Superposition Coding Scheme for Subcarrier & Bit Allocation in OFDM System

Ashish Tiwari, Mukesh Kumar, A.K.Jaiswal, Rohini Saxena

Abstract: Orthogonal Frequency Division Multiple Access (OFDMA) refers to aradio transmission technique based on dividing the frequency channelinto 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 toeliminate or reduce intersymbol interference (ISI) by increasing the symbol time largeenough so that the induced delays produced by channel are only insignificant portionof the symbol duration, which is typically less than 10 % and the delay spread being agood measure of this in wireless channels [1]. In OFDM subcarriers are chosen in sucha 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 knowthat symbol duration is proportional to the data rate, dividing the data stream into manyparallel streams enhances the symbol duration of each individual stream so that finallythe delay spread is only a small part of the symbol duration. In OFDM the subcarriersare chosen in such a way that they are all orthogonal to one another over the symbol duration,

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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 fixedresource allocation, where we do not utilize the knowledge of channel state informationand users are having predetermined knowledge of subcarriers provided to them. Thisallocation is also known as static resource allocation [6]. Another one is dynamic resourceallocation, where each user take full advantage of channel gain information in selectingthe best subcarrier for it in order to increase the total throughput of the system [6],[7].

Again based on different optimization problem resource allocation canbe divided into two parts-first is MA optimization for real time users [5],[10],[12],[14],[16], with anobjective to minimize the total transmit power while maintaining the rate and Bit ErrorRate (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 theconstraint 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 informationat 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.edegraded user S1 and the signal related to the potential user S2 the transmitted signal Sis defined as follows:

$$S = S1 + S2=A. \quad (2.1)$$

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

A single transmit and receive antenna is considered. S^1denotes the received signal corresponding to the degraded user side and $\hat{S_2}$ is the received signal corresponding to the potential user side. The expression for $\hat{S_1}$ and $\hat{S_2}$ as follows:

$$\hat{S_1}=h^*_{deg}S+Z^*_{deg} \quad (2.2)$$

$$\hat{S_2}=h^*_{pot}S+Z^*_{pot} \quad (2.3)$$

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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 [3].U^*_{pot}'s signal is considered as a noise by $U^*_{deg}$and then U^*_{deg}decodes its own signal from $S_1^{\wedge}$.

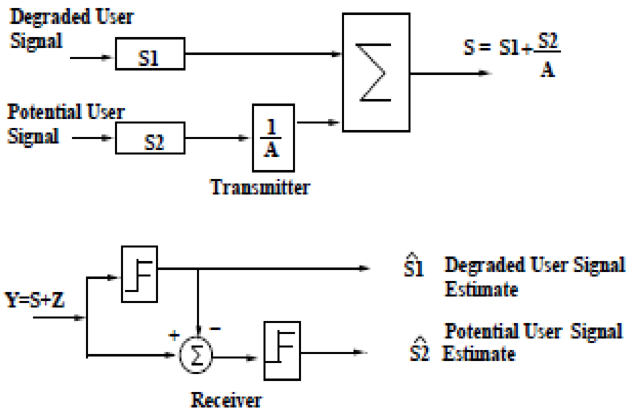

Fig. 2.1 Transmission and reception scheme for superposition coding

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 $S^{\wedge}_1$. 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 $S^{\wedge}_2$ to decode S_2

III.ALGORITHMS WITH SPERPOSITION 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,.....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-SCalgorithm 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 Δpwm_{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 εU_n and n $\varepsilon\, S_n$. Set S= S_n S_k=Ø, ∀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 εU_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 no. of bits transmitted by user k on subcarrier n*, then obtain $SNR_{min}min$ from Table- I

ii. Adjust transmit power P_{n*} to get SNRk,n* = $(P_{n*}(h_{kn*})^2)$ / $(\sigma^2_{k,n*})$ 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 εU_{rt}

(a) Find n* = arg$max_{n\varepsilon\, S}$ h_{kn}

(b) Calculate the marginal utility $\Delta\, p_{kn*}$using the fast marginal utility calculation approach [7].

4. While S ≠ Ø

(a) Find (k*, n*)= arg$max_{n\varepsilon\, S}$ $\Delta\, p_{kn}$.

(b) Seta_{k*n*}=1, βk,ndeg=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$max_{n\varepsilon\, S}$ h_{kn}

ii. Calculate the marginal utility p_{kn*} using the fast marginal utility calculation approach.

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

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

B. Rate Adaptive Algorithm with Superposition Coding Scheme

RA resource allocation algorithm meant to achieve the maximum total throughput of non-realtimeusers (including Potential and degraded) with the constraint of overall transmitpower and user rate proportionality. In this

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algorithm, we separately perform subcarrierand 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 $\mathcal{E}$ U_{nrt} and n $\mathcal{E}$ S_{nrt}. Set S=S^*_{nrt},.

Calculate b_{kn} as

$$b_{kn} = [\log_2(1+\frac{h_{kn}}{\Gamma\sigma^2}\frac{P_{nrt}}{|S_{nrt}|})]$$

(b) Power initialization: for all subcarriers, we evaluate the initial transmit power as 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.

3. *akn* is the subcarrier allocation results and *Sk* 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 $\mathcal{E}$ U_{nrt} and n $\mathcal{E}$ U_{nrt} and n $\mathcal{E}$ 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 using the subcarrier allocation indicator $\beta_{k,n}^{pot}$ obtained from subcarrier allocation step.

2. While (1)

(a) Find k= arg mink ((R_k/Ω_k)
(b) Find n=arg min n $\mathcal{E}$ S_{k*} Δ P_{k*n*}.
(c) if P+ Δ P_{k*n*}≤ 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. 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

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

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≤K) and (Potential User=Not found) do
3. if SNRm,n*≥SNR^{pot}_{min}then
4. Potential User=Found and m^* =m,
5. b_{m*n*}=2 bits , Set a_{m*n*}=1 β^{pot}_{m*n*}=1

$$S_{pot}(m^*) = S_{pot}(m^*) \cup \{n^*\}$$

6. else
   m=m+1
7. end

Table 4.1 Threshold value of SNRkmin 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

IV. RESULTS& DISCUSSION

we evaluate the performance of the MA-SC and RA-SC algorithmby MATLAB.In Fig. 4.1, Wrt=8 and Rrqk =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 totransmit 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 to be same, i.e power become constant for both MA-SC and MA after 58 subcarriers have been allocated to real time users.

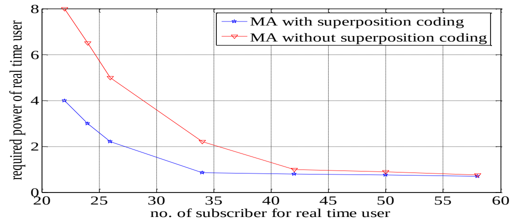

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Fig. 4.1 Required power by real time user vs number of subcarrier for real time user.

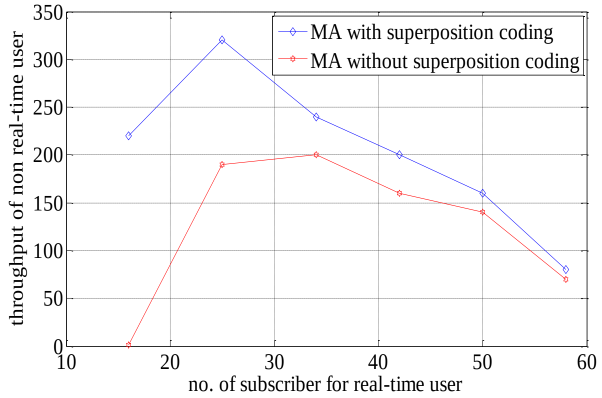

Fig. 4.2 Total throughput for non realtime user vs number of subcarrier used by real time user.

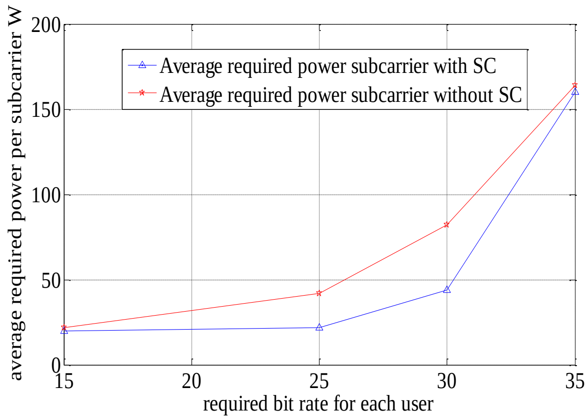

Fig. 4.3 Average required power per subcarrier vs req bit rate.

In Fig. 4.2, Wnrt=8 and Ωk=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 34subcarriers 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. Wrt 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

Superpositioncoding 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(WnrtN) 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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