCs. Even though the probability of achieving the optimum is not very high when the normalized sum rate is higher, we can find that the average performance loss still keeps in a very low value. Therefore, the above results have shown our proposed *DPRA* algorithm is a near-optimal algorithm.

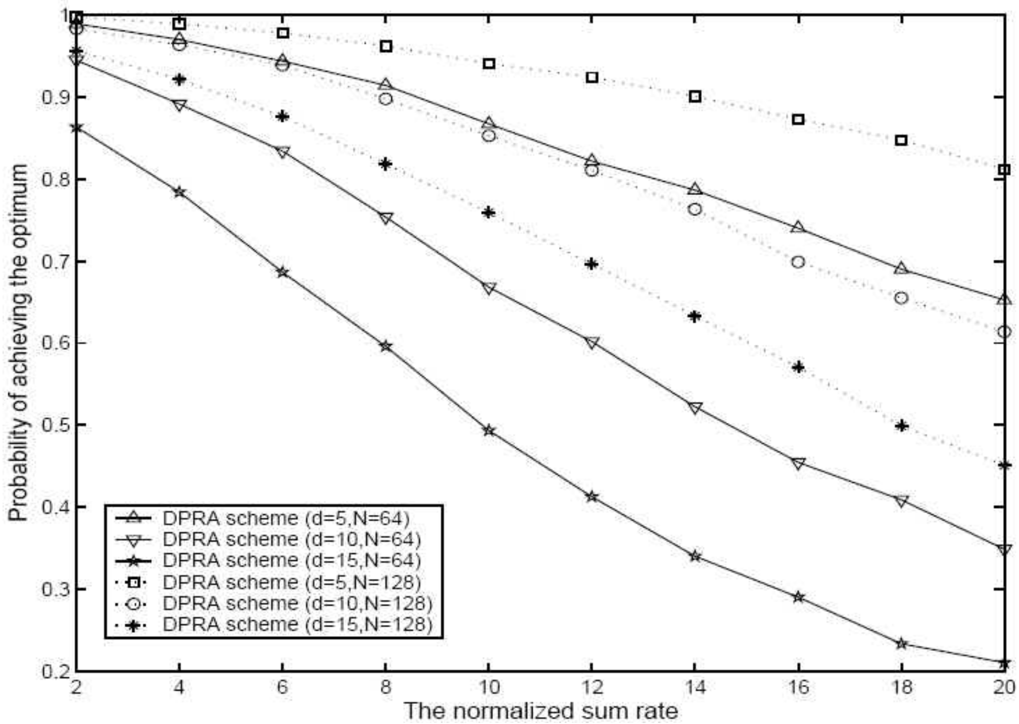

Figure 2. Probabilities of *DPRA* algorithm achieving the optimum solution

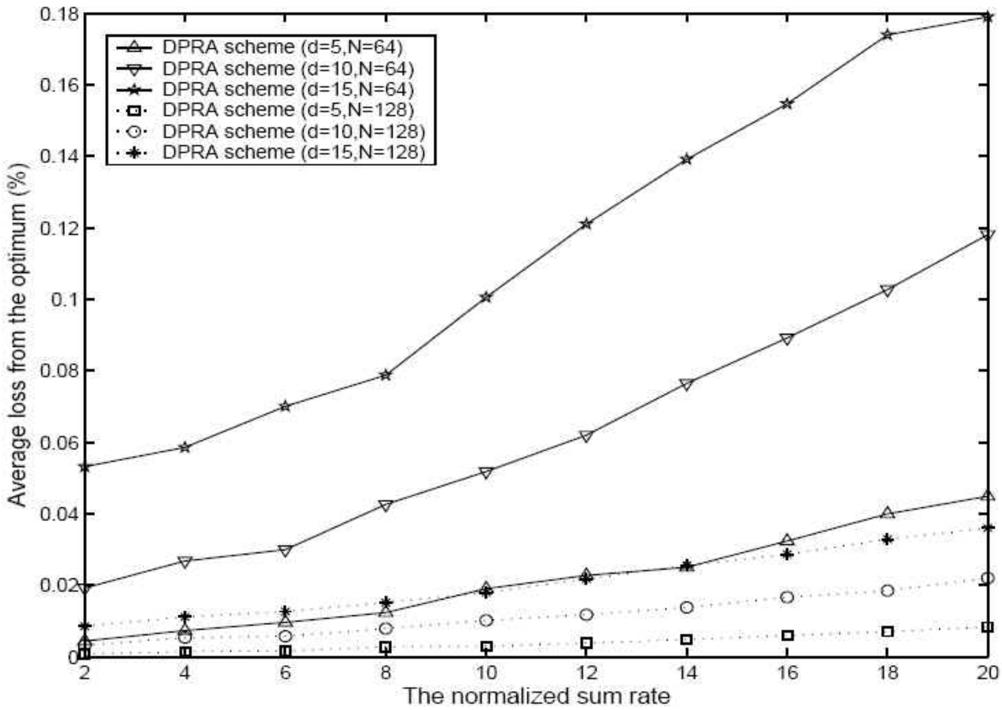

Figure 3. Average performance loss (with respect to the optimum solution) of *DPRA* algorithm

V. Conclusion

The purpose of this contribution is to present efficient algorithms for solving constrained optimization problems arisen in radio resource allocation for wireless multi-user multi-media communication networks. For many cases, the best radio resource allocation strategy is a water-filling-like solution and the search of such an optimal strategy is accomplished by a greedy approach, which is not only time-consuming but also takes large memory space. We suggest efficient procedures for obtaining near-optimal solutions. Hence, we introduce an efficient iterative algorithm based on Dynamic Programming method. The above algorithm in this contribution has much reduced complexity and suffers only minor performance degradation within the range of interest. Consequently, it is possible to have a low-complexity algorithm for adaptive radio resource allocation without large performance degradation from optimal solution.

VI. Proposed Sections/Subsections in the Table of Content (ToC)

This contribution is to present efficient algorithms of adaptive radio resource allocation and show that low complexity algorithms can be obtained without large performance degradation. According to IEEE 802.16 standard documents, current system does not support the function of adaptive radio resource allocation to adaptively allocate radio resources, such as power and subchannels, to multiple users or services with different QoS requirements. This may induce inefficiency of bandwidth utilization and power waste in the system, especially for band-limited wireless networks. Therefore, it is suggested to include this functionality in IEEE 802.16m system to enhance bandwidth efficiency for multi-user multimedia communications to achieve QoS requirements. Required modifications to current system and proposed sections/subsections in ToC are shown as follows.

Proposed sections/subsections in ToC:

--Start of the Text--

[*Adopt the following text in the ToC of P802.16m System Description Document (SDD)*]

x.y Adaptive radio resource allocation

[*In order to support this functionality, it is required to provide minimum data rate of each user or service from upper layers for adaptive radio resource allocation. The information can be assigned in MAC layer. With this information, the designed algorithm calculates optimum or suboptimum solution to efficiently allocate radio resources, such as power and subchannels, to users or services based on current wireless channel status. Since it was shown that low complexity algorithms are obtainable without much performance loss, the inclusion of this functionality will not contribute much complexity in the transceiver design.*]

--End of the Text--

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