Performance evaluation of interference reduction model in dense small cells networks using genetic algorithms and clustering from simulations with 4K (Ultra-High Definition) and Voice over IP loads.

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Abstract

Almost every day, new types of smartphones are introduced in the market, with greater processing capacities and that support applications with better performance which consume data at high speed, in a scale that can reach 20 Gbps. Therefore, new architectures should be made to offer this feature. The Small Cells (SCs), a technology that uses the licensed frequencies of cellular telephone networks, but works with low power, has been presented as a tool that can help to solve this and other problems, among them, the offer of a better signal quality in indoors environments. However, because these SCs, which can also be called Access Points (APs), work with low power, they must be installed next to each other, which will create an environment called Dense Networks (DenseNets). Thus, if this environment is developed incorrectly, instead of increasing the quality of services offered to subscribers of cell lines, this infrastructure would make it impossible to use mobile devices at this location. Due this fact, this paper presents the developing of a method for interference mitigation in dense Small Cell LTE networks, by clustering access points in frequency bands using a paradigm of the computational intelligence, more specifically, the Genetic Algorithm (GA). Among some improvements, this model presented approximately a reduction of 94% in amount of packets loss to the video applications and related to the VOIP application, its performance increased in more than 95% the average of throughput.

Keywords: DenseNets, Interference, Clustering.

1. Introduction

The popularization of mobile devices, such as smartphones, tablets, notebooks, ultrabooks and smartwear, is pushing forward the mobile telecommunication networks expansion. In 2015, those devices summed up for 7.4 billion in existence, by which 3.5 billion possess a mobile internet broadband subscription [1]. According to [2], by the end of 2020, the number of connections coming from smartphones will suffer a 2.6 billion increase, on which developing countries like India and China will represent 90% of these new connections. Improvements to LTE will connect laptops to a huge amount of sensors and other devices, making it possible to use applications that today would not be able to operate because they require high reliability and low latency, such as applications aimed at the health care of users in real time, economic applications among others.

Mobile networks of 4th generation (4G), in special, the LTE ones, are in a fast paced arising through the world. In 2015, the 4G reached the mark of 1 billion of connections [3]. As reported by [4], 80% of mobile traffic occurs in indoor environments. Because of physical and structural particularities, these locations suffer from poor to even no connection at all with the cellular big towers (Macrocells) signals. As example, we have buildings and metro tunnels [5], houses, universities, malls and hospitals [6].

In order to solve the coverage problems, the Small Cells were designed. According [7], Small Cells are "[...] low-powered radio access nodes that operate in licensed and unlicensed spectrum that have a range of 10 meter to several hundred meters." These little access points (APs) have the capacity of extend the coverage of LTE signals in specific and located places, where the tower signal is weak or null. Small Cells are like mini cellular towers which provide signal, and thus, communication between the client and the service provider through the local broadband internet connection link of the place, similar to a Wi-Fi router.

The Small Cell term covers at least 5 cells types, like metrocells, picocells and femtocells, which specifications vary according to the ambient they are deployed, like corporative,
In the numerator, we have the source power, whereas in the denominator, we have three variables: the sum covers all the values of the interfering nodes, $N_0$ is the value of the white noise of the channel and $\lambda$ is density, which indicates the percentage of femtocells turned on at a particular time. With the SINR values of all nodes, the number of cluster is estimated in the following manner: if the SINR value is below the minimum threshold established ($L_i$), where the threshold is a power value in dB, then a new cluster is added. Otherwise, no cluster is added.

In order to find all the interference values caused by the Small Cells, we needed to insert a virtual user into the mathematical model. This user is characterized by a spatial point in the scenario. For this point, we computed the power of the source node and the power of each interfering node. The received power value is given by Eq. 2, and its value is used to compute the interference value through Eq. 3:

$$ P_r = \frac{EIRP \cdot Gr}{L_s} $$

(2)

In Equation (2) in the numerator, we have the product of EIRP, which is the irradiated power with respect to the isotropic radiator, $Gr$, which is the gain of the antennas of the APs and $L_s$ is the path loss.

$$ W_{ij} = \frac{P_i}{P_j} $$

(3)

In Equation 3, $W_{ij}$ stands for the interference that the AP j causes in the user connected to the AP i. These values are derived from the column or row index of a matrix whose values are the identifiers of each Small Cell in the scenario. So, if we have a 10 x 10 matrix, $W_{12}$ means that we will compute the interference caused by the Small Cell 2 causes in the user connected to Small Cell 1. $P_i$ and $P_j$ are the powers of the signals received from the source and the interference, respectively.

In order to execute the next step, a code was created for MATLAB which generated 20 individuals [14], that is, 20 chromosomes and each one of them had 60 Small Cells. This starting generation of individuals was then reinserted into MATLAB to give randomness to the original process, which is the collection of input data for the second algorithm. An example of a chromosome representing a network with 12 APs (numbers ranging from 1-12) and 3 clusters is shown in the figure 1.

![Fig. 1. Example of possible chromosome](image)

At the execution of the GA, we needed to extract the parents of the 20 individuals, which were the chromosomes that presented the best features related to the increase in the SINR value for all the Small Cells. Therefore, this growing parameter was used to determine the fitness of the individual and its possibilities of passing to the selection stage.

The selection method used was the roulette wheel, in which the fittest individuals (those with the highest SINR) have a higher chance of being selected. We used the PMX - Partially Mapped Crossover [15] to avoid internal Small Cell redundancies inside each chromosome. All the stages of the GA occurred recursively until the stop criterion was achieved, which is 1000 generations.
In order to know which chromosome is the fittest, we took the central limit theorem into account, that is, having a number of samples above 30, the distribution of the mean values is almost normal and, therefore, the distribution of the mean values of the sample tend to be the same as the mean of the population. 

So, the GA was executed 31 times, resulting in 31 different chromosomes, with 60 positions, each position representing a Small Cell of the scenario. The mean received powers were computed for each of the 31 chromosomes, and then we computed the mean of these 31 new values. It was computed the confidence interval of these 31 new values with a error margin of 5%, which propitiated the selection of the chromosome which had the mean of the received powers closer to the upper limit of the confidence interval, which represents the SINR after clusterization.

The AG pseudocode is shown in figure 2.

Algorithm 1: Procedures performed by the Genetic Algorithm

Data: INITIAL population of solutions (individuals)
Result: STORE the individual with the best fitness
begin
Create a random initial population of solutions (individuals);
Initial population becomes the actual generation;
epoch ← 0;
stopcreation ← 1000;
while epoch < stopcreation do
FOR each individual of the actual population;
COMPUTE fitness of the individuals;
SELECT parents from the actual population by using roulette;
CROSSOVER the selected parents, generating children;
FOR each generated child;
TEST for a possible chance of mutation;
Children become the actual generation;
epoch + 1;
end
STORE the individual with the best fitness;
end

Fig. 2. Genetic Algorithms procedures

Lastly, below was inserted the figure 3 that graphically characterizes what would be a scenario before and after clustering.

Fig. 3. Scenario before and after clustering

3. Simulations

Among several simulators, the OPNET Modeler - Education Version 17.5 was chosen because it is a software recognized in the literature and it presents a characteristic that accelerated the process of transfer of the mathematical model to the simulation: the approach by graphical modeling. In this tool was created an environment as close as possible to the reality of DenseNets, which may represent a mall or even a floor of a commercial building, both still in the planning phase using the Brownfield project vision. There were 120 smartphones connected, without mobility, to 60 Small Cells arranged at a distance of 10 meters, both horizontally and vertically, as can be seen in figure 4, which was extracted from [16]. This scenario was chosen, because in [16] there were no tests made with simulated loads of applications such as VoIP or Videos in high resolution. The number of clusters was the same as in [16], this happened because there was no increase in the number of Small Cells, but in the number of users' equipment and the loads of applications consumed by smartphones. The scenario has only one floor.

Aiming to represent a real indoor environment, which has many obstacles that can degrade the signal emitted by the APs, in this scenario the propagation loss model called Indoor Office Environment - ITU-R M.1225 was considered, which presents the following mathematical equation:

\[ L = 37 + 30\log(10)R + 18.3n\left(\frac{n + 2}{n + 1}\right)^{-0.46} \]  

(4)

In the equation, R represents the distance in meters between the transmitter and receiver and n the number of floors of the construction, in this case zero (0). In the equation the loss of propagation has its scale in decibel (dB). In the scenario smartphones use two types of applications: Video in high resolution (4K) and Voice over Internet Protocol - VoIP. The physical characteristics of the devices are shown in Table 1, which were extracted from [17] and the loads of the applications that were inserted into the OPNET are described in Table 2 that were extracted from [18] and [19], respectively.

<table>
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<tr>
<th>Table 1: Configuration parameters</th>
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<td>Parameters</td>
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<tr>
<td>Antenna Gain dBi</td>
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<tr>
<td>Duplexing Scheme</td>
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<tr>
<td>Path Loss Model</td>
</tr>
<tr>
<td>Fading dB</td>
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<tr>
<td>Number of TX/RX antennas</td>
</tr>
<tr>
<td>Transmission Power dBm</td>
</tr>
<tr>
<td>Number of users connected (in each)</td>
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<td>Antenna type</td>
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<th>User Equipments (UE)</th>
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<tr>
<td>Antenna type</td>
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Table 2. VoIP and Video configuration parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Video application</td>
<td></td>
</tr>
<tr>
<td>Frame interarrival time</td>
<td>60 frames per second</td>
</tr>
<tr>
<td>Frame size</td>
<td>4096x2160 pixels</td>
</tr>
<tr>
<td>Start time offset</td>
<td>uniform (50,3600)</td>
</tr>
<tr>
<td>Duration</td>
<td>End of profile</td>
</tr>
<tr>
<td>Inter repetition time</td>
<td>300 seconds</td>
</tr>
<tr>
<td>VoIP application</td>
<td></td>
</tr>
<tr>
<td>Encoder Scheme</td>
<td>G.711</td>
</tr>
<tr>
<td>Type of Service</td>
<td>Best Effort</td>
</tr>
<tr>
<td>Signaling</td>
<td>SIP</td>
</tr>
<tr>
<td>Compression delay</td>
<td>0.00075 seconds</td>
</tr>
<tr>
<td>Decompression delay</td>
<td>0.00075 seconds</td>
</tr>
<tr>
<td>Duration of profile run</td>
<td>End of profile</td>
</tr>
<tr>
<td>Inter repetition time</td>
<td>300 s</td>
</tr>
</tbody>
</table>

In the simulations, global and individual data were analyzed. For the individual analysis, 4 nodes were chosen and this choice was due to the fact that they are all in different clusters, both when the Small Cells were divided in 4 clusters and in 6 clusters.

Due to the fact that the application with voice load over IP has passed more than 30 hours without presenting result, we have resolved to make some changes in the connections between the devices described in [16]. The links between the Small Cells and the IP cloud remained over PPP_adv connections, which simulate the network backbone, but an Evolved Packet Core - EPCs was included. The two EPCs were connected to one gateway and the cloud by the links PPP_DS3, with a data rate of 44.4Mbps. A new 10Gbps connection has been inserted between the gateway and the application server.

Each simulation lasted 5 minutes or 300 seconds, with a Warm-Up time of 100 seconds. This period was chosen because about 5 minutes of simulation we realized that the system reached a state of equilibrium in which it did not evolve.

The hardware used in the simulations consisted of 4 processors with nominal frequency of 2 GHz, 4 MB of cache memory and 8 GB of RAM.

4. Results

When there was no clustering, there was no data traffic between any mobile device and the application server, this fact proves that a solution proposal for dense environments is of extreme importance.

4.1. Video application

One important information is that after the inclusion of one Evolved Packet Core and the increase of the throughput through another PPP_DS3 connection, there was no 4K video stream when the Small Cells were divided in 4 clusters, that is, in the moment that the 60 Small Cells were divided into 4 groups, each using a 10MHz bandwidth, there was no flow of data across to the whole scenario.

Figure 5 shows one of the causes for the lack of flow when using 4 clusters, since the average of lost packets grows during the 5 minutes of simulation. This fact occurs due to the interference that still exists in the environment, because when the Small Cells are divided into 6 clusters, this rate decreases as can be seen through the figure 6 and there is a video stream, as we can see through the graph which symbolizes the global flow shown in figure 7.

4.2. VoIP application

At the time of the simulation using the load of the VoIP application, we noticed that there was a substantial growth between the times when the Small Cells were divided between 4 and 6 clusters. In the first situation, there was a growth in the flow from 0 to 380 bits in 240 seconds. However, when the APs were divided in 6 clusters, the global flow presented a growth, almost completely in linear scale, where in the same 240 seconds it reached a flow rate of 145,000 bits and this can be seen through figures 8 and 9.
Another very important analysis that must be done when planning the networks that will use VoIP technology is the delay because it can directly affect the quality of communications. Based on technical analysis, the International Telecommunication Union - ITU in its recommendation [20] defines that delays in the range between 0 and 150 ms guarantee a high level of iteration between participants of a telephone call, since delays in the range between 150 and 400 ms provide an acceptable level of interaction between the interlocutors and delays above 400 ms are not acceptable for VoIP communications.

Fig. 8. Average of global throughput – 4 clusters – VoIP

Fig. 9. Average of global throughput – 6 clusters – VoIP

Therefore, through figures 10 and 11 it is observed that the clustering helped to maintain the pattern specified by the ITU related to the delay and that between the two forms of clustering or a difference of approximately 10 ms throughout the simulation times for the traffic that was used.

Fig. 10. Average of global delay – 4 clusters – VoIP

Fig. 11. Average of global delay – 6 clusters – VoIP

Another variable that must be taken into account for the verification of the quality of services offered to the communications networks that use VoIP technology is the loss of packets, because if there is a certain amount of packets lost there will be no understanding of what is spoken between communicators.

Fig. 12. Average of packets dropped RX – 4 clusters – VoIP

Fig. 13. Average of packets dropped RX – 6 clusters – VoIP

Fig. 14. Average of packets dropped TX – 4 clusters – VoIP
Thus, by analyzing this last variable, the model provided a significant reduction in the amount of packets lost, both in reception and in transmission. In Figure 12, which represents the division of the 60 Small Cells into 4 clusters, we can see that there is a peak of 140 packets lost when the elapsed time of simulation arrives in approximately 290 seconds. But, looking at figure 13, division into 6 clusters, we note that the highest value related to packet loss at download times, in all 5 minutes of simulation, it is around 50 packets, i.e. a drop around of 180%.

When we look at Figures 14 and 15 it seems that there is no the same relation of lost packets, but when we calculate the average of the packets lost in the uplink sense in the whole simulation, we noticed that when there were 4 subbands, there is a Average of 27 packets lost per second, but when 6 subbands were used the average was 14 packets lost, that is, a reduction of 92.86%.

This means that the main idea presented in this article, that is, the original genetic algorithm described in [16], can be used not only with applications in which we find a small data flow, but also in several types of services that are widely offered nowadays requiring high quality and bandwidth rates like VoIP or videos using high definition technologies like 4K.

5. Conclusion

Because the usage patterns of the new cellular networks are facing drastic changes, especially in the number of connected users and the high availability of bandwidth and speed imposed by the new applications of the new smartphones, new architectures have to be implemented since are no longer able to meet these new challenges. For this reason, Small Cells are being implemented in various environments in order to provide quality subscribers to cellular networks. However, these new installations must be preceded by a thorough study, otherwise, there may be no solution, but more problems for users, such as co-channel interference. The co-channel interference reduction model presented in this paper performed its task, providing better conditions for the exchange of traffic in dense networks of Small Cells. Through this article, it was demonstrated that the model is not efficient only when applied in scenarios where subscribers of telephone lines use services through low bandwidth spectrum applications, but also in places where there is a high concentration of people making use of applications that require higher bandwidth and high speed.

However, the quality of the signal can still be improved and the number of Small Cells can be increased so that venues such as stadiums, convention centers or even large avenues can benefit from the use of this technology.

References

[8] In-building, outdoor small cells to handle quarter of mobile traffic by 2016”, Infonetics, Jan 2013.

