

Reinforcement Learning for Resource Allocation in Multiuser OFDM Systems

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Abstract

In cellular mobile communications the subcarriers are repeatedly used for best utilizing the assigned frequency spectrum. The assignment of channels for users is complex and involves high computation time. Wong et al [15] proposed a heuristic algorithm to achieve the suboptimal solution for sub-carrier assignment. This proposal was based on constructive assignment in real time situation with prosperous results. However, the algorithm involves computational complexity. In this paper we propose reinforcement learning algorithm for sub-carrier assignment to the users in a way that the total transmit power is minimized. Reinforcement learning algorithms are frequently used for optimization problems and are related to dynamic programming algorithms. Simulation results show that proposed reinforcement learning is robust and outperforms the heuristic algorithm proposed by Wong et al.

Keywords: Reinforcement Learning, Heuristic Algorithm, frequency spectrum, OFDM, Subcarrier, modulation

Introduction

Wireless communication became a vibrant research area in the communication field due to an increased use of wireless systems and progress in VLSI technology. Continuous research improved the performance, type of usage, adaptability of traffic conditions, reuse of partitioning schemes, effect of hand-offs, prioritization schemes, and better tools to communicate over wireless channels. However there are still challenges to meet for better, reliable and fast performance with unpredictable, unknown statistical characteristics of the aggregate traffic.

Orthogonal Frequency Division Multiplexing (OFDM) has emerged as a major multiple access scheme for new wireless communication systems. High spectral efficiency can be obtained by OFDM in which inter-symbol interference (ISI) is eliminated over multi-path channels. By combining the adaptive modulation (AM) with OFDM, we can achieve better performance over frequency selective fading channels. The AM in OFDM is, based on the channel characteristics including the number of bits to be transmitted, the level of modulation and the transmission power in each channel. The channels with their properties are selected to increase the transmission bit rate or reduce the required transmit power. In a frequency selective fading channel, the combination of adaptive modulation and OFDM can utilize the merits of both technologies and channel properties to attract the user's interests.

The greedy algorithm (adaptive bit allocation algorithm) for single user OFDM system gives an optimal solution to minimize the overall bit power allocation [2, 6]. The greedy algorithm may not be suitable in multiuser environment because a channel/subcarrier will be best for one user but not another. An optimum solution using the greedy algorithm may be possible when the overall subcarriers are allocated to users by adaptive subcarrier allocation in the OFDM systems [16]. Rohling et al. [9] presented a simple greedy algorithm, and showed that it performs better than simple banded Orthogonal Frequency Division Multiple Access. Wahlqvist et al. [11] showed that dynamic resource allocation can improve quality of service.

The problem of subcarrier and bit allocation in multiuser OFDM is very complex; so the solution can be categorized as static and dynamic allocation. The static subcarrier allocation uses fixed resource allocation schemes (TDMA, FDMA). In these schemes, the channel conditions are ignored and each user is allocated a predetermined time slot or frequency band to apply OFDM system with AM. Consequently, the allocated resources to users are under utilized due to AM and subcarriers that appear in deep fade for one user may not be in deep fade for other users [12, 13]. The problem is taken care of by dynamically allocating the subcarrier, bit, and power to different users based on the instantaneous channel information that minimize overall transmit power. Wong et al. [14] proposed iterative searching algorithm that applies Lagrangian relaxation for optimum multiuser subcarrier, bit, and power allocation. The algorithm is close to the lower bound with requirement of high and complex computation. Ehsan's [1] algorithm over-simplifies the subcarrier allocation but could not fully utilize the multiuser diversity. Zhang [17] proposed water-filling algorithm similar to Wong's [14, 15, 16] algorithm to avoid computational complexity.

System Model and Problem Formulation

The configuration of the multiuser adaptive OFDM downlink transmission is shown in the Figure 1. We assume the system has K users and N subcarriers. The system assigns a subset of N subcarriers to a user and determines the number of bits/symbol per each assigned subcarrier on downlink transmission. Let $c_{n,k} \in \{0, 1, 2, \dots, M\}$ denote the number of bits of the n^{th} subcarrier, which is assigned to the k^{th} user. R_k is the number of bits that need to be transmitted in an OFDM symbol. M is the maximum number of information bits per symbol that can be transmitted by each subcarrier.

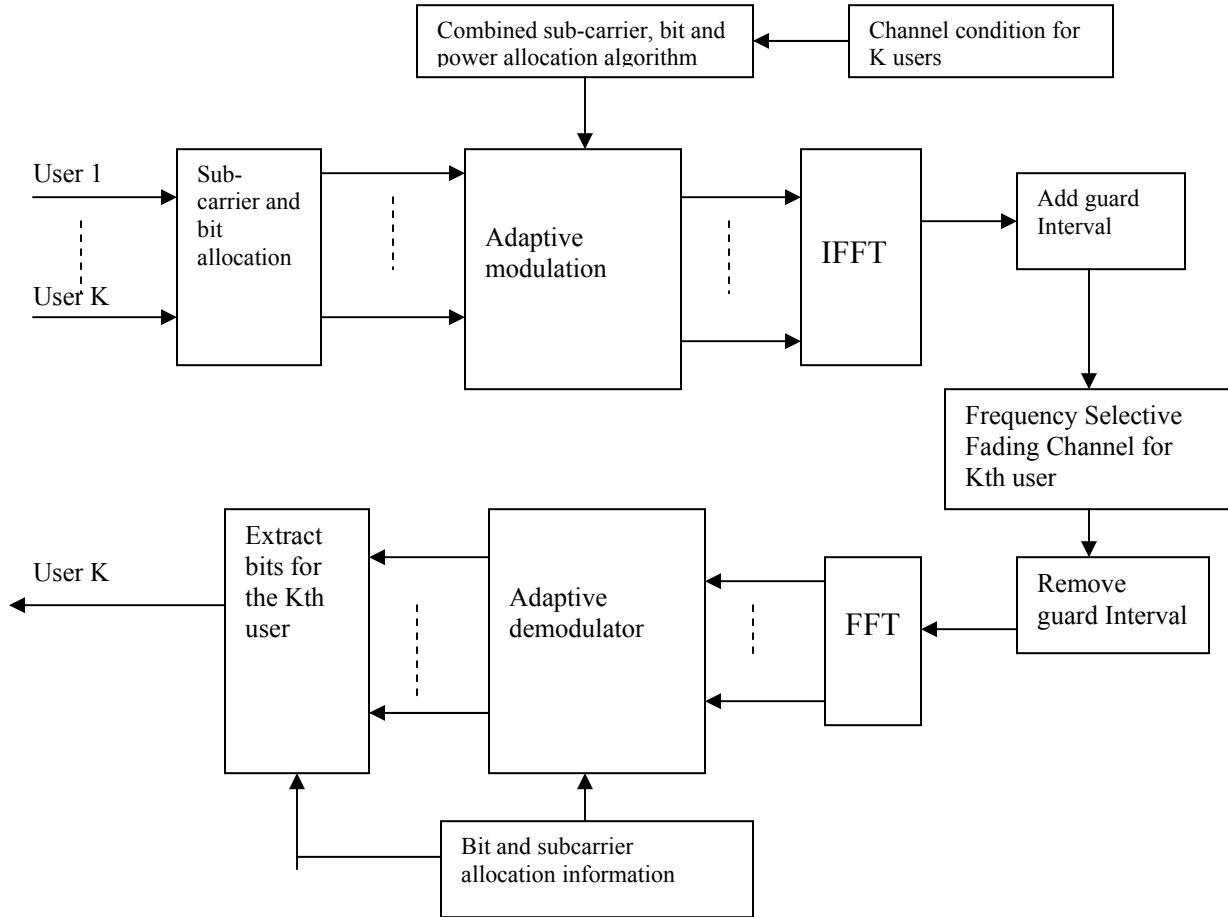


Figure 1: Schematic Model of the OFDM System

The parameter $c_{n,k}$ determines the adaptive modulation mode (BPSK, 16 QAM, or 64 QAM) for transmission for each carrier. Let $\alpha_{n,k}$ denote the channel gains over all N subcarriers for the k^{th} user. The required transmit power for the specified bit error rate at $c_{n,k}$ bits per symbol is equal to

$$P_{n,k} = \frac{f_k(c_{n,k})}{\alpha_{n,k}^2} \quad \text{----- (1)}$$

For the multiuser OFDM systems under consideration, we do not allow more than one user to share a subcarrier. To formulate the allocation problem, we define

$$\rho = \begin{cases} 1, & \text{if } c_{n,k} \neq 0 \\ 0, & \text{if } c_{n,k} = 0 \end{cases} \quad \text{----- (2)}$$

Variable $\rho_{n,k}$ is either 1 or 0, and the sum of all $\rho_{n,k}$ is equal to 1 for any particular n. This implies that only one user can employ the nth subcarrier. The required transmit power can be written as

$$P_{n,k} = \sum_{n=1}^N \sum_{k=1}^K \frac{f_k(c_{n,k})}{\alpha_{n,k}^2} * \rho_{n,k} \quad \text{----- (3)}$$

The subcarrier, bit and power allocation problem for minimizing the total transmit power can be formulated:

$$\min_{r_{n,k}, \rho_{n,k}} \sum_{n=1}^N \sum_{k=1}^K \frac{f_k(c_{n,k})}{\alpha_{n,k}^2} * \rho_{n,k} \quad \text{----- (4)}$$

Subject to

$$\sum_{k=1}^K \rho_{n,k} = 1, \text{ for } n = 1, \dots, N \quad \text{----- (5)}$$

$$\sum_{n=1}^N \sum_{k=1}^K \rho_{n,k} = N \quad \text{----- (6)}$$

$$c_{n,k} \in \{0, 1, 2, \dots, M\}$$

$$R_k = \sum_{n=1}^N \alpha_{n,k} \quad \text{for } k = 1, \dots, K \quad \text{----- (7)}$$

and the required power for supporting c bits/symbol at a given BER (bit error rate) [8] is

$$f(c_{k,n}) = \frac{N_0}{3} [Q^{-1}(\frac{BER_n}{4})]^2 \cdot (2^r - 1) \quad \text{----- (8)}$$

where

$$Q(x) = \frac{1}{\sqrt{2\Pi}} \int_x^\infty e^{-t^2/2} dt \quad \text{----- (9)}$$

and

$f(c_{k,n})$ is convex and increasing in c and that $f(0) = 0$

Subcarrier allocation

In our calculations, we have taken K=128, subcarriers and data rates R= 24, 128, 236, 340. The modulations used were QPSK, 16 QAM, and 64 QAM. Initially, we calculated the optimum power allocation with higher bit rate using heuristic algorithm using MatLab tool. Figure 2 shows that the optimum power allocation for transferring data with data rate in the range 24 to 360 that outperforms Wong's and Chen's algorithm [3, 15]. The power allocation against bit error rate (BER = 10⁻³) is shown in Figure 3. We compared our results with Wong's [15] and Jan-Jap's [5] results. The average power allocation in the present case with BER = 10⁻³ is less than 12db whereas both Wong [15] and Jan-Jap [5] required more than 14 db.

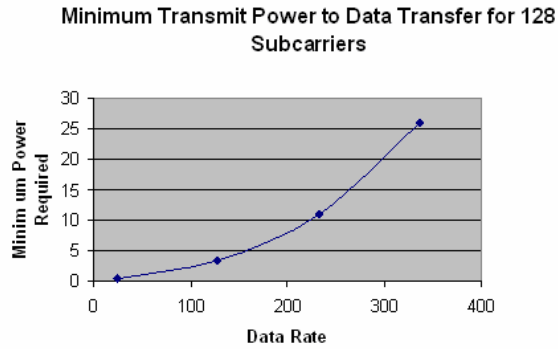


Figure 2: Data rate against power requirement

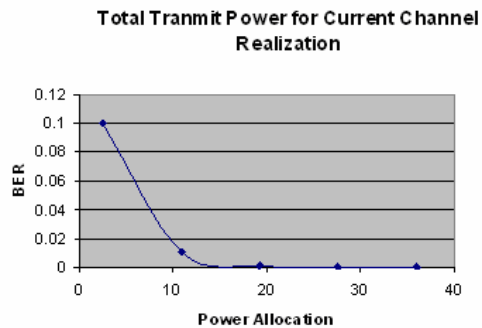


Figure 3: Power Allocation against BER with data rate 300

In reinforcement learning [7, 10], the autonomous agents assume initial characteristics of a subcarrier state and then maximizes the total reward that it receives from the starting state. We assume a Q (state, action) function that maximizes the channel gains with optimum power allocation. The reinforcement learning approach was discussed individually by Tom Mitchell [10] and Goldberg [4] in classifier systems. Table 1 shows the settings of the options in the genetic algorithm tool of MatLab. The results in figure 4 that shows best and mean fitness =12.9891, which matches the Signal to Noise Ratio (SNR) of Wong [15] with BER = 10^{-3} . The computations further provide the information that the computations are exponentially expensive as we increase the penalty rate above 10. So we set the penalty at 10 in reinforcement learning parameter. Figure 5 shows the computations by keeping the same reinforcement learning rate, the penalty 10, and selection as stochastic and fitness scaling as proportional. The difference is that number of children and distance between individual is close to uniform in stochastic selection (Figure 5) where it is highly random in roulette selection (Figure 4).

Conclusions

A reinforcement learning technique for optimum resource allocation in multiuser OFDM systems was proposed. The reinforcement model was described by Tom Mitchell [10] and Goldberg [4]. Initially, the optimum power allocation was calculated with various data transfer rates and power allocation with fixed bit error rates (BER= 10^{-3}). The results are encouraging compared to Wong [15], Zhan [17], and Jan-Jaap [5]. Finally using reinforcement learning technique, it was observed that the number of children was uniform in evaluation when stochastic selection and adaptive feasible mutation parameters were set in genetic algorithms tool of MatLab package (see Table 1, Figure 4 and Table 2, Figure 5). It was observed that the computations were very expensive as the bidding rate parameter increases from 10 to 20 in reinforcement learning. With bidding rate 10 the distance between the individual is closer in stochastic selection and scattered in roulette selection. Hence, the parameter setting stochastic selection is more appropriate. It is concluded that in the subcarrier resource allocation problem of multiuser OFDM system the reinforcement technique is an alternative and better choice.

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Table 1 : Option settings step 1 in gatool (genetic algorithm tool)

Population Size: 20	Fitness Scaling (scaling function): Rank	Selection: Roulette
Reproduction:	Mutation fraction: Gaussian	Crossover function: Heuristic
Elite count – 2	scale: 1.0	Ratio:1.2
Crossover fraction: 0.8	shrink: 1.0	
Migration-Direction: Forward	Algorithm Settings:	Hybrid function: pattern search
Fraction: 0.2	Individual Penalty: 10	
Interval: 20	Penalty factor: 100	

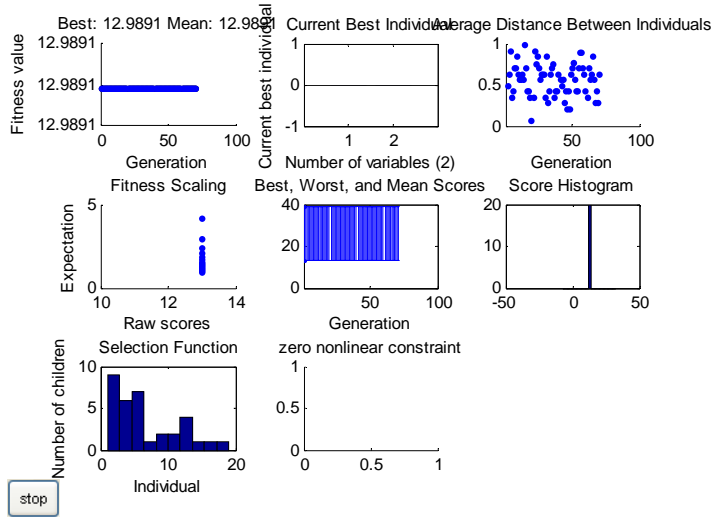


Figure 4: Reinforcement Learning Approach with BER = 10⁻³

Table 2: Option settings step 2 in gatool (genetic algorithm tool)

Population Size: 20	Fitness Scaling (scaling function): <i>proportional</i>	Selection: <i>stochastic uniform</i>
Reproduction:	Mutation fraction: <i>adaptive feasible</i>	Crossover function: Heuristic
Elite count – 2	scale: 1.0	Ratio:1.2
Crossover fraction: 0.8	shrink: 1.0	
Migration-Direction: Forward	Algorithm Settings:	Hybrid function: <i>fminsearch</i>
Fraction: 0.2	Individual Penalty: 10	
Interval: 20	Penalty factor: 100	

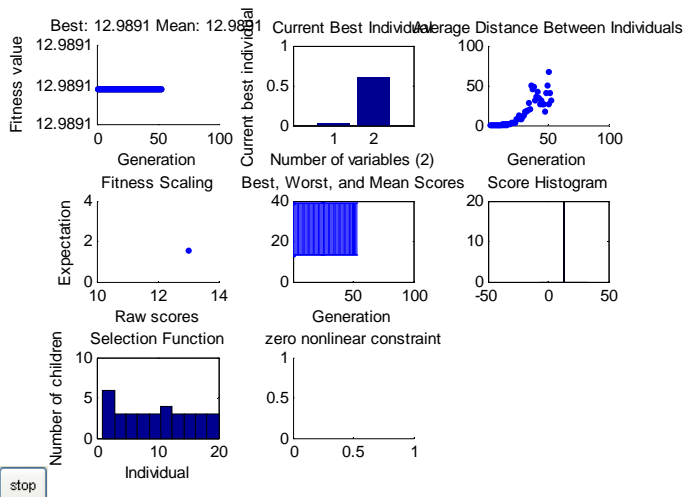


Figure 5: Reinforcement Learning with BER = 10⁻³ with Proportional Fitness and Stochastic Selection

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