# Resource Allocation Mechanism for Massive MIMO

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***Abstract*—Nowadays, mobile users need faster data speeds and more reliable service. The next generation of wireless networks 5G pledges to commit that, and much more. Multiple-Input, Multiple-Output (MIMO) technology in 5G networks is studied in this paper, with emphasis on the achieved performance in terms of achieved Bandwidth. Multi-antenna technologies, such as MIMO, are anticipated to play a key role in 5G systems, as they will have to handle much higher speeds than today's cellular networks and greater network traffic. Specifically, we will refer to Massive MIMO (Ma-MIMO) technology. In this paper, a resource allocation mechanism is proposed from the Base Station (BS) to the available antennas, using the Knapsack Problem (KP) algorithm. Our goal is to evaluate user access throughput to the antennas and to study the case where the BS allocates resources, according to the channel rate it receives from each User Equipment (UE). The scenario executed is about serving the maximum number of UE connected to the BS, in high quality services. Finally, we simulate the results in MATLAB, in order to be able to evaluate the Quality of Service (QoS) that is provided to the UE by the BS, with the resource allocation technique that is proposed.**

***Keywords-Massive MIMO; 5G; Knapsack Problem; wireless users; resource block.***

## I. INTRODUCTION

Some of the main reasons that lead us to the direction of 5G networks is the necessity for greater capacity, improved Data Rate (DR), decreased latency, massive device connectivity, lower cost and better Quality of Service (QoS) It is expected these days that around 2020, a new fifth generation of mobile networks (5G) is going to be developed. The 5G network is the next major generation of cellular mobile communications beyond the current 4G/IMT-Advanced standards. It is anticipated to maintain a significant quantity of mobile data traffic and a really big number of wireless connections to deliver better cost and energy efficiency, as well as QoS in respect of communication delay, reliability, and security. In order to achieve that, five brand-new technologies are designed, including millimeter waves, small cells, Massive MIMO (Ma-MIMO), full duplex, and beamforming.

With a primary adjust of the proper systems that refer to both communication and localization, location-aware communication can be perceived and a huge number of Location Based Services can be supported. 5G networks have a superior transmission scheme named Beam Division Multiple Access (BDMA). This technology serves simultaneously multiple User Equipment (UE) via different beams. Considering the communication between the Base Station (BS) and the UE, an orthogonal beam is dispensed to each mobile user. In this way, the capacity of the system is increased, owing to the BDMA technique that divides the antenna beam conforming to the UE position [1].

Ma-MIMO technology is a key enabler and foundational component when it comes to creating the next generation of network standards. MIMO stands for Multiple-input multiple-output. It is characterized by wireless systems, that allow to transmit and receive simultaneously more than one data signal over the same radio channel. This is accomplished by using separate antennas in the transmit and receive end for each data signal. In our days, 4G BSs have a dozen ports for antennas that handle all cellular traffic. From those twelve, eight of them are for transmitters and four for receivers. On the contrary, 5G BSs can support about a hundred ports, which signifies that on a single array many more antennas can fit.

In previous research work, a greedy–knapsack algorithm is proposed to analyze system performance. The authors of [2] evaluate UE that wait to be served. Then, they choose from a set of UE to maximize system performance in an optimal way, without exceeding the available bandwidth capacity in LTE networks. Other work like [3], remodel the number of transmit antennas as a Knapsack Problem (KP). Furthermore, the authors of [4] investigate the Signal-to-Interference-plus-Noise Ratio (*SINR)* precoding for Ma-MIMO systems, since they need to bring quality to a satisfactory level. Related work like [2][3][4], have explored the resource allocation technique using the KP formulation.

In this paper, a resource allocation mechanism from the BS to the available antennas is proposed, using the KP algorithm. This algorithm is a different approach of MIMO technology, as it seeks to serve as many UE as possible, with the support of a great service level. Our goal is to evaluate user access throughput to the antennas and to study the case where the BS allocates resources, according to the channel rate it receives from each antenna. The scenario described is about serving the maximum number of UE connected to the BS whereas some UE are on limits of a cell. It is very important for the proposed mechanism to manage to serve these UE, achieving a satisfying level of QoS, in terms of achieved Bandwidth. The resource allocation mechanism is proposed in a Ma-MIMO system. However, the results presented, are based on calculations, using a smaller number of users at every base station, in order to present the experiments effectively. Finally, we will simulate the proposed algorithm in MATLAB, in order to be able to evaluate if the UE's requests are served in an optimal way. To achieve this, we apply the 0-1 Knapsack Algorithm in our implementation. The variations in the number of UE connected to the BS, interference and other simulation parameters, will also be analyzed.

The rest of this paper is organized as follows. Section II provides a thorough analysis of the System Model in Ma-MIMO. Section III provides the proposed mechanism for the resource allocation. Section IV provides the simulation setup for our scenario. In Section V, we display and discuss the results from the simulation that evaluate our system model. Finally, in Section VI, we state our summarized conclusion for this paper and provide insights for future work.

## II. System Model

MIMO is an antenna technology for wireless communication that uses multiple transmission and receiving antennas. The antennas at the source and the destination are unified to reduce errors and optimize data speed [5]. This technology offers enormous advantages with respect to energy efficiency, spectral efficiency, robustness and reliability [6]. MIMO specifically attributes to a practical technique for sending and receiving more than one data signal simultaneously over the same radio channel taking advantage of multipath propagation. In practice, the channel between the transmitter and receiver is estimated from orthogonal pilot sequences, which are limited by the coherence time of the channel [7].

Concerning Ma-MIMO technology, the term has been produced for using a much larger number of antennas per location. As reported by the authors of [6], the main idea is to use large antenna arrays at the BS to simultaneously serve many autonomous terminals. Ma-MIMO technology relies on a plain processing of signals from all the antennas at BS. Therefore, with more ports for antennas the BS can serve more UE at the same time and obtain better beamforming. This greatly improves the BS's capacity and range. Still, using antenna panels covering 360 °, the classic antenna boundary problems can be avoided, since the BS (Ma-MIMO) can thus be adapted in the optimal way to the UE's movement in different directions. Moreover, the antenna arrays can be located in different positions at each BS, which then allows for optimal transmission of signals from different antenna locations.

As pointed out by the authors of [8][9] and the authors of [10] consider a Ma-MIMO network with K links using the same time–frequency resource, ending up in co-channel interference. Therefore, the target link $k$ receives data that constitute an additive combination of required signal, interference, and noise. They use scalars $x_k$ to declare the transmitted signals by the $k$-th link's transmitter and they depicted the received signal, $y_k$, at user $k$, as:

$$y_k = r_k^+ H_{k,k}^+ t_k x_k + \sum_{i=1, i\neq k}^{K} r_k^+ H_{k,i}^+ t_i x_i + r_k^+ n_k \quad (1)$$

where $t_k$ represents the $M \times 1$ precoding vector and $r_k$ is a $N \times 1$ beamforming vector. Finally, $n_k$ represents the Gaussian noise vector at the receiver, while $H_{k,i}$ is the $M \times N$ channel state matrix from receiver $k$ to transmitter $i$.

More research has been done in order to achieve a better resource allocation regarding the DownLink (DL) network. In [2], a greedy–knapsack algorithm is presented to estimate UE, which are waiting for scheduling. Then, they choose an optimal set of UE in order to maximize the performance of the system. Certainly, this needs to be done without exceeding the disposable bandwidth capacity in LTE networks. Furthermore, as presented in [3], so as to produce a service with an achievable quality, the number of the antennas at the source required, is determined by modifying it as a KP. Also, the BS transmits a signal vector with beamforming and is clarified in [3]. Moreover, in [4] the authors express the receiving signal of user $k$ in cell $j$, as well as the *DL SINR* in a Ma-MIMO system and according to them, the DL *SINR* of user $k$ in cell $j$ is expressed as:

$$SINR_{j,k} = \frac{\left|f_{j\,k}^{j}\ a_{j\,k}\right|2}{1+\sum_{i=1,i\neq j}^{I}\sum_{k=1}^{K}\left|f_{j\,k}^{j}\ a_{j\,k}\right|2} \quad (2)$$

where $q_{ik}$ is DL transmission signals and $I = E\,[q_{ik}\, q_{ik}^{H}]$. Also, $a_{jk}$ is the precoding matrix and $f_{jk}^{j}$ is the channel matrix from the base station of cell $j$ to UE $k$ of cell $j$. Based on the research of the above authors, we will present an optimal Knapsack algorithm for resource allocation from the BS to UE and evaluate user access throughput.

In MIMO systems, multiple refers to the streams that the source sends by multiple transmit antennas. These streams go through a matrix channel, which is composed of all $N_t$, $N_r$ paths between the $N_t$ and $N_r$. $N_t$ stands for all the antennas at the transmitter and $N_r$ stands for all the antennas at the receiver. Then, the received signal vectors reach to the destination. Likewise, this happens through the multiple receive antennas and it decodes the received signal vectors into the prototype information. A narrowband flat fading MIMO system is modelled by the authors of [11] as:

$$y = Hx + n \quad (3)$$

where $y$ and $x$ are the receive and transmit vectors respectively. $H$ refers to the channel matrix and $n$ represents the noise vector.

In our case UE connects to a Macro Cell BS for DL asking for a DR that can be provided by a BS, based on DL SINR. In our research, for two UE that are located within the same cell we suppose that there is no interference between them, as they can be equally delegated to non-interfering sets or Resource Block (RB). RB is a flexible resource structure, where the time-frequency spectrum is split into orthogonal RBs [12]. First, *DR* is computed as:

$$DR = B_{RB} * \log_2(1 + SINR_{j,i}) \quad (4)$$

where $B_{RB}$ corresponds to the bandwidth of a specific *RB* and $SINR_{j,i}$ is the signal-to-interference-plus-noise ratio between UE *j* and BS *i*. *DR* is the data rate for the whole system and is equal to the Macro Cell data rate. This helps to achieve higher spectral efficiency. The number of RBs that a UE (suppose $UE_j$) demands from a particular BS aiming at a desired rate, is computed below:

$$R_{j,i} = \left\lceil \frac{g_i}{B_{RB} * \log_2(1 + SINR_{j,i})} \right\rceil \quad (5)$$

where $g_j$ corresponds to the UE throughput demands and DRj refers to the desired Data Rate for the $UE_j$.

## III. Proposed Mechanism

Figure 1 represents the topology of the 5G network we will perform. In order to get a better estimate of the results, our suggested scenario is depicted below.

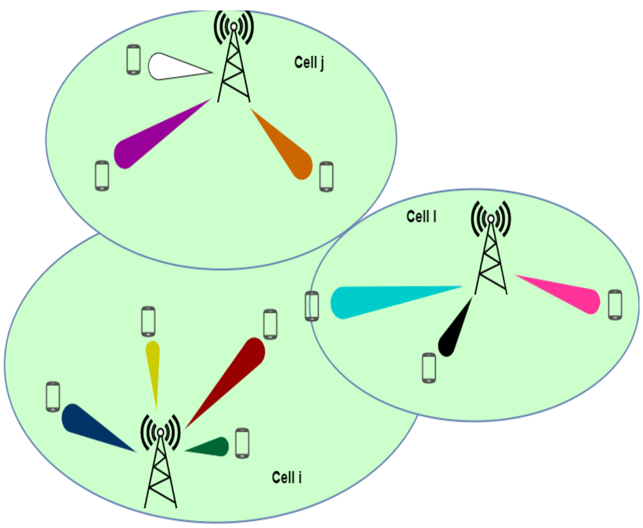


Figure 1. Topology of 5G network.

### A. Scenario

We study the case where the maximum number of UE connected to the BS is optimally served. The scenario is depicted in cell *i* and cell *j*, where each BS serves more UE at the same time and obtains better beamforming. Later in our simulations we will explain the QoS provided to the UE. This scenario concerns the case of a number of UE who need to be served, whereas some others are located at the limit of a cell, as UE in cell *l*, who can be served by the BS of either cell *i*, cell *j*, or cell *l*. Obviously, the decision on which BS will serve that UE located at the limits, will be taken using the Knapsack Algorithm approach. In this way, we try to improve existing solutions from previous research that use the KP formulation, aiming at achieving a high level of QoS for all UE.

### B. Knapsack Problem (KP)

For the purpose of reaching a satisfying level of QoS, in our approach we apply the 0-1 Knapsack Algorithm. The KP is an implementation of combinatorial optimization. Considering a set of objects, each with weight ($w_i$) and value ($v_i$), it determines the number of each object in a collection so that the total weight is less than or equal to a given threshold (*W*) and the total value is as high as possible. Given a set of items (suppose *n* items) we want to maximize our profit [13]:

$$\sum_{i=1}^{n} U_i X_i \quad (6)$$

We assume that we have a bag that can hold a set of *m* (*m* < *n*) item. For each item we define a variable $X_i$. With this said, we set $X_i = 1$, when an item belongs in the set of selected items, or $X_i = 0$, when an item is not chosen. Apparently, according to the previous equation (6), for our set of selected items:

$$\sum_{i=1}^{n} U_i X_i \leq W \quad (7)$$

$U_i$ represents the value of the item in the knapsack and *W* represents the knapsack's capacity. Thus, the goal is to maximize the sum of the values of the items, so that the sum of the weights, is less than or equal to the knapsack's limited space (*W*). We study the case of a resource allocation technique using the KP algorithm, from the BS to the available antennas. The main goal is to evaluate user access throughput to the antennas. Every BS has the same threshold (*W*) and is ready to serve the UE. Three variables are considered. The number of BS in our topology scheme, the number of UE and a counter for the total weight. As the BSs are allocated with equal RB (*W*) and while the counter for the total weight is lower or equal to the given threshold (*W*), we check the weight and value for each UE. There are two actions that take place. First of all we have to check that UE's weight ($w_i$) is less than the given threshold and if so, we add the value of this UE ($v_i$) to a list. Obviously, if UE's weight ($w_i$) is greater than the given threshold, we reject that UE right away and continue to the next UE. Next, each BS checks the list and allocates RB to all the UE that have the smallest $v_i$, until the counter is less or equal than *W*.

More specifically, for our KP, $w_i$ is considered as the bandwidth that the UE needs and $v_i$, as the distance of the UE from the BS. Moreover, in our KP we define ($X_i$) and $X_i = 1$, when a UE belongs in the list or $X_i = 0$, when a UE is not selected. Therefore, our mechanism is trying to serve the biggest number of UE with the minimum distance from the BS, in an optimal performance. Although the results presented depict calculations, in which a smaller number of users was used at every base station, the resource allocation mechanism is proposed in a Ma-MIMO system.

**Algorithm 1** Resource Allocation Mechanism for UE – A KP Formulation

```
Number of BSj
Number of UEi
for each BSj do
    allocate same RB (W)
    for each UEi do
        find distance from BSj
        vi = distance
        check wi,vi
        if wi < W then
            create list with wi,vi
        end if
        else reject UEi and check next
            while counter <= W do
                check list and allocate RB to UEi with the
                minimum vi
            end while
    end for
end for
```

Figure 2. Proposed Algorithm

Considering the proposed mechanism and based on the System Model that was presented above, in the next Section we will describe each parameter needed for the results.

## IV. Simulation Setup

In this Section, each parameter needed for the simulations that will be executed in MATLAB is described, while the simulations are given in the next Section.

The air interface defined by the 3rd Generation Partnership Project (3GPP) for 5G is known as New Radio (NR). Frequency bands for 5G NR are divided into two different frequency ranges. Frequency Range 1 (FR1) below 6 GHz and Frequency Range 2 (FR2), each with different capabilities. According to the authors of [14], the range of channel bandwidth defined for FR2 is 50 MHz up to 400 MHz, with two-channel aggregation supported in 3GPP Release 15. Frequencies of up to 300 GHz are used in 5G systems. The higher the frequency, the greater the ability to support high data transfer speeds without interfering with other wireless signals or becoming very cluttered. We will now describe in Table I all the parameters needed for our mechanism.

TABLE I. Default Parameters

| Parameter | Setting |
|---|---|
| COST Hata Model | Macro Cells |
| Network Deployment | 19 Macro Cells |
| Transmission | MIMO |
| UE Distribution | Uniform Distribution |
| Number of UE (K) | 100/200/500/1000 |
| DL Bandwidth in BS | 400 MHz |
| UL Bandwidth in UE | (50-400 MHz) – randomly generated |

In our simulations we consider an area that consists of 19 Macro Cells (omni directional with an inter-site distance of 375m), as shown below in Figure 3. Macro Cells are used in suburban, city and rural areas. Regarding the simulation deployment scenario, our simulation network contains a different number of UE ($K$). We will model its performance for K UE. First, we consider a BS that has a total Bandwidth of 400MHz ($W$) and there are 100 UE that need to be served. Then, we consider a BS that has a total Bandwidth of 400MHz ($W$) and there are 200 UE that need to be served. We also consider a BS that again has a total Bandwidth of 400MHz ($W$) and there are 500 UE that need to be served. Finally, we consider a BS that has a total Bandwidth of 400MHz ($W$) and there are 1000 UE that need to be served. In each example, the distance of the UE from the BS is estimated ($v_i$), whereas in each example the demands for bandwidth from each UE differ ($w_i$) and are randomly generated.

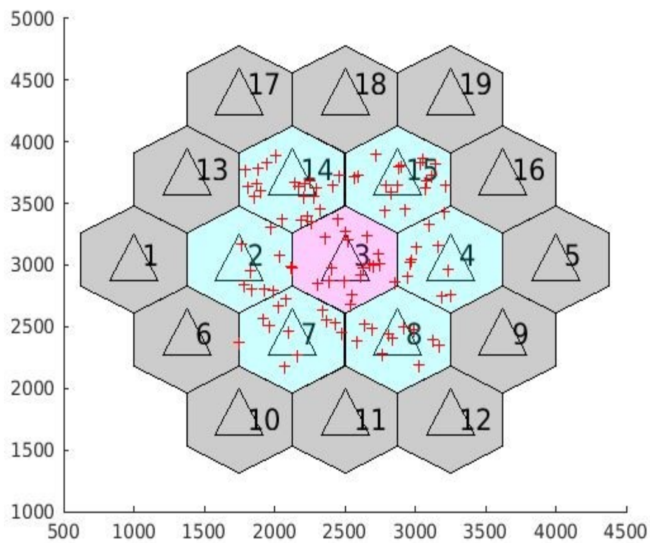


Figure 3. MATLAB simulated network.

Macro cells are depicted in Figure 3 as black triangles, whereas UE are depicted as red crosses.

## V. Simulation Results

In this Section, we analyze our experiments for multi-cell systems with random UE positions. In the simulations executed in MATLAB, we used every parameter described above and the results are given below. The Figures given below are from our simulations with 100 UE, while the DL Bandwidth in each BS is 400 MHz and the DL Bandwidth in each UE, is randomly generated in the interval [50-400 MHz]. Note that our Network Deployment is 19 Macro Cells but in Figure 3, UE are distributed in 7 Macro Cells. Nevertheless, the proposed mechanism is applied to our COST Hata Model, which includes 19 Macro Cells. These values were chosen for our parameters, in order to present the experiments in a better way.

To start with, the simulated network is described. We consider 100 UE that demand resources of our network. All UE are randomly generated with a personalized chance of appearing inside our area of interest that is served from a Macro Cell. Moreover, in the UpLink (UL) network, all UE have their personalized demands for Bandwidth that ranges from 50 – 400 MHz. As for the DL network, the Bandwidth is equal at all BS at 400MHz.

Concerning the simulation of our experiments, our simulated network with 100 UE, is depicted in Figure 3. Each UE's position is random and we simulated our experiments for a different number of UE. In this way, we create the value of distance between each UE and all the BSs. The signal power that the BS sends is proportional to the reciprocal distance between each UE and the BS. That is the reason why all active UE receive a signal power with the same intensity. The authors of [15] refer to this method as power control, supposing that the signal power that the BS sends changes continually, proportionally to the requirement. Following the above information, in Figure 4, the number of UE that normally connects to each BS, is presented with different colors, according to the minimum distance between them.

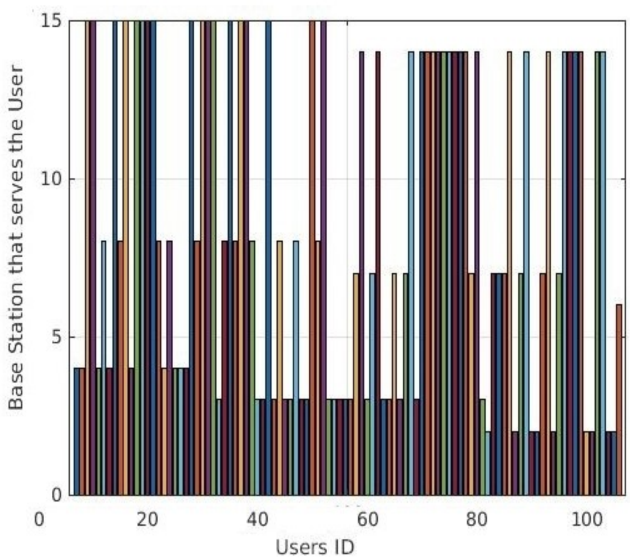

Figure 4. Number of UEs connected to the BS according to minimum distance.

Foremost, if the BS is transmitting data to the UE with a target SNR, the transmitted signal designed is based on the distance between the BS and the UE. To be more specific, if the distance between the Macro Cell and the UE is small, then the Macro Cell is capable of satisfying the target SNR. What is more, it performs that with a small transmit power. In other words, the signal that the Macro Cell sends includes some details about the distance between the Macro Cell and the UE [16]. In Figure 4, we can clearly see what the topology scheme shows us in Figure 3. More particularly, Figure 4 shows us exactly in which Macro Cell each UE will connect, under normal conditions. That means each UE's distance from each BS is computed and therefore we know which BS will serve the UE, according to the minimum distance between them.

Furthermore, in our experiments we continued applying the KP formulation to our mechanism and the three parameters needed were defined. Considering a number of UE as our set of objects, each of them has its demands for bandwidth, which is shown below as each UE's weight. The minimum distance for each UE was also defined, which determines the value. Finally, the total Bandwidth in each BS is 400 MHz and constitutes the given threshold. Our goal is to find the best Knapsack. Given a set of UE we want to maximize our profit, which in our case means that the best total value is a sum of all the values that are included in the KP. Hence, this can be considered as a small modification to the KP, because in this occasion, the value parameter is defined as the minimum distance between each UE and the BS. The bandwidth of each UE ($w_i$) and the total Bandwidth of every BS ($W$), are shown below in Figure 5.

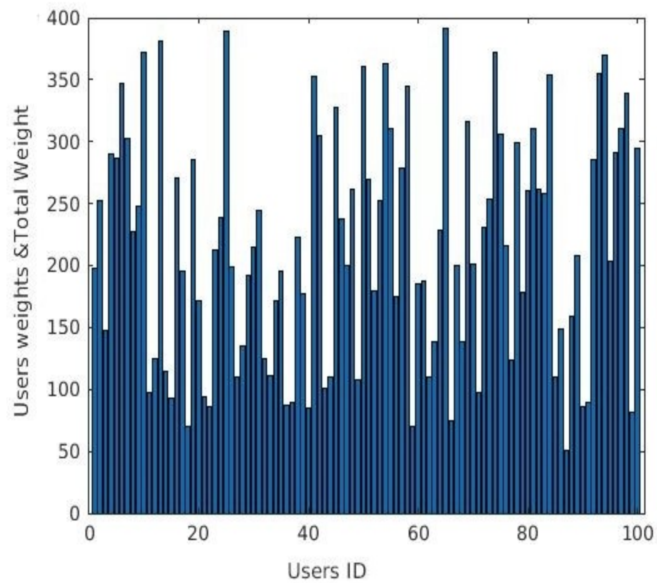

Figure 5. Number of each UE's weight connected to BS with total weight of 400MHz.

Finally, after our KP formulation and the resource allocation, Figure 6 presents the values of the best possible Knapsack in each BS. The value of the best possible Knapsack is computed as the sum of all the minimum distances of the UE that can be served by the BS, based on their weights that is each UE's quantity for bandwidth that they demand. Moreover, in every Knapsack formulation, the "amount of use" of each UE that is served by the BS was also computed. This refers to the variable $X_i$, which is $X_i = 1$, when a UE is selected to be served by the BS and $X_i = 0$, when a UE is not selected. This amount was computed for every UE in every BS. The "amount of use" of each UE, represents which UE were served by every BS. Therefore, the best possible Knapsack in each BS, is trying to serve the biggest number of UE with the minimum distance from each BS, in an optimal performance, as shown below in Figure 6.

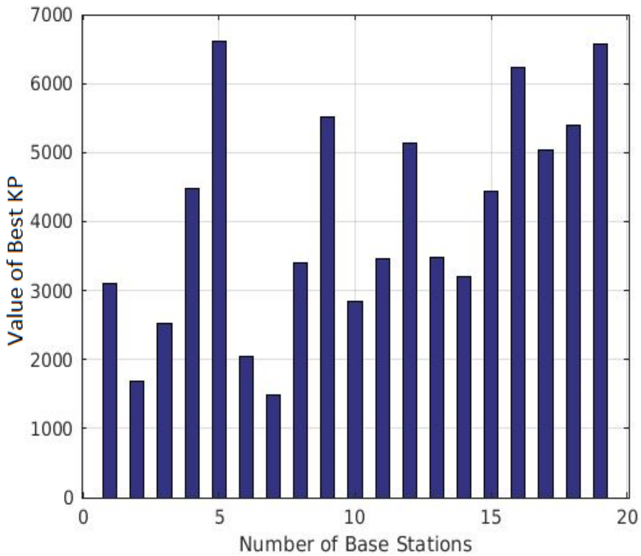


Figure 6. Number of BS and the value of best Knapsack for each BS.

From the above simulations we can clearly see that the results are different in each BS, but comparatively the values of the best possible Knapsack are optimal, as the distance in most of them remains small.

## VI. Conclusion And Future Work

From the produced results, the conclusion made, is that the KP formulation is a good technique to use when there is a great need to serve a maximum number of UE, with an optimum QoS, in respect of the achieved Bandwidth. Further research should be done using the KP formulation in a network deployment with Macro Cells and Pico Cells, where Macro Cells serve UE with the maximum distance, while Pico Cells serve UE with the minimum distance. In this way, the QoS in each UE will definitely be improved. More research is needed in Ma-MIMO when using KP formulation, as it can be an optimum solution when it comes to serving the maximum number of UE. Ma-MIMO technology uses multiple antennas at the transmitter and the receiver and this can be a great advantage for further research using KP formulation, in a sense of separating the UE in clusters, while each cluster will be served by the appropriate type of cell. Thus, each UE can be served optimally in a KP formulation, as each BS will serve the respective percentage of UE concerning their minimum distance. Again, this will offer each UE a great QoS, while it can reduce interference.

Finally, the rapid increasing of the data volume in mobile networks forces researchers to study Deep Learning. Machine Learning used in Ma-MIMO can produce different scenarios when using KP formulation, while it can supply us the tools to modify these mechanisms in real time and predict UE's and BS's behavior.

## References


[1] A. Gupta and R. K. Jha, "A Survey of 5G Network: Architecture and Emerging Technologies," in IEEE Access, vol. 3, pp. 1206-1232, 2015.

[2] N. Ferdosian, M. Othman, B. Mohd Ali, and K. Yeah Lun, "Greedy–knapsack algorithm for optimal downlink resource allocation in LTE networks", Springer Science+Business Media New York, vol. 22, no. 22, pp. 1427–1440, 2016.

[3] R. Husbands, Q. Ahmed, and J. Wang, "Transmit antenna selection for massive MIMO: A knapsack problem formulation," 2017 IEEE International Conference on Communications (ICC), Paris, 2017, pp. 1-6.

[4] J. Jing and X. Zheng, "A Downlink Max-SINR Precoding for Massive MIMO System", International Journal of Future Generation and Networking, vol. 7, no. 3, pp. 107-116, 2014.

[5] K. Ishimiya, J. Langbacka, Z. Ying, and J. Takada, "A Compact MIMO DRA Antenna," 2008 International Workshop on Antenna Technology: Small Antennas and Novel Metamaterials, Chiba, 2008, pp. 286-289.

[6] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, "Massive MIMO for next generation wireless systems," in IEEE Communications Magazine, vol. 52, no. 2, pp. 186-195, 2014.2.

[7] P. D. Selvam and K. S. Vishvaksenan, "Antenna Selection and Power Allocation in Massive MIMO", Radioengineering vol. 27, no. 1, pp. 340-346, 2019.4.

[8] R. S. Blum, "MIMO capacity with interference," in IEEE Journal on Selected Areas in Communications, vol. 21, no. 5, pp. 793-801, 2003.6.

[9] J. Ma, Y. J. Zhang, X. Su, and Y. Yao, "On capacity of wireless ad hoc networks with MIMO MMSE receivers," in IEEE Transactions on Wireless Communications, vol. 7, no. 12, pp. 5493-5503, 2008.12.

[10] B. Wang, Y. Chang, and D. Yang, "On the SINR in Massive MIMO Networks with MMSE Receivers," in IEEE Communications Letters, vol. 18, no. 11, pp. 1979-1982, 2014.11.

[11] M. Nasseri and B. Hamidrezav, "Iterative Channel Estimation Algorithm in Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing Systems", Journal of Computer Science, vol. 6, no. 2, pp. 224–228, 2010.

[12] H. Boostanimehr and V. K. Bhargava, "Unified and Distributed QoS-Driven Cell Association Algorithms in Heterogeneous Networks," in IEEE Transactions on Wireless Communications, vol. 14, no. 3, pp. 1650-1662, 2015.3.

[13] C. Lee, Z. Lee, and S. Su, "A New Approach for Solving 0/1 Knapsack Problem," 2006 IEEE International Conference on Systems, Man and Cybernetics, Taipei, 2006, pp. 3138-3143.

[14] Y. Sano, S. Okuyama, N. Lizasa, T. Takada, K. Ando, and N. Fujimura, "5G Radio Performance and Radio Resource Management Specifications", NTT DOCOMO Technical Journal, vol. 20, no. 3, pp. 79-95, 2019.1.

[15] A. Lebl, D. Mitić, T. Branimir, and Z. Markov, "Determination of Base Station Emission Power Change in a Mobile Network Cell with Movable Users", Radioengineering vol. 27, no. 4, pp. 1174-1182, 2018.9.

[16] L. Zhang, W. Zhou, W. Tang, G. Wu, and Z. Chen, "Estimating the distance between macro base station and users in heterogeneous networks," 2017 14th IEEE Annual Consumer Communications & Networking Conference (CCNC), Las Vegas, NV, 2017, pp. 928-932.