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Chapter 7
Resource Request Mapping Techniques for OFDMA networks

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Abstract Wireless broadband networks are designed to provide high quality services to multiple mobile users simultaneously. The IEEE 802.16e Mobile WiMAX standard uses Orthogonally Frequency Division Multiple Access (OFDMA) schema for frame structure. OFDMA defines rectangular resource allocation of time slots and frequency carriers, separating in this way the channel into multiple subcarriers. This structure is used for arranging the incoming user requests. Aimed to increase the bandwidth utilization, while arranging the incoming user requests into an effective way, we have considered and evaluated Bin-Packing algorithms. Subsequently in the following sections are presented analysis and design of various Bin packing algorithms developed in our simulator. Moreover, a combined algorithm is proposed, named Guillotine First Fit Algorithm and a new version of the Shelf First Fit Algorithm. Simulation's results concerning performance of implemented algorithms in different input values are gathered, analyzed and compared. The results are encouraging and provide indications regarding usage of the proposed algorithms in practice.

1 Introduction to Wireless Communication and Bin Packing Algorithms

The development of mobile communication technologies is influenced by furious rate improvements in information technology and industry. These transformations

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enabled greater usage of mobile communication facilities [1]. Another indication of mobile technologies expansion includes the improvements of mobile communication services from generation to generation [2-4]. Developed services comprise of: data transfer, international communication - roaming, multimedia services and voice over IP services, e-commerce, global positioning system services, and many other related services [5-8]. These facts lead to perceptions that mobile communication technologies are integral part of human's everyday life. Considering new services provided by different generations of mobile communication technologies [9], it is worth to mention that changes are required in both radio access part of the networks and in the core part, too [10]. Concerning the radio access part, various multiplexing techniques have been developed, such as: Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA), Wide Code Division Multiple Access (WCDMA), or Orthogonally Frequency Division Multiple Access (OFDMA).

Regardless of the generation of mobile communication technologies, the prior aim is the user satisfaction with the quality of offered services and the ability to be always ready to support different user requirements. For these reasons, large capacity of bandwidth is required. This implies higher data rates, support of more services and fulfillment of more user requirements in an efficient way. In order to accomplish these needs, various multiplexing techniques may help. One of them is OFDMA that is used in fourth generation (4G) technologies [11]. OFDMA is known as a technique used in 4th generation standard- WiMAX [12], and it defines a rectangular resource space (time by frequency) in which multiplexed user requests are arranged. This technique is widely used in new wireless networks of IEEE standard, digital television, audio broadcasting and 4G mobile communications [13].

Bin packing algorithms present a method which may be used to increase utilization of bandwidth and to organize incoming OFDMA multiplexed user requests in an efficient way. Two dimensions are needed, corresponding to time and frequency. These dimensions are used in algorithms as input values for width and height of one rectangle which needs to be arranged into a specific shelf/bin. Different bin-packing algorithms exist with different scaling factors, which imply the usage of different properties for arrangement. We can mention: Shelf algorithms, Guillotine-able algorithms, Skyline algorithms, Maximal Rectangle algorithms, etc. Besides the algorithm to use, the objective is to arrange user requirements in a most possible efficient way, in order to provide high bandwidth utilization.

The focus here is to arrange different requests, which are multiplexed using OFDMA schema. User requests are arranged in different time slots and frequency sub-carriers. These parameters are used as input dimensions for Bin Packing algorithms. Therefore, our first aim is to present a new version of Shelf First Fit Algorithm and a combined-new algorithm which we have named it Guillotine First Fit Algorithm. These algorithms are part of Bin Packing algorithms. Our second aim is to simulate and compare gathered results based on performance of these algorithms and their applicability on industrial world.

The structure of the chapter is as follows: Section 2 presents related research and proposed solution for bandwidth utilization; Section 3 discusses concatenation of user request dimensions in OFDMA and Bin packing algorithms, while section 4 presents a thorough view of the developed simulator. Next, the implemented algorithms are analyzed, especially Guillotine First Fit and Shelf First Fit. Section 6 presents the simulation results and critically discusses usage of each algorithm in industry. Finally, the last section provides the overall conclusions.

2 Related Research and Proposed Solutions for Bandwidth Utilization

A frequent problem that telecommunication industry confronts is the usage of a method which will increase bandwidth utilization while organizing incoming frames in an efficient way. Towards this problem, different schemas have been suggested. All these schemas propose usage of a specific algorithm, in some cases proposed an algorithm and in others developed one. However, compared to them, our application comprise of five developed and implemented algorithms each with a different working scenario, simulated with the aim to address the bandwidth optimization problem.

In [14] a simple heuristic algorithm is proposed for the two-dimensional rectangular mapping. This schema may be used for downlink bursts in IEEE 802.16e Mobile WiMAX, ensuring strict QoS requirements. The algorithm is called eOCSA (enhanced-One Column Striping with non-increasing Area first mapping) and it presents an approach for handling the rectangle mapping problem. It first maps the resources for each subscriber into a downlink burst in a rectangular type. There is also a prior version (OCSA) which maps the resource allocation blocks from bottom to top and right to left [15]. The eOCSA aim is to maximize the throughput through sorting the resource requests in a descending order (largest first). Then, they are mapped from bottom to top and right to left to allow the space for the variable.

Aimed to minimize the waste of utilized bandwidth, a group of researches in [16] proposed a method that dynamically adjusts the downlink-to-uplink ratio. Dynamic Ratio Determination (DRD) monitors the mapping operation of both downlink and uplink sub-frames, and while considering load balance it receives feedback from both processes and proceeds to the appropriate selection of the forthcoming downlink-to-uplink ratio.

The idea how to arrange two-dimensional blocks which consists of time and frequency of multiple-users in OFDMA networks is analyzed in [17]. The authors in this paper prove that the problem of resource allocation in IEEE 802.16 in NP-complete. They propose a low complexity heuristic algorithm to solve the length/width variable of the two-dimensional packing problem. The Weighted Less Flexibility First (WLFF) algorithm provides a set of guidelines to choose one allocation schema for each iteration. Gathered simulation results showed that the performance of WLFF is comparable to the recursive searching methods, while the complexity is much lower.

Similarly, aimed to maximize the available radio resources in WiMAX, the Greedy Scheduling Algorithm (GSA) is proposed [18]. This algorithm is capable of transforming 2D WiMAX OFDMA link packing problem into 1D searching problem.

3 Affiliation of User Request Dimensions in OFDMA and Bin Packing Algorithms

Bin Packing algorithms present methods which are used while observing packing problems. In these cases, a resource (one or more dimensional) is given and an amount of items which need to be packed there is defined. Two-dimensional Bin packing problems deal with allocation of a set of *n* rectangles, each having width and height dimensions, into a predefined number of bins without overlapping [19-22]. Hence, the idea is to use the minimum number of bins with the same capacity, in order to accommodate the incoming user requests [23].

In this type of problems, a number of elements with different parameters have to be packed into a finite number of bins [24- 26]. The objective is to minimize the number of used bins while arranging incoming rectangles. The affiliation with Orthogonally Frequency Division Multiple Access technique can be found in usage of Bin Packing algorithms to arrange user requests which are multiplexed using the same technique. Similarly to OFDMA, two dimensions are needed, which correspond to rectangle dimensions used in Bin Packing algorithms. In this way multiple user requests multiplexed in time and frequency diversity are represented as rectangles which have two dimensions, width and height corresponding to time and frequency.

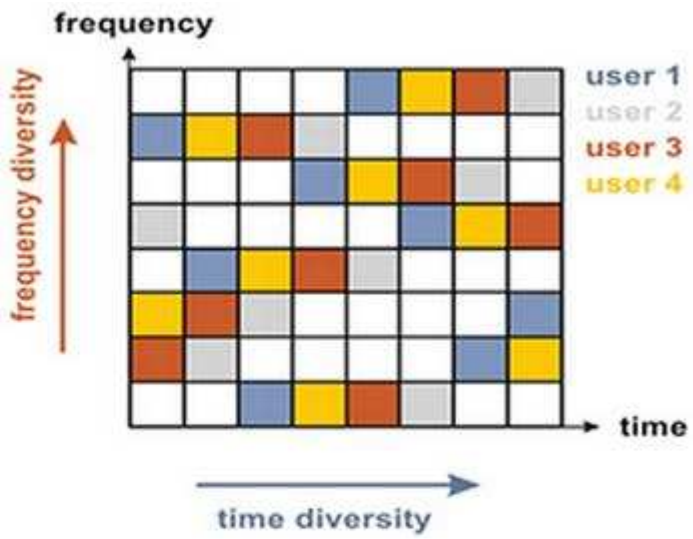


Fig.1. OFDMA multiplexing schema [27]

Orthogonally Frequency Division Multiple Access presents a multiplexing technique which enables simultaneous transmission and reception of multiple user requests even within a single channel on the so-called subchannels [28, 29]. In order for multiple user requests not to interfere or overlap, the time and frequency dimensions are used (Fig.1.). These dimensions are used in algorithms as input values for width and height of one rectangle which needs to be placed into a specific shelf/bin. Bin packing algorithms may consider different scaling factors which imply the usage of different properties for arrangement. In [30] the following most common algorithms are described:

- Shelf algorithms

  Present a case were a shelf is defined to be a subrectangle of the bin with width *Wb* and height *Hs*, and then as packing proceeds the rectangles are placed into shelves, bottom-up, and from left to right. In this category, different versions with the same base logic are included. Some of those algorithms are: Shelf Next Fit (SHELF-NF), Shelf First Fit (SHELF-FF), Shelf Best Width Fit (SHELF-BWF), Shelf Best Height Fit (SHELF-BHF), Shelf Best Area Fit (SHELF-BAF), etc. However, these algorithms seem to waste a lot of space.

- Guillotine-able algorithms

  Present a procedure of placing a rectangle to a corner of a free rectangle of the bin, after which the remaining L-shaped free space is split again into two disjoint rectangles. As in the first case, here different subcategories of this method are also defined, such as: Guillotine Best Area Fit (GUILLOTINE-BAF), Guillotine

Best Short Side Fit (GUILLOTINE-BSSF), Guillotine Worst Fit Rules, The Rectangle Merge Improvement (-RM), etc. These algorithms provide improvement compared to Shelf Algorithms, but the split line boundaries still cause problems with the practical performance.

- Skyline algorithms

  These algorithms propose a similar solution with Shelf Algorithms. However, the specific approach completes packing a lot faster than the ones using the Maximal Rectangles data structure.

- Maximal Rectangles algorithms

  These algorithms store a list of free rectangles that represent the free area of the bin and they perform an operation that essentially corresponds to picking both split axes at the same time.

Regardless the used algorithm, the primary aim is to map user requirements, which from algorithms' point of view are rectangles.

Before presenting more thorough analysis corresponding to the implementation of the chosen Bin Packing algorithms, a brief overview of the simulator features is presented in the next section.

4 Proposed Simulator of Network Request Mapping Techniques

The generic aim of our simulator is evaluation and optimization of resource sharing in OFDMA networks (like WiMAX or LTE). In this way we developed a program that has implemented different Bin Packing algorithms. The focus here is to arrange different requests that come from subscribers into a compact schema that will allow effective use of bandwidth. These requests are arranged in different time slots and frequency sub-carriers. Targeted groups for this application are internet or telephony provider companies that operate in 4G platform.

The user request mapping simulator, is developed using Java programming language and practicing Software Engineering methodologies. This application implements five Bin Packing algorithms. In order to simulate the considered algorithms, one should provide the input values to the application. The following are considered to be the input values:

- Dimensions of the bin
- Number of bins
- Dimensions of user requests

Provision of user request dimensions is implemented using three different methods, as presented in Fig.2.

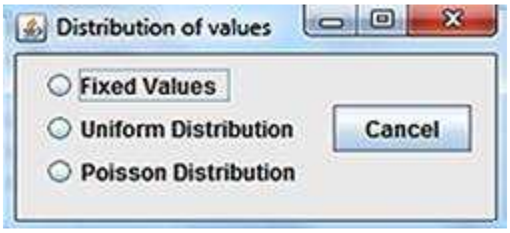


Fig.2. Distribution of values- GUI

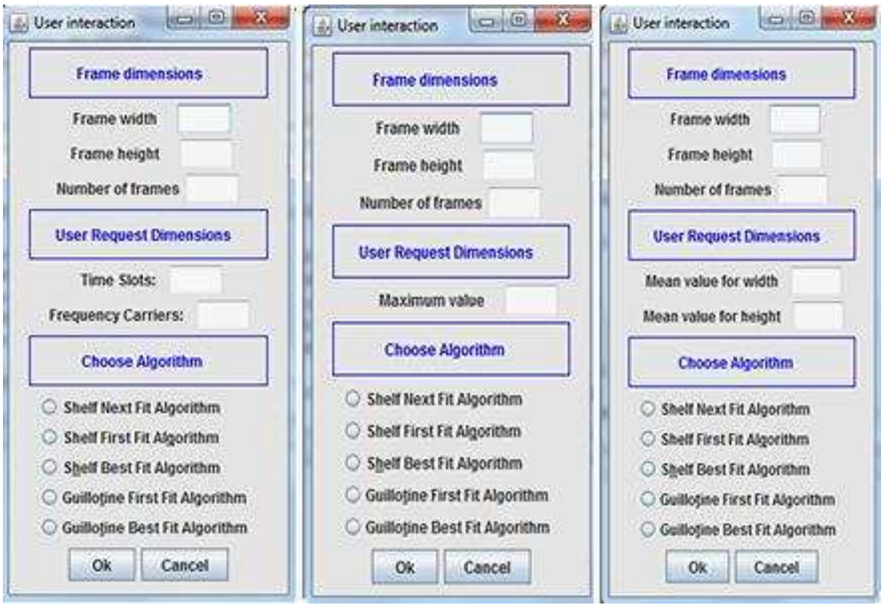
Specifically, they are set according to:

– Fixed value distribution
– Uniform distribution
– Poisson distribution

Considering the first method, two dimensions should be provided. These are: the user request dimensions of width and height. Final results, for all methods, include the number of arranged user requests into predefined frame dimensions, the number of idle slots, and their combination of values saved in a spreadsheet. Fixed value distribution, shown in Fig.3 a), is used while simulating our application only for testing reasons. The reason consists of: facts that in telecommunication applications there are rare or no cases where user requests have same sizes.

In this application, the random number generator is used to set the user request dimensions and a maximum number is pre-defined. This value is used as a maximum range value for generating user request dimensions. Hence, if the simulator user provides number 9, user request dimensions will have values ranging from 0 to 8. However, while simulating, we always add 1 in order to avoid user requests of null dimensions. The corresponding user interface while choosing Uniform Distribution is shown in Fig.3 b).

The third method of inputting user request dimensions is based on the Poisson value generator (Fig.3 c).). This method requires two mean values; one for the width of the user request and the other for the height. In this way, the generated user requests have dimensions which range close to the provided mean value.



a). b). c).

Fig.3. Distribution value types- GUI: a). Fixed values; b). Uniform Distribution; and c). Poisson distribution

Regardless of the used input method for user request dimensions, in the end of the simulation, the gathered results will be presented as a total number of arranged user requests and total number of idle slots. In order to view the combination of idle slots, we have also created the output part in a spreadsheet. This is part of the application, too.

The next section presents the detailed analysis and design steps of the implemented algorithms, starting with Shelf Algorithms and continuing with Guillotineable Algorithms.

5 Implemented Bin Packing Algorithms

Developed simulator consists of Bin packing algorithms that are applicable to our practical aim. Considering our objective- to provide an effective bandwidth utilization solution to a dynamic system (telecommunication system which has unpredictable user requests), we chose Shelf and Guillotine algorithms. In order to develop the application, which consists of five Bin Packing algorithms, we have used Software Engineering methodologies. While working with the simulator, terms like:

- Rectangle, present the user request. Implying that the user request time and frequency dimensions are equivalent with rectangle's width and height dimensions.
- Shelf and bin, present the frames that are going to be used in order to arrange user requests. Similarly shelf's dimensions correspond to frame dimensions.

These terms (rectangles, bin, or shelf) are used just for adoption with terms of Bin-packing algorithms.

Shelf algorithms, as the simplest methods of packing rectangles, are defined by two dimensions. Specifically, a shelf is considered a subrectangle of the bin with width (*Wb*) and height (*Hs*). The packing area is arranged with placement of rectangles into shelves from bottom-up, and from left to right. Hence, when packing a rectangle (*w, h*) onto the shelf (*Wb, Hs*) we have to choose whether to rotate it or not.

The orientation procedure, presented in Fig. 4, is applied to all Shelf Algorithms. This procedure considers the suitable orientation in which the rectangle will fit into the allocated area and arrange rectangles so as to save the predefined space. The orientation procedure consists of decision making, such as placing rectangles as follows:

- Upright: *R= (min (w, h), max (w, h));* or
- Sideways: *R= (max (w, h), min (w, h)).*

However, first of all we should have shelf dimensions. As it is presented in Fig. 4, we have initialized the Width to zero (*Wt*=0). It corresponds to the total used Width, which at the beginning of arrangement is zero. After we have the rectangle with its dimensions, we need to determine whether this is the first rectangle on a new shelf:

- If so, then we store it sideways in order to minimize the height of the new shelf.
- If not, then we need to see if the rectangle fits upright. For this reason in Fig. 4 we have the condition: *max* (*w, h*) <= *HeightS*. This condition checks if the maximum of rectangles' dimensions is lower than the shelf's height. If this condition is fulfilled, then the rectangle is stored upright, if not sideways.

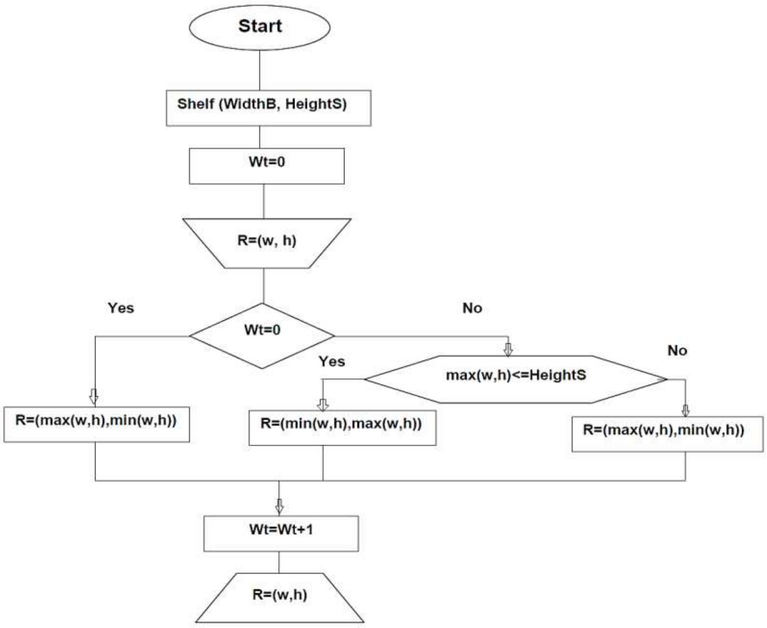


Fig.4. Orientation process in Shelf Algorithms

The Shelf Next Fit algorithm is one of the Shelf Algorithms that helps solve the packing problem. It first determines the proper orientation of the rectangle, and then it tries to fit it in the current open shelf. If the rectangle does not fit there, the algorithm opens a new shelf, if there is room for that; and if not it terminates execution. A closed shelf will not be opened again.

Shelf Best Width Fit Algorithm tries to minimize the remaining capacity or width of the shelf space. This algorithm is very similar to Shelf First Fit Algorithm which we will present in more detail in the next subsection.

5.1 Shelf First Fit Algorithm

Shelf First Fit Algorithm is an extension of Shelf Next Fit Algorithm. Therefore, based on the Shelf Next Fit Algorithm work methodology, we can conclude that it is wasteful to leave behind free spaces in old shelves while opening new ones [20, 22, 30, 31]. Shelf First Fit tries to look into those left areas, which in telecommunication point of view are idle slots, and fit the incoming rectangle/user request there. What differentiates our approach from the proposed working methodology of Shelf First Fit Algorithm proposed in [30], is that we first try to fit the incoming user request into the current open shelf and if it does not fit there, we search into the left areas starting from the lowest indexes. As shown in Fig. 5, this working methodology promotes a new version of Shelf First Fit algorithm. By all means of algorithm's performance, the execution time compared to Shelf Next Fit algorithm is longer.

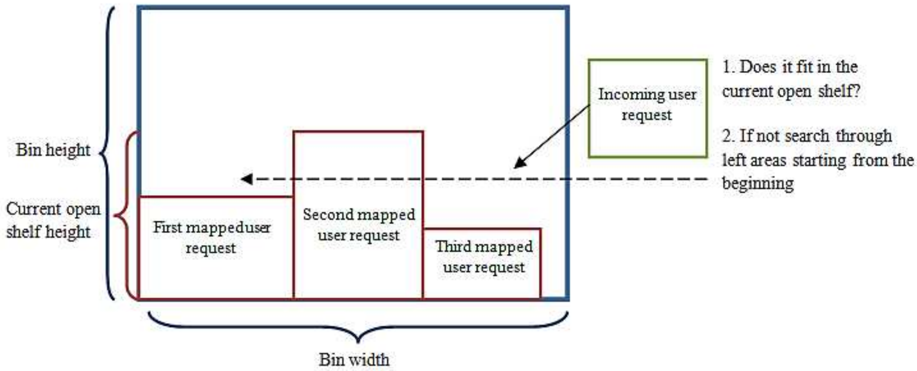


Fig.5. Shelf First Fit Algorithm's operating logic

5.2 Guillotine First Fit Algorithm

Guillotine Algorithms present our second proposed pack of algorithms for better bandwidth utilization. These algorithms are based on the operation of guillotine split placement. The objective here is to place an incoming rectangle in the corner of a free-picked rectangle of the bin. Then the guillotine split procedure is applied and the L-shaped free space is composed of two disjoint free rectangles which can further sub-divided. In this way we need to maintain a list of the composed rectangles which can be used to arrange other incoming rectangles.

Split choices used in Guillotine algorithms and operating logic are presented in Fig.6. The bin dimensions are represented by *W* and *H* (indicating Width and Height), while *w* and *h* present rectangle dimensions. Two composed rectangles from split procedure are presented as *F* and *F'*. The composed rectangles will have the remaining dimensions of the respective bin, as shown in Fig.6.

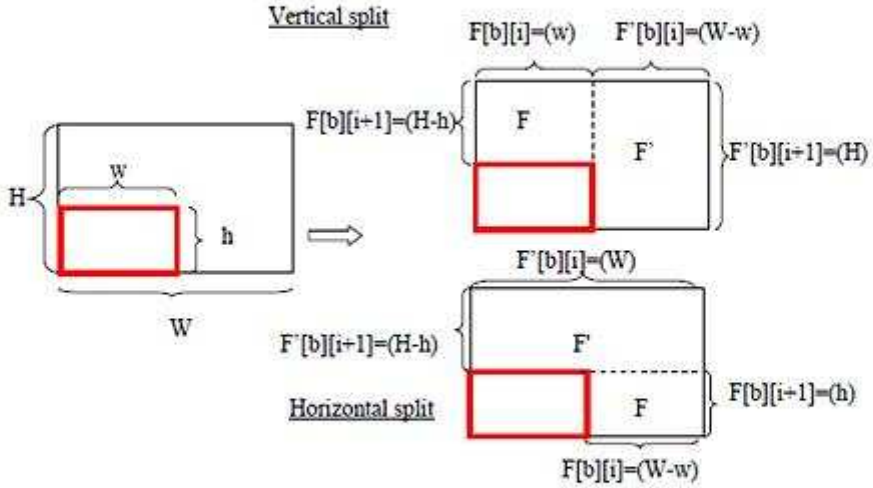


Fig.6. Split choices used in Guillotine Algorithms

Split procedure of Guillotine algorithms implies the possibility to choose between two possible directions. On behalf of this, we have combined two methods. The Shorter/Longer Axis Split Rule [30] is used to choose the direction of the split procedure. This method includes two possible prerequisites, that for the horizontal split ($w<h$) and for the vertical one ($w>h$). Therefore, while observing rectangle's dimensions we choose which one of the split directions to apply. Finally, we will have an arranged rectangle, and another two free and disjoint rectangles with corresponding dimensions as presented in Fig.6.

Guillotine Algorithm's operating logic combined with First Fit method provide a new combined algorithm which is used to arrange the incoming user requests (Fig. 7.). Guillotine First Fit Algorithm takes into consideration all free spaces through split rectangles and places the incoming rectangle into one of them, making the choice based on the numbering (as the name implies-first fit).

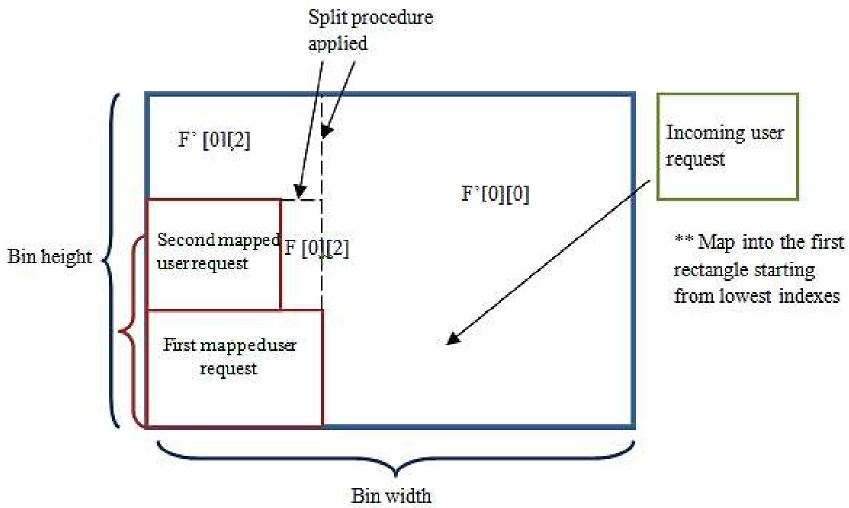


Fig.7. Guillotine First Fit Algorithm's operating logic

Detailed design milestones of proposed algorithms can be found in Appendix A. Workflow diagrams are presented based on these algorithms' operating logic. It is worth to mention that the implementation procedure is completely based on those diagrams.

6 Analysis of Simulation results

In this section we present and discuss the results gathered via our simulation application. The corresponding results are summarized based on the distribution mode of user requests. Whereas simulation user should at the beginning choose the method of distribution of the values for the corresponding user requests.

Consecutive simulations showed that while using Fixed Value Distribution, all Shelf Algorithms perform similarly. This due to the same user request dimensions. It is reminded that the Fixed Value Distribution uses once entered values for time slots and frequency carriers. In this way, while simulating using the same input dimensions for all algorithms we have gathered results shown in Table 1.

Table 1. Fixed Value Distribution

	Shelf dimensions	Number of Shelves	Time slots	Frequency carriers
Fixed Value Distribution	(27, 31)	30	12	15
	Total Mapped Slots	Total Idle Slots		
Shelf Next Fit	21600	3510		
Shelf First Fit	21600	3510		
Shelf Best Width Fit	21600	3510		
Guillotine First Fit	13500	11610		
Guillotine Best Fit	5400	19710		

Table 1 presents the input dimensions of the shelf, the number of shelves, and the values of time slots and frequency carriers. These parameters are provided by the user at the beginning of the execution. In the subsequent columns the total number of mapped slots (arranged user requests) and the total number of idle slots (left areas) are presented. Total values of the slots are calculated by summing the multiplied user request dimensions.

The gathered results are promising for Shelf Algorithms. By observing the performance of the Guillotine Algorithms, we can notice high number of idle slots. This, due to low number of used frames (30 in this case scenario) for arrangement of user requests. While increasing the number of frames, the performance of Guillotine algorithms is enhanced, as presented in next scenarios. However, as mentioned previously, Fixed Value Distribution is used in our application for testing reasons.

Focused to highlight results of our proposed algorithms, in this case Shelf First Fit new version and combined Guillotine First Fit algorithm, we tried to provide a comparison of their performance. Therefore, while changing the number of used frames we got following graphs, Fig.8 and Fig.9. We provided the same dimensions for both scenarios, but the number of used frames in the first case is 70 frames, while in the second case is 150. Hence, we used the Uniform Distribution or Random number generator, with bin dimensions (34, 36) and a maximum value of 22 (automatically generated used request dimensions will range from 1 to 22).

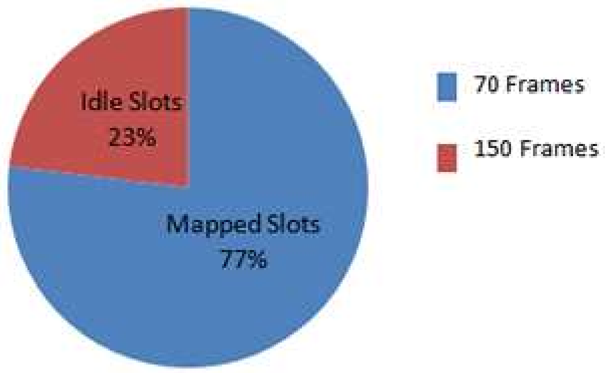


Fig.8. Uniform Distribution – Shelf First Fit Algorithm

Simulation results of Shelf First Fit Algorithm while using the Uniform Distribution are presented in Fig.8. As one can notice by doubling the number of used frames for user request arrangement, also the number of mapped and idle slots is doubled. From industrial application's point of view this is seen as positive performance. Taking into consideration telecommunication applications where the number of user requests most of the time is unforeseen, so does the number of frames that the application should use.

Same results are gathered for Guillotine First Fit algorithm (Fig.9). However, we can summarize performance of proposed Bin packing algorithms as follows:

- The performance of Shelf First Fit algorithm is highlighted in most of the case scenarios
- Guillotine First Fit algorithm performs better for higher number of frames, implying the possibility to arrange more user requests

Nevertheless considering others conclusions presented in [30], and our experience, the memory consumption and execution time make Guillotine algorithms more resourceful and useful for industrial applications.

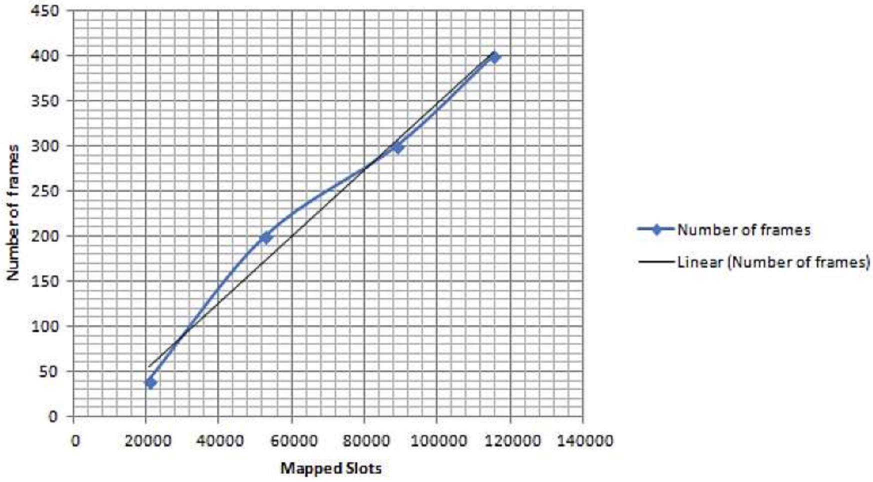
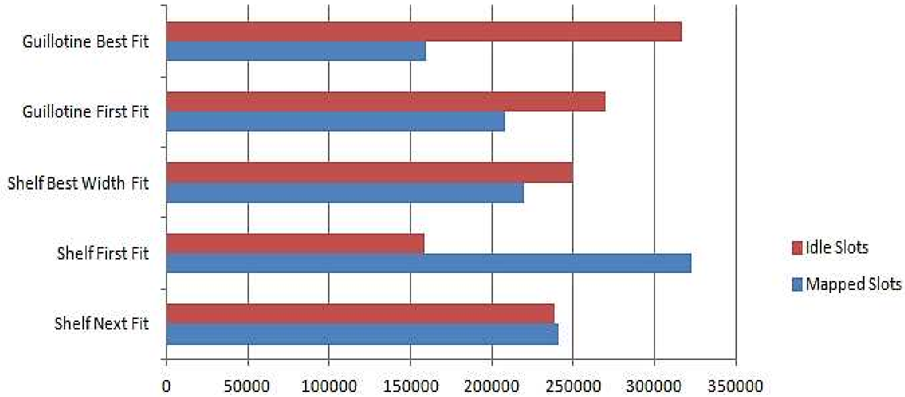


Fig.9. Uniform Distribution – Guillotine First Fit Algorithm

The third method of distribution of values implemented in our application implies Poisson distribution. This method generates user request dimensions based on manually entered mean values for the width and the height. For the simulations that are based on the Poisson distribution we used 200 frames, with user request dimensions having mean values of the width 24 and the height 27.



	Shelf Next Fit	Shelf First Fit	Shelf Best Width Fit	Guillotine First Fit	Guillotine Best Fit
Idle Slots	238726	158698	249265	269991	316803
Mapped Slots	241213	322395	219728	208409	159769

Fig.10. Gathered results while using Poisson Distribution

Overall results as total number of mapped slots and idle slots for each algorithm, while using Poisson distribution are presented in Fig.10. Similarly to the previous scenarios, the Shelf First Fit algorithm managed to arrange the highest number of user requests while generating the lowest number of idle slots. On the other hand, the Shelf Best Width Fit algorithm is very close to the best performance, too. It is reminded that the Shelf Best Width Fit uses the methodology of arranging the incoming user request into the left position where the remaining capacity is the lowest. Therefore, as we can notice from the corresponding graphs, the number of idle slots is lower compared to the Shelf Next Fit algorithm.

Guillotine First Fit algorithm performance compared to Shelf First Fit algorithm is considered proximate in the context of mapped user requests. Even though the total number of mapped and idle slots differs, the memory usage and simulation time in the case of Shelf First Fit algorithm are higher. This implies a tradeoff between delay, memory usage and efficiency.

7 Conclusions

Towards lowering the resource allocation problem in telecommunication areas, we propose different Bin-Packing algorithms which are designed for use in OFDMA networks.

The corresponding resource allocation techniques can be incorporated into small wireless broadband systems which use OFDMA as multiplexing scheme. Incoming parameters are provided as multiplexed values (time slots and frequency carriers) of user request, which should be arranged into the system's resource space depending on the available bandwidth. Hence, as a result at the end of execution the user requests are mapped to specific time-frequency slots, in a manner exploiting most of the free space left within the frame. The corresponding left areas are considered as idle slots, which vary depending on the specific case.

The implemented Bin-Packing algorithms exhibit different features and functionalities, which enable to compare and distinguish them for specific case scenarios where they can provide better bandwidth utilization.

The analysis of the results reveals that our new version of the Shelf First Fit algorithm was the most resourceful algorithm. However, the high memory requirements and execution time can be compensated by using the proposed Guillotine First Fit algorithm which also exhibits high performance. In the future, we plan to enhance the algorithms for considering QoS requirements as well.

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Appendix A

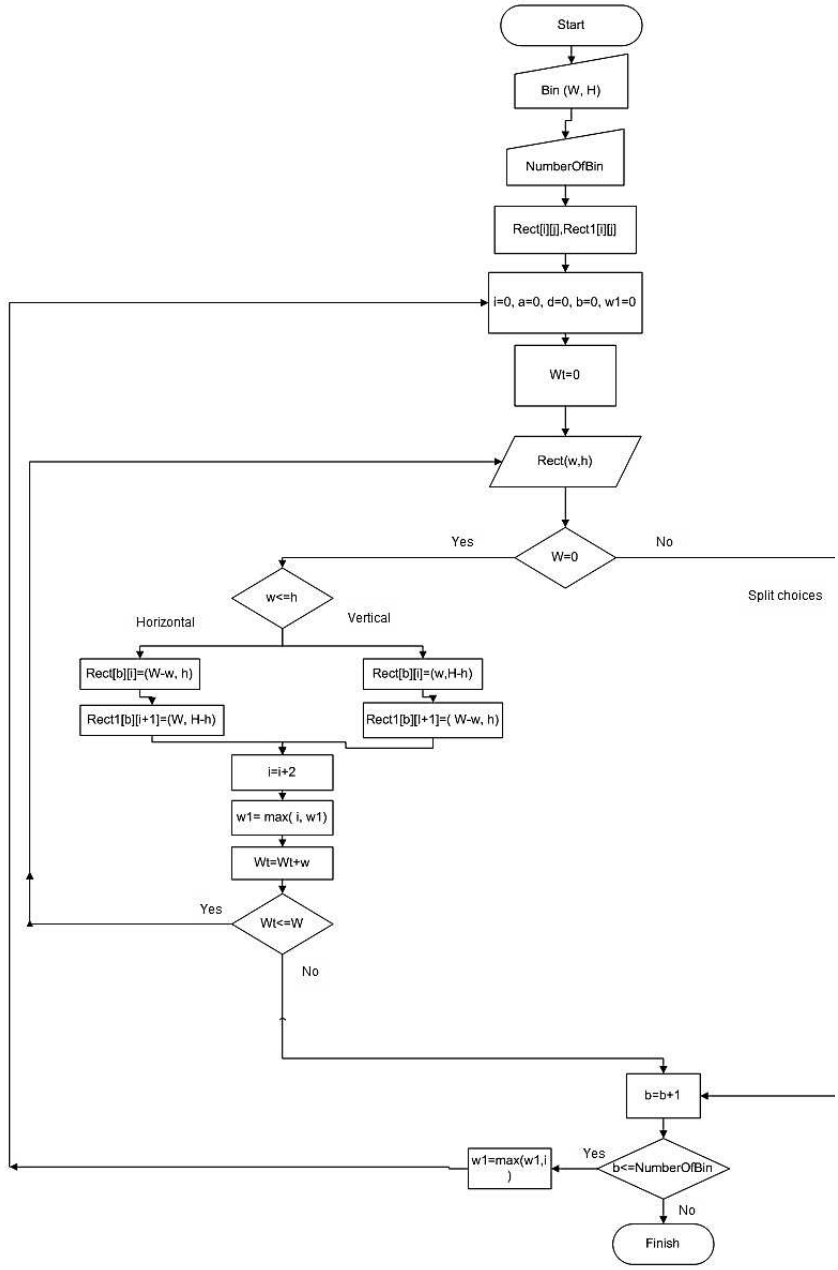

Fig.11. Workflow diagram of Guillotine First Fit Algorithm- Part 1

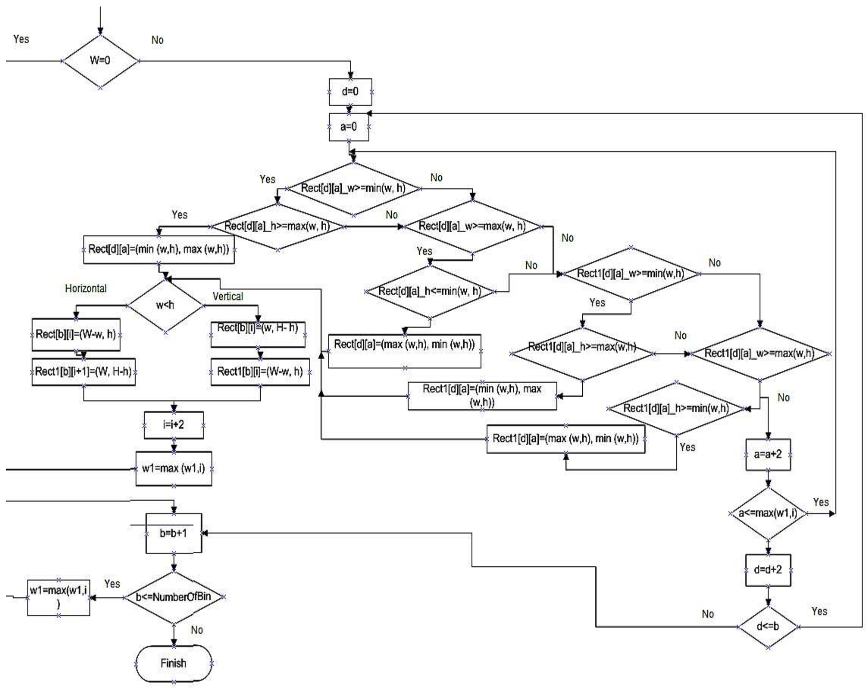

Fig.12. Workflow diagram of Guillotine First Fit Algorithm- Part 2

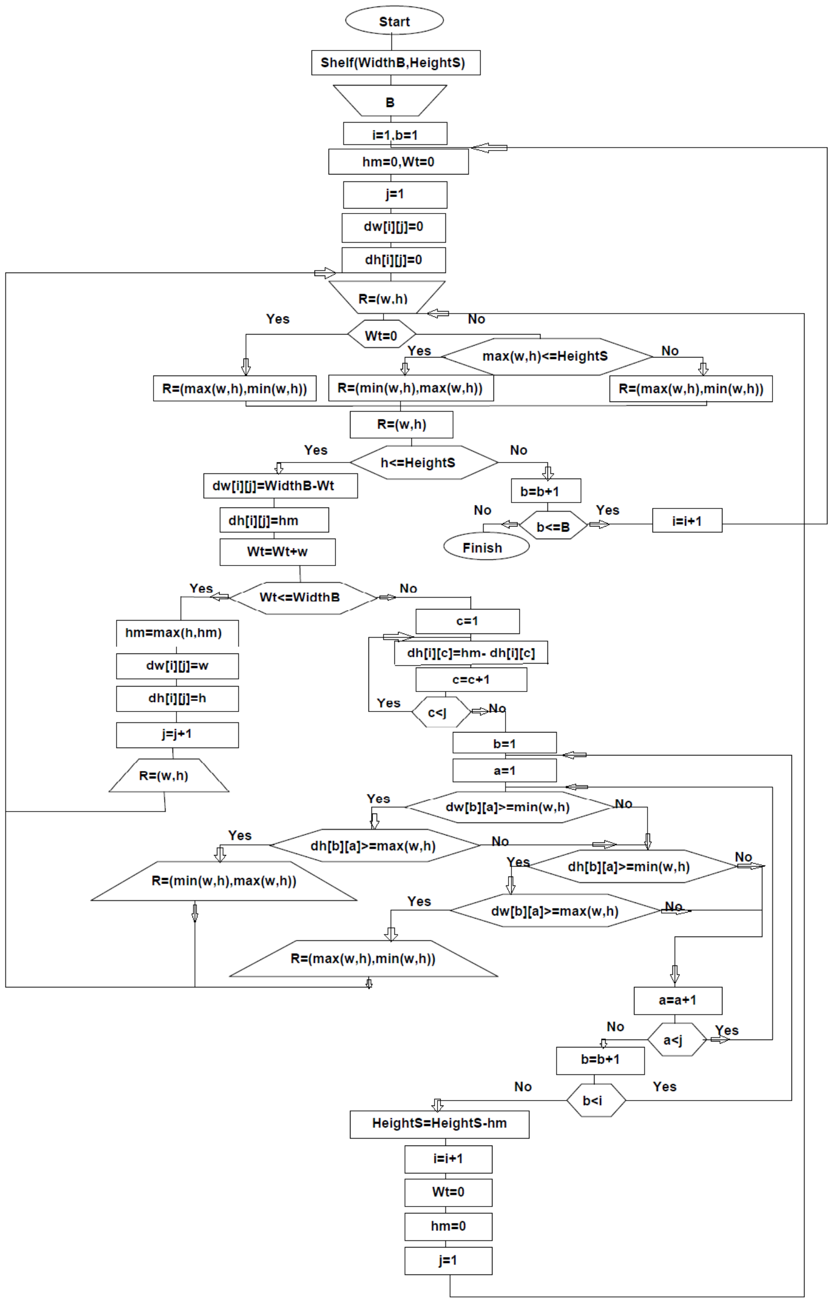

Fig.13. Workflow diagram of Shelf First Fit Algorithm

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