

# Superposition Coding Scheme for Subcarrier & Bit Allocation in OFDM System

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*Abstract-Orthogonal Frequency Division Multiple Access (OFDMA) refers to a radio transmission technique based on dividing the frequency channel into narrowband sub-channels. In this dissertation studied that margin adaptive - superposition coding (MA-SC) algorithm and rate adaptive - superposition coding (RA-SC) algorithm, where at most two users can share each subcarrier as compared to MA and RA algorithm, where each subcarrier is shared by only single user without SC scheme. Then 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 RA-SC algorithm is same as RA algorithm. In MA-SC, complexity increases in some of the steps due to addition of SC scheme over MA algorithm, but overall complexity remains the same. Matlab simulations are being carried out to show that the performance of algorithm in terms of power required and throughput.*

**Index Term-MA-SC, RA-SC, OFDM Superposition coding.**

## I. INTRODUCTION

OFDM is an efficient technique for providing high data rate system and its potential to eliminate or reduce intersymbol interference (ISI) by increasing the symbol time large enough so that the induced delays produced by channel are only insignificant portion of the symbol duration, which is typically less than 10 % and the delay spread being a good measure of this in wireless channels [1]. In OFDM subcarriers are chosen in such a way that subcarriers are orthogonal to each other over the symbol time. Therefore, systems supporting high-data-rate application [4], the symbol duration is small, as we know that symbol duration is proportional to the data rate, dividing the data stream into many parallel streams enhances the symbol duration of each individual stream so that finally the delay spread is only a small part of the symbol duration. In OFDM the subcarriers are chosen in such a way that they are all orthogonal to one another over the symbol duration,

So that there is no need to have any non overlapping subcarrier channels to eliminate inter carrier interference.

Resource allocation are generally of two types-first fixed resource allocation, where we do not utilize the knowledge of channel state information and users are having predetermined knowledge of subcarriers provided to them. This allocation is also known as static resource allocation [6]. Another one is dynamic resource allocation, where each user take full advantage of channel gain information in selecting the best subcarrier for it in order to increase the total throughput of the system [6],[7].

Again based on different optimization problem resource allocation can be divided into two parts-first is MA optimization for real time users [5],[10],[12],[14],[16], with an objective to minimize the total transmit power while maintaining the rate and Bit Error Rate (BER) requirements, second is RA optimization algorithm for non-realtime user [8],[9],[11],[13], with a principle of achieving the maximum system throughput subject with the constraint of overall transmit, BER requirement and proportional fairness requirement.

The rest of the paper is organized as follows: We have presented the superposition coding scheme in Section II. In Section III, we have introduced the algorithms with superposition coding such as Margin Adaptive and Rate Adaptive algorithms. Section IV presents results and discussion. Finally, conclusion are drawn in Section V.

## II. SUPERPOSITION CODING SCHEME

For simple superposition coding [2], we are having a single transmitter which transmit independent information at the same time to two or more receivers. Simple broadcasting system is considered, where the signal transmitted  $S$  is the resultant of signal corresponding to the far user i.e. degraded user  $S_1$  and the signal related to the potential user  $S_2$  the transmitted signal  $S$  is defined as follows:

$$S = S_1 + S_2 = A. \quad (2.1)$$

Where  $A$  is an attenuation factor that adjusts the power ratio between the degraded and potential user's data.

A single transmit and receive antenna is considered.  $S_1$  denotes the received signal corresponding to the degraded user side and  $S_2$  is the received signal corresponding to the potential user side. The expression for  $S_1$  and  $S_2$  as follows:

$$S_1 = h_{deg}^* S + Z_{deg}^* \quad (2.2)$$

$$S_2 = h_{pot}^* S + Z_{pot}^* \quad (2.3)$$

where  $h_{deg}^*$  and  $h_{pot}^*$  are channel gain,  $Z_{deg}^*$  and  $Z_{pot}^*$  are (AWGN) noise for degraded and potential user respectively.

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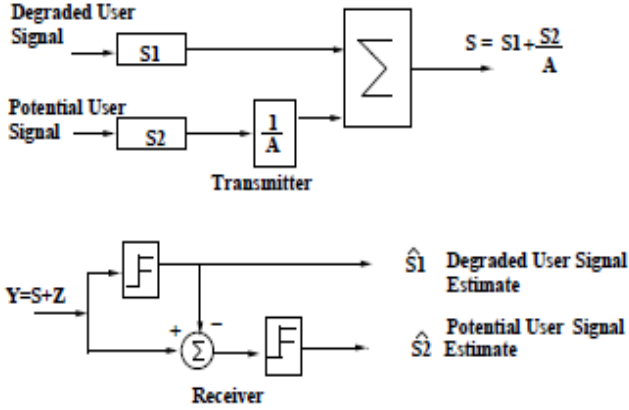
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The mechanism to decode the signal of degraded and potential user at receiver [3].  $U_{pot}^*$ 's signal is considered as a noise by  $U_{deg}^*$  and then  $U_{deg}^*$  decodes its own signal from  $\hat{S}_1$ .



**Fig. 2.1 Transmission and reception scheme for superposition coding**

The mechanism to decode the signal of degraded and potential user at receiver.  $U_{pot}^*$ '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  $S_2$

### III. ALGORITHMS WITH SUPERPOSITION CODING

Algorithms like margin adaptive and rate adaptive [15] are used with superposition coding. MA-SC algorithm and RA-SC algorithm in order to determine the power required by the real time user and throughput of non-real time user, where real and non-real time user includes both potential and degraded users. As we know that MA algorithm alone is used for real time users and in conjunction with SC is also best fitted for real time 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 comes out to be  $P_{rt}$ . The remaining power  $P_{nrt}$  is obtained by subtracting  $P_{rt}$  from total power  $P_T$ . And the remaining subcarrier is obtained as  $S_{nrt} = (1, 2, \dots, N) - P_{rt}$ . This remaining power and subcarrier is used by potential and degraded non real time user for calculating their throughput.

#### A. Margin Adaptive Algorithm with Superposition Coding Scheme

MA-SC algorithm is to minimize the total required power maintaining the bit rate requirement of real-time users including (Potential and degraded) users. The subcarrier used in this algorithm is  $S_{rt}$ . In this algorithm joint subcarrier allocation  $a_{kn}$  and bit allocation  $b_{kn}$  is considered. Since MA-SC is based on the notion of marginal utility of subcarrier defined in, which means the maximal power reduction when subcarrier  $n$  is additionally allocated to user  $k$ , which is denoted as  $\Delta p_{wm_{kn}}$ . The concept of marginal utility algorithm is used in MA-SC. The MA-SC 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  $k \in U_n$  and  $n \in S_n$ . Set  $S = S_n$ ,  $S_k = \emptyset$ ,  $\forall k$ .
- (b) Power initialization: for all subcarriers, we evaluate the initial transmit power as  $P_n = P_T / |S_n|$ , where  $P_T$  is the total power available at the base station.

#### 2. For each $k \in U_n$

- (a) Sort  $h_{kn}$  in ascending order
- (b) Find  $n^* = \arg \max_n \epsilon S h_{kn}$
- (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 no. of bits transmitted by user  $k$  on subcarrier  $n^*$ , then obtain  $SNR_{min}$  from Table- I
  - ii. Adjust transmit power  $P_{n^*}$  to get  $SNR_{k,n^*} = (P_{n^*} (h_{kn^*})^2) / (\sigma_{k,n^*}^2)$  equal to  $SNR_{min,deg}$  computed from previous step.
  - iii. For each user  $k$  recomputed the SNR
  - iv. Calling potential user finding algorithm.

#### 3. For each $k \in U_{rt}$

- (a) Find  $n^* = \arg \max_{n \in S} h_{kn}$
- (b) Calculate the marginal utility  $\Delta p_{kn^*}$  using the fast marginal utility calculation approach [7].
4. While  $S \neq \emptyset$ 
  - (a) Find  $(k^*, n^*) = \arg \max_{n \in S} \Delta p_{kn}$ .
  - (b) Set  $a_{k^*,n^*} = 1$ ,  $\beta_{k^*,n^*,deg} = 1$  and  $S = S - \{n^*\}$ ,  $S_k = S_k + \{n^*\}$ .
  - (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.
  - (e) For all user  $k$  that  $p_{kn^*} \neq 0$ 
    - i. Find  $n^* = \arg \max_{n \in S} h_{kn}$
    - ii. Calculate the marginal utility  $p_{kn^*}$  using the fast marginal utility calculation approach.

5.  $a_{kn}$  and  $b_{kn}$  is final subcarrier and bit allocation indicators. The overall transmit power is given as

$$P_{rt} = \sum_{k \in U_{rt}} \sum_{n \in S_{rt}} a_{kn} \frac{\Gamma \sigma^2}{h_{kn}} (2^{b_{kn}} - 1)$$

#### B. Rate Adaptive Algorithm with Superposition Coding Scheme

RA resource allocation algorithm meant to achieve the maximum total throughput of non-realtime users (including Potential and degraded) with the constraint of overall transmit power and user rate proportionality. In this algorithm, we separately perform subcarrier and bit allocation procedure.

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  $\beta_{k,n}^{pot}=0$ ,  $b_{kn}=0$ , and  $R_k=0$ , for  $k \in U_{nrt}$  and  $n \in S_{nrt}$ . Set  $S=S_{nrt}^*$ .

Calculate  $b_{kn}$  as

$$b_{kn} = \lceil \log_2 \left( 1 + \frac{h_{kn}}{\Gamma \sigma^2} \frac{P_{nrt}}{|S_{nrt}|} \right) \rceil$$

- (b) Power initialization: for all subcarriers, we evaluate the initial transmit power as  $pwr_n = P_{nrt}/|S_{nrt}|$ , where  $P_{nrt}$  is remaining power available at the base station

2. While  $S \neq \emptyset$

- (a) Find  $k^* = \arg \min_k (R_k/\Omega_k)$   
(b) Find  $n^* = \arg \max_n b_{k^*,n}$   
(c) set  $a_{k^*,n^*} = 1$ ,  $\beta_{k^*,n^*}^{deg} = 1$  and  $S = S - \{n^*\}$ ,  $S_{k^*} = S_{k^*} \cup \{n^*\}$ ,  $R_{k^*} = R_{k^*} + b_{k^*,n^*}$ .  
(d) looking for potential user as done in step 2(d) of MA-SC algorithm.
3.  $akn$  is the subcarrier allocation results and  $S_k$  is the subcarrier set assigned to user  $k$ . Bit allocation step using information from above as follows.

Inputs  $a_{kn}$ ,  $S_k$ , and  $\beta_{k,n}^{pot}$  Output  $R_T$ .

1. Initialisation

- (a) Set  $b_{kn}=0$ ,  $R_k=0$ , for  $k \in U_{nrt}$  and  $n \in U_{nrt}$  and  $n \in S_k$ , Initialise  $P=0$ .

$$\Delta P_{kn} = \frac{\Gamma \sigma^2}{h_{kn}} (2^{b_{kn}})$$

- (b) Transmit 2 bits to each user  $k$  using the subcarrier allocation indicator  $\beta_{k,n}^{pot}$  obtained from subcarrier allocation step.

2. While (1)

- (a) Find  $k = \arg \min_k ((R_k/\Omega_k))$   
(b) Find  $n = \arg \min_n n \in S_{k^*} \Delta P_{k^*,n^*}$ .  
(c) if  $P + \Delta P_{k^*,n^*} \leq P_{nrt}$   
update  $b_{k^*,n^*} = b_{k^*,n^*} + 1$ ,  $P = P + \Delta P_{k^*,n^*}$ ,  $R_k = R_k + 1$ ,

$$\Delta P_{k^*,n^*} = \frac{\Gamma \sigma^2}{h_{k^*,n^*}} (2^{b_{k^*,n^*}})$$

else

exit while loop;

end if-else.

3.  $b_{kn}$  is final bit allocation of the  $k_{th}$  user on the  $n_{th}$  subcarrier. The overall throughput of non-real time user is given by

$$R_T = \sum_{k \in U_{nrt}} \sum_{n \in S_{nrt}} a_{kn} b_{kn}.$$

C. Searching Potential User Algorithm

The algorithm for searching potential user is described below:

1. Set  $m=1$ , Potential user=Not found,
  2. while  $(m \leq K)$  and (Potential User=Not found) do
  3. if  $SNR_{m,n^*} \geq SNR_{min}^{pot}$  then
  4. Potential User=Found and  $m^* = m$ ,
  5.  $b_{m^*,n^*} = 2$  bits, Set  $a_{m^*,n^*} = 1$   $\beta_{m^*,n^*}^{pot} = 1$
- $$S_{pot}(m^*) = S_{pot}(m^*) \cup \{n^*\}$$
6. else
  - $m = m + 1$
  7. end

$R_{deg}^*$	$R_{pot}^*$	$SNR_{deg}^{min}$	$SNR_{pot}^{min}$
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

Table 4.1 Threshold value of SNR<sub>kmin</sub> using SC with SER = 10-3

IV. RESULTS& DISCUSSION

we evaluate the performance of the MA-SC and RA-SC algorithm by MATLAB. In Fig. 4.1,  $W_{rt}=8$  and  $R_{rqk}=16$  bits/OFDM symbol  $k$ . In proposed (MA-SC), power required to transmit a required number of bits for each real time user is reduced by (57.14 %), when 22 subcarriers are used and reduced by (64.28 %), when 24 subcarriers are used and reduced by (71 %), when 26 subcarriers are used and reduced by (30%), when 34 subcarriers are used in comparison to MA, 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 58 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 58 subcarriers have been allocated to real time users.

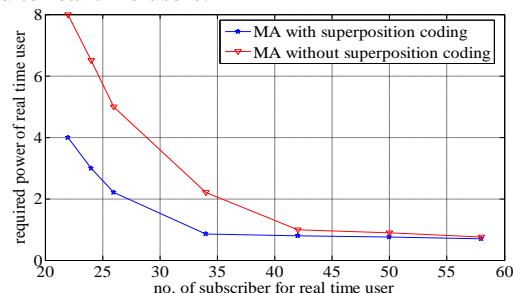
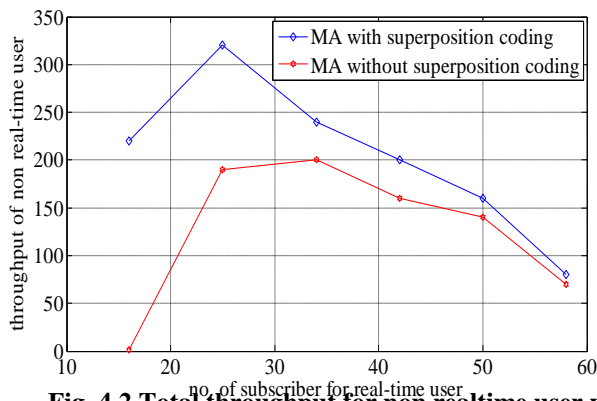
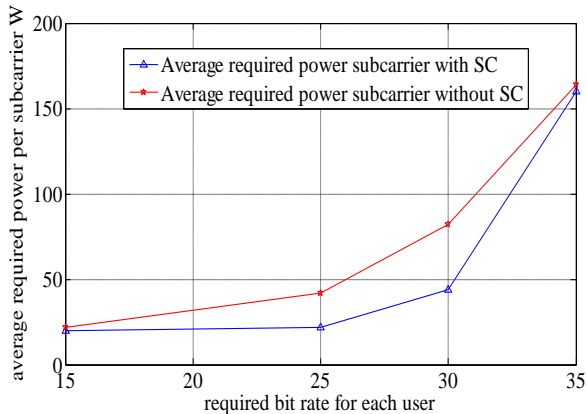


Fig. 4.1 Required power by real time user vs number of subcarrier for real time user.



**Fig. 4.2 Total throughput for non real-time user vs number of subcarrier used by real time user.**



**Fig. 4.3 Average required power per subcarrier vs req bit rate.**

In Fig. 4.2,  $W_{nrt}=8$  and  $\Omega_k=1/8$ ,  $k$ . We notice that there is significant increment in the system capacity by using RA-SC. With RA, throughput at 16 subcarriers is zero but with RA-SC, it is 235 bits/OFDM symbol and when 25 subcarriers are used, throughput increases from 185 bits/OFDM symbol to 310 bits/OFDM symbol and when 34 subcarriers are used, throughput increases from 193 bits/OFDM symbol to 258 bits/OFDM symbols and throughput increases further in comparison to RA algorithm for the remaining subcarriers.

In Fig. 4.3, average required power per subcarrier given as  $P_{rt}/N$  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.

## V. CONCLUSION

Superposition coding theorem in conjunction with MA algorithm for real time (potential and degraded) user for calculating the power required by real time users and then SC theorem in conjunction with RA algorithm for non-real time (potential and degraded) users for maximizing the throughput of the non-real time users, as system throughput is only dominated by throughput of non-real time users. Throughput of the real time user is fixed and provided. The

results shows that algorithm performs better than MA algorithm and RA algorithm without SC. 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. The complexity of remaining step is same. The overall computational complexity of RA-SC algorithm is same as RA algorithm. Superposition coding can be easily applied for OFDMA system to any allocation algorithm.

We have utilized Superposition Coding for resource allocation where only single transmit and receive antenna was used. But In future we would consider two antenna at both transmitter and receiver side which would requires STBC block coding to be done in conjunction with the SC Algorithm.

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