An Effective Subcarrier Allocation Algorithm for Future Wireless Communication Systems

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Abstract- This paper focuses on the algorithm for effective allocation of radio resources in future wireless communication systems. Conventionally the radio resources that have been used to add capacity to wireless communication systems are radio bandwidth and transmitter power. These two resources are simply not growing or improving at rates that can support expected demands for wireless capacity. Keeping in mind, the scarcity of spectrum resources, the challenge of providing better Qos (BER & Bit Rate) through supporting increased mobility and throughput of multimedia services can only be dealt with when elements of radio network are properly configured and suitable radio resource management algorithms applied along with efficient modulation and multiple access modes. The purpose of resource allocation is to intelligently allocate limited resources; it has been proved that the system spectral efficiency can be significantly enhanced by adjusting the allocation of carriers, power and constellation sizes in accordance with the user's channel conditions and traffic requirements. This paper is concerned with adaptive subcarrier allocation to users with their rate requirements put into consideration. Given that the complexity reduction is of big concern for practical implementation and that fixed power allocation leads to a negligible throughput penalty if the power is poured only in the sub channels with good channel gains, only subcarriers are adaptively allocated to users placed randomly in a cell and the constellation size is according to user's channel condition.

Introduction

In wireless communication system, the available radio resources are limited and scarce, and hence, how to use the limited resource to satisfy various service quality requirements and realize the fairness between different users is a key problem. The development of novel signal transmission techniques and advanced receiver signal processing methods allowed the significant rise in wireless capacity without attendant increase in bandwidth or power requirements. The techniques include Adaptive Modulation and Coding (AMC) and Radio Resource Management techniques (RRM) such as admission control, scheduling, sub-carrier allocation, and rate control. Efficient use of the radio resources is a very challenging task for future wireless communication systems due to the scarcity of the former, time varying channel conditions, and heterogeneous classes of traffics and very diverse QoS requirements of users.

Adaptive resource allocation involving adaptive modulation and coding (AMC), adaptive power distribution and hybrid multiple access has been identified as one of the key technologies for providing efficient utilization of the limited power and spectrum with better QoS guarantees in future wireless systems.

The three main functions of Resource Allocation Algorithms: Subcarrier allocation: Allocates subcarriers to multiple users considering channel condition and user requirement. That is creating a virtual channel between user and base station to transfer the data between them. The algorithm will consider all the advantages and properties of subcarriers before allocating them.

Bit allocation: Changes the number of transmitted bitsin each subcarrier according to instantaneous subcarrier channel quality. That is based channel condition we will increase of decrease the modulation level. If channel state is good we can higher modulation scheme and we can accommodate more number of bits on that subcarrier. If channel state is not up to the mark we will accommodate somewhat less number of bits on that carrier.

Power allocation: Maintains the channel link quality by distributing the transmission power over different subcarriers. That is the algorithm need to pour high power levels to the distant users and low Level of power to nearest users. This step will increase efficiency of the algorithm in terms of transmitted power but the complexity of the system will increase to include this power allocation in the algorithm.

Different Types of Allocation Algorithms:

1) Subcarrier and Bit allocation by fixed power allocation (rate adaptive)

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This algorithm considers that fixed power allocation leads to a negligible throughput penalty if only the power is poured on sub channels with good channel gains. With power equally distributed to the subcarriers, the problem complexity is reduced.

Advantages

- Complexity is reduced because the power allocation step is excluded from the algorithm.
- Processing time reduced comparatively as the system must respond quickly to cope up with the dynamic allocation.
- This algorithm is effectively using the property of subcarrier that is the algorithm checks for which user the subcarrier is giving high datarate.
- The total capacity of the system is comparatively high.

Disadvantage

- There is slight reduction in efficiency in terms of transmitted power because we are neglecting power allocation step.

2) Joint sub carrier and Power allocation (Both power and rate adaptive)

This algorithm takes care of all three (carrier, power, bit) allocations to increase the efficiency of algorithm. That is this algorithm considers also about the allocating the power effectively with the help of users channel conditions.

Advantages

- The total system throughput is high when compared to any of the resource allocation algorithms.
- Efficient in terms of transmitted power.
- Better users' satisfaction.

Disadvantages

- System complexity is increased due to inclusion of power allocation step in the algorithm.
- Processing time increased for the same reason.

3) Subcarrier and power allocation with fixed rate constraints (power adaptive)

This algorithm allocates sub carriers and power with keeping the constraints on rate requirements of users. This is similar to previous power allocation algorithm but the difference is only constraint on data requirement of all users in the system.

Advantages

- Efficient in terms of transmitted power
- Better system throughput
- Complexity reduced when compared to previous algorithm.

Disadvantages

- Fixed rate constraints will lead to users' dissatisfaction.
- Complexity and processing time are still high.

Our Algorithm

We have studied and observed and evaluated different allocation algorithms available and using presently. Of all those we have chosen one algorithm which overcomes all the tradeoffs effectively and we came to a conclusion that this is the efficient algorithm in terms of all the restrictions we have.

Working of Proposed (Primary) Algorithm:

The algorithm we have chosen consists of subcarrier and bit allocation but excludes power allocation.

Algorithm starts with the step of finding the best user whose channel condition is good compared all available users. Then in next step it will find subcarrier suitable to that particular user and assign it to that user. Then it will check for data requirement of user if requirement is satisfied then it will proceeds to the next user otherwise algorithm will allocates another suitable subcarrier to the same user to satisfy his data requirement completely.

Here the algorithm is starting with finding the best user with good channel gain indicates that the algorithm is trying to increase the system overall capacity as user with good channel gain receives higher data than user with low channel gain.

In this algorithm we are allocating subcarrier after considering suitable user to that subcarrier so reducing power allocation step will not affect much as we are pouring equal power levels on all subcarriers with good channel gains and also considering the assumption of probability that a subcarrier is in deep fade for all the users is very low. So the processing time of algorithm reduced comparatively.

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The optimization objective is to maximize the sum capacity while keeping users' rate requirements satisfied. The Algorithm consists of two steps. First, each sub carrier is assigned to the user with the largest SNR without considering the rate constraint. Then, sub carriers are reassigned to the users whose rate requirements are not satisfied in the first round.

Assumptions of Algorithm:

- Base station knows the instantaneous channel gains of all the users.(i.e. CSI)
- The probability that a subcarrier is in deep fade for all the users is very low (Wong, et al. 1999).
- Fixed power allocation leads to a negligible throughput penalty if only the power is poured on sub channels with good channel gains.

Problem Formulation for Algorithm:

We assume that the BS knows the instantaneous channel gains of all the users. Using the channel information, the BS applies the resource allocation algorithm (which may combine subcarrier, power and bit allocation algorithms) to assign different subcarriers to different users and the number of bits/OFDM symbol to be transmitted on each subcarrier. In our multi-user system, no subcarrier is allowed to be allocated to more than one user in the same cell.

i.e. $i_{k,n} = 1$(Assignment case) and $i_{k',n} = 0$ (no assignment case) for $\forall k \neq k'$

Where $i_{k,n}$ represents assignment indicator for allocation of nthsubcarrier to kth user.

We can define $c_{k,n} \in D$ as the number of bits to be assigned to nth subcarrier for the kth user and this is according to the user's channel condition and the adaptive modulator level allowed.

$D = \{1, 2, \ldots \ldots L\}$with L, the highest modulation level.

The adaptive modulator task is to map the $c_{k,n}$ bits into a QAM symbol and the latter is transmitted on subcarrier n with $p_{k,n}$transmit power. At the receiver, after removing the cyclic prefix and applying FFT, the user data symbols are extracted from the assigned subcarriers according to the subcarrier allocation information and the modulated symbols are mapped to bits according to the bit and power loading information. For user k with a requirement on BER, $c_{k,n}$ should be chosen according to the target BER and the received power level of user on subcarrier.

$$c_{k,n} = f(BER, p_{k,n}, g_{k,n})$$

Where,$g_{k,n}$ is the magnitude of the channel gain seen by the kth user on the nthsubcarrier.

With our consideration of fixed power allocation we can reduce the constraint on power allocation

$$\therefore p_{k,n} = \frac{P_{tot}}{N}, \quad \forall i_{k,n} = 1$$

If B is total available bandwidth and N is number of subcarriers and K is number of users.

Bits per OFDM symbol and the number of bits transmitted by user k are linked by

$$R_k = \sum_{n=1}^{N} i_{k,n} c_{k,n} \ ,$$

Therefore overall throughput $T = \sum_{k=1}^{K} R_k$

Our aim is to maximize overall throughput which is equivalent to

$$max \sum_{k=1}^{K} R_k = max \sum_{k=1}^{K} \sum_{n=1}^{N} i_{k,n} c_{k,n}$$

Subjected to

$\sum_{n=1}^{N} i_{k,n} c_{k,n} \geq r_k \forall k$with$i_{k,n} = 1 \Rightarrow i_{k',n} =$ 0whenever $k' \neq k$

Where r_k is the minimum rate requirement of kthuser.We can also write as $R_k = \frac{B}{N} \log_2(1 + SNR)$.

Terms to be used in Algorithm:

- Set of Subcarriers $W = \{1, 2, \ldots.. n, \ldots. N\}$
- Set of Users under consideration$U = \{1, 2, . k, \ldots. K\}$
- $r_k$is the kth user requirement of minimum number of bits.
- s_k is variable used to store number of bits assigned to k'th user and is initialized to zero for all k.

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- $c_{k,n}$ is number of bits assigned to the n'th subcarrier which will depends on k^{th} user channel conditions.
- $i_{k,n} = 1$, if ith subcarrier is assigned to kth user.
- $i_{k,n} = 0$, if ith subcarrier is not allocated to kth user.

Pseudo Code:

$$W = \{1, 2, \ldots\ldots n, \ldots. N\}$$

$$U = \{1, 2, \ldots\ldots k, \ldots. K\}$$

r_k isthe k^{th} user requirement of bits/symbol.

While $W \neq \emptyset$ and $U \neq \emptyset$

{

Find $k^* = \text{argmax}\ c_{k,n}\ \forall k \in U$ and $\forall n \in W$\\ returns the value of k at which $c_{k,n}$ is maximum in all possible combination of (k,n)

$q = \{c_{k_1^*}, c_{k_2^*}, \ldots\ldots\ldots c_{k_n^*}\}$ \\ q stores all best subcarriers of user k.

f1:

$n^* = \max_{n \in W} q$\\ n^*, the subcarrier with maximum value of '$c_{k,n}$' is allotted to user.

$s_k = s_k + c_{k^*,n^*}$ \\ s_k initialized to zero for all $k \in U$.

$W = W - \{n^*\}$

If ($s_k \geq r_k$)

{

$U = U - \{k^*\}$

}

else

{

$q = q - c_{k_n^*}$

goto f1

} \\ end of if condition

} \\ end of while loop

Modified Algorithm

We have slightly modified our previous algorithm so that to serve one specific case. That is, when there are very less number of users are there in a cell then we have surplus of subcarriers. We can increase the system throughput by allocating these additional subcarriers to the available limited number of users to increase their data rates as well as the total system throughput. This case exists mostly during night time. So by following this algorithm we can increase system overall capacity.

We have simulated all the cases for our primary algorithm as well as modified algorithm and static algorithm to compare the real time performances of these algorithm. We have observed that the modified algorithm is giving better results in all the test cases. So this is the efficient at all defined cases.

Special Cases:

1) More number of users and less numbers of subcarriers

This is more practical case which exists in real time. In this case we are going towards users' satisfaction. That is satisfying a user data requirement completely and going to next user. As this procedure mostly accepted in real time.

2) Less number of users and surplus of subcarriers

This case exists mostly during night time where number of users is very less. In this case we are using modified algorithm which increases the overall throughput of the system for the benefits of service provider.

Simulation and Results

We have taken the simulation environment to be frequency selective fading environment. So different sub-carriers will have different channel gains for different users (this is because of user diversity). For the simulation purpose we have randomly generated the SNRs that could be achieved when different sub-carriers are allocated to different users. We have randomly generated a SNR matrix (named as SNRS) in which the rows are users and the columns are sub-carriers. In the matrix SNRS, a

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particular element SNRS(i,j) represents the SNR that could be achieved when a jth sub-carrier is allocated to ith user. As we have the SNRs, the task is to find out the channel capacities that could be achieved with the respective SNRs. So we have used the Shannon Capacity formula for finding out the channel capacities. The formula for Shannon Channel Capacity is:

$$C = B\log_2(1+\frac{S}{N})$$

where, C = Channel capacity

B = Bandwidth of the channel

S/N = SNR

We have created a matrix for channel capacities also. The name of the matrix is CKN and the element CKN(i,j) represents the channel capacity that could we achieved when the jth sub-carrier is allocated to the ith user. So, now the task is to check our sub-carrier allocation algorithm for different cases i.e, for different number of users, different number of users and their data requirements.

The Bandwidth of each channel is taken to be 3 MHz. And using the above SNR values the channel capacities are found The assignment matrix for the 20 user – 20 sub-carrier case is given below. Here when the matrix element is ‘1’ it means that the user corresponding to the row of that element is allocated the sub-carrier corresponding to the column of that element.

In the matrix it can be observed that one column contains at most only one ‘1’ because one sub-carrier can be allocated to only one user. It can also be observed that each row can have any number of ‘1’s because more than one sub-carrier can be allocated to a user if his data requirement was not satisfied by one sub-carrier. In this case as there are 20 users and 20 sub-carriers if some user gets 2 sub-carriers some other user will not be allocated any sub-carrier. In the above case you can observe that the 10th user has been allocated 2 sub-carriers but the 12th user was not allocated any sub-carriers.

Now, the data rates that could be achieved when we assign the subcarriers statically to users are shown in the next table. In this static allocation the first sub-carrier is allocated to first user, the second subcarrier to the second user and so on up to 20 users. It can be seen that none of the users requirement was satisfied and also the data rates achieved are very low.

It can be observed from the above graph that there is a huge improvement in the total system throughput when allocation is done dynamically using our algorithm.

Case 2:*5 users – 20 sub-carriers case.*

In this case also the bandwidth of each subcarrier is taken to be 3MHz. In this case it can be observed that the number of users is less than the number of subcarriers. So, there is an abundance of carriers. The assignment matrix for this case is shown below. Remember that rows correspond to users and columns correspond to subcarriers.

In the assignment matrix it can be seen that so many subcarriers are not being used. This is because once the assigned data rate to a user with allocated subcarriers crosses his minimum data requirement which is 3Mbps the algorithm stops allocating subcarriers to that user and moves to another user. Finally, when all the users get their minimum data requirement the algorithm finally stops. So, in such a case our modified algorithm is used where, at first our primary algorithm is used till the minimum data rate requirements of all the users is reached and then the extra part of the algorithm comes into play, where every left over subcarrier will be allocated to the best users corresponding to that subcarrier. In this way the users will get very high data rates and at the same time the total system throughput will be the maximum possible for that system with the given number of users.

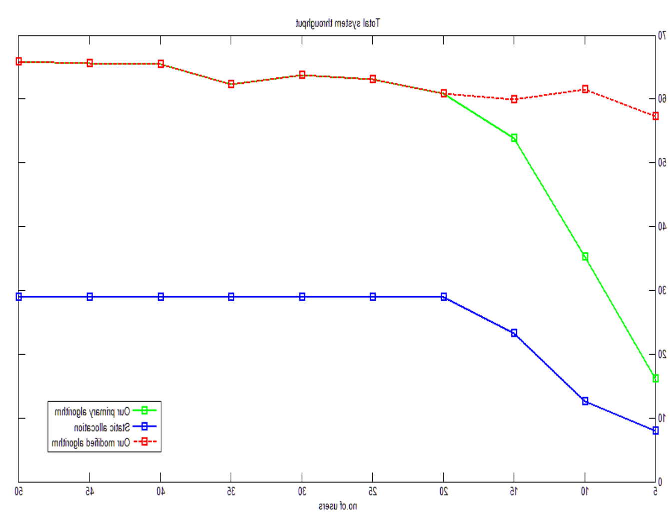

Figure 1: Total system throughput comparison for different algorithms.

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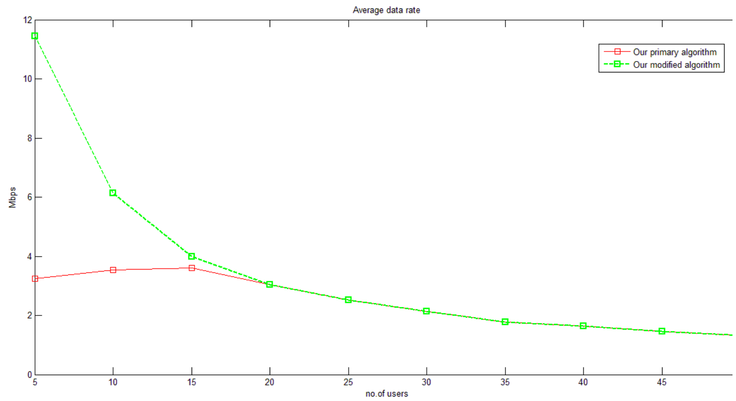

Figure 2: Average data rate comparison for both our algorithms.

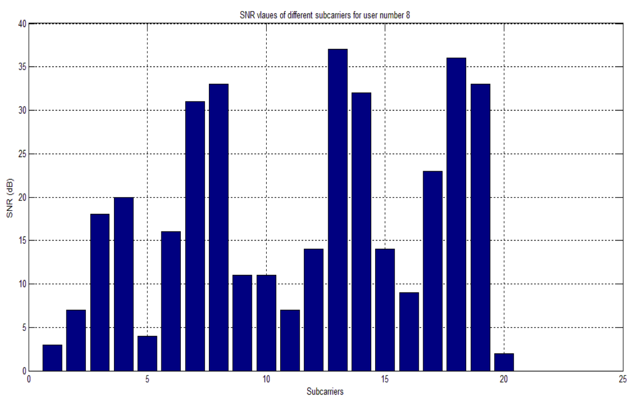

Figure 9: SNR values of different subcarriers of a particular user.

Conclusion:

After studying so many other algorithms in the literature we came to a decision that our algorithm is the best one among the others and best suits future OFDM systems and computing capabilities because the algorithm is optimized in all the aspects like the total system performance, computing complexity, power allocation, total system throughput, user satisfaction etc.

When it comes to system performance the algorithm gives best performance in terms of total system throughput and the user satisfaction will also be very good till the number of users becomes very large than the number of subcarriers. In terms of computational complexity the algorithm gives very much optimized performance because the power need not be allocated adaptively and this is because we are already pouring the power into the sub channels which give maximum SNR to the users, so the attenuation will be low and the power can be poured equally into all the subcarriers and this leads to a very negligible throughput penalty.

When it comes to the fairness among the users as long as the number of users in the system becomes very large than the number of subcarriers, the fairness will be good because all the users who will be allocated the subcarriers will be assigned the data rates which are more than their minimum data requirement and only few users will be left out without getting any service. In the present days the radius of the cells is decreasing and the probability that the number of users will be very large than the number of subcarriers will be very less.

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