An Algorithm for Automatic Base Station Placement in Cellular Network Deployment

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Abstract. The optimal base station placement is a serious problem in cellular wireless networks. In this paper we propose a method that automatically distributes the base stations on a studied scenario, maintaining coverage requirement and enabling the transmission of traffic demands distributed over the area. A city scenario with normal demands is examined and the advantages/disadvantages of this method are discussed. Numerical results on coverage, as well as graphical results on radio coverage maps are presented as base for main consequences; the results are compared to another simple planning algorithm.

Key words: cellular network planning, coverage, capacity

1 Introduction

The radio planning of cellular wireless network is a highly investigated topic, because operators can save budget using a cost efficient planning method. The performance of a mobile network is mainly characterized by the received signal strength and signal to interference ratio at the mobile's position, hence the coverage of the network. The coverage is mainly affected by transmit power and radio propagation, hence depends on the environment the network is set up in. Gaining better coverage in a cellular network is thus a key objective of mobile networking industry. One straightforward way to enhance coverage is installing new base stations, however this is a costly solution. Developing and using an algorithm that automatically plans the positions of base stations, that provide the necessary coverage and capacity over the area with the least number of stations is thus of utmost importance.

Our research is focused on the development and investigation of such an automatic planning algorithm. The frequency adaptation and power control are very simple in our simulation model. If we used more complex algorithms of these properties then our method would give best results.

This new algorithm is based on a clustering method which is very popular suggestion for planning, the K-means algorithm. However, most of the methods based on K-means concentrate either on dimensioning or optimization and they require prediction of number of beginning clusters, which is not straightforward, see e.g. [1][2]. In [6], the authors have focussed attention on special K-means clustering with fixed number of cluster. This may produce good area coverage and have a small amount of overlap between cells. However, such a network will probably not be able to satisfy the traffic demands within the cell of each antenna. In contrast, our method does both the dimensioning and optimization steps 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 fulfill 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. Important notice that the location algorithm creates the clusters by the properties of base station which were initialized at the beginning.

2 Modelling environment

Our goal is to investigate the capability of new algorithm in mobile networks and evaluate coverage, signal to noise ratio (SNR) and quality of transmission in the network. In order to achieve our goal, we used our own developed software which simulates a mobile network, where base stations can be added easily. The model of the environment and the network implemented in the simulator is detailed in the following.

Since the communication range is an important property, the distances between nodes are displayed precisely on the graphic screen. The signal power and SNR are also shown on the screen with color spectrum changed gradually from weak to strong. Based on the signal power, we can calculate the coverage area of a given cell. The SNR parameter guides us to derive an estimated overall performance of the network.

We assume that the network to be developed by the algorithm (and the software tool implementing it) is the novel 3GPP LTE (Long Term Evolution) network. However, the method can be applied to any other radio network, even to subsequent ones (e.g. LTE Advanced). The algorithm assumes that a Radio Resource Control (RRC) mechanism is present, that allocates radio resources to different cells according to arbitrary rules. In LTE, this practically means that RRC allocates Physical Resource Blocks (PRB) to cells (a PRB is 12 OFDM subcarriers transmitted in a 1 ms subframe).

2.1 Simulated terrain

The environment of simulations is composed of three different layers. The first is the flat geographical layer which helps the speed of simulation. The second is the layer of buildings and roads. In the following, we assume that this is a large city with big houses, but other terrain types are also applicable. For the numerical results presented below, we assumed a 9 km^2 city area. The roads are generated by an algorithm that creates first the road network with confluence. The buildings will be placed near the roads with random height. The last is the layer of demands which created in according to the following scheme.

Traffic demands are given per unit area in bits per second (practically: per pixel of the map). If the position is near a road or a confluence then demand of this place will be higher, the demand is function of distance from the road. The model assumes that more traffic is demanded within buildings as well, as in reality high rate applications are used at home or in office, rather than outdoor. In the calculations presented below, the aggregate required bit rate is 900 Mb/s for the entire map.

2.2 Antenna Model

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

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

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

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.

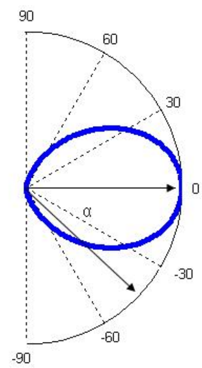

Fig. 1. Horizontal characteristic of Sector Antenna

The vertical characteristic is described by the next equation (3).

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

We can employ this equation (3) in all direction where α is the vertical angle of the main direction of sector antenna and x is the vertical angle of changing vector. We can use this type of antenna in base stations by selecting parameters. 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 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)

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

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

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

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.

3 Description of the algorithm

3.1 K-means clustering

The method is based on the K-means clustering algorithm, that is briefly presented in this section. This is a dynamic clustering which attempts to directly decompose the datas into disjoint clusters. We use this algorithm to cluster the demands and form sets of them (cells). The criterion function (ρ(x,y)), which has to be minimized, is the distance between a given location of demand within the sector (x) and the position of serving base station (y) weighted by the demand of x.

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

$$C_i^t = \{x_j : \rho(x_j, m_j) < \rho(x_j, m_i^*) \ for \ all \ i^*\} \tag{6}$$

where x_j is the location of demand, m_i is the centroid of the i^{th} cluster (the position of serving base station). C_i^t is the closest cluster of x_j demand at the t^{th} step. The other is update step.

$$m_i^{(t+1)} = \frac{1}{\#C_i^t} \sum_{x \subset C_i^t} x_j \tag{7}$$

where $\#C_i^t$ is the number and x is the location of demand within i^{th} cluster (C_i). This equation (7) calculates the new means to be the center point in the cluster.

3.2 Input and Output Parameters

The input parameters of simulation are the two dimension map that includes positions of roads and buildings. The distribution of traffic demands, as well as properties of base stations (power, antenna parameters) are also given. As the algorithm uses the radio resource available, ultimately the available bandwidth is also given. The output of the algorithm is the locations of the base stations that are needed to provide coverage and serve all traffic demands. Along with this and the information on available spectrum and traffic demands, the frequency utilization and the spectral efficiency of the network are also main outputs of the algorithm.

3.3 The Planning Algorithm

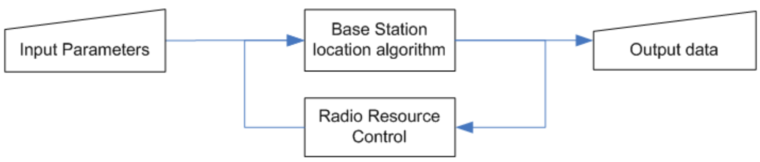

Fig. 2. Main flowchart diagram of RF planning algorithm

Our planning algorithm can be realized as a closed loop (Figure 2). The location algorithm waits for the input parameters, and the results of Radio Resource Control which includes allocation of radio resources (PRBs) to traffic demands. As the main contribution of this paper is the base station location algorithm (LA), the applied RRC in the subsequent analysis is supposed to be a very simple, basic operation. Namely, in the evaluations below the available band (20 MHz, 100 PRBs in LTE) is divided to three non-overlapping regions, allocated to the three sectorized cells of each base station. This simple RRC sends to location algorithm the status of service. If a sector is overloaded (the demands in its coverage cannot be served with the fixed band available), then the LA has to eliminate this problem and tries to serve the given area with more stations. This cycle will run until all demands are served. However, the performance of the RRC might severely effect the output of the total algorithm.

At the beginning, the initial parameters are fed to the algorithm, practically from a database and a single base station is placed into the center of the area. In the next step, the received signal power from each antenna to every position at the map is calculated. The calculation of received signal power is based on equation (8)

$$RS = TS + TAgain - PL + RAgain - C \tag{8}$$

where RS is the received signal in dBm, TS is the transmitter power in dB, $TAgain$ is the gain of transmitter antenna in dB(taking into account antenna characteristics), PL is the pathloss in dB, $RAgain$ is the gain of receiver antenna in dB, C is the fading margin in dB. This counting is executed for every position of map from all antennas. The next step is the RRC operation. First of all we will search the highest value of received signal for every position and note this value and origin of this signal (antennaID). We suppose that within the network the "best server" policy is followed, that is in each position the traffic is served with the sector that's signal strength is the highest at the position. The algorithm at this point assigns every location to the sector that will serve it. Then all the received signals using the same bands are summed up at the location, as these are interfering the primary signal. Now we can compute value of SINR using (9).

$$SINR = \frac{maxSignal}{Interference + Noise} \tag{9}$$

The power of thermal noise is taken to be -101 dBm in the evaluations. In the following step we will predict the required bandwidth (number of PRBs) for each sector, to serve its demands. The relationship between SINR and required frequency for serving a given demand is based on the so called Alpha-Shannon Formula, suggested to be used for LTE networks (10)[4]

$$SpectralEfficiency = \alpha * \log_2(1 + 10^{\frac{SINR}{10*impfactor}}) \tag{10}$$

where α=0.75, $impfactor$ = 1.25, and $SINR$ is Signal Noise Interference ratio at the actual point in dB. The number of required frequency bands per sector is thus given by (11)

$$\sum_{point\ of\ sector} \frac{demand}{SpectralEfficiency} \tag{11}$$

After this step it turns out that the sector is able to serve its actual demands or not. The following steps belong to the LA (Figure 3). Searches the "most unserved" sector, that is the sector where the actual service differs from the demand with the highest amount. If no such sector is found (all demands are served), than the algorithm terminates. Otherwise the algorithm locates a new base station near the serving antenna of sector in the main direction. The following step is the running of K-means clustering algorithm. The necessary ρ(xj,mi) metric is the distance between a given location within the sector (xj) and the position of serving base station (mi) weighted by the demand of xj. The idea of this step is to force the algorithm to locate base stations near higher demands. K-means clustering runs six cycles, along with RRC.

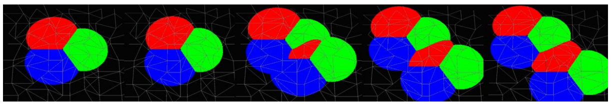

Fig. 3. Mechanism of Location Algorithm

The detailed flowchart diagram of the algorithm is presented in Figure 4.

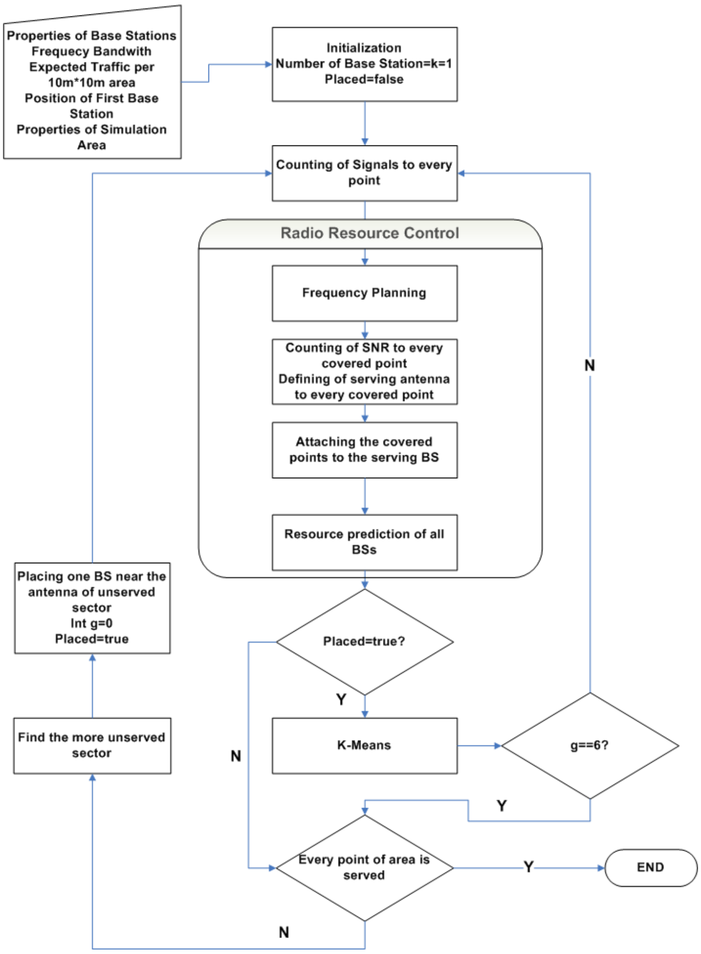

Fig. 4. Detailed flowchart diagram of RF planning algorithm

4 Numerical results

The algorithm was used in a terrain of 9 km^2, modelling a center of a big city. The overall traffic demand was 900 Mbps, the available bandwidth is 20 MHz.

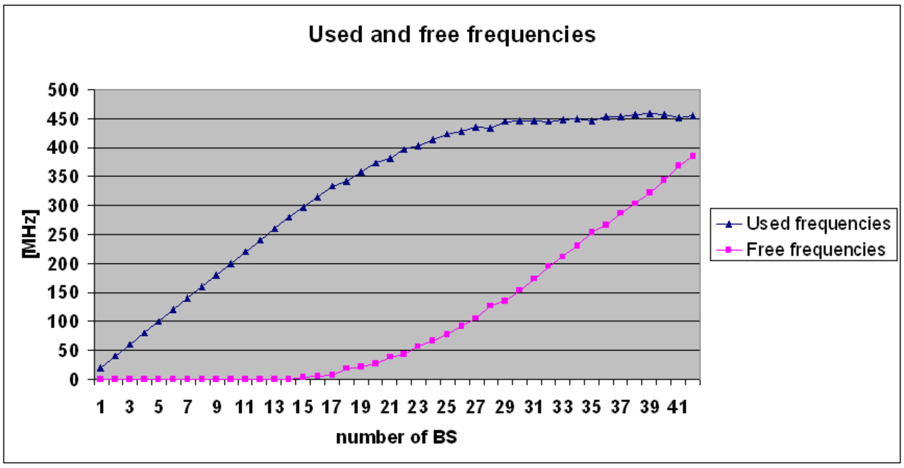

Fig. 5. Used and free frequency band during the running of planning algorithm

In Figure 5 the total amount of used and unused frequency bands is presented, as the algorithm placed more and more base stations over the area. The amount of total used and unused frequency is determined by means of summing up all used (and unused) bandwidths for all cells in the network. We see, that the used total bandwidth is reaching its maximum for about 30 base stations (meaning that most of the demands are served at this point), but 10 more base stations are needed to attain 100% coverage and service. This then result in the increase of unused bandwidth, meaning that the service of the last couple of percentage of demands seriously increase inefficiency. The consequences of this are that a given reasonable service requirement (in terms of coverage and capacity), say 95% (meaning that 5% of the area might remain uncovered and 5% of the demands might not be served) can save a lot in terms of required base station numbers. On the other hand, if more advanced RRC would be assumed and modelled (that allocates PRBs adaptively to demands), the efficiency of used spectrum would be higher, thus less base stations would be enough (however, the aim of this work is not to develop an optimal RRC method, but to plan the network with any given RRC).

In Figure 6, the spectral efficiency of the network is presented, as the algorithm places new base stations over the area. It reaches its peak quite early, for about 13 base stations. This means that the placement of new stations will not increase spectral efficiency, however to serve all demands (and to provide more capacity), more stations are needed. A slight decrease in spectral efficiency can

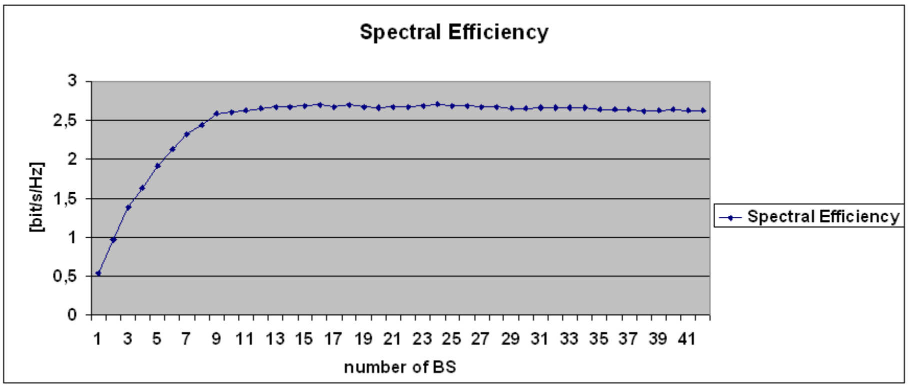

Fig. 6. Spectral efficiency during the running of planning algorithm

also be observed in case of higher numbers of base stations, that is for the same reasons that was concluded regarding Figure 5.

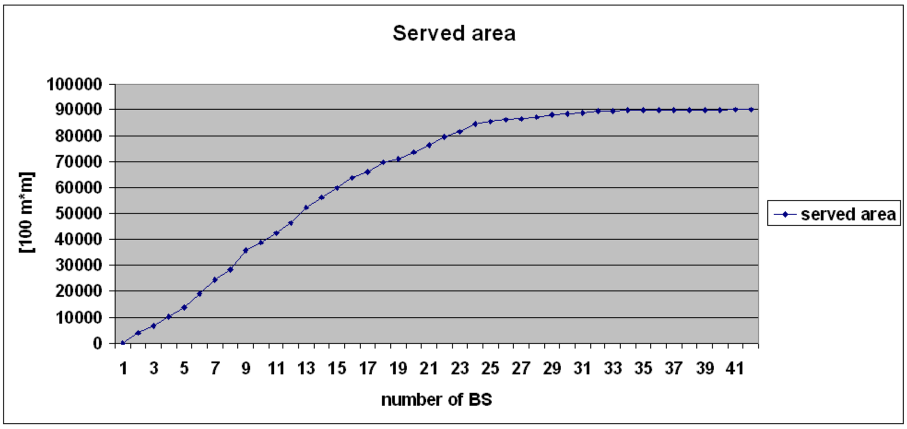

Fig. 7. Size of served area during the running of planning algorithm

Figure 7 shows how the served area is increasing over the iterations of the algorithm. Again, it can be concluded, that the area of 9 km^2 is well served by around 30 stations, the rest are needed to cover negligible holes in coverage.

The algorithm proposed was compared to the results of a traditional base station placement following a regular hexagonal grid. Figure 8 shows how the served area increases as the number of base stations increase in this regular grid. We can conclude that our proposed algorithm covers the area with half the number of base stations, that is a very reasonable performance increase.

Fig. 8. Size of served area for different hexagonal BS location

5 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 an 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, although it is concluded that by means of loosening coverage/capacity requirements, or by using advanced RRC algorithms, the number of necessary base stations might be significantly reduced.

References

1. Omar H. Karam, Lamia Fattouh, Nourhan Youssef, Ahmad E. Abdelazim.: Employing Clustering Techniques in Planning Wireless Local Loop Communication Systems: PlanAir,11th International Conference On Artificial Intelligence Applications Cairo, Egypt, February 23-26, (2005)
2. Ajay R. Mishra, Advanced Cellular Network Planning and Optimization, pp. 15–197,John Wiley & Sons Ltd. (2007)
3. Savo G Glisic, Advanced Wireless Networks 4G, pp. 667–694,John Wiley & Sons Ltd.(2006)
4. Abdul Basit, Dimensioning of LTE Network, Description of Models and Tool, Coverage and Capacity Estimation of 3GPP Long Term Evolution radio interface(2009)
5. Les Barclay, Propagation of Radiowaves, p. 194, The Institution of Electrical Engineers, London (2003)
6. Harish Ramamurthy, Abhay Karandikar: B-Hive: A cell planning tool for urban wireless networks, 9th National Conference on Communications, (2003)