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Use of Geolocation in ACP Systems

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Abstract

Mobile network operators try to keep up with the growing demands of the users and use different bands and carriers, which itself increases the interference of the system and degrades the network quality. It is almost impossible to detect and resolve these issues one by one due to the scale and complexity of the system. Therefore, more and more operators are introducing the solutions that can automatically change network settings and improve network quality. Automated Cell Planning module uses different algorithms that requires optimization and efficiency improvement. This can be accomplished by splitting the cluster into small bins and selecting worst areas for brute force attack that can reduce the number of iteration hundreds of times. Reducing the number of possible settings decreases the computation time and makes the whole process more efficient. Study and simulation of our new approach is given below.

Keywords: Geolocation; SON; 5G; ACP; tilt; LTE; automation.

1. Introduction

Considering the modern customers growing demands that urges mobile operators deploying the multiple carriers and sectors increasing the number of cells exponentially, which in turn leads to the base stations overlapping, overshooting or polluting each other. Because of the huge numbers, it is almost impossible to solve these problems without computing systems and optimal algorithms. In fact, mobile network operators are now focusing to the automated planning and self-organizing systems, that allows to increase network quality while reducing operating costs. One of the leading branches in 3GPP organization on automated parameter changes in mobile systems is Automated Cell Planning (ACP) [1].

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Adjusting the antenna tilt or transmit power is technically very easy, but the challenge is to find optimal settings. The solution to this problem becomes simpler if the subscriber locations are known, as it has a great impact on the overall interference and noise levels of the cell, especially for the users at the edge of the cell, as they need more power to exceed the interference level for getting proper service. Changing parameters on one cell affects the neighboring base stations. For this reason, the boundary of the cell and its covered area should be optimized by configuring the sector parameters considering the fact that high power base station delivers better service quality in its coverage area, but leads to high interference around the stations and can produce far worse results at the cluster level. Based on the problems described above, cellular coverage planning can be described as a large, multi-variable equation [2].

2. Problem formulation

Previous automated cell planning systems use the brute force method that requires all parameters to be simulated for all possible values. Of course, this method allows us to choose the best from all available options, but it is very inefficient and long-lasting process for large systems. If the number of cells in the cluster is n and the number of different possible tilts for each cell is Ti, then the number of iterations required by the brute force method is [3]:

$$I = \prod_{i=1}^{n} Ti \tag{1}$$

If we introduce another parameter for these cells, such as the transmission power, the number of available iterations can be recorded as follows:

$$I = \prod_{i=1}^{n} (Ti * Pi) \tag{2}$$

Where Pi is the number of different possible power values for the cell. With even more generalizations and more options, we get [4]:

$$I = \prod_{i=1}^{n} \prod_{j=1}^{p} Rji \tag{3}$$

Where, p is the number of adjustable parameters, and Rj is the number of different values of the given parameter. As mentioned above, the brute force algorithm is not efficient and requires very complex calculations, for example, if we take 1000 cells, where each cell can be set from 0 to 9 degrees, we will need 10^{12} iterations that require a large amount of computation resources. Considering the fact that modern 4G or 5G base station is configured with an average of 15-24 cells, even a small cluster using this method becomes very expensive and long-lasting process. In order to increase the efficiency of automatic cell planning module, we need to develop a mechanism to pre-determine the settings that can result the system degradations and exclude them. This will significantly reduce the number of iterations, which in turn improve quality and shorten the calculation time. We can use two methods to reduce the number of iterations. The first method is based on worst performing cells ranked by quality of service, congestion, dropped or blocked calls. Selected base stations and its first-tier neighbors are aligned first in the list where the brute force method is used. The second method ranks the worst covered areas and uses the brute force method on the cells that are covering this particular problematic area. The electrical antenna tilt directly affects the base station coverage as well as its first-tier neighbors. Because of this and the fact that it can be changed remotely, electrical tilt changes are the most popular parameter that is used in ACP systems [5]. Received signal strength and load balance can be controlled by the thresholds that can cause the degradation or even loss of coverage. That’s why, it is necessary to analyze the capacity of the neighboring sectors making our task even more complex. The change of antenna tilt on a cell causes the change in the coverage area of this sector and affects the level of interference of the surrounding cells. Therefore, it becomes necessary for one or more neighboring sectors to offload the traffic to maintain or improve overall quality of service. With all this in mind, changing the cluster parameter in the cluster requires a complete consideration of the system of nearby stations. As mentioned above, each parameter change affects surrounding cells and the whole process can be described by classical multi-variable equation with the maximization of different components: coverage, quality of service and capacity. For simplicity, we will consider the system, where the highest priority is the signal to interference and noise ratio improvement, because it is directly related to spectral efficiency and user throughput. The cluster is divided into 100x100 meters quadrants and average SINR value (Sb) is calculated for each bin:

$$S_b = \frac{\sum_i^n \bar{\mathrm{S}}(i)}{n} \qquad (4)$$

where Si is the SINR of nth call at the end of the session, and n is number of the subscribers inside the bin. To calculate the system average SINR value [6]:

$$S = \frac{\sum_i^N S_b(i)}{N} \qquad (5)$$

Where N is the number of bins in the cluster. For each bin we need to rank serving cells by signal strength. Best serving cell is considered the main carrier and the others as a of interference. Any antenna tilt change in the cluster will change the signal level for every bin where the base station signal is propagated, regardless the fact whether it is the best server or not. Accordingly, if any particular cell signal level is increased in a bin, it is necessary to check all the signal levels in that bin and recalculate the mean value of the SINRs.

3. Calculation of the signal level changes caused by antenna tilt

The angle between the main direction of the antenna and the horizon is called the antenna tilt, measured in degrees. Its value is positive if the antenna is down-tilted towards the horizon and is negative if the antenna is up-tilted toward the horizon.

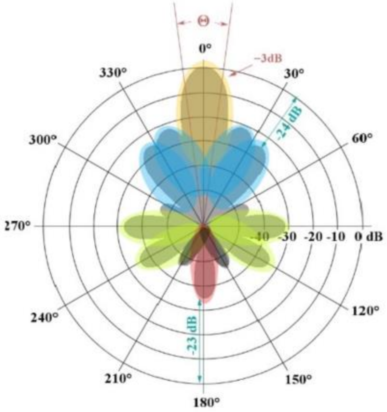

Figure 1: Antenna Radiation Diagram

The antenna tilt can be changed mechanically and electronically.

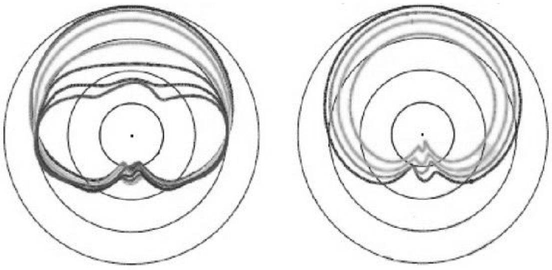

Figure 2: Comparison of mechanical and electronic tilts

The change in signal level for a given bin is calculated as follows:

$$\Delta_i = F(To_i) - F(Tn_i) \qquad (6)$$

where, F is a function that shows the relation of antenna amplification on the antenna tilt. T_o is existing antenna tilt value and the Tn – is the new tilt. Total antenna gain in horizontal plane is calculated with the following formula [7]:

$$F(T) = G - \min\left(12 * \left(\frac{\varphi}{BW_h}\right)^2, Fr\right) - \min\left(12 * \left(\frac{\theta - T}{BW_v}\right)^2, Sl\right) \qquad (7)$$

where, G is the antenna gain, BWh and BWv are horizontal and vertical beam widths, the Fr is the front to end ratio, φ is the horizontal angle between the subscriber and the antenna direction, the S l is the side-lobe and θ is the vertical angle between antenna tilt and the subscriber, which is calculated from the following formula:

$$\theta = atan\left(\frac{h_{BS} - h_m}{dist}\right) \qquad (8)$$

Where, h_{BS} is the height of the antenna, h_m is the height of the subscriber, *dist* is the distance between the customer and the base station. The variation of signal level affects SINR value which can be calculated as follows:

$$S_i = \begin{cases} R_i = Rb_i & S_i + \Delta_i \\ R_i \neq Rb_i & R_i - 10 * Lg\left(10^{\frac{(Rb_i - Sb_i)}{10}} - 10^{\frac{(R_i)}{10}} + 10^{\frac{(R_i - \Delta_i)}{10}}\right) \end{cases} \qquad (9)$$

The signal output (P_L) depends on the distance and frequency, which in our case is 700 MHz:

$$P_L = 124.6 + 37.6\log(d) \qquad (10)$$

where, d is the distance in km. Hence, the received signal level on the mobile receiver will be:

$$P_r = P_t - P_L + G_h(\varphi) + G_v(\theta) \qquad (11)$$

where, P_t is the power transmitted from the base station, while G_h and G_v are the horizontal and vertical gain of the antenna at the corresponding angles. Customers always connect to the cells having best signal strength and quality. Following formula can be used for calculating SINR of terminal j which is connected to base station i [8]:

$$\left(\frac{S}{I}\right)_j = \frac{\frac{P_{t,i} * G_{i,j}}{L_{i,j}}}{\sum_{k \neq i}^{n} \frac{P_{t,k} * G_{i,k}}{L_{i,k}}} \qquad (12)$$

If the traffic density of any cell exceeds density of the surrounding cells, which is caused by the subscriber locations close to the base station, it increases the interference of the cell dramatically, as the value of SIR is inversely proportional to the distance. Parameter changes recommended by ACP module requires heuristic method to check all available tilt settings for each antenna in order to achieve maximum system SINR value and improve overall quality of service. We also need to use classical gradient ascent methodology, which allows us to find best configuration for base stations that affects the overall interference for both internal and external bins.

$$I = \sum_{j=1}^{w} \prod_{i=1}^{b_j} Ti \qquad (13)$$

where, w is the number of bad bins and bj is the number of cells affecting this particular bin. If w=N then there is no improvement in efficiency comparing to the regular brute force attack as the number of iterations will be the same, but in most cases, only the improvement of the worst 10% (w=N/10) will give us the good results and decreases the number of iteration 1000 times.

$$\lim_{w \to n} \sum_{j=1}^{w} \prod_{i=1}^{b_j} Ti = \prod_{i=1}^{n} Ti \qquad (14)$$

As described above, the $\beta(i)$ reflects the influence of each parameter change on the overall system SINR. Gradient ascent method is required for each object in a group to calculate recommended settings for each base station [9]:

$$\Delta P_{TX}(i) = \begin{cases} -1, & \beta(i) \le \beta_{min} \\ 0, & \beta_{min} < \beta(i) \le \beta_{max} \\ 1, & \beta_{max} \le \beta(i) \end{cases} \tag{15}$$

Where β_{min} and β_{max} are the lower and upper bound for changes.

4. Description of the simulation

The model and parameters described above were used during the simulation. A cluster consisting of 24 base stations and 72 cells was selected. The location of the subscribers and the signal measurements were also collected for 1 day (15998 records totally). Complex terrain profile was also considered, as it was necessary to get as close as possible to the actual conditions during the simulation.

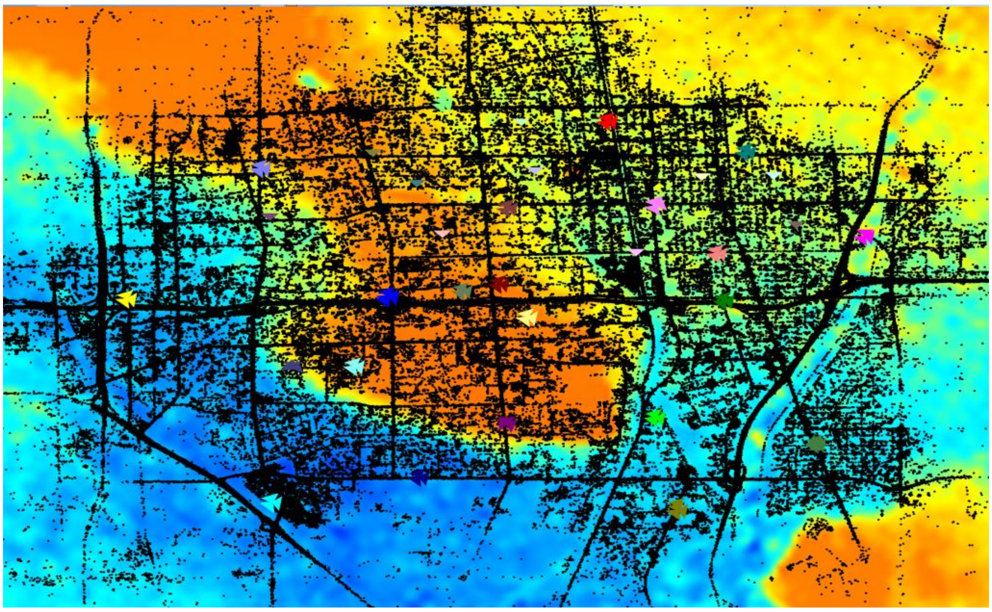

Figure 3: Clusters for simulation

The additional parameters required for the simulation are given in the table below:

The values of the existing tilts for each base station were changed in different iterations. The main goal was to down-tilt the congested cells and offload traffic to the neighboring stations. The cell load can be calculated using the ratio of the connected subscribers to the maximum possible number of subscribers. In the first stage, we detect overshooting cells and tilt the ones that are most likely to interfere with the rest of the stations and degrade the quality of services as well as the overall spectral efficiency. However, we must consider the coverage factor to avoid a complete loss of service.

Table 1: Simulation settings

Parameter	Meaning
Antenna Height	25 -40 m
Subscriber height	1.5 m
The radius of the cell	200- 800 m
Path loss	L = 128.1 + 37.6 * log (d)
Transmission power	46 dBm
Antenna amplification	17 dbi
Horizontal beam-width of antenna	60
Vertical beam-width of antenna	12
Tilt change	+2, 0, -2
Tilting augmentation step	1
Type of tilt	Electronic

In the second phase, we detect the overlapping cells and boost the strongest while tilting the other one. This process enhances and sharpens the cell edges between stations and improves quality for subscribers that are located far away. In the third stage, we find the most polluted cells, which have many subscribers connected to the different stations next to each other, proving that these cells only degrade the quality of service and reduce their overall system health. In the fourth stage we start bin analysis and rank them according to the SINR values.

Table 2: Iteration values

Iteration	**Changes**	**Rsrp**	**Snr**	**Bad bins**	**Dist**	**Over shooting**	**Pollution**
0	B01C, 3; B 02A, 2;	-102.52	1.76	2273	1.43	16.14	0.52
1	B01C, 1; B 02A, 0;	-102.50	1.83	2453	1.43	16.23	0.52
2	B01C, 3; B 02A, 0;	-102.51	1.80	2467	1.43	16.19	0.52
3	B01C, 5; B 02A, 2;	-102.53	1.78	2483	1.43	16.19	0.52
4	B01C, 1; B 02A, 2;	-102.51	1.79	2473	1.43	16.20	0.52
5	B01C, 3; B 02A, 2;	-102.52	1.76	2488	1.43	16.14	0.52
6	B01C, 5; B 02A, 4;	-102.53	1.81	2468	1.43	16.21	0.52
7	B01C, 1; B 02A, 4;	-102.51	1.83	2459	1.43	16.22	0.52
8	B01C, 3; B 02A, 4;	-102.52	1.80	2474	1.43	16.18	0.52
9	B03A, 2; B 04A, 3; B05A, 2; B06B, 0; B07A, 3;	-102.52	1.76	2273	1.43	16.14	0.52
10	B03A, 2; B 04A, 3; B05A, 2; B06B, 0; B07A, 3;	-102.50	1.83	2453	1.43	16.23	0.52
11	B03A, 4; B 04A, 5; B05A, 4; B06B, 0; B07A, 1;	-102.49	1.95	2402	1.43	16.13	0.52
12	B03A, 0; B 04A, 5; B05A, 4; B06B, 0; B07A, 1;	-102.48	1.95	2397	1.43	16.29	0.52
13	B03A, 2; B 04A, 5; B05A, 4; B06B, 0; B07A, 1;	-102.49	1.91	2414	1.43	16.27	0.52
14	B03A, 4; B 04A, 1; B05A, 4; B06B, 0; B07A, 1;	-102.49	1.95	2399	1.43	16.12	0.52
15	B03A, 0; B 04A, 1; B05A, 4; B06B, 0; B07A, 1;	-102.47	1.95	2394	1.43	16.28	0.52
16	B03A, 2; B 04A, 1; B05A, 4; B06B, 0; B07A, 1;	-102.49	1.91	2411	1.43	16.26	0.52

Our goal is to analyze the worst nth bins one by one and determine the optimal tilt values for all the cells covering the area. During each iteration different tilts are set and average SINR of the entire cluster are calculated.

The purpose of this procedure is to maximize the predefined parameter, which in our case is SINR. For maximizing the given value, it is necessary to calculate the average SINR for each iteration and compare it with the existing and previous iteration values:

$$Smax = Max\ (Si, S, S\ p) \qquad (13)$$

After 560 iterations we covered worst 10% of the bins and the results for each iteration is is shown in the Fig. 4:

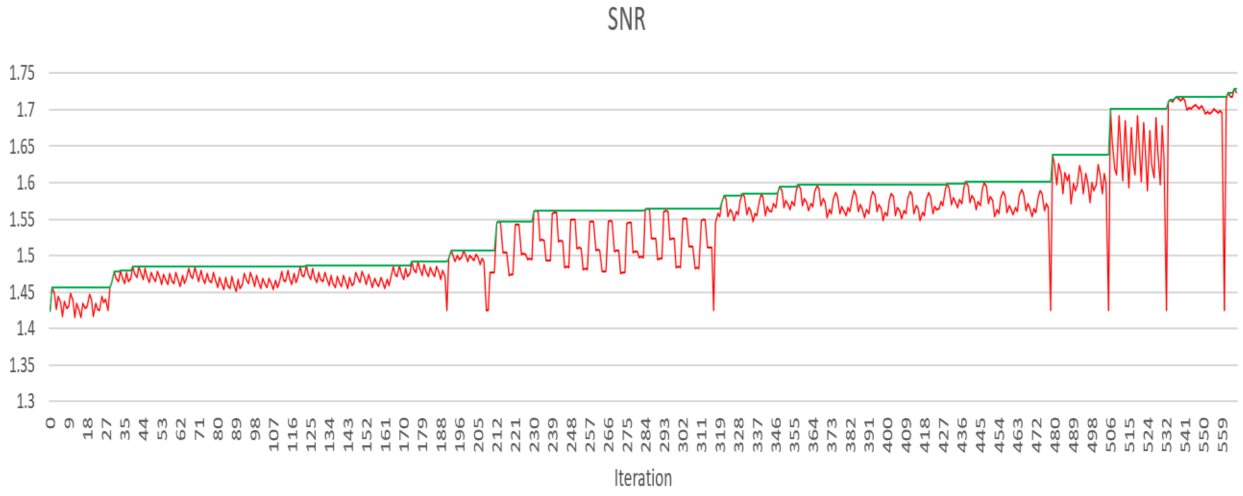

Figure 4: Simulation result SINR improvement

Along with the SINR, other indicators need to be monitored. Fig. 5 shows the dependence of the mean signal level to the iterations, which shows that with the network quality the signal level can also be improved.

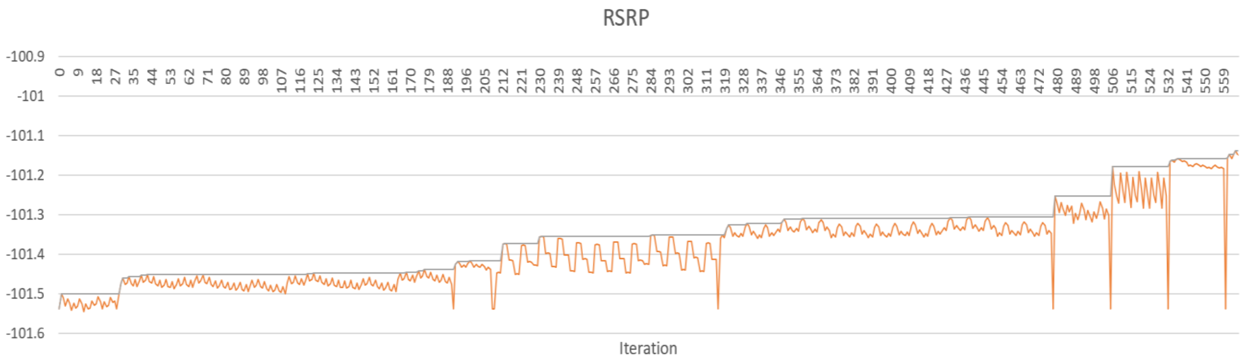

Figure 5: Simulation results, improving signal level

System spectral efficiency can be measured by Channel Quality Indicator CQI which is also shown on the chart below:

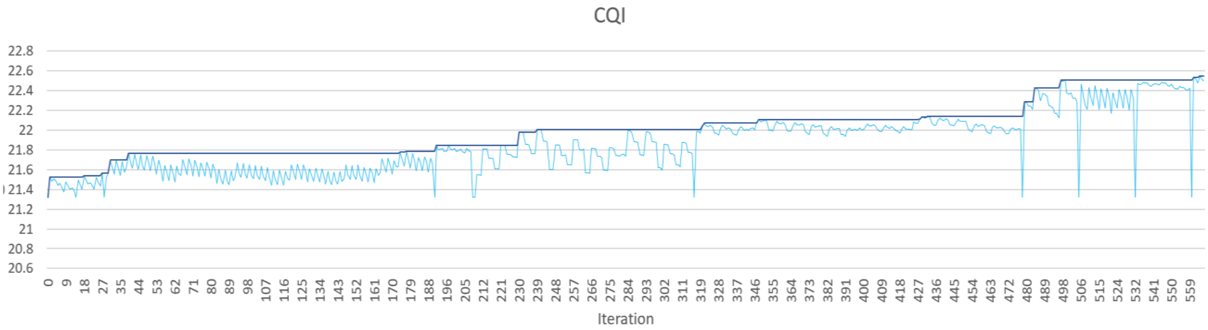

Figure 6: Simulation result: Improvement of CQI

Also, it is very important to a count number of the bins with the poor quality that needs to be maintained or reduced. Fig. 7 shows the bad bin count relation to the iterations:

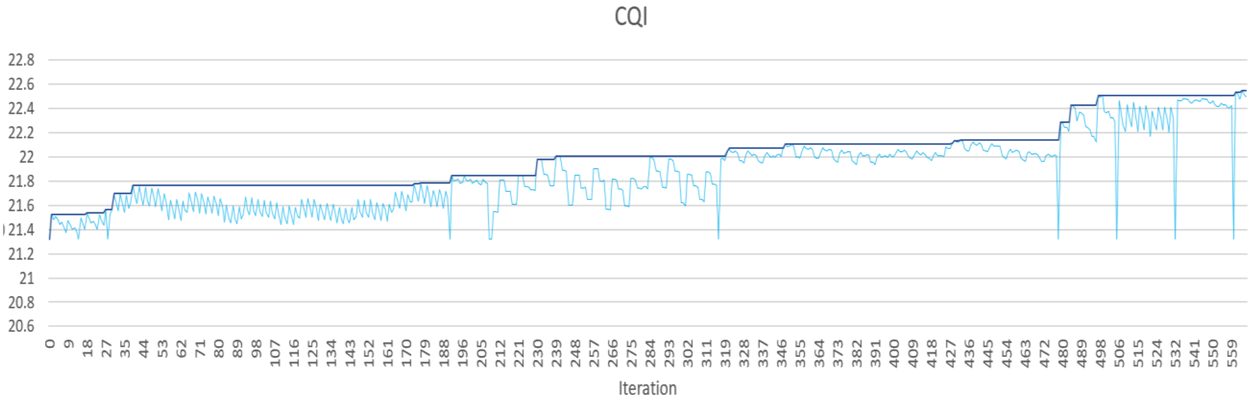

Figure 7: Simulation result: Number of bad bins

The simulation results showed a 41 % improvement in network quality, while a slight change in the average signal level, providing improved spectral efficiency, download speed and overall service quality.

Table 3: Simulation results

Pointer	**Rsrp**	**Snr**	**Bad bins**	**Distance**	**Overshooting**	**Pollution**
Existing	-102.524	1.756998	2273	1.426268	16.13705	0.516307
Simulated	-102.269	2.487396	2141	1.424926	16.00254	0.516307
Improvement	0.25%	41.57%	-5.81%	-0.09%	-0.83%	0.00%

Visualization of network improvement can also be presented as a map showing the geographical distribution of the entire cluster SINR. Comparison of these two snapshots on Fig. 8 allows us to understand what areas will be improved or worsened.

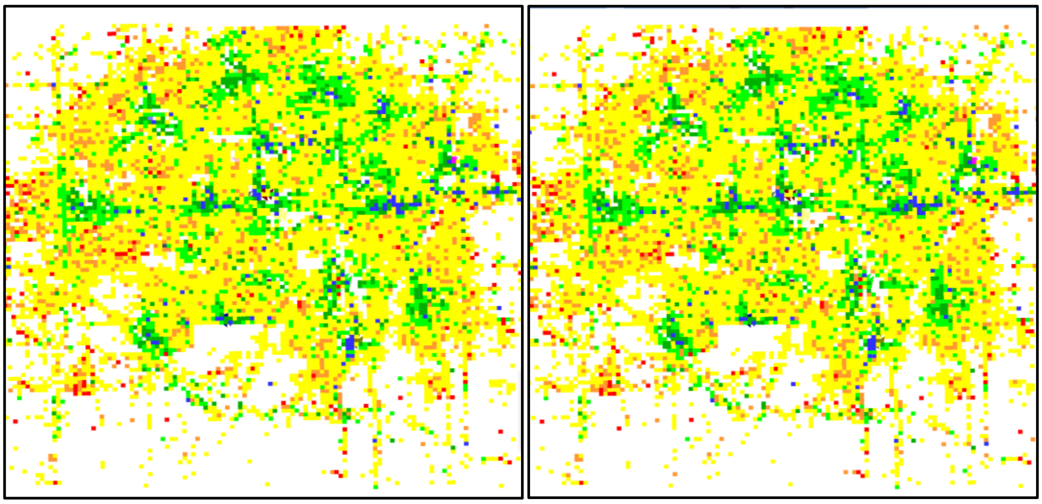

Figure 8: Comparison of SIR before and after the change

The simulation can also be evaluated by a histogram where the bins are grouped up to 4 dB and their sample are counted for each group:

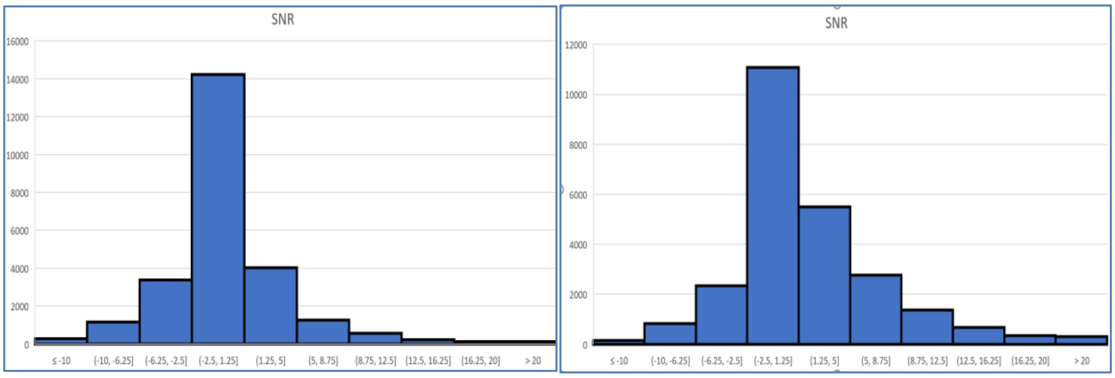

Figure 8: Comparison of Changes: Histogram

The distribution shown in Fig. 9 shows that the number of bins having SINR value better than 5 dB is significantly increased, which is a real sign of improvement in total cluster quality and increased spectral efficiency.

5. Conclusion

The focus of this paper is to evaluate existing ACP algorithms for 4G and 5G wireless network and develop the new, efficient algorithm with the intention to maximize system SINR and improve overall system spectral efficiency. We conducted cluster level simulations in order to assess computation time improvement. The simulation results show that the proposed Worst Bin Brute Force Algorithm can deliver better performance of the module itself. And most importantly, the results also prove that proposed algorithm can improve the system stability, duration and CPU load while achieving reasonable quality improvements. The provided formulae above show that the existing algorithms are limited for large systems. Therefore, we proposed to divide them into small clusters that can be processed in parallel. Due to the exponential dependency of the number of the cells in selected area we found that the best performance can be achieved at the area containing not more than 1000x1000 bins. Furthermore, using MMR for ACP is innovative approach that does not require decoding tons of binary files and has better accuracy. In order to make the algorithm more flexible we can consider more configurable variables, such as transmit power, azimuth, height, etc. However, as mentioned above, its implementation can dramatically increase calculation time due to computational complexity.

6. Recommendations

1. Due to expensive computation procedures and long-lasting calculation, ACP module integration into SON systems seems to be very problematic. We need to include more parameters to make ACP module more flexible and add more intelligence to detect and exclude the problematic settings that will reduce the number of iterations even more and reduces the calculation time. We used different geolocation methods in our previous studies and found that mobile measurement-based geolocation shows much better results than CTR or RTT+TA based location detection**.** However, this methodology can also be adopted for any type of geolocation data sources. Use of geolocated measurements can fill the gap between the customer based and network element based optimization tactics. We also found in our previous work that multi-user network resource allocation and distribution can also affect the system load and can be used in customized packet scheduling algorithms [10]. Efficient algorithm will give us opportunity to scale it on large systems, detect the problematic cells and improve the network quality in a timely manner.

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