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A Study On Resource Allocation Aspects For Wireless Networks

J. Praisy Jasper Pondhivya,
PG scholar, PET Engineering College

K. Madhan Kumar,
Associate Professor, PET Engineering College

Abstract

Resource allocation is one of the most challenging tasks in the wireless networks. Many schemes exist in literature to allocate the available resources to users. Different schemes employ different algorithms to allocate the subcarrier, bits, data rate, transmit power, bandwidth etc. to different users in the network while satisfying the desired constraints posed by the users like utility maximization, power reduction, throughput maximization and so on. Adaptive modulation is also used in order to effectively handle the network resources. In this paper, some of the existing resource allocation schemes and their performance is discussed.

1. Introduction

Wireless networks are expected to support a variety of applications with diverse QoS requirements. The limited availability of network resources kindles the need to effectively utilize these resources such that all the users are able to satisfy their QoS needs in a more efficient way. Radio resource allocations for multiple users have been widely studied in literature [1]-[5]. For high data rate transmission of signals over wireless radio channels orthogonal frequency division multiplexing is an assuring multiple access technique. Hence a lot of research works are focused on providing a good resource allocation scheme for OFDM networks [1]-[3]. In [3], the authors proposed a joint subcarrier and power allocation scheme with the aim of maximizing the total utility of the users. But this is mainly suitable for users in the uplink of the OFDMA systems. The resource allocation for CDMA networks is discussed in [4],[5]. In [4], the authors investigated radio resource allocation for multiple mobile stations (MSs) on the downlink of a code division multiple access (CDMA) network employing adaptive modulation and coding and multicodes. But these works focus on CDMA systems that require the use of a central controller to coordinate different users' resource allocation to satisfy the system requirements. Recently, the attention is on distributed resource allocation in which each user performs its own resource allocation without requiring a central controller. The distributed resource allocation for CDMA data network is analyzed in [6]. Here the power allocation is formulated as a non-cooperative game. A new pay-off function is defined with which a user can obtain a generalization of the asymptotic result on spectral efficiency of CDMA systems. In [7] a game theoretic approach is used to study the effects of modulation on energy efficiency of the CDMA networks. The above works [1]-[7] assumed the availability of perfect channel state information (CSI) in their resource allocation frame work. But this is not the actual situation in practical case. Especially in a distributed network, multiple access interference (MAI) leads to noisier channel estimation. The effects of imperfect knowledge in CSI are also taken into account in [8]-[12]. An adaptive multi-user resource allocation for multicarrier direct sequence code division multiple access networks and the effect of imperfect CSI on the adaptive resource allocation framework is proposed in [8] and [12]. The authors of [11] projected the process of allocating the network resource as network utility maximization (NUM) for OFDMA networks with imperfect CSI.

The main focus of this paper is to discuss various resource allocation methods present in the literature for various types of wireless networks and to analyze their performance.

2. Literature review

2.1. Power Control Game For Multirate CDMA Network

Increase in demands for multimedia services has led to an increase in need for different data rate services. The bitrate requirement may vary from a few kbps to as much as 2 Mbps. Chi Wan Sung and Wing Shing Wong [6] proposed a non co-operative game for multirate CDMA system. Multi rate CDMA system can be designed in many ways. The scheme used in this paper is variable spreading gain access.
For a single cell CDMA system with N active terminals, each user transmits its signals at different rates. However all users have the same chip rate, hence the signals are spread to the same bandwidth. In the Power Control Game (PCG), the users are regarded as players of the game. Each player has a pay-off function. The payoff of the player is its throughput. Hence this game is called throughput maximization game (TMG). Also in order to improve the performance of the system, a new pricing function mechanism is introduced. This is used in order to prevent the interference among the users. Whenever a user's transmission causes interference to the transmission of other users, a price is charged for creating interference. This pricing function is the ratio of the normalized received power to the total received power plus noise at the base station. Then a new payoff function is defined for each player by subtracting this new pricing function from the payoff considered without pricing. This new game is called Throughput maximization game with pricing (TMGP). The spectral efficiency (total throughput per bandwidth) for Binary Input Gaussian Output (BIGO) channel and Binary Symmetric Channel (BSC) channel are derived and analyzed. This analysis is performed in terms of ratio of energy per bit to interference spectral density(E_b/J_o) and spectral efficiency η.

Table 1 Spectral efficiency for BIGO and BSC channels

E_b/J_o	Spectral efficiency	
	BIGO	BSC
0	1.40	0.90
2	0.45	0.42
4	0.25	0.25
6	0.15	0.17

From the Table 1, it is seen that the spectral efficiency is a decreasing function of E_b/J_o. The maximum spectral efficiency is achieved when $E_b/J_o$is zerofor both types of channels. Also the spectral efficiency achieved for BIGO channel is higher than that achieved for BSC channel for any value of E_b/J_o.

In this paper, it is also proved that multirate CDMA system with a given rate vector can achieve the same spectral efficiency as a single rate CDMA system. With the introduced pricing, the game is shown to possess unique Nash equilibrium. This equilibrium maximizes the total throughput over a hyperplane with fixed total power.

2.2.Subcarrier And Power Allocation For OFDMA Network

Cho Yiu Ng, and Chi Wan Sung [3] proposed a joint sub carrier and power allocation method for the uplink of the OFDMA system. The uplink of an OFDMA transmission system with K users and N subcarriers is considered. The system is assumed to be synchronized and so it is almost free from multi-user interference (MUI). Here, the resource allocation strategy is formulated with the aim of maximizing the total utility of the users. The utility of the users is a function of the user's throughput. The total available subcarriers are assigned one by one to the users sequentially. Whenever a subcarrier is assigned, all users update their power allocation. Then another subcarrier is assigned. This process of allocating the subcarrier and power simultaneously continues until all the available subcarriers are assigned. Each user is allocated sub carrier uniquely and hence the power allocation of the users is independent of each other. This is done by maximizing the utiliy function which is equivalent to maximizing the throughput.
The optimal power allocation is water filling over all the subcarriers and the water filling solution is given as follows:

$$p_{i,j} = x_{i,j}\left[v_i - \frac{1}{g_{i,j}}\right]^+ \qquad (1)$$

Where $p_{i,j}$ is the power allocated to subcarrier j by user i, $x_{i,j}$ is the binary decision variable of subcarrier allocation, $g_{i,j}$ is the ratio of the channel gain to noise power of subcarrier j of user i, and $[x]^+ = \max\{0, x\}$, v_i is a constant which is commonly called the water level of user i such that

$$\sum_{j=1}^{N} p_{i,j} = P_i \qquad (2)$$

Where N represents the number of subcarriers and P_i is the total power of user i.

The Base Station (BS) executes the subcarrier and power allocation algorithm shown in Figure 1 to allocate the subcarrier and power for each user. The subcarrier allocation strategy may possibly be throughput optimization, proportional fairness or max-min fairness.

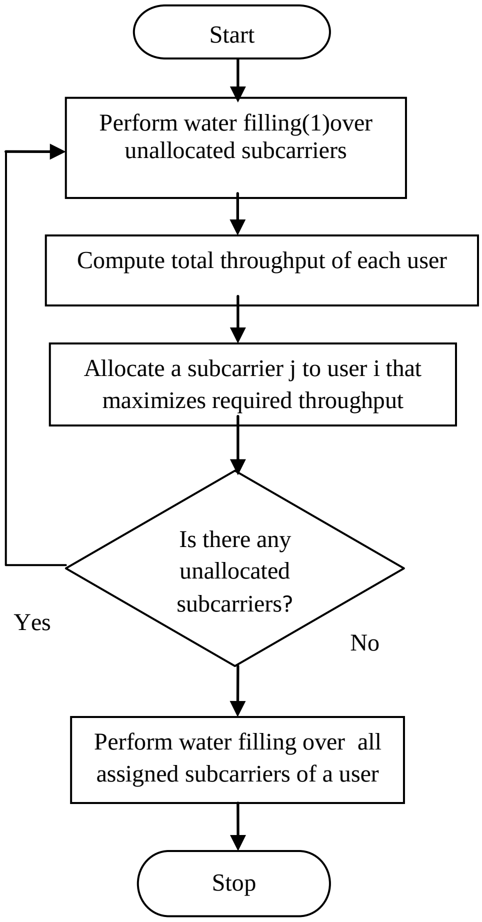

Figure 1 Flow diagram for subcarriers and power allocation

This algorithm has a time complexity of O (KN $\log_2$N), where K, N denotes the number of users and subcarriers respectively. The solution obtained by this method is shown to be pareto optimal within a very large neighbourhood. The throughput of the users increases with an increase in the number of subcarriers. Also as the number of users increases, the throughput further increases. The performance of this algorithm is close to that of the optimal solution.

2.3. Adaptive Modulation For CDMA Network

Adaptive modulation improves the spectral efficiency in wireless networks. Farhad Meshkati, Andrea J.Goldsmith, H.Vincent Poor and Stuart C. Schwartz [7] studied the effect of constellation size on energy efficiency of wireless networks using a game theoretic approach. This is posed as a non-cooperative game in which the users are allowed to choose their transmit power, symbol rate and modulation size with the aim of maximizing the utility function. The utility function defined here is the ratio of the throughput to the transmit power. For a user k, the utility function is given by

$$u_k = \frac{T_k}{p_k} \tag{3}$$

Where u_k is its utility function, T_k is the throughput and p_k is the transmit power of user k.

For the utility function given in (3), the best strategy is to transmit the symbols with the lowest order modulation. Also it is implied that being energy efficient is not spectrally efficient.If a user switches to a higher order modulation from a lower order one for the same bandwidth and symbol rate, the spectral efficiency increase at the cost of energy efficiency. When the system has an additional delay QoS constraint, the same game is slightly modified in which each player maximizes its own utility in addition to satisfying the delay QoS constraint. This delay includes both transmission and queuing delays. For this case also it is shown that to maximize the energy efficiency, the user must always choose the lowest order modulation for which the delay constraint is satisfied. The solution obtained by this method is proved to possess Nash Equilibrium. The effect of Trellis coded modulation (TCM) on energy efficiency is analyzed using the game theoretic approach. A comparative analysis of energy efficiency and signal to interference ratio (SIR) obtained for coded and uncoded schemes for different modulation size is given in the following table.

Table 2 Comparison of coded and uncoded systems

Modulation Size	Uncoded Systems		Coded Systems	
	SIR	Energy Efficiency	SIR	Energy Efficiency
2	9.1	0.19	8.1	0.29
4	15.7	0.08	14.2	0.13
6	21.6	0.03	20.4	0.04
8	27.3	0.01	26.3	0.16

From Table 2, it is found that with coding scheme, the signal to interference ratio is decreased relative to that of the uncoded scheme but however the energy efficiency of the users is increased considerably. Also, it is seen that higher energy efficiency is achieved for lower order modulation compared to that of the higher order modulation.

2.4. Resource Allocation for OFDMA Networkwith Imperfect CSI

Mohamad Khattar Awad,Veluppillai Mahinthan,Mehri Mehrjoo, Xuemin (Sherman) Shen and Jon W. Mark[11], proposed a scheme for allocation of subcarrier, rates and power in OFDMA network. The OFDMA systems transmit the wideband signal as multiple narrowband signals over subbands that are supported by subcarriers and with a bandwidth that is less than the channel coherence bandwidth. The main focus of [11] is to allocate network resources with imperfect channel state information (CSI), and for multiple classes of service that demands diverse QoS requirements. This system works for a Point to Multipoint(PMP) network with a single Base Station(BS) to support multiple subscriber stations. The BS performs the resource allocation for all its subscriber station. The BS has two layers: Physical (PHY) and Medium Access Control (MAC) layer. The Resource Allocation Unit (RAU) and Call Admission Control (CAC) unit are present within the MAC layer. The physical layer is responsible for feeding the CSI of all subcarriers to the RAU. The RAU in turn allocates the resources to all subscribers. The CSI is updated every OFDMA frame. Based on the CSI, the resources allocation process is updated. The CAC unit receives the resource allocation results from RAU and updates it based on network requirements.The resource allocation is modeled as constrained Network Utility Maximization (NUM) problem, with the objective of maximizing the subscribers' utility functions. The constraints are network specific. The authors considered the constraints to be per-service aggregate rate limit, power limitation and exclusive subcarrier allocation. The exclusive subcarrier assignment constraint results in nonconvex feasible space. Hence it is solved in dual domain by decomposition of the dual problem into a hierarchy of sub problems that are solved easily than the primal. This hierarchichal decomposition of the problem is shown in Figure 2.

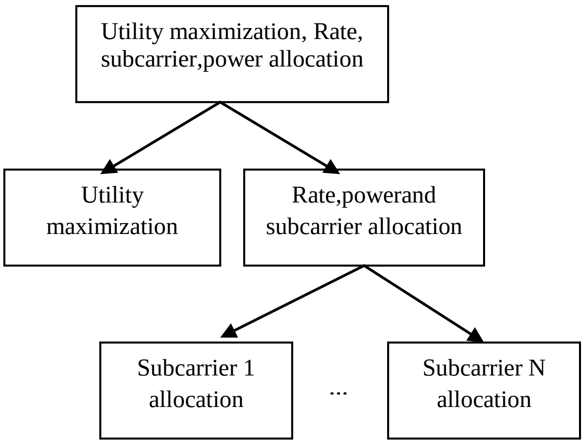

Figure 2 Hierarchy of dual problem decomposition

The master dual problem sets prices for resources and reports them to decomposed sub problems. This master dual problem represents utility maximization, subcarrier, rates and power allocation. This is decomposed into two subproblems: (1) Utility maximization and (2)Subcarrier, Power, Rate allocation. The second subproblem is complicated to solve, hence is again decomposed into a number of subproblems. This number equals the number of subcarriers. Then each of these subproblems is solved coordinated by the master dual problem.

In the Figure 2, the topmost box represents the master dual problem that is in turn decomposed into sub problems.A subcarrier is exclusively allocated to the particular subscriberthat maximizes the following equation:

$$\arg\max_{s} \delta^{s} E[r_n^s] - \nu p_n^s, \quad \forall n \qquad (4)$$

Where $E[r_n^s]$ is the expected rate and p_n^s represents the required power to support the expected rate, δ^srepresents the rate allocation for the sth subscriber.This scheme has low computation complexity due to dual decomposition approach. Also, this resource allocation scheme maintains the aggregate rate limit for each service class in a multiservice class network. The expected rate achieved by a subscriber increases as the power to noise ratio increases. Also, this rate is highest when the RAU has perfect knowledge of the CSI. Incase of imperfect CSI, the expected rate achieved decreases depending on the amount of the channel estimation error.

2.5. Adaptive Resource Allocation for Distributed Network

Adaptive resource allocation for a distributed multi carrier DS-CDMA networks is proposed in [12]. Zhuwei Wang, Dacheng Yang and Laurence B. Milstein considered the resource allocation process in a distributed fashion where each user allocates his/her resources based on the condition of the channel while satisfying its own requirements without requiring the use of a central coordinator to co-ordinate resource allocation. A distributed network with users randomly deployed within a given region is considered. A transmitter and a receiver communicate with each other and form one to one communication pair.
A suboptimal non-cooperative game is proposed to adaptively allocate the transmit power,available subchannels and alphabet size. Each user present in the network has a maximum power constraint and packet throughput requirement. The users optimally choose the resources necessary for transmission satisfying the required constraints. This resource allocation problem is solved in dual domain. For this, a bisection algorithm is proposed that adaptively allocates the resources to each user. In each time slot, the transmitters employ this algorithm simultaneously. Then the receivers estimates the CSI and

feeds back to the corresponding transmitters for updating its local signal to interference plus noise ratio (SINR) periodically. Since the transmission spectrum and power profile of users change, the SINR at the channel may be different during each time slot. Thus the bisection algorithm is used iteratively by the users to adjust the available sub channels, transmit power allocation and modulation size to satisfy the throughput requirement and transmit power constraint. If the constraints are satisfied, then the users transmit with allocated resources, otherwise the users stop transmission. Also the effect of imperfect CSI on adaptive resource allocation process is analyzed and found that the performance of this algorithm is better than equal power allocation scheme when the channel estimation error ratio (CEER) is small. But as the CEER increases, the performance degradation is observed compared to that of equal power allocation scheme.

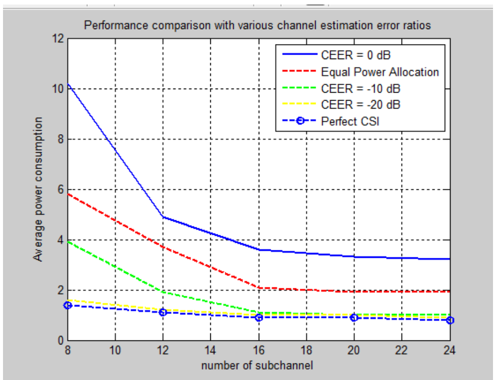

Figure 3 Performance analysis with various channel estimation errors

Figure 3 shows the effect of available subchannels on average power consumption for various CEERs. It is seen that as the number of available subchannels increases, the average power consumption decreases. Also, from the above result, it is inferred that the power consumption is small when the channel estimation errors are small. As the channel estimation error increases, the average power consumption increases, and becomes higher than that of equal power allocation when CEER is 0dB. From these results, it is concluded that this adaptive resource allocation algorithm works well when the channel estimation error ratio(CEER) is small.

3. Conclusion

In this paper, a brief survey of various resource allocation schemes present in the literature for different networks is discussed and their performance is analyzed. Each scheme employs a different algorithm to allocate specific resources to the users. It is found that the performance of these resource allocation schemes relies on the available resources in the network and on the requirements of the users. The choice of a particular algorithm for resource allocation depends mainly on the type of network employed, type of resources to be handled, QoS needs of the users demanding the resource allocation and the availability of channel state information.

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