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A Survey on Uplink and Downlink Radio Resource Management in Wireless networks

[1]T.Padmapriya

[1]Research Scholar/ Dept of ECE, Pondicherry Engineering College, Puducherry

***Abstract*—OFDMA is the access scheme used in the third and fourth generation wireless cellular networks. Proper allocation of bandwidth and power is essential for ensuring the optimal performance and utilization of the resources in the OFDMA based cellular networks. The resource allocation in uplink direction and downlink directional will need different approaches. In uplink direction, different categories of algorithms like static, dynamic, centralized, distributed, instantaneous, stochastic, single cell, multi-cell, optimal, suboptimal algorithms are followed. In case of downlink direction, margin adaptive and rate adaptive algorithms are followed. In this paper, resource allocation and scheduling schemes in both uplink and downlink of OFDMA are considered. Various resource allocation approaches and the challenges faced are discussed.**

Keywords—Resource allocation, scheduling, OFDMA, single cell and multi cell.

In a multi user cellular networks, on the other hand, new challenges arise as the number of the users in the system increases dynamically. These challenges include dynamic subcarrier allocation, adaptive power allocation, admission control and capacity planning. The first two are also referred to as radio resource allocation.

In a multiuser OFDM system, there is a need for a multiple access scheme to allocate the subcarriers and the power to the users. In static subcarrier allocation schemes, each user is assigned predetermined time slots or frequency bands respectively regardless of the channel status. In dynamic subcarrier allocation schemes, the channel status is also considered during resource allocation.

This paper is organized as follows. Section II discusses some related work in resource allocation. Section III discusses the uplink resource allocation techniques. Section IV discusses the downlink resource allocation techniques. Finally, section V presents an overview of future research directions.

I. Introduction

Modern Wireless cellular networks have to satisfy the increasing demands for high data rate mobile services. In order to meet the increasing number of cellular subscribers and the need for faster and more reliable data services, orthogonal frequency division multiple access (OFDMA) has been selected as the multiple access scheme for wireless systems such as LTE and WiMAX.

OFDM is based on the concept of multicarrier transmission. The idea is to divide the broadband channel into several sub channels each with smaller bandwidth. The high rate data stream is then split into various small sub streams of lower data rate which are modulated and transmitted simultaneously on the subcarriers.

In this paper, we present various resource allocation and scheduling methods in OFDMA wireless networks. We focus on both the uplink and downlink directions. In addition, the increase in demand for real-time applications such as video telephony and voice-over-IP necessitates the efficient uplink and downlink scheduling algorithms in wireless communication systems to be implemented.

In a single user system, the user can use the total power to transmit on N subcarriers; the system is then optimized by exploiting the frequency selectivity of the channel and dynamically adapting the modulation type and transmit power on each subcarrier. These dynamic power allocation schemes have shown significant performance gain in terms of throughput compared to static schemes.

II. Related Work

A number of works have been done related to resource allocation in wireless cellular networks in general and in OFDMA networks in particular. This section lists some of these works.

1. In [1] Elias Yaacoub and Zaher Dawy discussed various uplink resource allocation algorithms in detail. But the resource allocation in pico cells, Self-Organizing Networks, femto cells and MIMO are not analysed in this.
2. In [2] Sanam Sadr et al., discussed various downlink resource allocation algorithms in detail. But resource allocation in MIMO and multi-cell systems are not analysed in this.
3. In [5] and [6], G.Song and Y.Li proposed theoretical framework and implementation of a cross layer solution for resource allocation in OFDMA networks. The solution with this approach is non-linear and needs linear approximation to improve performance.
4. In [9], G. Song and Y. Li proposed an adaptive power and sub carrier allocation based on utility

maximization. Here they use cross layer information to perform optimum resource allocation while maximizing the utility at user level. This approach also suffers when rate of change of channel fading statistics increases.

5. In [11], Ian C. Wong and Brian.L.Evans proposed the ergodic rate maximization on downlink OFDMA resource allocation in details. While this approach is less complex and provides maximum performance when rate of change of channel fading statistics is lesser, then the rate of change for channel fading statistics increases, it causes performance overhead.

III. Uplink Resource Allocation

3.1 Centralized Single Cell Scheduling

In centralized scheduling, both in the downlink and uplink directions, the base station (BS) performs the scheduling process. Decisions are made at the BS and communicated to mobile users. Various scheduling approaches include sum rate maximization, general utility maximization, achieving a desired quality of service (QoS) with minimum power, and ergodic sum-rate maximization [1]. In sum-rate maximization, the subcarrier allocation is separated from power allocation to achieve optimal solution. Each subcarrier is allocated to the user with the best channel condition. Utility maximization is used to achieve fairness for all the users [9]. In these works the classical Shannon capacity is used to model the rate. In some approaches, the desired Quality of Service is achieved while minimizing the transmit power. Bit loading over the allocated subcarriers is done to achieve this. Most of the existing work focuses on channel aware resource allocation assuming the channel state information (CSI) is known at the scheduler, and that there is always data available to transmit. However, there are channel-aware queue-aware algorithms where the buffer lengths and the queue states of each user are taken into account [12].

In case of instantaneous scheduling, parameters like sum-rate are maximized at each scheduling instant based upon the frequency and multi-user diversity. In Ergodic scheduling time dimension also is used along with frequency and multiuser diversity dimensions, and optimization is done from long term point of view. In both approaches, the utility maximization is used either using continuous rates or a discrete set of rates.

Due to the distributed power constraint, the scheduling problem in the uplink direction is more complicated than that in the downlink direction. The power is allocated by base station in the downlink, whereas in uplink, it is allocated by each user. So, resource allocation should be done at per user basis.

In case of instantaneous scheduling, the allocation problem is divided into two sub problems. A greedy algorithm with water filling is used to allocate power for each user on its allocated subcarriers. Then using the marginal functions, the optimal (user, subcarrier) pair is found. Steps are repeated until all subcarriers are allocated [1]. Fairness can be added to the approach of by allocating subcarriers to a given user until its required rate is reached then the user is excluded from the allocation of the remaining subcarriers. In another approach, water-filling is performed for each user on all unallocated subcarriers in addition to the subcarriers allocated to that user before searching for the optimal (user, subcarrier) pair. In some approaches, the power allocation problem is modelled as a non-cooperative game. Maximum signal to noise ratio is used to determine the sub carrier allocation. The power is updated using equations based on a defined pricing function. In some algorithms, convex optimization problems are used to model the instantaneous sum rate maximization and dual decomposition approach is used to solve the problem.

To find the optimal solution in instantaneous sum-rate maximization in OFDMA uplink, the Lagrangian parameters have to be computed which causes the power constraint for each user being scheduled. One Lagrangian parameter is needed for each user. Sub gradient techniques are used to compute these parameters. For large number of users, the convergence of sub gradient techniques will need more iterations [5]. Ergodic scheduling can be used to reduce such complexity and it uses time dimension as an additional parameter in the scheduling process.

The scheduling algorithms generally use the Shannon capacity formula for Gaussian channels, $\log_2(1 + SNR)$. This expression assumes that infinite length code words are generated according to a normal distribution. However, in practice, due to a fixed number of modulation and coding schemes, only a discrete set of rates are achievable.

Various algorithms which use discrete rates treat the problem of the transmit power minimization given per user minimum rate constraints. This problem is the dual formulation of the sum-rate maximization problem, in which the sum-rate is maximized given a maximum power constraint. These algorithms follow a three-step approach to resource allocation with discrete rates: estimating the number of subcarriers to be allocated to each user, selecting and allocating the appropriate subcarriers, and using bit loading to allocate the power on these subcarriers. Selecting the best sub-algorithm in the literature for each of the three steps, a new algorithm has been developed, where the focus is on the downlink power minimization problem [1]. Since the maximization function is not continuous the problem becomes harder to solve due to the loss of convexity. However, for the downlink case, due to the quasi-concave nature of the maximization problem with discrete rates, the optimal dual solution can be reached with zero duality gap as in the continuous rates scenario. Same approach can be extended to the uplink solution with discrete rates.

While the ergodic sum-rate maximization solutions are easier to implement than the optimal instantaneous sum-rate maximization solutions, they need an initialization phase to compute the Lagrangian via iterative sub gradient iterations, and a tracking of the channel probability density function to repeat the calculations when necessary [11]. As number of users increase, the computational load increases at the BS, since the number of Lagrangian parameters increases with the number of users. Furthermore, for optimal solution, the transmit power should be communicated to the users on each allocated subcarrier every TTI, since water-filling algorithms are used to determine the optimal solution. This causes an increase in signalling overhead. Hence, the suboptimal algorithms which achieve a performance close to the optimal solution are proposed instead.

Further, it has been researched whether the equal power allocation over subcarriers can approximate the optimal solution using suboptimal algorithms. Here, no sub gradient iterations will be needed, and there is no need to inform about the transmission power to each user since power is equally divided between the users. Only subcarrier allocation has to be transmitted to the users. For the uplink, in case of continuous scenario, equal power allocation approximates the optimal instantaneous water-filling solution.

3.2 Distributed Scheduling

In centralized scheduling, allocation decisions are made at a central entity, the base station. In current wireless systems, users are expecting seamless access to a variety of bandwidth demanding services. Mobile devices capable of supporting multiple standards are more common. Current research is not only ongoing on enhancing scheduling techniques within a given network, but also on optimizing the resource allocation in heterogeneous networks. This involves selecting the best network to serve a mobile user, among several networks with completely different access technologies and the benefits of distributed resource allocation are being widely investigated. In distributed scenarios, mobile devices have more autonomy in making transmission decisions. Game theory is a useful tool used to model the decision making process of mobile devices. Both cooperative and non-cooperative game theoretic methods for multiple access have been analysed. Distributed scheduling is usually studied in the context of ad-hoc networks, relay based networks, and sensor networks. Distributed channel allocation schemes for wireless LANs are also actively researched.

Distributed scheduling can be in the presence of a certain infrastructure, where distributed antennas are placed throughout the cell area while being connected to a central BS. This corresponds to a distributed BS scenario, which constitutes an alternative to fixed relaying schemes, since it achieves the same benefits in terms of capacity and coverage extension while preserving the wireless bandwidth. The second aspect corresponds to scenarios where mobile users are actually involved in the scheduling process.

Distributed base stations (DBSs) and remote radio heads (RRHs) have been used to increase the coverage and capacity of wireless networks in a cost effective way. It consists of a centrally located BS enclosure connected to RRHs via fibre optic cables. DBSs were initially proposed to improve indoor coverage of cellular systems where a building is treated as a single cell with several distributed antennas rather than either multiple pico cells each with a dedicated antenna or as a single cell with one central antenna. The DBS approach allows avoiding excessive handovers in the first case and significant fading in the latter. With DBS scheduling, it is shown that maximum ratio combining (MRC) in the uplink achieves a considerable capacity and coverage enhancement, but simultaneous transmission in the downlink reduces performance since it increases the inter cell interference. A solution for this problem consists of selecting only the RRH with best channel to the user to ensure the best downlink performance with DBSs. Selection combining in the uplink provides considerable enhancement over centralized BSs and constitutes a good trade-off between performance and complexity when compared to MRC.

The RRHs may be installed at desired locations (e.g., equidistant along the cell boundary) or at random locations. It has been found that as the number of RRHs increases, the performance converges to that of regularly deployed RRHs. In case of both fixed and random RRH locations, the gains achieved by a DBS system are shown to increase with the number of RRHs up to a certain limit where the gain obtained after using an additional RRH is negligible. This limit is considered to be between four and seven RRHs for the regular RRH positions, and seven for the random RRH positions.

In case of distributed scheduling with user cooperation, the Channel State Information (CSI) is exchanged between the users. To limit the overhead due to the exchange of CSI information, a CSI quantization method has been proposed to reduce the number of feedback bits. This results in the performance closer to that of centralized approach.

Distributed scheduling without user cooperation also is possible. Here users are grouped into various priority levels depending upon the channel state information on each sub carrier. Users with higher priority are given preference during channel allocation before their counterparts. To allow fairness, probabilistic transmission approach is used which prevents starvation for lower priority users.

ALOHA, slotted ALOHA or reservation ALOHA have been adapted for distributed resource allocation without user cooperation.

3.3 Multi Cell Scenarios

In case of multi-cell networks, inter-cell interference has to be taken into account during scheduling. To limit the inter-cell interference, several techniques for reusing the frequencies are used. There are static reuse techniques based upon the fractional frequency reuse (FFR). Here the cell is divided into an inner area where the same frequency is reused in all cells and outer area where only the subset of frequencies is reused. Such a scheme has been shown in Fig 1.

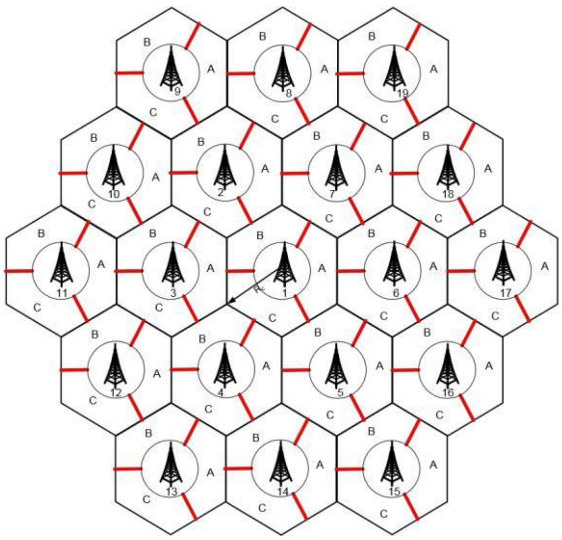

Fig 1. Fractional Frequency Reuse

There are also dynamic frequency reuse techniques where all the frequencies are allowed to be used by all the cells and various techniques are used to avoid interference or handle interference. Inter cell coordination is used to maximize the overall system capacity by disabling cells which do not offer enough capacity to overcome the interference. In case of ad-hoc networks, pricing is used to handle inter cell interference. Here each user sets a price to be paid by other users in case of interference caused by them. The transmission power is used based upon the price. Pricing is imposed not on the sub carrier level but on the total transmission power of the user.

Also there are techniques where no pricing is used but based upon the probabilistic on-off scheduling on each subcarrier within the cell depending on the interference level.

IV. DOWNLINK RESOURCE ALLOCATION

In the downlink of a multi-user OFDMA system, the base station BS should communicate with various users using limited resources (bandwidth and power).

Using the available channel state information, the combined subcarrier, bit and power allocation algorithms are applied by transmitter to assign subcarriers to different users and the number of bits/OFDM symbol to be transmitted on each subcarrier. The number of bits assigned and corresponding modulation scheme determines the power allocated to each subcarrier. In transmitter, inverse fast Fourier transform is used to convert the complex symbols at the output of the modulators into an OFDM symbol in time domain. Before transmission, the time domain samples are added a cyclic prefix which is the copy of the last portion of the data symbol. The size of cyclic extension is chosen to serve as a guard interval to ensure the orthogonality between the subcarriers. This type of multicarrier modulation is also called cyclic prefix OFDM (CP-OFDM). The ISI could be eliminated provided that the amount of time dispersion from the channel is smaller than the duration of the guard interval. CP-OFDM provides the best performance-complexity trade-off.

With each OFDM symbol, a separate control channel is used to pass the subcarrier and bit allocation information; therefore, for the users only the bits on their respective assigned subcarriers need to be decoded. In the receiver, after the guard interval is removed, fast Fourier transform is used to transform the time samples into modulated symbols. Then, the demodulators are configured using the bit allocation and demodulated bits are extracted from the subcarriers assigned to each user based on the subcarrier information.

The goal of resource allocation in an OFDMA system with N subcarriers and K users is to estimate the elements of matrix $C=[c_{k,n}]_K\times N$ specifying which subcarrier should be assigned to which user and vector $p=[p_n]_N\times 1$ specifying power allocation to each subcarrier [2]. The elements of matrix C are calculated, assuming that subcarriers are not shared by different users. The data rate of a multiuser OFDM system is maximum when each subcarrier is assigned to only one user with the best channel gain for that subcarrier and the power is distributed among the subcarriers using water-filling. Based upon the power constraints of the system, the elements of vector p are determined. Only one total power constraint exists in the downlink of a multiuser system whereas multiple power constraints exist for the uplink depending on the number of users.

Channel prediction algorithms for flat fading channels have been investigated extensively in the context of OFDM. While multiple estimates in time or frequency improves the average spectral efficiency and robustness of the system to larger estimation error and longer delay, the system overhead will be increased due to transmission of feedback channel information. Therefore, channel prediction methods that reduce the amount of feedback overhead are being researched. The impact of non-ideal CSI knowledge on design and performance of radio resource allocation strategies are also being investigated.

In case of frequency selecting fading in OFDMA networks, different subcarriers of each user suffer from different fading levels due to frequency selectivity of the channel a.k.a. frequency diversity (per user). The sub channels of different users vary independently due to different physical locations of the users. The channel state information is used by the transmitter to perform the subcarrier and power allocation to achieve the best performance in the system.

Each subcarrier in OFDMA scheme can have different modulation scheme and each modulation scheme provides a trade-off between spectral efficiency and BER. When fixed modulation scheme is used in such systems, the carrier modulation is implemented such that it maintains reasonable performance when channel conditions are poor. So, these schemes are designed to handle worst channel conditions.

Using adaptive modulation, the subcarrier modulation can be matched to SNR to maximize the overall spectral efficiency. But implementing adaptive modulation needs channel state information and feedback between receiver and transmitter. If channel conditions change faster than the flow of CSI and feedback, the performance of adaptive schemes will be poor. Also, since overhead information has to be regularly transmitted between transmitter and receiver, both should know the modulation schemes used which causes further increase of overhead between them.

Two major types of dynamic resource allocation schemes in downlink currently used are margin adaptive and rate adaptive. In case of margin adaptive schemes, the total transmit power is minimized while making sure that each user has the required QoS in terms of data rate and BER. In case of rate adaptive schemes, the data rate is maximized with constraint on total transmit power.

If each user with best channel gain is allocated the sub channels, it provides maximum throughput in multi user system. But if path loss differences among users is large, such an allocation will cause users with high channel gains to be allocated more subcarriers leaving those with poor channel gains with lesser no of sub carriers.

V. Conclusion

In this paper various uplink and downlink resource allocation schemes for wireless network have been discussed. In case of uplink resource allocation, various challenges (e.g. Channel allocation and interference handling) are there in resource allocation for femto cells, Self-Organizing Networks and MIMO (Multi antenna systems for Multiple Input and Multiple Output) which can be addressed by extending the resource allocation schemes mentioned above. In case of downlink resource allocation schemes, work can be carried out on improving the resource allocation schemes on noisy channels with channel state information.

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