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Adaptive Bandwidth Allocation for Downlink Ofdma Systems: A New Hybrid Approach for Bandwidth Allocation

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Abstract: Functionality and operation of Radio Resource Management (RRM) are deeply presented in this paper. Discussion of algorithms is also provided. We look mainly to solve the problem of dynamic subcarrier allocation algorithm for Orthogonal Frequency-division Multiple Access (OFDMA) systems. The Rate Adaptive optimization (RA) problem, which maximizes the sum of user data rates subject to total power constraint and individual guaranteed rates, is considered. We describe in this paper BABS (Bandwidth Allocation Based on SNR) algorithm and its different version, which are an intelligent dynamic subcarrier allocation algorithm. We compare the BABS and modified BABS algorithms. Simulation results underline the efficiency of this algorithm and show that the modified BABS gives better performance and results compared with the BABS algorithm.

Key Words: Radio Resource Management, dynamic subcarrier allocation, Rate Adaptive optimization, OFDMA.

INTRODUCTION

The Radio Resource Management tasks performed by cellular systems include admission control, channel assignment, power control and handoff (*Nishith et al.*, 2005). High speed wireless services are increasingly in demand and a need for more throughput per bandwidth to accommodate more users with higher data rates and better Quality Of Service (QoS). In Orthogonal Frequency Division Multiple Access systems (OFDMA), the adaptive resource allocation can significantly improve spectral efficiency (*Woo*, *et al.*, 2008). We explored our problem in this context. The aim of this paper is to introduce the problem of bandwidth allocation among users in an OFDMA system. In the OFDMA system, each user is assigned a subset of the subcarriers for use and each carrier is assigned to one user (*ouwais*, *et al.*, 2008). OFDMA is the most use and robust techniques, it is promise for broadband wireless networks and has been chosen for the IEEE 802.16 standard. Moreover, in this technique bandwidth is divided into subsets which are assigned to distinct users during one OFDM symbol duration.

Generally, Radio Resource Management (RRM) is the level control of radio transmission characteristics in wireless communication systems. Over the last years, resource allocation and RRM in OFDMA involves strategies and algorithms for scheduling and controlling and has been subject of new research activities. Our goal from RRM aims utilizing the radio spectrum resources as optimality as possible.

Several papers focus on static and dynamic (adaptive) resources allocation. Our interest is to present and develop the basic principle of the dynamic radio resources management. The static RRM will not be the object of our study, we refer to other references for that.

The remainder of the paper is organized as following; section II presents the adaptive resources allocation for OFDMA systems. The subcarrier assignment for downlink OFDMA systems is investigated in section III. In section IV, simulation results are presented and we proposed a new approach for bandwidth allocation in section V. The paper is concluded in section VI.

Adaptive Resources Allocation for OFDMA Systems: The adaptive resource allocation schemes consist to adjust the radio parameters network to the traffic load, user positions, QoS etc. Power control, link adaptation and Dynamic Channel Allocation (DCA) examples of the adaptive radio resources management. In our case, the dynamic channel allocation is our main objective and we try to make recommendations at this subject. One of the biggest advantages of OFDM systems is the ability to allocate power and rate optimally across frequency (*kivanc,* 2005).

The structure of the adaptive multiuser OFDM system under consideration is shown in the following part of our study. In this part we present the system model used and formally introduces the problem being in this paper.

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System model
Our system is built as:

- N: is the number of subcarriers needed for modeled data,
- n: the number of subcarriers needed for each users. This number is variable and
- depends to the rate and QoS of considered,
- K: the number of users,
- R_k (k: 1..K): is the rate of the k_{th} user in *bits/s*

If we consider R as the total rate, the rate of each subcarrier can be represented by the following expression:

$$R_{subcarrier} = \frac{R}{N} \quad (1)$$

And the rate for one user is given as:

$$R_{user} = * \frac{R}{N} \quad (2)$$

For the problem formulation, we consider the Rate Adaptive optimization problem (RA), that maximizes the sum of user data rates subject to total power constraint and individual guaranteed rates (*Leng, et al.*, 2005). In the next section, various types of optimization problems are described and the RA problem is formulated. We want to describe in details all types of optimization technics except that looking for RA optimization.

$$\begin{cases} \max \sum_{u}^{U} = 1^{r} u \\ Subject\ to\ P_{Tr\max'}\ (1 \le u \le U) \\ and\ r_u \ge r_u^0 \end{cases} \quad (3)$$

Where U is the total number of users, N is the number of OFDMA subcarriers, P_{tr},max, is the total power constraint, r and r^o are, respectively the data rate and data rate constraint (minimum data rate) for user u.

In a radio resources allocation, two different approaches are proposed. The first one *ApproachA*, considers that subcarriers assignment (step 1) and power allocation (step 2) are two steps which can be carried separately. However, *AppproachB*, makes the subcarriers assignment and power allocation simultaneously (*Carle,* 2008). Fig. 2 represent these two distincts approaches.

Subcarrier Assignment for Downlink OFDMA systems: Generally, the problem of radio resource allocation especially if we considered the subcarrier assignment, is divided into two separated tasks. In this paper we take the same strategy as in (*Carle*, 2008; *kivanc, et al.*,2000 and *Pfletschinger, et al.*, 2002). The previous tasks can be so expressed by the following steps:

- Determine the number of subcarriers to be allocated to each user,
- Assign each subcarrier to one specific user.

The first task presents the aim of our work. It is known as the bandwidth allocation problem. The second one as subcarrier assignment. In this case we will focus in the first question, because the seconde won't be part of our work.

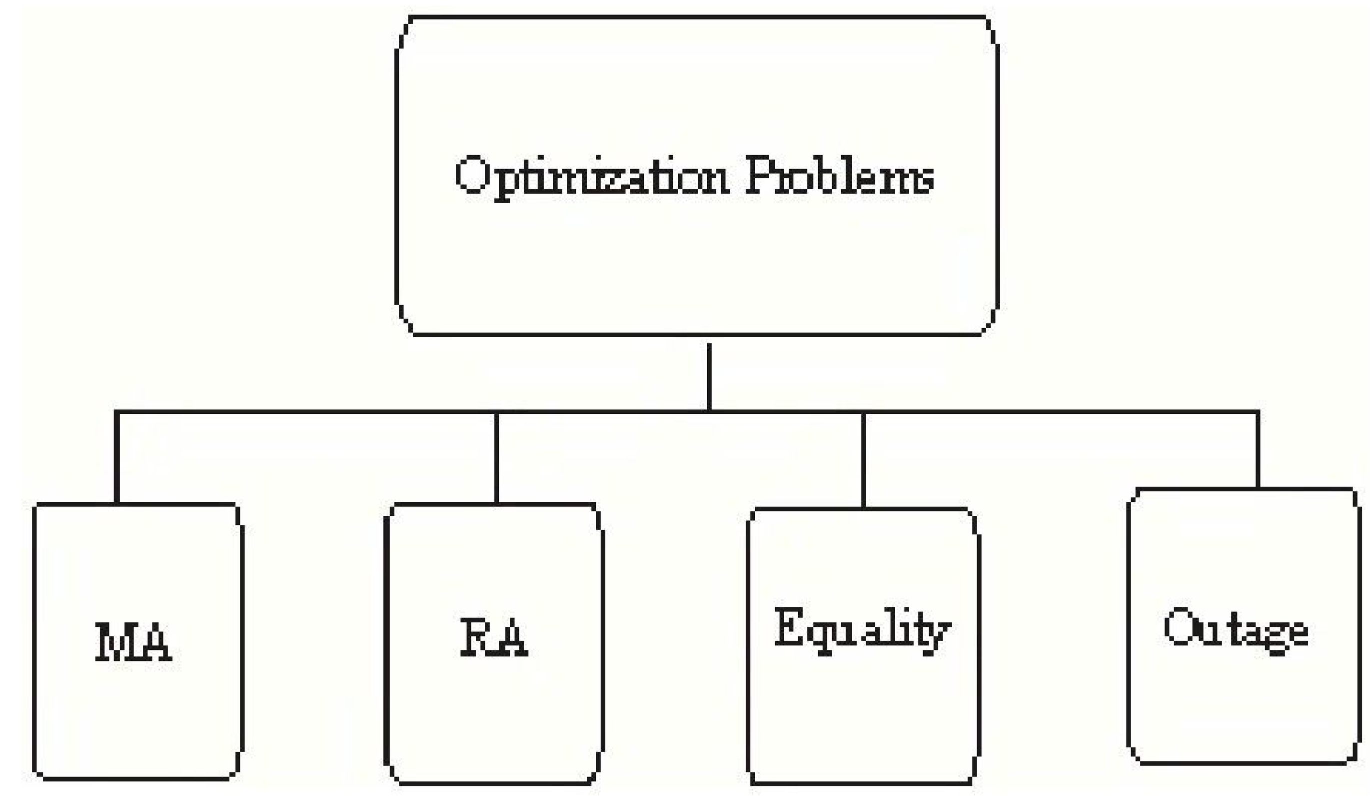

Fig. 1: Various types of optimization problems

- RA (Rate Adaptive optimization problem),
- MA (Margin Adaptive optimization problem),
- Equity optimization problem,
- Outage optimization problem.

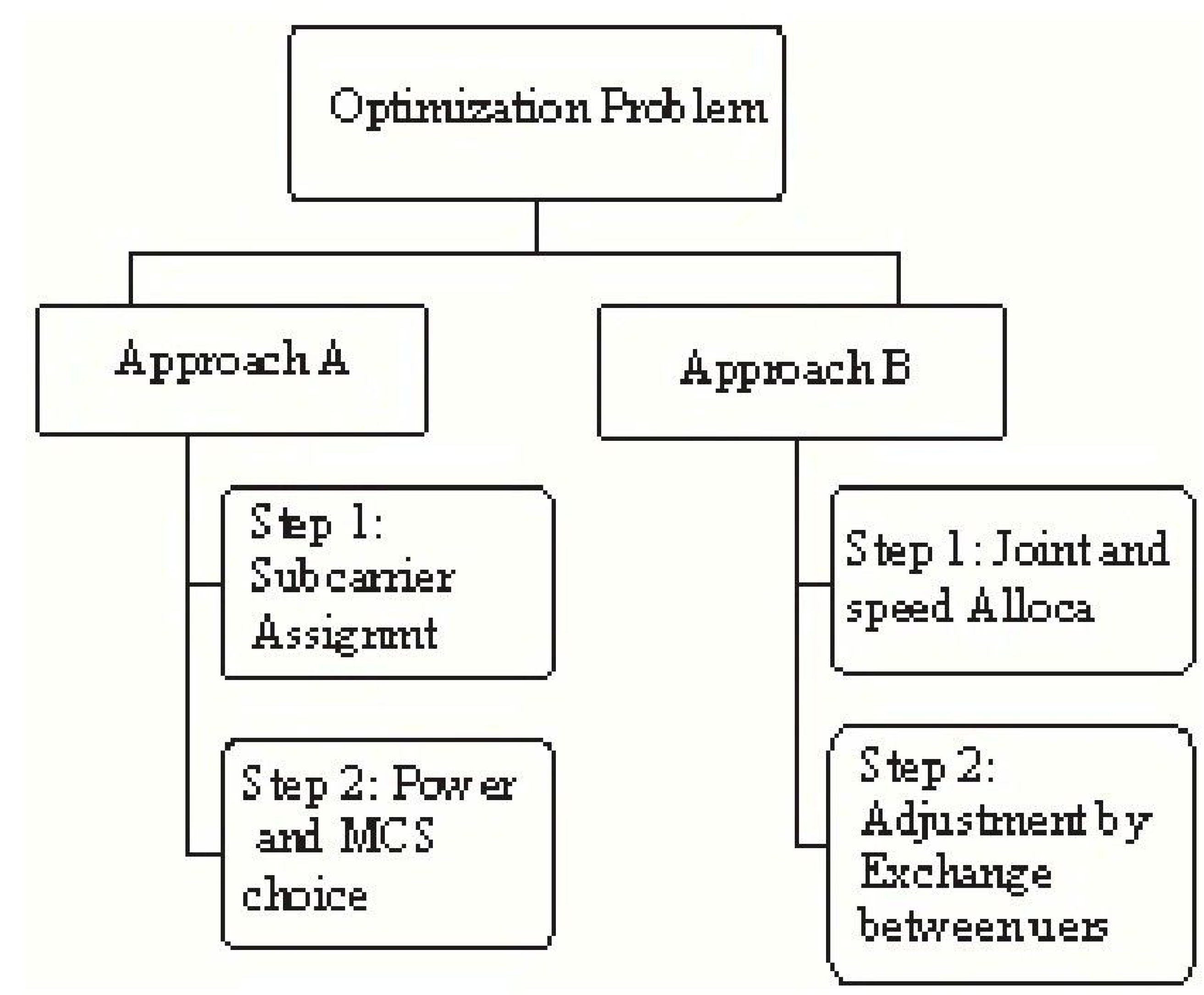

Fig. 2: Different approaches for an optimization, techniques

MATERIALS AND METHODS

Bandwidth Allocation problem: In this section, our objective is to determine for each user u, the number of subcarriers N_u. For this reason, various algorithms are proposed for resolving this type of problem. The most of bandwidth allocation algorithms for OFDMA downlink system, uses the first approach (*ApproachA*), because the majority of the algorithms which uses *ApproachB*, solves an MA problem (*Leng*, *et al.*, 06).

Bandwidth Allocation Algorithms: We attempt in this part to solve the bandwidth allocation problem, i.e., determining the number of subcarriers for each user. We describe the bandwidth allocation algorithms, in this section. The optimum solution to the bandwidth allocation problem can be found by an algorithm as illustrated in the following paragraph. This algorithm is known as Bandwidth Assignment Based on SNR (BABS). The aim of this algorithm, is to decide the minimum number of sub-channels to be assigned to satisfy the required data rate of each user. An average SNR *(Signal to Noise Ratio)* for each user must be used in order to decide the number of subcarriers that user will have (*kivanc, et al.*, 2001; *Ko, et al.*, 2006).

Consider the problem described in section II, supposing that H_k is the channel gain of user k on every subcarrier n. The channel gain on every subcarrier is defined as (kivanc, *et al.*, 2001).

$$H_k = \sum_{n=0}^{N-1} \left| H_k(n)^2 \right| / N \qquad (4)$$

Let user k be allocated m_k subcarriers. If the gain on every subcarrier is the same, the optimal rate power allocation to transmit can be expressed by:

$$R_T = \frac{R^k \min}{m_k} \qquad (5)$$

In this case, the total transmission power can be rephrased as:

$$R_T = m_k f\left(\frac{r^k \min}{m_k} \right) / H_k \qquad (6)$$

Our objective is to find a set of m_k subcarriers when $k = 1..k$.

To find the optimal distribution of subcarriers among users given the flat channel assumption, a Bandwidth Allocation Based on SNR (BABS) algorithm is proposed. The BABS algorithm can be defined by the following steps:

- Allocate to each user the minimal number of subcarrier which is needed,
- if the total number of requested subcarrier higher than the available total number of subcarrier N, we eliminate the users having the minimum subcarrier allocated,
- if the total number of requested subcarrier is lower than the available total number of subcarrier N, we allocate the additional subcarriers to the users, which is reduced his transmission power when we added an

additional subcarrier.
The previous algorithm is defined by:

$$m_k \leftarrow \left\lceil \frac{R^k \min}{R \max} \right\rceil, k = 1,..,K$$

$$while \sum_{K}^{K} = 1 m_k > N, do$$

$$k^* \leftarrow \arg\min_{1 \le k \le k} m_k$$

$$m_k^* \leftarrow 0$$

$$endwhile$$

$$while \sum_{k}^{k} = 1 m_k < N, do$$

$$G_k \leftarrow \frac{m_k + 1}{H_k} f\left(\frac{R^k \min}{R \max} \right) - \frac{m_k}{H_k} f\left(\frac{R^k \min}{R \max} \right)$$

$$k = 1,..,K$$

$$l \leftarrow \arg\min_{1 \le k \le k} G_k$$

$$m_l \leftarrow m_l + 1$$

$$endwhile$$

Algorithm.1: Bandwidth Allocation Based on SNR Algorithm (BABS)

In the BABS algorithm, we eliminate users which have the minimum subcarrier to allocated if $m_k > N$. As a result, users with high data rate have a privilege compared with others. While this type of users need a lot of subcarriers.

Likewise, it is more better to eliminate one user with high data rate and high number of subcarriers for guaranteing a service to several users instead serving few users with a high quality of service. Consequently, all users can having the same probability to be served. For this reason, the modified BABS algorithm was appeared and the aim objective of this algorithm is to eliminate the user whose, the needed number of subcarriers is the most near to the difference between the number of subcarriers needed by the system and the available number.

The modified BABS algorithm can be expressed as following:

$$R^1_{\min} \le R^2_{\min} \le \ldots \le R^k_{\min}$$

$$m_k \leftarrow \left\lceil \frac{R^k_{\min}}{R_{\max}} \right\rceil, k = 1,..,K$$

$$while \sum_{k=1}^{k} m_k - N \le \max_{1 \le k \le k} m_k \; or \; \max_{1 \le k \le k} m_k > N, do$$

$k^* \leftarrow \arg\max_{1\le k\le K} m_k$

$m_{k^*} \leftarrow 0$

endwhile

while $\sum_{k=1}^{K} m_k > N$, *do*

$K^* \leftarrow \arg m_{k-1} < \sum_{k=1}^{K} m_k - N \le m_k$

$m_{k^*} \leftarrow 0$

endwhile

while $\sum_{k=1}^{K} m_k < N$, *do*

$$G_k \leftarrow \frac{m_k+1}{H_k} f\left(\frac{R_{min}^k}{R_k+1}\right) - \frac{m_k}{H_k} f\left(\frac{R_{min}^k}{R_k}\right) \quad k = 1,..,K$$

$l \leftarrow \arg\min_{1\le k\le K} G_k$

$m_l \leftarrow m_l + 1$

endwhile

Algorithm.2: Modified Bandwidth Allocation Based on SNR Algorithm (MBABS)

Here $R^k min$ is the minimum required number of bits per unit time for user k and R_{max} is the maximum number of bits that can be transmitted from a subcarrier.

Numerical results: The system under consideration has parameters given in the following Table.

Table 1: System Parameters

Available Number of Subcarrier	64
Number of Users	10
Max Number of Bits/Subcarrier	08
Requested Number of Bits/user	160
Max available Data Rate	512
Channel Type	Rayleigh

Fig.3, compares the data rate of the BABS algorithm with that of the modified BABS. In this comparison, bandwidth allocation is performed using the modified BABS algorithm. On top of that, we plot the maximum available data rate and required data rate.

The gap between data rate obtained through BABS and modified BABS Algorithm is shown in Fig.4.

We observe, that the modified BABS algorithm allow an important gain of data rate than the BABS algorithm. We can see also in the same figure a clear gap between the two algorithms.

Fig.5 shows a comparison of the transmitted power, when bandwidth allocation is performed using BABS and modified BABS algorithm. The transmitted power of the BABS algorithm is more important than that of the modified BABS. The requested power is also comparable with the two previous parameters. We conclude that the advantages of the two algorithms is to optimize the transmission power in comparaison with that requested.

Finally and for more details, we attempt to plot the bits distribution on the subcarriers. When the number of users is 10, the number of hopeless bits per user is more important with the BABS algorithm than the number of

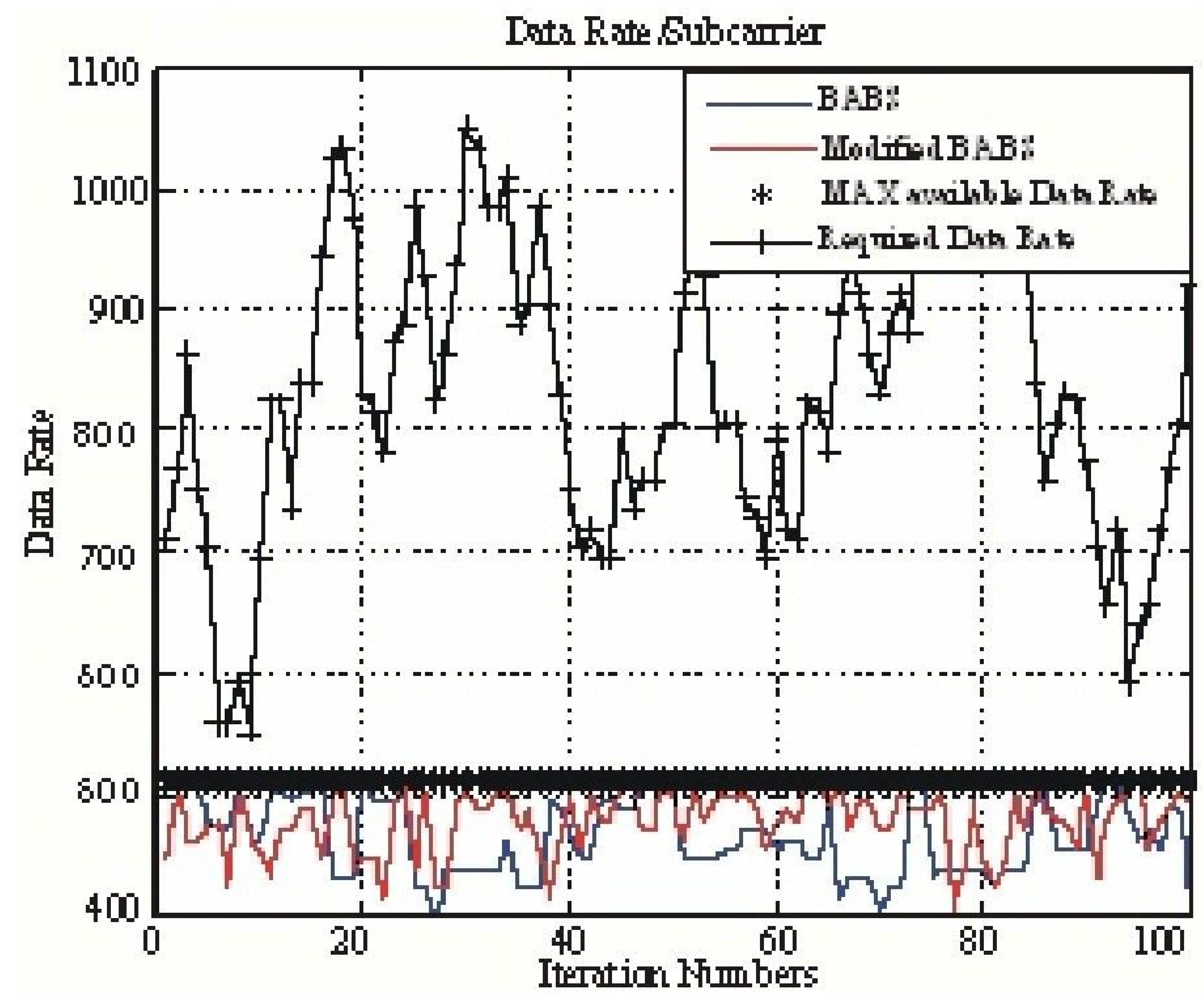

Fig. 3: Data Rate per Subcarrier with BABS and BABS Algorithms

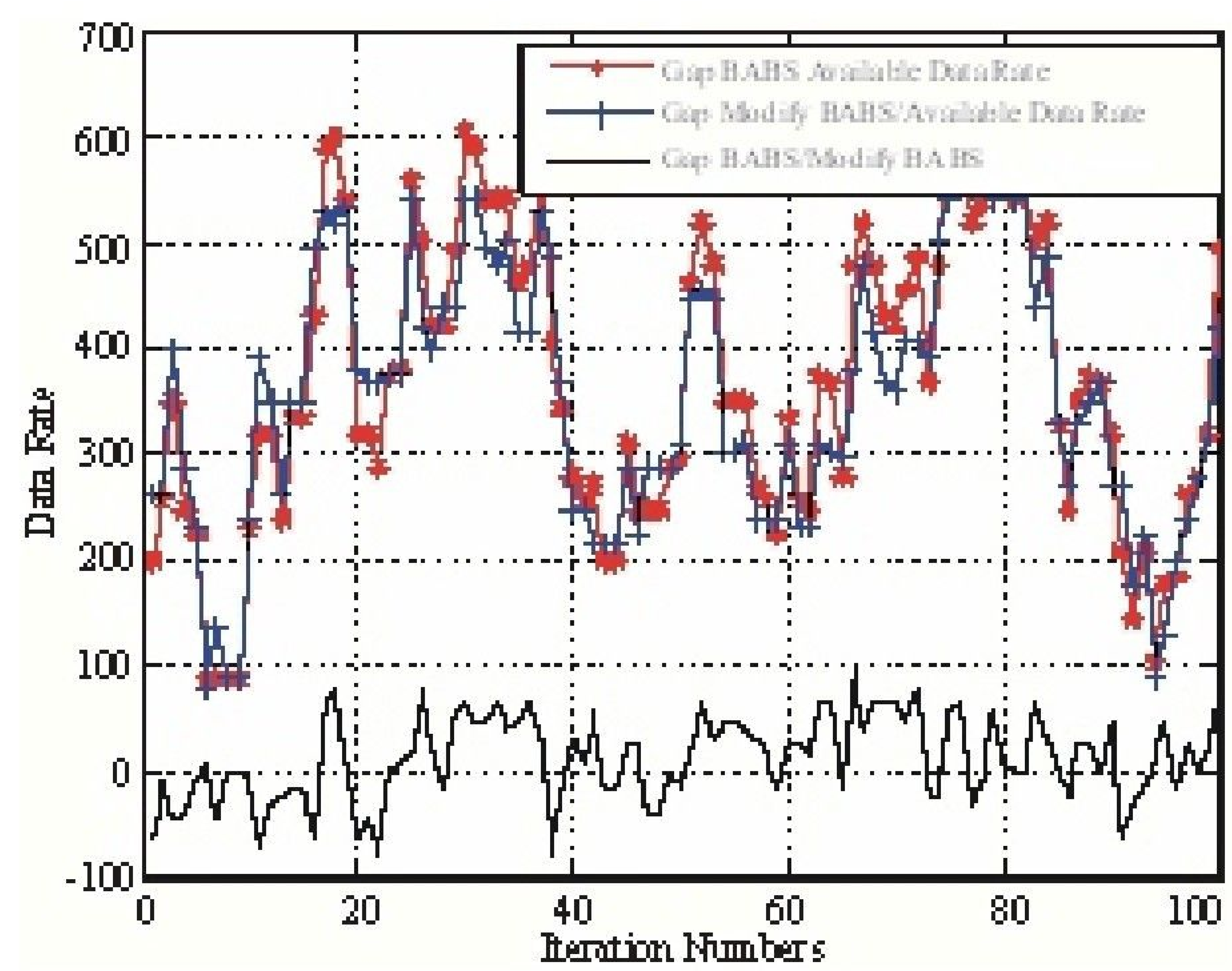

Fig. 4: Gap between the different obtained Data Rate

hopeless bits per user in fig. 6 with modified BABS algorithm as shown in fig. 6.

Proposed Solution: Hybrid BABS Algorithm (HBABS): As proved in the literature, OFDMA system an optimal choice leading to maximize the data rate under a limited power constraint.

Here, the two farmer algorithms described before would be exploited as contributed and putted recommendation for new research works. That for what we will present our new appro ch for the algorithm BABS named Hybrid BABS (HBABS).

The new approach of algorithm is described as following:

- First: based on the BABS algorithm, decide the number of subcarriers m_k needed for each user,
- Second: The modified BABS algorithm, serves then to find the optimal distribution of subcarriers among users.

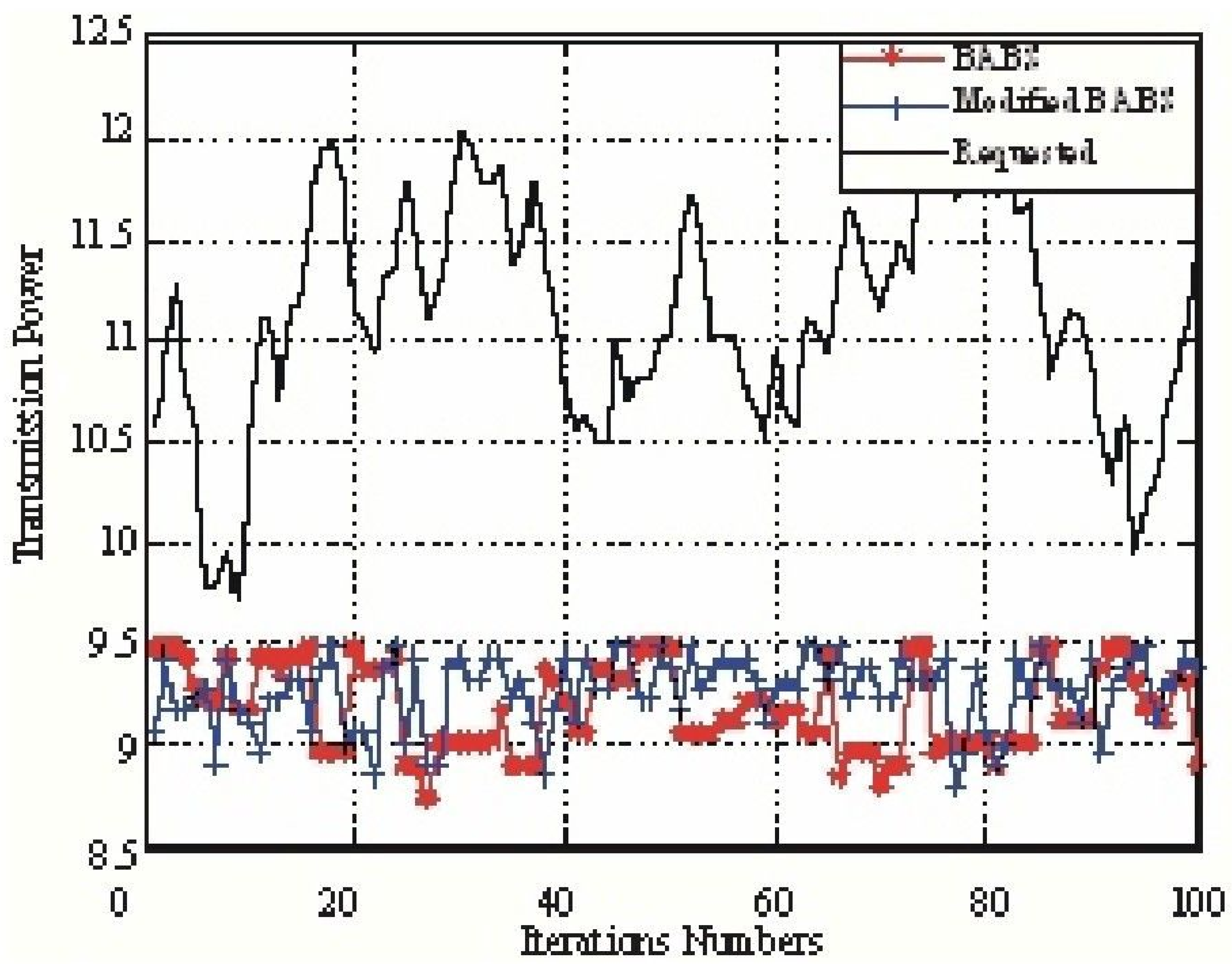

Fig. 5: Transmission Power with BABS and modified BABS Algorithms

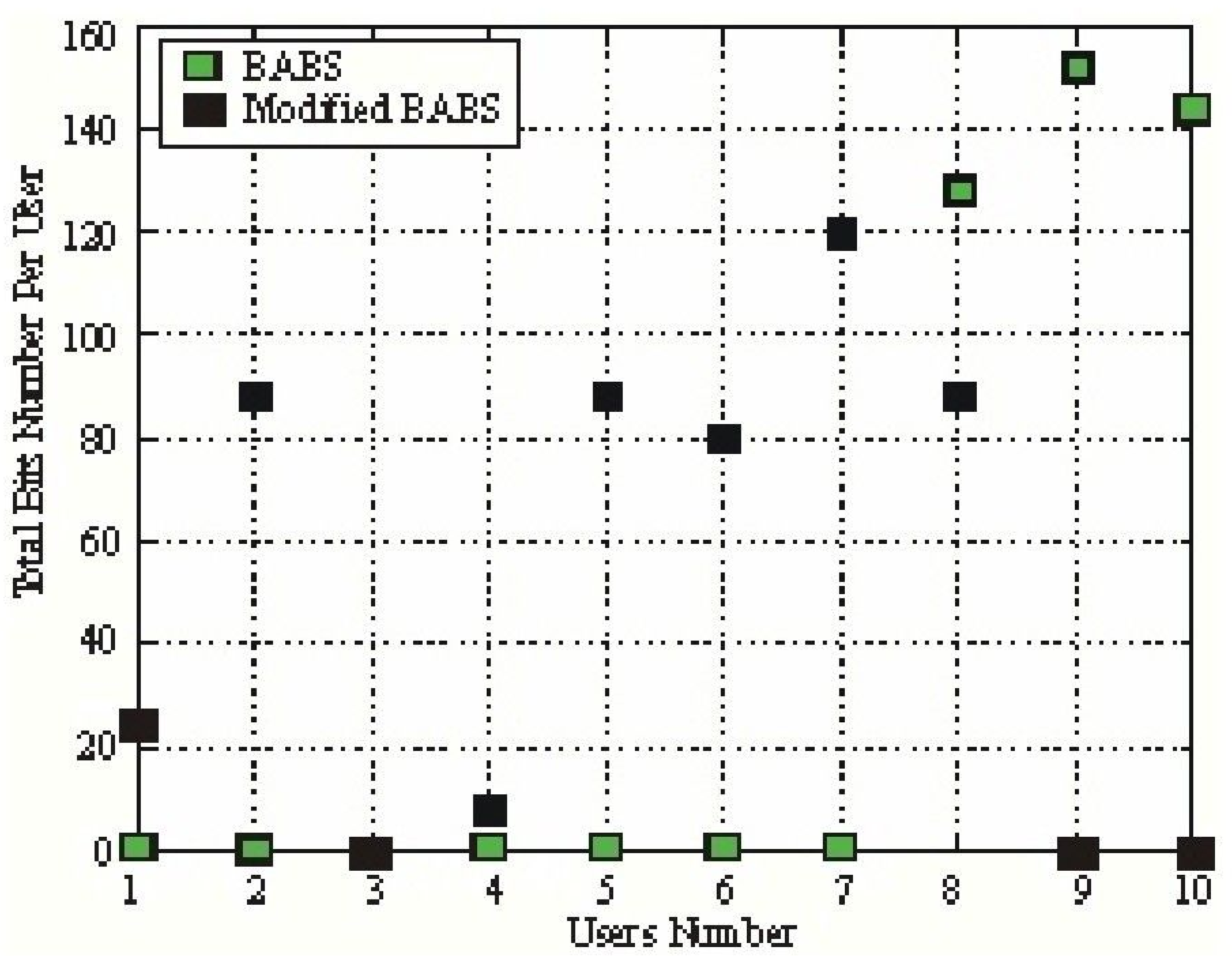

Fig. 6: Bits distribution on the subcarriers per user

- Finally: Allocate the subcarriers which have the maximum data rate obtained through the BABS and modified BABS algorithm.

This contribution is more explained through the fig. 7.

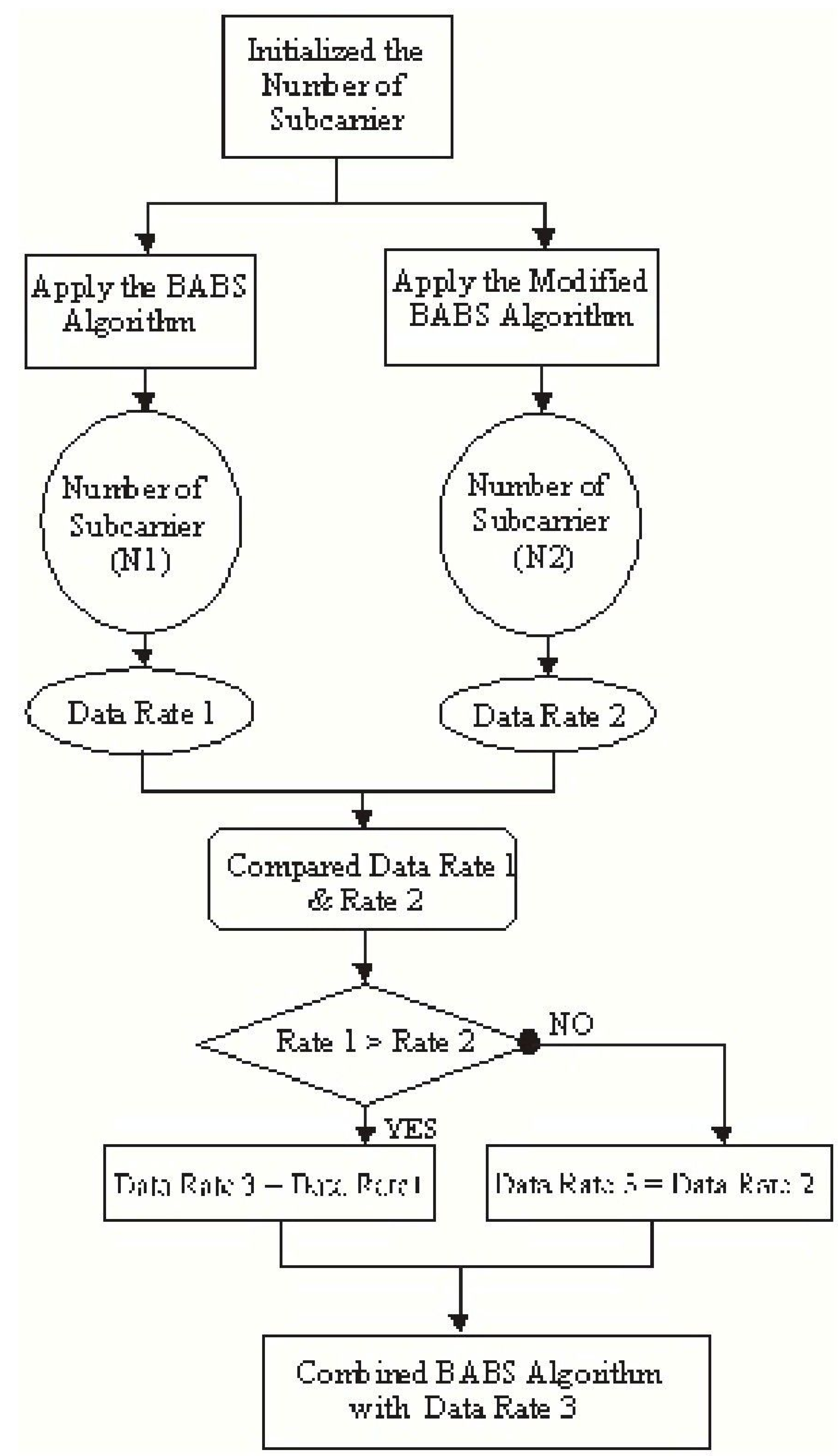

Fig. 7: Proposed Algorithm: Hybrid Bandwidth Allocation Based on SNR Algorithm

Performance Validation: In this section, the performance data rate by the proposed Hybrid BABS (HBABS) algorithm is validated. Fig. 8 shows the data rate per subcarrier for the HBABS algorithm, we can see also in the same figure a comparison between modified BABS and combined BABS. We can observe, that the Hybrid BABS (HBABS) permit to obtain an important data rate than the modified BABS algorithm which is more efficient when compared with the BABS algorithm in the previous section. The Hybrid BABS is more efficient and robust than the two lasts algorithms.

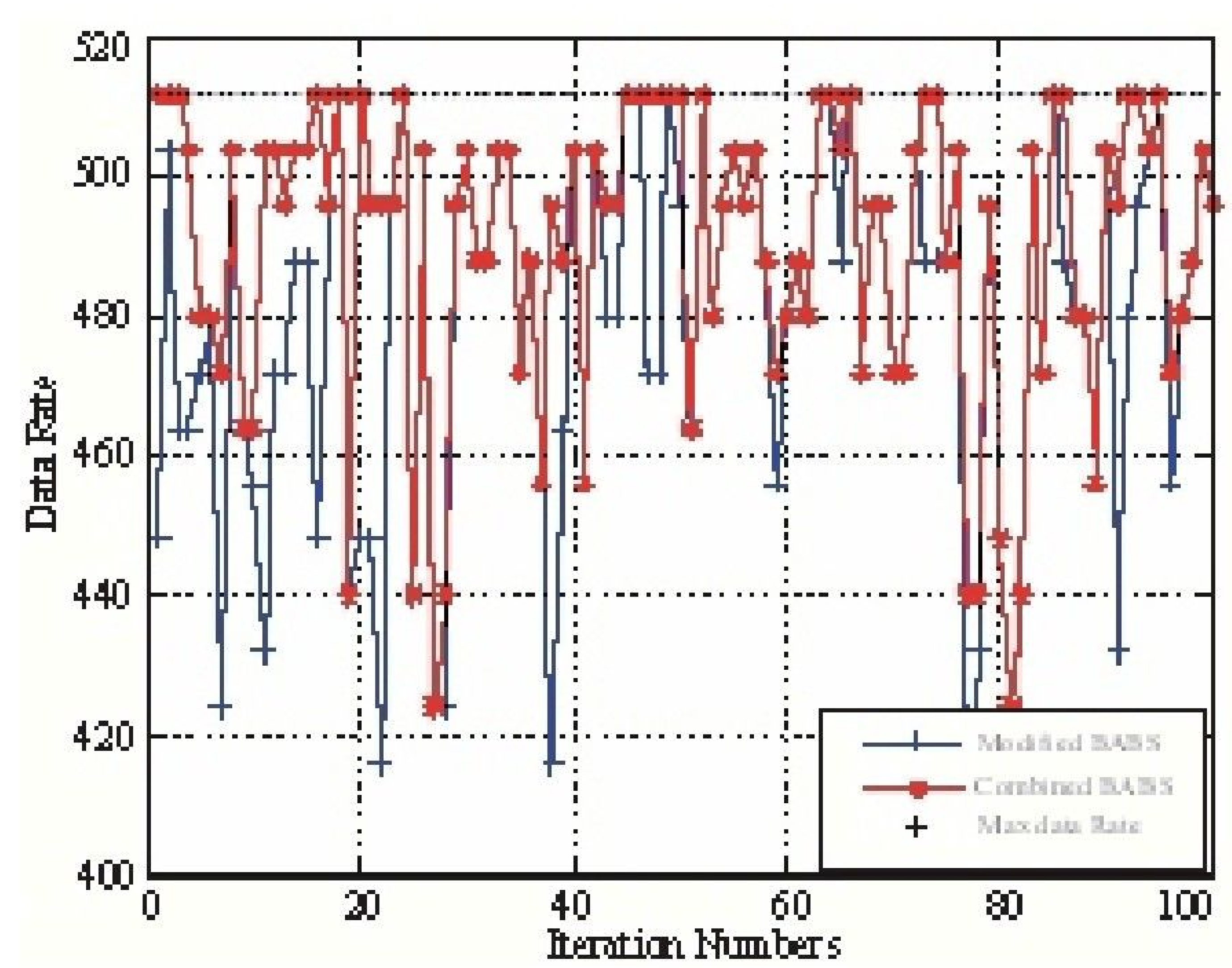

Fig. 8: Comparison between Hybrid and Modified BABS algorithms

CONCLUSION

In this paper, we have considered an efficient subcarrier allocation algorithms. A computationally class of algorithms for allocating subcarriers among users in multicarrier system, such as; Bandwidth Allocation Based on SNR (BABS) and Modified BABS algorithms has been described. The two previous algorithms enables the new approach of bandwidth allocation problem with low computational complexity than the others. We have called our algorithm: Hybrid Bandwidth Allocation Algorithm (HBABS). This approach allows efficient results in terms of data rate and power transmission. Simulation shows that a better resource allocation strategy has been achieved by a new approach in practical system.

Appendix: The objective is to find a set of *k* feasible bandwidth allocation, defined below (*kivanc*,2005):

Definition: Let the bandwidth allocation, $[m_k]$, be the set of integers $\{m_k : 1 \le k \le K\}$, where m_k represents the number of carriers assigned to user *k*. Let *F* denote the set of feasible bandwidth allocations, i.e. $[m_k] \in F$ if and only $[m_k]$ satisfies the following equations:

$$\sum_{k}^{K]} = 1 m_k = N \tag{7}$$

$$m_k \in \left\{ \left\lceil \frac{R^k_{\min}}{R_{\max}} \right\rceil, \ldots, N \right\}, 1 \le k \le K \tag{8}$$

When the gain on every subcarrier is the same, the optimal rate-power allocation is to transmit $\frac{R^k_{\min}}{R_{\max}}$ bits on each subcarrier, resulting in total transmission power $m_k f\left(\frac{R^k_{\min}}{m_k}\right)/H_k$. Define the transmission power when m_k carriers are allocated to user *k*:

$$G_k(m_k) = \frac{m_k}{H_k} f\left(\frac{R^k_{\min}}{m_k}\right) \tag{9}$$

Whenever a new carrier is allocated to user k, the power received at the base station from user k is reduced by:

$$F_k(m_k) = H_k\, G_k(m_k + 1) - H_k\, G_k(m_k) \tag{10}$$

To find th optimal distribution of subcarriers among users given the flat channel assumption, a greedy descent algorithm is proposed, similar to discrete waterfilling. The Bandwidth Assignment Based on SNR (BABS) algorithm is depicted in page.3.

Assumption (a): Assume that the set of feasible bandwidth allocation, F, for the optimization problem described in equation (8) is not empty, i.e. there exist at least one distribution of carriers $[l_k]$ that satisfies Equations (7)-(8).

Assumption (b): Assume that for all user k, the function $F_k(m_k)$ defined in Equation (10):

- Negative definite

$$F_k(m_k) < 0 \; \forall m_k \in N$$

- A monotonically increasing function of m_k,

$$F_k(m_k + 1) > F_k(m_k) \; \forall m_k \in N$$

The last assumption is always true for that flat fading channels when the rate power function is strictly convex and uniformly increasing, like the rate-power function in (*kivanc*, 2005).

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