Automatic Base Station Deployment Algorithm in Next Generation Cellular Networks

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Abstract. The optimal base station placement and effective radio resource management are of paramount importance tasks in cellular wireless networks. This paper deals with automatic planning of base station sites on a studied scenario, maintaining coverage requirement and enabling the transmission of traffic demands distributed over the area. A city scenario with different demands is examined and the advantages/disadvantages of this method are discussed. The planner and optimizing tasks are based on an iterative K-Means clustering method. The planning method involves base station positioning and selecting antenna main lobe direction. Results of the output network deployment of this algorithm are shown, with various traffic loads over the studied area.

Keywords: cellular network planning, coverage, capacity.

1 Introduction

The radio planning of cellular wireless networks is a highly investigated topic, because operators can save budget using a cost efficient planning method. The planning of network must satisfy the interests of operators such as high spectral efficiency and low infrastructure cost. Developing and using an algorithm that automatically plans the positions of base stations and provides the necessary coverage and capacity over the area with small number of stations is thus of utmost importance. However, planning of the forthcoming 3GPP Long Term Evolution (LTE) networks, with its specific radio interface features is less covered in the literature yet.

The effective placement is a complex problem. The designer has to choose the optimal positions of base stations and directions of antennas. Frequency planning is not an issue in 3G networks, as the basic spread spectrum radio interface allows the deployment of reuse 1 scheme, that is each cell may use the same frequency band. However, the forthcoming 3GPP LTE network is based on OFDMA (Orthogonal Frequency Division Multiple Access) technology, where both the frequency band and timeslots are radio resources, effective radio resource management (distributing radio resource in frequency and time) algorithms should operate. Hence the frequency band may be dynamically used at the cell where is needed, effectively resulting in a dynamic frequency distribution among cells.

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This basic property and operation should be taken into account right during the network planning phase, otherwise the resulting deployment may be inefficient and wasting spectrum resource.

Our research is focused on the development and investigation of such an automatic planning algorithm. The optimization task is based on a clustering method which is very popular suggestion for planning, the K-means algorithm. However, most of the methods that use K-means concentrate either on dimensioning or optimization of the network and they require prediction of number of beginning clusters, which is not straightforward, see e.g. [1][2]. In [3][7-10] cellular network planning solutions were targeted, however the authors hasn't considered the full complexity of problem. Their main task is the base station positioning criteria, and they use simplified model. In [11] the author has proposed a complex algorithm with base station selection and configuration. However, in this paper the basic assumption of having a given maximum traffic load expressed in Erlangs per cell is not applicable if we consider next generation networks, that mainly carry high speed data services and cannot be characterised by a simple capacity measure due to the varying nature of radio channel (both over time and over positions in the area), the aplied adaptive modulation and coding.

In contrast, our method does both the dimensioning and optimization steps of cellular planning and does not require initial estimations, rather can start with an empty (in terms of number of base stations) area, with an arbitrarily placed single base station and places the necessary stations over this. However, if required, the algorithm might be used starting with an initial arbitrary network topology (location of arbitrary number of base stations) and places new base stations to fulfil coverage and capacity requirements. This is useful in the case when network deployment strategy has to be planned in order to serve increasing capacity demands in an already running network. It is important to note that the location algorithm creates the clusters based on the properties of base station which were initialized at the beginning. The frequency adaptation relies on the structures of base stations.

This rest of the paper is composed as follows. In Section 2 the basic modelling environment of the cellular network is characterised. In the Section 3 the aims of planning algorithm are described. It is followed by the Section 4 that details the planning algorithm. In Section 5 the results are showed by different graphs. The last Section 6 includes our conclusion.

2 Modelling Environment

The terrain where the planning method could be used can be simply described by the set of applicable coordinates over the area and the given traffic amount over the area, assigned to any subset of the coordinates on the terrain. For the sake of easier understanding, the method is described using concrete example area on which our examinations were conducted.

The environment of our evaluations is a 9 km^2 square city area, which is modelled as having three different layers. This layering approach does not have significance in terms of the planning algorithm, but for the numerical calculations we condicted. The first is the flat geographical layer which is followed by layer of roads and buildings. Any point of the area is defined by Cartesian coordinates. The resolution of the coordinates is 100 m^2 in our example, so x and y are supported on the interval [0..300]. We note the points where traffic demands of users are supposed to be known by DP (Demand Point).

$$\mathcal{DP} = \{DP_1, DP_2, ..., DP_m\}$$

where m is the number of DPs in our environment. These points are represented by (x_i,y_i,d_i), where x_i, y_i are the coordinates and d_i are the demands of DPs ($1 \leq i \leq m$), expressed in kbps. The d_i parameter in our model depends on the location of the DP. According to our assumptions those DPs that are placed within buildings has higher demands. Morover, our model assumes that along the roads we find more users, hence DPs are placed more frequently along roads and their traffic requirement is higher as well.

The aim of the lanning algorithm will be to serve all DPs, so we have to compute the required resource that is provided by base stations.

2.1 Base Station Model

Base Station (BS) is the equipment that provides the radio resource to our wireless network. We suppose that a BS operates three cells through three sectorised antennas.

The BSs are represented by

$$\mathcal{BS} = \{BS_1, BS_2, ..., BS_n\}$$

where n is the number of BSs in our environment.

2.2 Antenna Model

To keep the model realistic, sectorized antennas are assumed. The antenna horizontal characteristic is described by equations (1) and (2),

$$IF\ \alpha \leq 90,\ then\ Power = \cos^2(\alpha) * pw. \tag{1}$$

$$IF\ \alpha > 90,\ then\ Power = 0 \tag{2}$$

where α is an angle between the main direction of sector antenna and a changing vector pointing towards the actual location under examination and *pw* is the transmitter gain extended by antenna gain. Hence, during the calculations, signal strength is determined (along with the path loss model) according to the direction of a given point of the map.

The vertical characteristic is described by (3).

$$Power = \cos^2(\alpha - x) * pw\ . \tag{3}$$

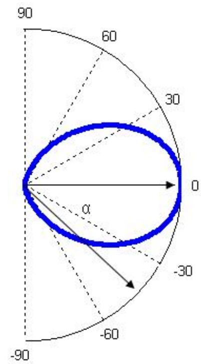

Fig. 1. Horizontal characteristic of Sector Antenna

We can employ (3) in all directions where α is the vertical angle of the main direction of sector antenna and x is the vertical angle of changing vector. The BS-s are planned with the traditional layout, namely three sector antennas with 120 degrees separation between their main directions.

2.3 Propagation Models

We use COST 231 path loss model for big city environment in our simulations. This has the advantage that it can be implemented easily without expensive geographical database, yet it is accurate enough, captures major properties of propagation and used widely in cellular network planning. This model is a function of the carrier frequency f which range from 50 MHz to 2 GHz, of the effective height of base station h_b and the effective height of mobile h_m [5]. The attenuation is given by equation (4)

$$A_p = 46.3 + 33.9 * \log_{10} f - 13.82 * \log_{10} h_b + (44.9 - 6.55 * \log_{10} h_b) * \log_{10} d - a(h_m) + C_m \quad (4)$$

where for large cities and $f \geq 400$MHz.

$$a(h_m) = 3.2 * (\log_{10}(11.75 * h_m))^2 - 4.97 \quad (5)$$

and C_m=3dB in large cities. Along with this model, a slow fading is also taken into account by means of a single fading margin expressed in dB. We extended this model by out to indoor propagation. If a DP is localized in a building, than the strength of signal will be decrease 10 dB.

2.4 Signal Propagation

We can describe the signal propagation by the next equation

$$RS_{i,j}(DP_n) = TS_{i,j} + TAgain_{i,j} - PL + RAgain - C \quad (6)$$

where $\mathrm{RS}_{i,j}(\mathrm{DP}_n)$ is the received signal of n^{th} DP from j^{th} transmitter of i^{th} BS in dBm, $TS_{i,j}$ is the transmitter power of j^{th} transmitter of i^{th} BS in dB, $TAgain_{i,j}$ is the gain of j^{th} transmitter of i^{th} BS in dB(taking into account antenna characteristics), PL is the pathloss in dB (COST-231), $RAgain$ is the gain of receiver antenna in dB, C is the fading margin in dB. This calculation is executed for every DP of the map from all transmitters.

2.5 Sector

A sector is defined as the set of DPs that are covered by same transmitter. The "best server" policy is followed within the network.

$$S_{i,j} = \{DP_h : RS_{i,j}(DP_h) \geq min \; and \; RS_{i,j}(DP_h) \geq RS_{l,k}(DP_h) \\ 1 \leq i, l \leq n, \; 1 \leq j, k \leq 3, \; i \neq l, \; j \neq k\}$$

where min is the minimal strength of signal that the mobile phone can receive that.

3 Aim Description

The efficiency of mobile wireless networks is described by serving bit rate per cell value. This metric depends on the distribution of SINR (Signal to Noise plus Inerference Ratio) values of the given cell. The main task, that the mobile phones can receive the signal stronger than the overall interferences in any point. Consequently the SINR values of DPs have to be increase by an efficiency planning algorithm. The cost of infrastructure is the other key factor. If we used any amount of BSs within our network, then we could serve our demands assuredly lavish in spending.

Possibility of increasing of efficiency:

- Observing of signal propagation. This is very important factor, because we can save resource if the high demand DPs are served by small number of frequencies. This effect can be achieved, if the BSs are placed near these DPs. The received serving signal will be stronger and interference is constant in these positions, so the SINR will be higher. The spectral efficiency of DPs can be increase if they are placed on the beam. If the directions of DPs are subtended smaller angle with the main direction of serving antenna, then the received serving signal will be stronger.
- Efficient frequency adaptation. This factor is also very important, because we can increase SINR value in the position of user if the neighbour interference signals are controlled.

3.1 Coverage

An important task, that the coverage criteria of DPs is guaranteed. If every DPs are covered by any sector then this requirement is accomplished.

$$\forall DP_i \in S_{j,k} \; i \in (0..m), \; j \in (0..n), \; k \in (1..3)$$

3.2 Computing of Signal to Noise Plus Inerference Ratio

Another important task that the demands of DPs are served. The resources of network can be managed by frequency adaptation and power management. Our planning procedure uses the properties of LTE radio resource management (RRM). This type of RRM uses OFDMA multiplexing scheme in the LTE downlink. The whole spectrum is divided subcarriers which bandwidth is 15 KHz. Furthermore the time is also divided slots. The users are allocated a specific number of subcarriers for a predetermined amount of time. A PRB is defined as consisting of 12 consecutive subcarriers for one subframe (1 msec) in duration. PRB is the smallest element of resource allocation assigned by the base station scheduler. First of all we have to calculate the amount of interference signals. An interfering transmitter can be defined as equipment that provides the DP with signal strength that is stronger than service threshold but is not the best server. This effect can be observed if the best server and the interfering transmitter send the signals by same PRB. We can describe the SINR by the next equation.

$$SINR_h = \frac{RS_{i,j}(DP_h)}{\sum_{k=1}^{n} \sum_{l=1}^{3} RS_{k,l}(DP_h) + Noise}, NOT(k = i \; and \; l = j) \tag{7}$$

The power of thermal noise (Noise) is taken to be -101 dBm in the evaluations.

3.3 Spectral Efficiency

The relationship between SINR and spectral efficiency is given by the so called Alpha-Shannon Formula, suggested to be used for LTE networks [4].

$$SpectralEfficiency_h = \alpha * \log_2(1 + 10^{\frac{SINR_h}{10*impfactor}}) \tag{8}$$

where α=0.75, $impfactor$=1.25, and $SINR_h$ is Signal Noise Interference ratio at the DP_h in dB. The unit of spectral efficiency is expressed bit/sec/Hz, so one PRB can carry to DP_h 180*1024*0.001*$SpectralEfficiency_h$ bits per second. Furthermore the number of required PRBs of DP_h can be defined by

$$NumberofPRB_h = \frac{d_h}{180 * 1024 * 0.001 * SpectralEfficiency_h} \tag{9}$$

If we calculate the required PRBs in all sectors then we can decide that the actual sector can serve the covered DPs.

3.4 Objective Function

We have to define an objective function, that demonstrates our aim. The overall using packet resource blocks are

$$UsedPRBs = \sum_{\forall DP_i} NumberofPRB_i \tag{10}$$

Our main tasks are to serve all demands and cover the entire map as well as minimize $UsedPRBs$. We can more decrease the number of used PRBs, if the spectral efficiency are increased in the positions of high demand points. The aim of proposed algorithm is to guarantee the higher SINR value in these points.

3.5 Initialization

Before the planning is started we have to give some key parameters of model. These are the placing of DPs and the power of transmitters. The map of roads and buildings is constant in all simulations.

4 The Planning Algorithm

The core method of our algorithm is the K-means clustering. This mechanism will shift the BSs and will rotate our antennas.

4.1 K-Means Clustering

This produces a separation of the objects into groups from which the metric to be minimized can be calculated. We use this algorithm to cluster the DPs and form sets of them (sectors). The criterion function ($\rho(\mathrm{x}_i,\mathrm{m}_j)$ which has to be minimized, is the distance measure between an object (x_i) and the cluster centre (m_j) [6].

The first is the assignment step. Join each demand to the closest cluster.

$$C_i^t = \{x_j : \rho(x_j, m_j) < \rho(x_j, m_i^*) \; for \; all \; i^*\} \tag{11}$$

C_i^t is the closest cluster of x_j demand at the t^{th} step. The other is update step.

$$m_i^{(t+1)} = \frac{1}{\#C_i^t} \sum_{x \subset C_i^t} x_j \tag{12}$$

where $\#C_i^t$ is the number and x is the location of DP within i^{th} cluster (C_i). This equation (12) calculates the new means to be the center point in the cluster.

The algorithm is composed of the following steps:

1. Place K points into the space represented by the DPs that are being clustered. These points represent initial group centroids (BSs).
2. Assign each DP to the group that has the closest centroid. (Assignment step)
3. When all DPs have been assigned, recalculate the properties of the K centroids. (Update step)
4. Repeat Steps 2 and 3 until the centroids no longer move or our counter of iteration expire.

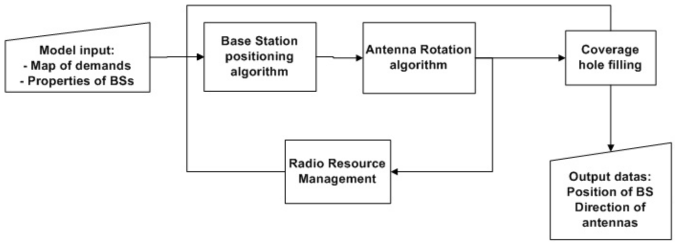

Fig. 2. Main flowchart diagram of RF planning algorithm

4.2 Main Algorithm

Our Planning Algorithm (PA) is made up of four interdependent blocks (Figure 2). This procedure will run until all DPs will be served. At the beginning PA places one BS to the center of map. The next step is a conjunct procedure (CP). In CP we will create the sectors and calculate SINR for all covered DPs (6)(7). The BS placement and the antenna rotation will run alternately six times. After some cycles the moving of BSs and the rotation of antennas will decrease, hence we intuitively chose the K-means clustering to run for six cycles. CP will run after every BS positioning and antenna rotation mechanism.

The BS positioning algorithm is based on K-means. The centroids of clusters are the BSs. The assignment step is the procedure of sector creation, but one cluster will be made up of three sectors of one BS. The necessary $\rho(\mathrm{x}_i,\mathrm{m}_j)$ metric is the strength of received signal in x_i position (position of DP_i) from m_j position of transmitter. In the update step the position of covered DP (x_i) will be weighted by the demands of DP (d_i). $\#C$ is the amount of demands of covered DPs within the cluster. The aim of this procedure, that the DPs with higher demand are positioned near the serving transmitter, so we can save resource by higher SINR values.

The antenna rotation algorithm is also based on K-means clustering. In the previous procedure we achieved that the higher demands will be placed close to serving transmitters. Our frequency adaptation will run with a frequency reuse factor of 1, so every adjacent sector will be interfering. Our aim that the directions of covered DPs with higher demand are subtended smaller angle with the main direction of serving antenna. The assignment step is also the procedure of sector creation. In the update step x_i is the subtended angle between the direction of covered DP_i within the sector and the main direction of serving transmitter weighted by the demands of DP d_i. $\#C$ is the amount of demands of covered DPs within the cluster. The clusters of this K-means procedure are also the three covered sectors of BSs, so the rotation of three antennas will happen equally.

After six cycles will run the Radio Resource Management (RRM). This is made up of PRB adaptation (Figure 3) mechanism and power allocation. The power allocation is very simple, because every PRB will be transmitted maximal or null strength by transmitter. The PRB adaptation is a cycle procedure which will assign the required number of PRBs in every sector.

We choose the first PRB (0 subcarrier, 0 subframe) in all sectors and adapt to the unserved DP with the highest SINR. If the adaptation of actual PRB is successful in every sector, then we will choose the next PRB. If one sector is served, then the transmitter of this will not transmit on the remaining PRBs and we have to run the CP without this transmitter. This procedure run until serving of all DPs is successful. After that we will find the most unserved sector (MUS). If the greatest number of required PRBs is less than the number of available PRBs of actual sector then we haven't MUS and the algorithm will run the coverage filling procedure. Otherwise the algorithm locates a new base station near the serving antenna of MUS in the main direction and CP, positioning and rotation procedures will start again. The DPs of MUS will connect with the new placed BS, because the new signals will arrive from nearer position. The update step of BS positioning will shift them. We can see this mechanism on Figure 4.

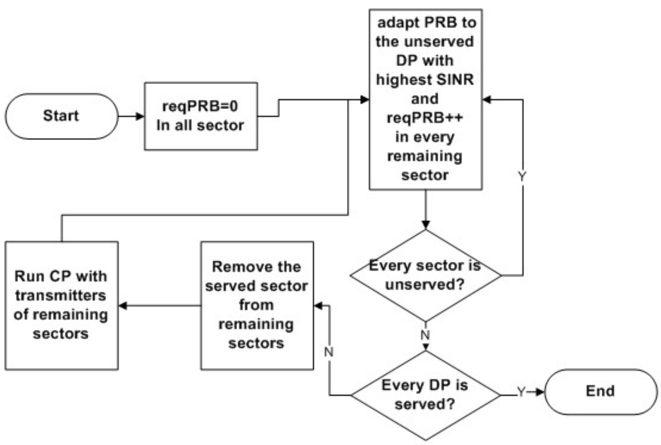

Fig. 3. PRB adaptation

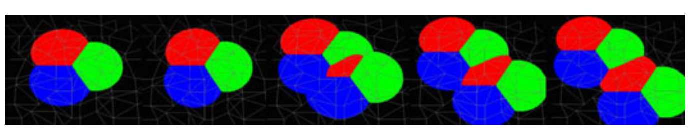

Fig. 4. Mechanism of BS positioning

The coverage filling procedure will find the uncovered DPs. If this method don't find anything then we are ready. Else we have to cover this DP by a new BS, and run the above procedure.

The detailed flowchart diagram of the algorithm is presented in Figure 5.

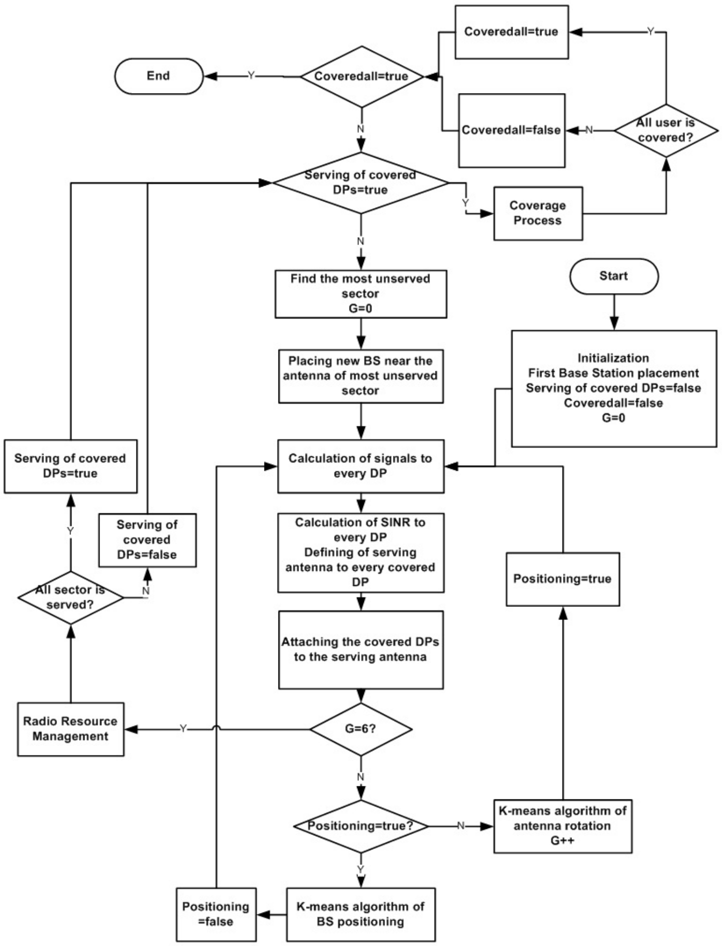

Fig. 5. Extended planning algorithm

5 Results

We ran the planning algorithm with different overall demands (50Mbit/sec-2500Mbit/sec) and different powers of transmitters (1W,30W). The properties of DPs will be changed in every simulation. We use 20 Mhz spectrum allocation and the frequency reusing factor is 1. All transmitters can use the whole spectrum (100*1000 PRBs per sec). The required service treshold value is -115 dBm. The next figure (Figure 5) will show the required number of BSs if we use the transmitters with 1W or 30W power. We represented 98 and 100 percentile serving of the entire DPs.

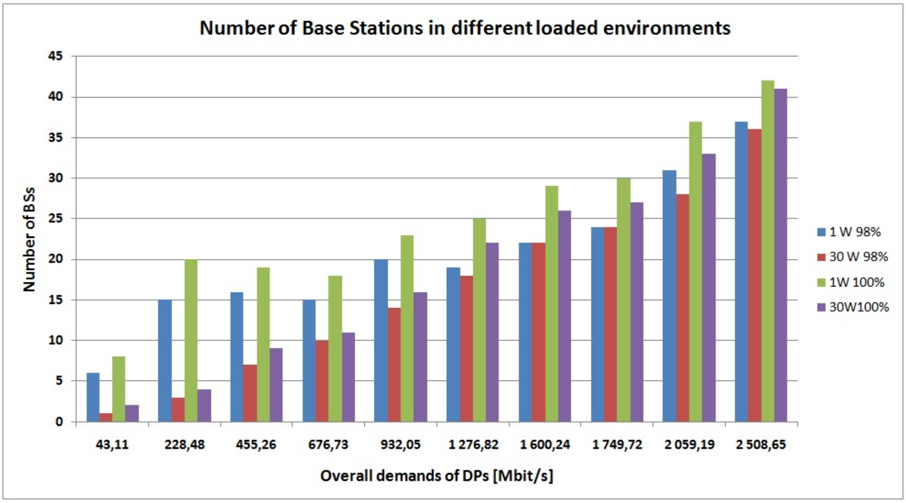

Fig. 6. Number of Base Stations in different loaded environments

We can see on this graphic (Figure 6) that the simulations with 1W power and small overall demands require a great number of BS. The reason of this that the PA focussed the coverage criteria. The transmitter with 1W didn't able to cover the far DPs. The other problem is the users who stay home, because the small strength of signal can't pass the serving threshold owing to the shading of walls. The required number of BSs stagnates from 226 Mbit/s to 676 Mbit/s. The reason of this, that the loading of sectors is low in 226 Mbit/s case and this loading will increase later. The simulations with 30W power place BSs with large coverage, so at the beginning the DPs will be served by few BSs. If the overall demands are higher, then the simulations with 1W and 30W power will use similar number of BSs. In this situation the algorithm will focus the serving criteria of the demands and new BSs have to be placed in both case. The BSs will be placed nearer and nearer, so the SINR values of DPs will be similary in both case. We can see that the full serving requires more BSs than the 98 percental serving in both type of transmitter.

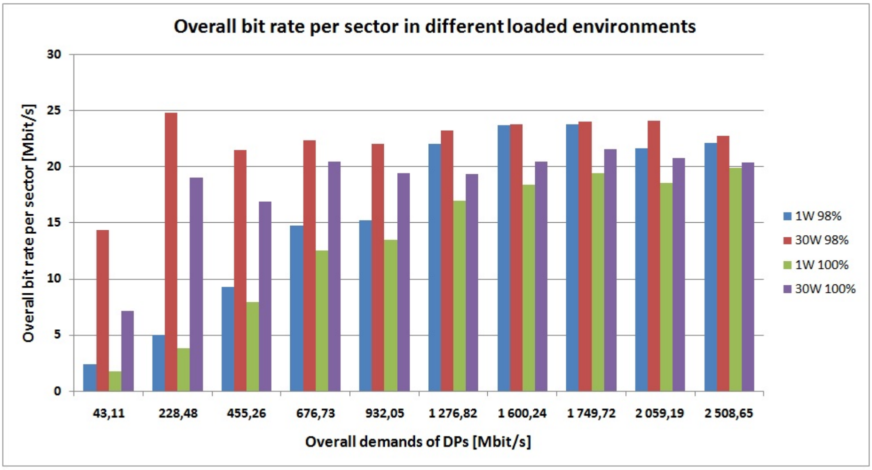

Fig. 7. Overall bit rate per sector in different loaded environments

We can see on this figure (Figure 7) the average bit rate per sector in different simulations. The transmitter with 30W power results similar bit rate per sector ($\approx$ 20Mbit/s in the case of 100% serving and $\approx$ 22Mbit/s in the case of 98% serving) in all simulations. The transmitter with 1W results different bit rate per sector in the simulations. At the beginning we placed small overall demands on the map but we need cover all DPs, so the PA will place more small sectors and the average bit rate will decrease. In the next some simulations the overall demands will increase but the number of BSs are pretty much the same, so the average bit rate per cell will increase. At the end of simulations both type of transmitter will result similary bit rate per cell values.

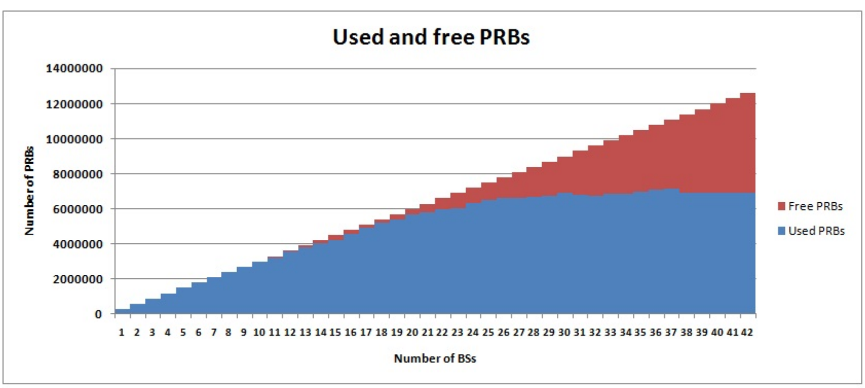

Fig. 8. Number of used and free PRBs during the running of planning algorithm in the simulation with 2508,65 Mbit/s overall demand and 1W power of transmitter

We can see on this diagram (Figure 8) that the number of free PRBs will increase during simulations, because the number of required PRBs will decrease in some sectors owing to the new BS placing. If we analyze the end state of simulations, then we can propose the required spectrum allocation of sectors, because we will see the required number of PRBs of every sector.

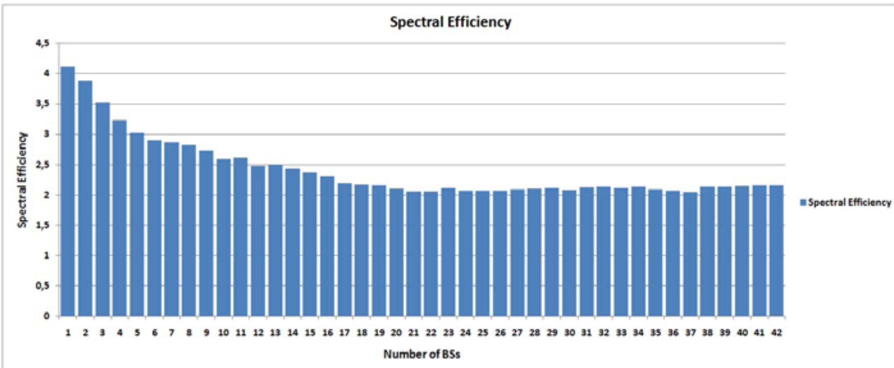

Fig. 9. Spectral efficiency during the running of planning algorithm in the simulation with 2508,65 Mbit/s overall demand and 1W power of transmitter

In Figure 9, the average spectral efficiency of the network is presented, as the algorithm places new base stations over the area. We can see that the average spectral efficiency will decrease continuously then will stagnate. This stagnation means that the planning algorithm efficient, because the average SINR of the network won't be decrease if we use more BSs.

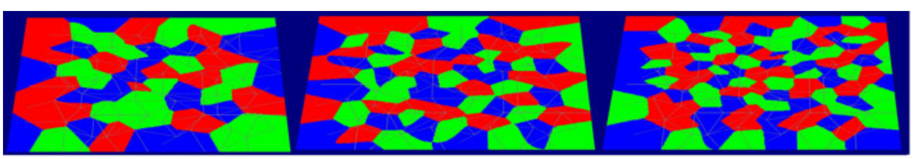

Fig. 10. End states of the simulations with 676,73, 932,05, 2059,19 Mbit/s overall demands

We can see on this picture (Figure 10) the results of three different simulations. If we give poorly overall demands then the average sizes of sectors will be larger. This property of sectors will be decrease if the environment is more loaded.

6 Conclusions

In this paper a novel algorithm was shown, that enables the automatic placement and determination of the number of base stations, that can serve a cellular network area with given traffic conditions. The algorithm is based on realistic assumptions and can be used for any legacy system, with arbitrary Radio Resource Control method applied in the network. Numerical methods were presented, showing that the algorithm reaches total coverage and allows the service of all traffic demands. Future work will investigate an effective power management which will included in RRM.

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