Application of Superposition Coding for Subcarrier and Bit Allocation in Downlink OFDM Systems

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***Abstract*—Orthogonal frequency division multiplexing (OFDM) is well known for multicarrier modulation technique in which a high data rate stream is divided into different parallel lower data stream. In this paper, we study the margin adaptive - superposition coding (MA-SC) algorithm and rate adaptive - superposition coding (RA-SC) algorithm, where at most two user can share each subcarrier as compared to MA and RA algorithm, where each subcarrier is shared by only single user without SC scheme. We apply SC scheme over MA and RA to achieve maximum system throughput with separate power constraint for real and non real time users, ensuring that QoS requirement for real time and proportional fairness among non real time users is satisfied. The overall computational complexity of proposed modified RA-SC algorithm is same as RA algorithm. In the modified proposed MA-SC, complexity increases in some of the steps due to addition of SC scheme over MA algorithm, but overall complexity remains the same. Monte-Carlo simulations are being carried out to show that the proposed algorithm improves the performance in terms of power required and throughput.**

***Index Terms*—MA-SC, OFDM, RA-SC.**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is an efficient technique for providing high data rate system and its ability to increase the symbol time large enough so that the induced delays produced by channel are only insignificant portion of the symbol duration, which makes OFDM system capable of reducing or eliminating intersymbol interference (ISI) [1].

Resource allocation are generally of two types-first fixed or static resource allocation, where we do not utilize the knowledge of channel state information (CSI) and users have predetermined knowledge of subcarriers on which they can transmit. Another one is dynamic resource allocation, where each user take advantage of CSI in selecting the best subcarrier for them. Again based on different optimization problem, resource allocation can be divided in two parts-first is margin adaptive (MA) optimization for real time users discussed in [2]-[6], which minimizes the overall transmit power assuring that bit error rate (BER) and bit rate requirements is satisfied, second is rate adaptive (RA) optimization algorithm for non-realtime users discussed in [8]-[11], with a principle of maximizing the system throughput having constraints of overall transmit power, proportional fairness and BER requirement.

Both MA for real time user and RA for non real time user is considered in paper [7], which utilizes heterogeneous services to maximize the overall system throughput under the total transmit power constraint making sure that the proportional fairness among non-realtime users and QoS requirement of real time users is satisfied. In [8], in order to achieve the effective capacity for multicast transmission SC technique is used without taking multiuser access technique into account. Simple watermarking system is proposed in [9], which allows two classes to be transmitted on the same channel with the same frequency plan.

A suboptimal algorithm with an objective to achieve maximum system throughput is discussed in [10] with traffic requirement of users. SC is used in [11] to perform subcarrier, bit and power allocation by allowing at most two users to share same subcarrier. But they have applied this scheme for only real time users without taking non real time users into account. In [11] and [12], author first allocate a subcarrier to a weakest link or far user and allow these subcarrier to be shared by a potential user (near to the BS) using SC scheme. In [6], resource allocation algorithm without integer bit constraint for heterogeneous services in practical adaptive OFDMA systems is considered, which is further investigated in [7] for adaptive resource allocation problem in OFDMA systems with heterogeneous services.

In this paper, we extend the allocation strategy proposed in [7] by introducing the SC scheme [11] on both MA and RA algorithm, when considering the real time and non real time users respectively and we assume perfect knowledge of CSI at BS. The proposed MA-SC and RA-SC algorithm achieves maximum throughput with power constraint of real and non real time users, satisfying QoS requirement and proportional fairness of real and non real time users respectively. We also add some new constraints to [7], explained in sect. II to satisfy the requirement of SC theorem. (MA-SC) algorithm based on marginal utility of subcarrier, determines power required by real time users P^{*}_{rt} by allowing first degraded real time user (far from BS) to look for the best subcarrier for him on the basis of channel gain then potential real time user (near to BS) is allowed to share the same subcarrier by transmitting small amount of power without deteriorating the performance of degraded user. (RA-SC) algorithm gives the throughput of non real time user by utilizing the remaining power P^{*}_{nrt} and SC scheme as followed in MA-SC. In MA-SC, inclusion of potential user algorithm in fourth step increases the complexity to $O(W_{rt}N)$ from O(N) of MA algorithm [7], where Wrt is total number of real time users and N is total

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number of subcarriers and $N>W_{rt}$. However, the overall complexity of MA-SC remain same as MA algorithm [7]. In the proposed RA-SC, the complexity remains the same as that of RA [7].

The layout of paper as follows: Sect. II describes optimization problem of bit and subcarrier allocation. Sect. III explains SC theorem. Sect. IV explains (MA-SC) and (RA-SC) algorithms. Sect. V presents simulation results. Finally, conclusions are drawn in Sect. VI.

II. Optimization Problem

The optimization problem of the subcarrier and bit allocation algorithm with inclusion of SC for both real time (degraded and potential) user and non real time (degraded and potential) is to maximize system throughput, ensuring the bit rate requirement of realtime users and the proportional fairness among non-realtime users subject to power constraint for real and non real time users.

Let us have W users that include Wrt realtime (degraded and potential) users and Wnrt non-realtime (degraded and potential) users with requirement of BER & bit rate and without requirement of bit rate respectively. The complete set of realtime users and non-realtime users which contain both degraded and potential users are denoted by U^*_{rt} and U^*_{nrt} respectively. The downlink channel gain of the k_{th} ($1<k<M$) user on the n_{th} ($1<n<N$) subcarrier is given by h^*_{kn}.

The optimization scheme [1] is modified with increased constraints described below:

$$R_T = max_{a^*_{kn}\varepsilon[0,1] b^*_{kn}\varepsilon L} \sum_{k\varepsilon U^*_{nrt}} \sum_{n=1}^{N} a^*_{kn} b^*_{kn} \quad (1)$$

The maximization is subjected to the constraints given below:

C1: $\sum_{k=1}^{K} a^*_{kn} \le 2, \forall$ n

C2: $R_k = R_k^{req}$, $\forall$ k ε U^*_{rt}

C3: $R_i/\Omega_i = R_j/\Omega_j$, $\forall$ i, j ε U^*_{nrt}

C4: $\sum_{n\varepsilon S^*_{rt}} p_n \le P_T$, $\sum_{n\varepsilon S^*_{nrt}} pwr_n \le P^*_{nrt}$

C5: $p_n \ge 0$, $pwr_n \ge 0$

C6: $\sum_{k=1}^{K} \beta^{pot}_{k,n} \le 1$, $\sum_{k=1}^{K} \beta^{deg}_{k,n} \le 1$, $\forall$ n

C7: $\beta^{deg}_{k,n} \beta^{pot}_{k,n} = 0$, $\forall$ n, $\forall$ k

C8: $\sum_{k=1}^{K} \sum_{n\varepsilon S^*_{nrt}} a^*_{kn} p^*_{kn} \le P^*_{nrt}$

Here, L denotes the set of natural numbers; C1 guarantees that each subcarrier can be shared by at most two user. The bit rate requirement R^k_{req} of realtime users k is indicated by C2. One can achieve the proportional fairness for non-realtime users using C3 with rate weight of user k denoted by Ω_k satisfies $\sum_{k\varepsilon U*nrt} \Omega k = 1$. In C4, the sum of power on each real and non real time subcarriers should be less than equal to P_T and P^*nrt respectively. C5 indicates power on each real and non real time subcarriers should be positive. C6 denotes subcarrier allocation indicator for the potential and degraded user. C7 explains that one user cannot be considered as potential and degraded on the same subcarrier. C8 is maximum power constraint for non real time users.

III. Superposition Coding Scheme

Superposition coding [11] allows at most two users to share each subcarrier for their transmission. Independent resultant information S corresponding to the degraded and potential user S_1 and S_2 respectively is transmitted to two or more receivers at the same time.

$$S= S_1+S_2/A \quad (2)$$

where A equal to 8 is ratio of adjusted power between the degraded and potential user signal. Single tx and rx antenna is used. The signal received at receiver Y is decoded into $\hat{S}_1$ and $\hat{S}_2$ (expressed below), which denotes the received signal corresponding to the degraded and potential user side respectively.

$$\hat{S}_1=h^*_{deg}S+Z^*_{deg} \quad (3)$$

$$\hat{S}_2=h^*_{pot}S+Z^*_{pot} \quad (4)$$

where h^*_{deg} and h^*_{pot} are channel gain, Z^*_{deg} and Z^*_{pot} are (AWGN) noise for degraded and potential user respectively.

The mechanism to decode the signal of degraded and potential user at receiver is similar to [11]. U^*_{pot} 's signal is considered as a noise by U^*_{deg} and then U^*_{deg} decodes its own signal from $\hat{S}_1$. Now the turn for the potential user to decode its own signal. Successive interference cancelation (SIC) is performed by U^*_{pot} who has the best channel gain. This means that at potential user side, when S_1 is decoded, U^*_{pot} moves away from $\hat{S}_2$ to decode S_2. Some practical simplification [11] is being done to reduce the complexity which are as follows:

1) Potential user can only transmit 2 bits using QPSK modulation, otherwise potential user S_2 is not allowed to transmit any information.
2) In order to know that a particular user is potential or not on a specific subcarrier, a predetermined threshold given in Table I is used for comparison with user's SNR.

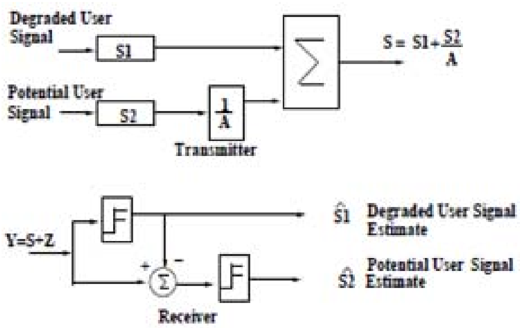

Fig. 1. Transmission and Reception Scheme for SC [9].

IV. The Subcarrier and Bit Allocation Technique

In this section, we develop (MA-SC) and (RA-SC) algorithm in order to determine the power required by the real time user and throughput of non-real time user respectively, where real and non real time user consist of potential and degraded users. The total power available at the base station

P_T is utilized in such a way that power required by the real time (degraded and potential) user using MA-SC comes out to be P^*_{rt}. The remaining power P^*_{nrt} is obtained by subtracting P^*_{rt} from total power P_T and remaining subcarrier is obtained as S*nrt=(1,2,.....N)-S*rt. This remaining power and subcarrier is used in RA-SC for calculating the throughput of non real time (potential and degraded) users.

A. Margin Adaptive Algorithm with Superposition Coding scheme

The objective of (MA-SC) algorithm is to achieve minimization of total required power satisfying the requirement of bit rate for realtime (Potential and degraded) users and constraint $\sum_{n\varepsilon S*rt} p_n \leq P_T$. S^*_{rt} is total subcarriers available to the real time users. In this algorithm, joint subcarrier a^*_{kn} and bit allocation b^*_{kn} is considered. MA-SC is based on the notion of marginal utility of subcarrier [7], which gives the maximum reduction in power, when subcarrier n is additionally allocated to user k, which is denoted as Δpwm_{kn}. MA algorithm [7] is modified by introducing SC scheme [11]. The proposed modified algorithm is described below:

Input S*rt, P_T and Output P*rt.

1. Initialization

a) set $a^*_{kn}=0$, $b^*_{kn}=0$, $\beta_{k,n}^{deg}=0$ and $\beta_{k,n}^{pot}=0$ for k $\mathcal{E}$ U^*_n and n $\mathcal{E}$ S^*_n. Set $S=S^*_n$, $S_k=\emptyset$ and Spot= Ø, ∀ k .

b) Power initialization: the amount of power on each real time subcarrier S^*_n is $p_n= P_T /|S^*_n|$, where P_T is the total power available at the base station.

2. for each k $\mathcal{E}$ U^*_n

a) Sort h^*_{kn} in ascending order

b) Find $n^*=\arg\max_{n\,\varepsilon\, S} h^*_{kn}$

c) set $a^*_{kn*}=1$, $\beta_{k,n*}^{deg}=1$ and $b^*_{kn*}=R_k^{req}$, S=S-{n*}, $S_k=S_k$ +{n*}.

d) looking for potential user

i. From b^*_{kn*}, determine the number of bits transmitted by user k on subcarrier n*, then obtain SNR_{deg}^{min} from Table I

ii. Adjust transmit power pn* to get $SNR_{k,n*}=(p_{n*}(h^*_{kn*})^2)/(\sigma^2_{k,n*})$ equal to SNR_{min}^{deg} from Table I.

iii. for each user k recompute the SNR

iv. call potential user finding algorithm described in section IV(c).

3. for each k $\mathcal{E}$ U^*_n

a) Find $n^*=\arg\max_{n\,\varepsilon\, S} h^*_{kn.}$

b) Calculate marginal utility $\Delta pwm_{k,n*}$ using the approach explained in [7].

4. While S≠ Ø

a) Find $(k^*,n^*)=\arg\max_{k,n\,\varepsilon\, S} \Delta pwm_{k,n}$

b) set $a^*_{k*,n*}=1$, ,$\beta_{k*,n*}^{deg}=1$, S=S-{n*}, $S_k= S_k$+{n*}

c) Redistribute the required bits of user k* to subcarrier set $S_{k*.}$

d) looking for potential user as done in 2(d) of same algorithm with k is replaced by k*.

e) for all user k whose Δ pwmkn* using the approach explained in [7].

5. a^*_{kn} and b*kn is final subcarrier and bit allocarion indicators. The overall transmit power is given as

$$P^*_{rt} = \sum_{k\varepsilon U^*_{rt}} \sum_{n\varepsilon S^*_{rt}} a^*_{kn} \frac{\Gamma\sigma^2}{h^*_{kn}} (2^{b^*_{kn}} - 1)$$

Explanation: The subcarrier and bit allocation indicators is initialized in first stage along with the separate allocation coefficients for both degraded $\beta_{k,n}^{deg}$ and potential user $\beta_{k,n}^{pot}$. S have the knowledge of the unallocated subcarrier, S_k and S_{pot} will depict the subcarrier set assigned to degraded users and potential users respectively. Also in first stage, equal amount of power P_T is allocated on different subcarriers S*rt, where | . | denotes the cardinality of a set.

In the second stage, subcarrier which is not being utilized and also has the maximum channel gain is assigned to user at each iteration. These users are degraded real time users, who can transmit the total number of bits available to them by bit rate requirement on subcarrier recently found at each iteration. Then we look for the potential user who can transmit 2 bits on same subcarrier using the SC. To look for potential user, the no. of bits transmitted by degraded user and 2 bits by potential user is compared in the Table I and corresponding SNR_{deg}^{min} is found. Then transmit power p_{n*} is compensated inorder to adjust

$SNR_{k,n}{}^*=p_n{}^*(h^*_{k,n*})^2 /(\sigma^2_{k,n*})$ equal to SNR_{deg}^{min} so that constraint $\sum_{n\,\varepsilon S*rt} pn$ is satisfied and then we recompute the SNR on the subcarrier n* for each user k. After that, we compare the SNR of all the potential users with the SNR_{pot}^{min} to decide that if a share allocation on the subcarrier n* is possible or not and if possible i.e potential user is found, then we add n* to S_{pot}. It is also important to note that one user cannot be considered as potential and degraded on the same subcarrier.

In the third stage, we calculate the marginal utility [7] of the unassigned subcarrier that are having the highest channel gain for each user. In following subcarrier selection stage, we would select only those subcarrier that are having largest marginal utility.

In the fourth stage, we jointly select an unallocated subcarrier and a particular user that are having the largest marginal utility, and we allocate this subcarrier to the selected user. Then we redistribute part of the required bits of the user to the recently added subcarrier. After this, we look for the potential user as done in step 2(d). There may be possibility that selected subcarrier is the best subcarrier for other users, then in that case the marginal utility of another unallocated subcarrier for those users are necessary to be calculated. Finally, we obtain subcarrier and bit allocation results and the overall power required to allocate all the subcarriers. In MA-SC, inclusion of potential user algorithm in fourth step increases the complexity to O(WrtN) from O(N) of MA algorithm [7]. However, the complexity of remaining step would remain same as MA [7], with no change in overall complexity.

B. Rate Adaptive Algorithm with Superposition Coding Scheme

RA-SC algorithm maximizes the total throughput of non-realtime (Potential and degraded) users by allowing both potential and degraded user to share the same subcarrier, subject to non real time power constraint C8 of optimization problem along with constraint $\sum_{n \varepsilon S*nrt} pwr_n \leq P^*_{nrt}$ and user rate proportionality. In this algorithm, we separately perform subcarrier and bit allocation procedure. RA algorithm [7] is modified by introducing SC scheme [11]. Modified subcarrier allocation step including SC is given below:

Input: S^*_{nrt}, P^*_{nrt} Output: R_T .

1. Initialisation

a) set $a^*_{kn}=0$, $b^*_{kn}=0$, $\beta_{k,n}^{deg}=0$ and $\beta_{k,n}^{pot}=0$, $b^*_{kn}=$, $S_k=\emptyset$ Spot= Ø and R_k= Ø, for k ε U^*_{nrt} and n ε S^*_{nrt}. Set $S=S^*_{nrt}$,. Calculate b^*_{kn} as

$$b^*_{kn} = \lfloor \log_2(1+\frac{h^*_{kn}}{\Gamma\sigma^2}\frac{P^*_{nrt}}{|S^*_{nrt}|}) \rfloor$$

b) power initialization: the amount of power on each real time subcarrier S*nrt is pwrn=$P^*_{nrt}/|S^*_{nrt}|$, where P^*_{nrt} is remaining power available at the base station

2. While S≠Ø

a) Find k*=arg mink (R_k/Ω_k)

b) Find n*=arg max $b^*_{k^*n}$

c) set $a^*_{k^*n^*}=1$, $\beta_{k,n}^{deg}=1$ and S=S-{n*}, $S_{k^*}= S_{k^*}+\{n^*\}$,$R_{k^*}=R_{k^*}+b^*_{k^*n^*}$.

d) looking for potential user as done in step 2(d) of MA-SC algorithm, with k and p_n is replaced by k* and pwrn respectively.

3. a^*_{kn} is the total subcarrier allocation indicator, S_k and S_{pot} is the sucarrier set assigned to degraded and potential user respectively.

Bit allocation step using information from above as follows.

Inputs a^*_{kn}, S_k, S_{pot} and P^*_{nrt}. Output R_T.

1. Initialisation

a) Set $b^*_{kn}=0$,$R_k=0$,for k ε U^*_{nrt} and n ε U^*_{nrt} and n ε S_k, Initalise P=0.

$$\Delta P^*_{kn} = \frac{\Gamma\sigma^2}{h^*_{kn}}(2^{b^*_{kn}})$$

b) Transmit 2 bits to each user k according to subcarrier allocation set Spot obtained from subcarrier allocation step. These users are potential users.

2. While (1)

a) Find k*= arg mink ((R_k/Ω_k)

b) Find n*=arg min n ε S_k* Δ $P^*_{k^*n^*}$.

c) if P+ Δ $P^*_{k^*n^*} \leq P^*_{nrt}$ update $b^*_{k^*n^*}= b^*_{k^*n^*}+1$, P=P+ Δ $P^*_{k^*n^*}$, $R_k= R_k+1$,

$$\Delta P^*_{k^*n^*} = \frac{\Gamma\sigma^2}{h^*_{k^*n^*}}(2^{b^*_{k^*n^*}})$$

else

exit while loop;

end if-else.

3. The final bit allocation of the k_{th} user on the n_{th} subcarrier is given as b^*_{kn}. The overall throughput of non real time user is given by

$$R_T = \sum_{k \varepsilon U^*_{nrt}} \sum_{n \varepsilon S^*_{nrt}} a^*_{kn} b^*_{kn}.$$

Explanation: The subcarrier allocation step is repeated up to the length of $|S^*_{nrt}|$, where | . | denotes the cardinality of a set and we initialize the subcarrier allocation indicator along with separate allocation coefficients for both degraded and potential user. S_k and Spot are subcarrier set allocated to degraded and potential users respectively. S keeps the knowledge of the unallocated subcarriers.The remaining power P^*_{nrt} is equally divided among the remaining subcarrier $|S^*_{nrt}|$. User rate proportionality is guaranteed by allowing that user to choose a subcarrier which has minimum normalized transmit rate R_k/Ω_k . Now, selected user will choose that subcarrier which has highest transmit rate and these users are named as degraded users. Then we will look for potential user, who can transmit 2 bits on same subcarrier using SC. To look for potential user, we need to follow the same step as followed in 2(d) and 4(d) of (MA-SC) algorithm. One user cannot be considered as potential and degraded on the same subcarrier. After all the subcarriers in S^*_{nrt} are assigned, we obtain the total subcarrier allocation indicator a^*_{kn} and the final assigned subcarrier set S_k and Spot of degraded and potential users respectively. These three a^*_{kn}, S_k and Spot are the input to bit allocation step.

The bit and corresponding power is allocated by bit allocation step on each subcarrier. Bit allocation step is similar to the subcarrier allocation step which assures to satisfy the user rate proportionality by allocating one bit to the user,who has least normalized rate R_k/Ω_k And we also allocate 2 bits to potential user according to subcarrier allocation set Spot. The next step allocate bits to degraded users.

In each iteration, the user will allocate additional bit to that subcarrier, which requires the least power. The bit allocation step ceases, when power allocated reaches the non real time power constraint P^*_{nrt}. With the addition of power initialization in 1st step, potential user algorithm in 2nd step of RA-SC (subcarrier allocation algorithm) and transmission of 2 bits to potential user of RA-SC (bit allocation algorithm) requires the complexity of O(N), O(W_{nrt}N) and O(W_{nrt}N) respectively. The overall complexity of RA-SC algorithm O(N^2) would remain same as RA algorithm [7].

C. Potential User Find Algorithm

The algorithm for searching potential user [11] is described below:

- Set m=1, Potential user=Not found,
- while (m≤K) and (Potential User=Not found) do
- if SNRm,n*≥SNRpotmin then
- Potential User=Found and m^*=m,
- b*m*n*=, Set $a^*_{m^*n^*}=1$ $\beta^{pot}_{m^*n^*}=1$
- $S_{pot}(m^*) = S_{pot}(m^*) \bigcup \{n^*\}$
- else

  m=m+1
- end

TABLE I: THRESHOLD VALUE OF SNR_K^{MIN} USING SC WITH SER=10^{-3}

R^*_{deg}	R^*_{pot}	SNR^{min}_{deg}	SNR^{min}_{pot}
2	2	11.0 dB	28.4 dB
4	2	18.3 dB	35.4 dB
6	2	24.6 dB	41.6 dB
8	2	30.7 dB	47.1 dB
10	2	36.9 dB	53.7 dB
12	2	42.9 dB	59.8 dB
14	2	48.9 dB	65.8 dB
16	2	54.9 dB	71.8 dB

The Table I of [11] is expanded for R^*_{deg}=16 bits, where R^*_{deg} and R^*_{pot} are bits transmitted by degraded and potential user respectively. We assume that same service is broadcasted to each user, which satisfy the following condition:

$SER_{degrad}(S_1) \leq 10^{-3}$, measured at degraded user side.

$SER_{potent}(S_2) \leq 10^{-3}$, measured at potential user side.

V. Simulation Evaluation

A. Simulation Setup

MATLAB tool has been utilized to evaluate the performance of the proposed MA-SC and RA-SC algorithm. Three-path rayleigh fading channel has been considered for simulation with an exponential power delay profile, whose variances are computed by $d^{-\alpha}$ path-loss model for rayleigh fading channel, with α=3. The total power P_T at BS is 6.4 W. Bandwidth assigned for OFDM system is 5MHz, over this bandwidth BS will allocate 64 subcarriers. The average channel gain for both realtime (potential and degraded) users or non realtime (potential and degraded) users is chosen randomly within (0.1,1). The bit error rate considered for each user is equal to 10^{-3} the SNR gap of OFDM system is about 5.48 dB. AWGN's variance at each receiver is assumed to be equal, i.e σ^2=1mW.

The number of real time users and non real time users are equal to 8, and each user has the bit rate requirement R_k^{req} equal to 16 bits/OFDM symbol, and the rate weight of each non real time user satisfies: Ω_k=1/8, forall k ε U^*_{nrt}. Averaging is done over 1000 network topologies over 100 OFDM symbols for each results.

B. Simulation Results

In Fig. 2, W_{rt}=8 and R_k^{req}=16 bits/OFDM symbol forall k ε U^*_{rt}.. In proposed (MA-SC), power required to transmit a required number of bits for each real time user is reduced by (57.14 %), when 19 subcarriers are used and reduced by (64.28 %), when 21 subcarriers are used and reduced by (71 %), when 24 subcarriers are used and reduced by (30%), when 32 subcarriers are used in comparison to MA [7], but now it requires to find the potential user at each iteration to transmit 2 bits to the user on the same subcarrier which had already been used by the degraded user. When we allocate 56 subcarriers, power required by real time user using MA and MA-SC algorithm comes out to be same, i.e., power become constant for both MA-SC and MA after 56 subcarriers have been allocated to real time users.

In Fig. 3, W_{nrt}=8 and Ω_k =1/8, forall k ε U^*_{nrt}. We notice that there is significant increment in the system capacity by using RA-SC. With RA [7], throughput at 16 subcarriers is zero but with RA-SC, it is 235 bits/OFDM symbol and when 24 subcarriers are used, throughput increases from 185 bits/OFDM symbol to 310 bits/OFDM symbol and when 32 subcarriers are used, throughput increases from 193 bits/OFDM symbol to 258 bits/OFDM symbols and throughput increases further in comparison to RA algorithm [7] for the remaining subcarriers.

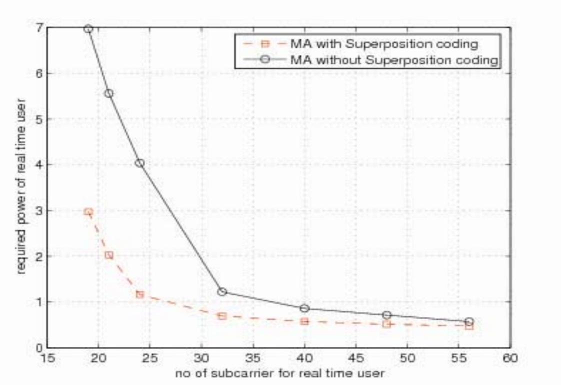

Fig. 2. Required power by real time user versus number of subcarriers for realtime user

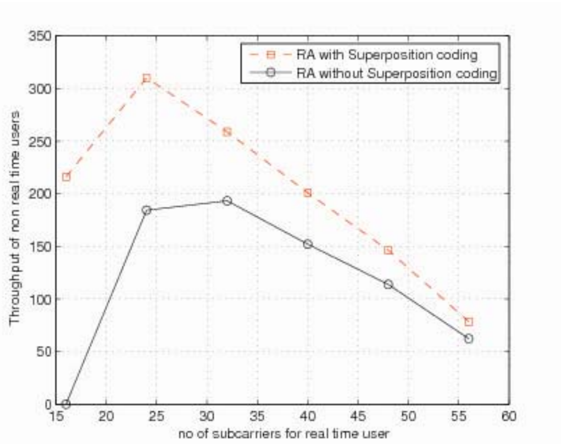

Fig. 3. Total throughput for non-realtime user v number of subcarriers used by real time user

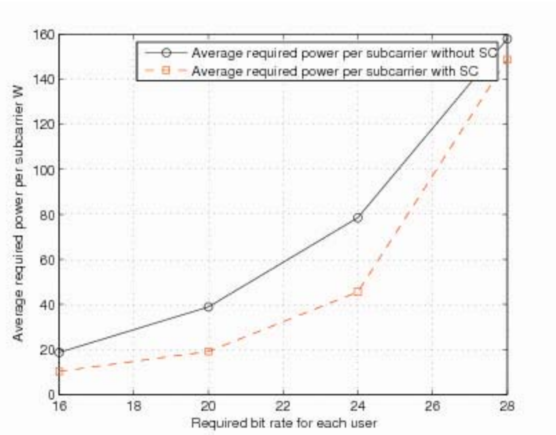

Fig. 4. Average required power per subcarrier vs required bit rate

In Fig. 4, average required power per subcarrier given as P^*_{rt} /(N σ^2) is reduced as the power required by real time users is reduced. W_{rt} varies from 4 to 8. When 16 bits are used then average power per subcarrier is reduced by 26 % and when 20 bits are taken then average power per subcarrier is reduced by 48.7 % and when 24 bits are taken average power per subcarrier is reduced by 48.18 % and it decreases further, when we go upto 28 bits. The bits required for Fig. 4 are taken in range from 16 to 28 bits/OFDM symbol for each user and elsewhere bits required have been taken equal to 16 bits/OFDM symbol.

VI. CONCLUSION

In this paper, we first study MA-SC algorithm, which jointly considers subcarrier and bit allocation for calculating the power required by real time (potential and degraded) users and then RA-SC algorithm, which separately allocate bit and subcarrier for maximizing the throughput of the non real time (potential and degraded) users utilizing the P*nrt & Snrt. In both algorithms, each subcarrier is shared by at most two users as compared to MA and RA algorithm without SC scheme. System throughput is only dominated by throughput of non real time users, as throughput of the real time user is fixed and provided. The results show that our proposed algorithm performs better than MA and RA algorithm without SC [7]. In MA-SC, inclusion of potential user algorithm in fourth step increases the complexity to $O(W_{nrt}N)$ from O(N) of MA algorithm [7]. The complexity of remaining step is same. The overall computational complexity of RA-SC algorithm is same as RA algorithm [7]. SC can be easily applied to any allocation algorithm for OFDM system as: whenever a subcarrier n is allocated to a user k, then we calculate $SNR_{k,n}$ and compare this $SNR_{k,n}$ to SNR_{pot}^{min} from Table I so that we can have ac idea that how many bits can be transmitted and we treat this user as degraded. After this, we search for the potential user u, who can use this remaining power for transmission of 2 more bits on the same subcarrier n. Then we can declare user k as potential if its $SNR_{k,n}$ is greater than SNR_{pot}^{min} determined in Table I.

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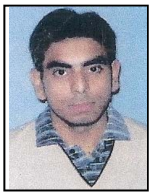

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