An Efficient Resource Allocation Using Load Matrix Concept for Cellular System

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Abstract: Efficient radio resource allocation in cellular systems envisages the assignment of the number of subcarriers and relative transmission format on the basis of link quality. Traditional schemes have approached this problem mainly focusing on resources within a cell and to large extent ignoring effects of multi-cell architecture. In this paper we propose an optimum centralized radio resource allocator for the multi-cell scenario of cellular system which allows to highly out-performing iterative decentralized allocation strategies based on local optimization criteria. Simulation results show significant improvement in the resource utilization and overall network performance. Results show that maintaining cell interference within a margin instead of a hard target can significantly improve resource utilization.

I. Introduction

Resource allocation of the cellular systems is facing new challenges created by the demand for emerging services and applications. Wide range of services with diverse Quality of Service (QoS) requirements is becoming more popular and widely used [1]. The demand of higher bandwidth and data rates has been increased substantially during recent years. This has made it so important for future mobile cellular systems to implement an efficient resource allocation scheme .To achieve such a far-reaching goal, it is well known [2] that wireless systems should exploit multi-user diversity in order to share the radio resources among users with good channel conditions. However, the decision about which terminal is allowed to transmit is a difficult task on account of mutual interactions among mobile users due to radio interference. A variety of resource allocation strategies and schemes, mainly for downlink. In resource allocations were based on the specific characteristic resulting in minimization of power consumption [3]-[8] or maximization of system capacity. Under mixed service traffic including both real-time and non-real time services ,efficient resource allocation from a shared resource pool is a challenging task due to varied and stringent QoS requirements .In [4] a fixed resource partitioning method in which total resource pool was partitioned between different service classes and independent resource schedulers were responsible for each resource partition whereas in scheduling [5] is more unified and partitioning was dynamic to enhance spectral efficiency. Another approach towards resource allocation, called Utility Based Approach (UBA), tries to maximize the total network utility and thereby enhancing resource allocation. For example, pricing is a well-known utility function [6] for resource allocation. User's QoS as utility function and then converts the resource allocation problem in to a non-cooperative game [7], where each user tries to maximize its own utility. A downlink resource allocation method based on dynamic pricing was proposed in [8][9][10] was aimed to maximize the summation of users utility. On the link level, adaptive transmission is one of the most recent technologies being investigated for enhancing the spectral efficiency [11] in future cellular systems. Fast scheduling together with adaptive modulation-coding, facilitates exploitation of channel variations resulting in multi-user diversity gains [12]. This approach takes advantage of instantaneous channel conditions of different users where the channel fading are relatively independent. The basic advantage of decentralized over centralized approach is due to its fast response to dynamic and fast varying environment of mobile systems for resource allocation. However, the decentralized scheduling algorithms have an inherent short coming, due to their vulnerability to inter-cell interference, which has not been addressed yet. In other words, considerable proportion of Rise over Thermal Noise (RoT) at the base station is made up from multiple access inter-cell interference which the base station has little knowledge about or control upon. This in turn may lead the system to interference outage and poor resource utilization particularly when interfering cells have similar traffic load variations. We address inter-cell interference problem of scheduling process by introducing a new and efficient resource allocation strategy called Load Matrix (LM). The aim of resource allocation in wireless cellular system is to assign radio resources to individual users in a way to achieve maximum system capacity whilst meeting the required quality of service.

This paper is organized as follows:

Section II, describes the system model. Section III, introduces the Single-cell scenario, i.e., a scenario where no extra cell interference is present, and proposes an optimization approach which is based on network flow formulation. Section IV, proposes a centralized optimization approach for the multi-cell scenario. Section V, describes a possible decentralized allocation strategy for the multi-cell scenario. Section VI, shows the results obtained for the centralized and the decentralized allocation strategies .Finally, Section VII, provides conclusive remarks.

II. System Model

A. Importance of Inter-Cell Interference Optimization

Uplink cell capacity in interference-limited systems is basically limited by the total received power at the base station .As the uplink load increases, user terminals have to increase their transmit power substantially to overcome the increased interference level at the base station. Due to the fact that the transmit power of user terminals is limited, total received power at the base station actually limits the uplink capacity .In decentralized scheduling, each base station assigns radio resources (i.e. rate and time) to its users until the estimated RoT reaches a predefined target value, RoT target. We assume RoT target is a fixed target value set by the network controller to maintain the uplink interference level. The main short coming for decentralized scheduling in general becomes more visible in a multi-cell scenario where a considerable proportion of RoT is inter-cell interference and base station has little knowledge about and control upon. By inter-cell interference any signal will received by a base station coming from those users which belong to other cells.

B. Resource Allocation Problem

A basic scenario is considered where resource allocation is down to assigning transmission rate and time to individual users with the objective of throughput maximization. To analyze the problem, we begin with the single cell scenario and then extend the conclusion to the multi-cell case. Without loss of generality, we assume that transmission rates are chosen from a limited set of rates .Let $S_{i,1}$ denote Candidate Rate Set (CRS) of user *i*, which includes all the allowed transmission rates for the user to choose. Rate"0" is always included in $S_{i,1}$ and will be chosen if the user is not scheduled to transmit in the current scheduling instant. We treat transmission rates in different CRSs as different items even if they have the same rate value:

$$S_{i,1} \cap S_{j,1} = \Phi \ \forall i \neq j \qquad (1)$$

Let S_1 denote the union of all the CRSs from $S_{1,1}$ to $S_{M_1,1}$ and M_1 is the total number of users in the cell sharing the radio resource pool .Choosing an element t from set S_1 is an assignment action, which means allocating a specific transmission rate to a particular user.

II. Single-Cell Scenario

If we are given a set of subcarriers *M* = *{1, . . . , m}*, a set of users *U* = *{1, . . . , n}*in the cell. Transmission requirements for a given user *i* set the corresponding rate R_i. Due to interference phenomena, users cannot share sub-carriers. Given a certain Signal-to-Interference Ratio (SIR), the ideal rate achievable on a channel that spans a bandwidth *B* is $R = B\eta$, where $\eta = log_2(1 + SIR)$ is the channel spectral efficiency in bit/s/Hz. Depending on the users rate requirements and on channel condition, the BS sets for each user a target spectral efficiency. The spectral efficiency η_i for user i is set so that the rate constraint R_i can be converted into an integer number of sub-carriers $r_i = R_i / \eta_i$. In particular, setting the spectral efficiency η_i is tantamount to set the target SIR_i for user i: $SIR_i = 2\ \eta_i - 1$. If sub-carrier j is assigned to user i, it requires a transmission power $p_i(j)$ equal to

$$p_i(j) = SIR_i \frac{BNo}{G_i(j)} \qquad (2)$$

Where SIR_i is the Signal-to-Interference Ratio of user i to achieve target spectral efficiency η_i, $G_i(j)$ is the channel gain of user i on sub-carrier j and N_0 is the power spectral density of the zero-mean thermal noise.

IV. Multi-Cell Scenario

In this section, the Multi-cell scenario is addressed, and the downlink transmission is considered. In particular, we address the problem of allocating sub-carriers among users, in such a way that users transmission requirements, in terms of Transmission quality and throughput are satisfied. The objective is to minimize the overall transmission power. The problem in the multi-cell scenario is formally described in the following. We are given a set of sub carriers $M = \{1, \ldots, m\}$, a set of cells $\{1, \ldots, K\}$, and for each cell k *for* a set of users $U_k = \{1, \ldots, n_k\}$. Let $U = \bigcup_{k=1}^{K} U_k$ be the set of all users in the system. Fo reach user i, we denote by $b(i)$ the cell of user i. Hence, $b(i) = k$ for all $i \in U_k$. Having set for each user a certain target spectral efficiency, transmission requirements for a given user i correspond to a certain number of sub-carriers r_i. In general, users belonging to different cells can share the same sub-carrier (while interference phenomena do not allow to users in the same cell to transmit on the same sub-carrier). However, the power to transmit on a given sub-carrier increases as the number of user's transmitting on those sub-carrier increases. More precisely, let $S(j)$ be the set of users (belonging to different cells) which are assigned with same sub-carrier j. Hence, the transmission powers requested by users in $S(j)$ on sub-carrier j are linked by the following relations.

$$\mathrm{SIR_i} = \frac{\mathrm{G_i(j)p_i(j)}}{\sum \mathrm{h \in s(j), h \neq i G_i^{b(h)}(j)Ph(j) + BNo}} \qquad (3)$$

where SIR_i is the target Signal-to-Interference Ratio corresponding to the spectral efficiency η_i of user i, $G_i(j)$is the channel gain of user i on sub-carrier j,$G_i^k(j)$ is the channel gain between user i and the base station of cell $k \neq b(i)$ on sub-carrier j. values G_i^K(j) are a measure of the interference between user i and users of other cells transmitting on the same sub-carrier j. In Equation (2), we refer to the term $\sum h \in s(j), h \neq i(G_i^{b(h)}$(j)) Ph (j) as *to interference term* .Thus, being SIR_i the target SIR corresponding to the spectral efficiency η_i, we use (2) to determine the power p_i(j)

$$P_i(j) = SIR_i \frac{\sum h \in s(j), h \neq i G_i^{(j)}(j)Ph(j) + BNo}{G_i(j)} \qquad (4)$$

It is to be noted that, power $p_i(j)$ increases as the interference term increases, moreover, the interference term depends on the set of users, other than i, which are assigned the same sub carrier. On the other hand, if only user i is assigned sub-carrier j(i.e. if the Interference term is 0),by (3) is power $p_i(j) = \frac{SIR_i BNo}{G_i(j)}$.

V. Load Matrix Concept

One of the main challenges in resource allocation in a multi cell system is the control of inter-cell interference. In uplink scheduling, the basic problem is to assign appropriate transmission rate and time to all active users in such a way that result in maximum radio resource utilization across the network whilst satisfying the QoS requirements of all the users. Amongst other constraints, another important factor in the resource allocation is the users transmit power.

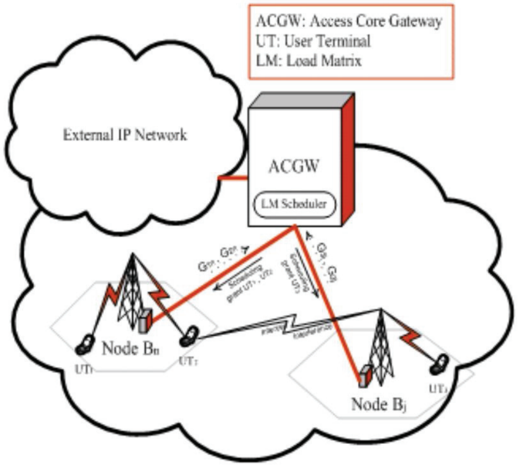

Fig 1.Centralized LM scheduling in a 3G LTE system

Load Matrix (LM) can be regarded as a data base containing the load factors of all active users in the network. LM scheduling can be implemented in both centralized and decentralized strategies. In a decentralized LM scheduling, each base station should implement identical LM database. For simplicity, we only present the centralized LM scheduling where a central scheduler entity assigns radio resources to all the users in the network. Figure 1 illustrates an example of LM scheduling implementation based on the proposed system architecture for the 3 rd Generation Long-Term Evolution (3G LTE). We assume the averaged channel gain (over the scheduling period) from users to base stations is known to scheduler prior to rate assignment.

VI. Simulation Results

To evaluate the performance of the LM concept, extensive system level simulations have been carried out and to emphasize the impact of other cell interference existing in both centralized and decentralized scheduling algorithms. Another important objective is to show the performance of the scheduling algorithms compared with the upper-bound limit rather than comparison between different algorithms. Comparison with the upper-bound limit is a better indication of scheduling algorithm efficiency. The upper-bound limit on the interference outage performance is defined as a "step function" in CDF of RoT interference out age performance directly

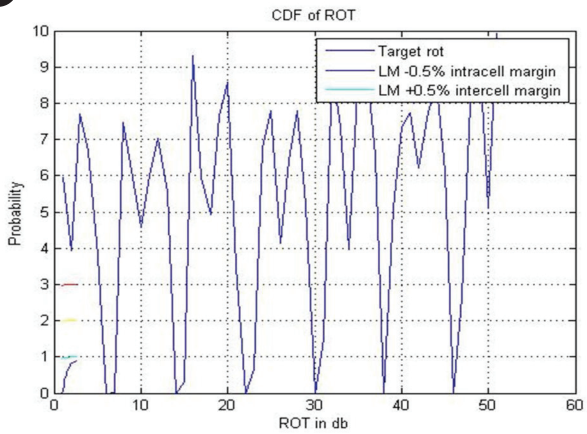

Fig 2.ROT fluctuation in a multi-cell scenario

Affects all other performance measures like throughput and packet delay. The comparison with the benchmark algorithm is provided here as an example to show the effectiveness of the LM scheduling compared with atypical scheduling algorithm used. General comparison between centralized and decentralized scheduling is already available in existing methods. The system level simulation models 19 Omni directional cell structure with 10 users per cell randomly and uniformly distributed. The resource allocation performance is carried out in terms of interference outage probability, averaged cell throughput and packet delay

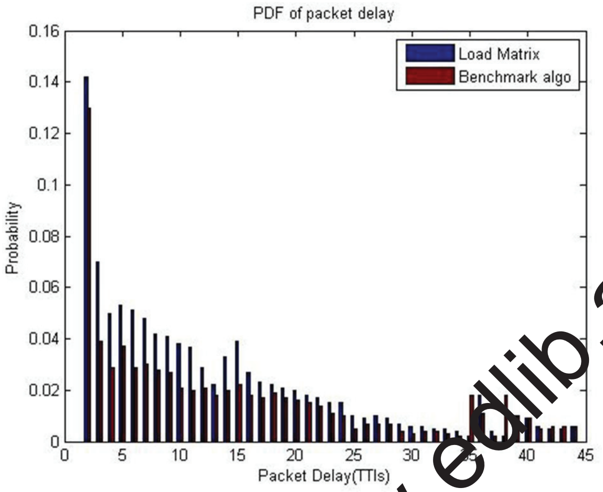

Fig 3.PDF (Histogram) of packet delay

The simulation results provided here are of two different types. The first type is to show the impact of the margin concept (both inter-cell and intra-cell) on the interference outage performance. The second type illustrates the performance of the LM (based on the best margin setup) compared with the benchmark algorithm and the upper bound limit in terms of interference outage.

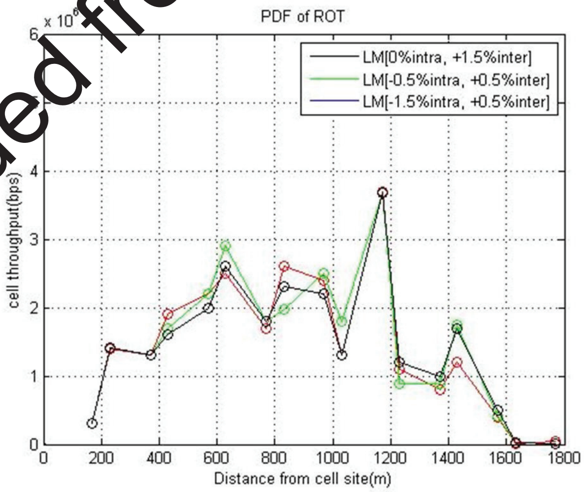

Fig 4.Average service throughput versus distance

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The proposed centralized resource allocation strategy is characterized by huge implementation complexity, and, hence, it can be hardly implemented in the real world. To be specific, while the distributed heuristic achieves a convergence point (in the positive case convergence is achieved) in few simulations seconds, the centralized approach requires several hundreds of seconds to come out with the optimum solution.

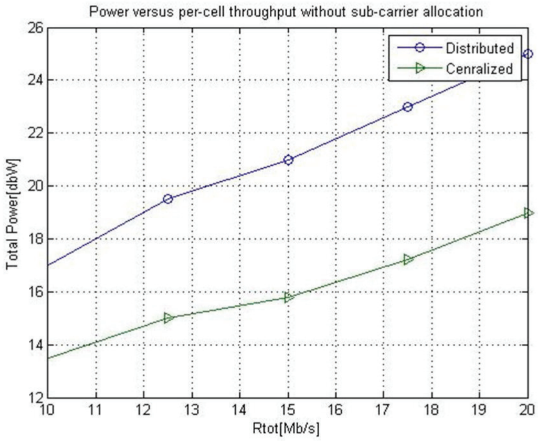

Fig 5 .Power vesus per-cell throught without sub-carrier allocation.

However, despite its implementation complexity, it is very useful for its ability of catching the essence of interference limit a tions in cellular systems. We consider two different scenarios .In the first case we assume that all users adopt the same transmission format, i.e., if $\eta_i = \eta$ for all users on all sub-carriers. Since the rate per sub-carrier is $B\eta$, the condition to achieve the requested R_{tot} is that $\eta = \frac{R_{tot}}{8*B}$. Note that, in this case, each user is assigned a fixed number of sub-carriers n_i= 2.The results relative to this first case are shown in Fig .5. The algorithm presented is supposed to achieve better performance than just assigning the same amount of resources to all users regards less of their channels. The results relative to this second case are shown in Fig.6.

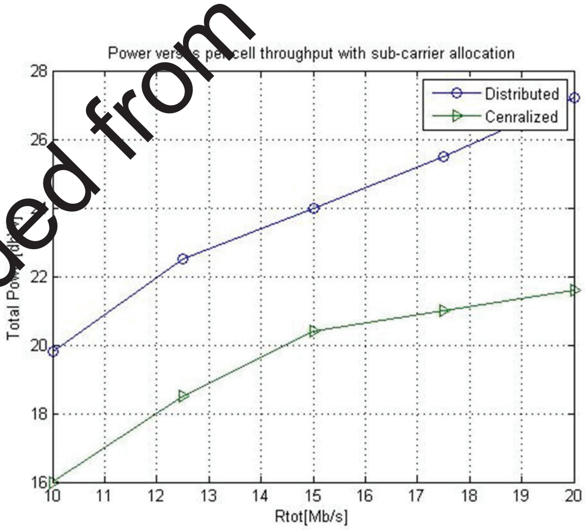

Fig 6. Power versus per-cell throughput with sub-carrier allocation.

VII. Conclusion

A novel approach towards efficient resource allocation for future wireless cellular systems was presented. The vulnerability of traditional resource allocation and scheduling schemes to inter-cell interference resulting in interference fluctuations was demonstrated. Such interference fluctuation, results incapacity wastage and excessive packet delay performance .The Load Matrix concept presented addresses this problem specifically and provides an efficient resource allocation by jointly considering inter-cell and intra-cell interference before making decision on allocating radio resources .this paper to produce the performance results, the concept is generic for single-carrier spread spectrum based systems. In case of multi-carrier systems, the load on subcarriers can differ significantly and therefore RoT (averaged) is no longer a good measure for load over all subcarriers. It is worth noting that the sub-carrier allocation algorithm described in leads to performance degradation for both the centralized and the distributed heuristic cases. This is because users at cell border tends to consume the most of the resources (i.e., they are assigned the most of sub-carriers), thus producing interference over the neighbor cells over a large set of sub-carriers. Hence, since in this case neighbor cells are forced to use those (few) sub-carriers which experiment low interference, the diversity gain tends to be missed. This effect has not been foreseen in previous works dealing with a single-cell environment, and is one of the most interesting results of this study.

VIII .References

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