

# Optimization of massive connections in 5G networks for IoT

Pablo Zapata Cano  
Dept. Lenguajes y Ciencias de la  
Computación  
Universidad de Málaga  
Spain  
[phzc@lcc.uma.es](mailto:phzc@lcc.uma.es)

Alejandro Ramirez-Arroyo  
Dept. of Signal Theory, Telematics and  
Communications,  
Universidad de Granada-CITIC  
Spain  
[alexrufox@gmail.com](mailto:alexrufox@gmail.com)

Francisco Luna Valero  
Dept. Lenguajes y Ciencias de la  
Computación  
Universidad de Málaga  
Spain  
[flv@lcc.uma.es](mailto:flv@lcc.uma.es)

Antonio Valenzuela-Valdés  
Dept. of Signal Theory, Telematics and  
Communications,  
Universidad de Granada-CITIC  
Spain  
[antonio.valenzuela.valdes@gmail.com](mailto:antonio.valenzuela.valdes@gmail.com)

Pedro A. Castillo-Valdivieso  
Dept. of Architecture and Computer  
Technology,  
Universidad de Granada-CITIC  
Spain  
[pacv@ugr.es](mailto:pacv@ugr.es)

Juan Fco. Valenzuela Valdés  
Dept. of Signal Theory, Telematics and  
Communications,  
Universidad de Granada-CITIC  
Spain  
[juanvalenzuela@ugr.es](mailto:juanvalenzuela@ugr.es)

**Abstract**— The expected traffic demands for the coming years requires a major technology development. Indeed, from 2017 to 2022, the global annual traffic growth is estimated to reach 220%. This annual growth leads in turn to an increase in the number of uses connected to IP networks, going from 2.4 to 3.6 devices connected per person. Currently, 4G networks are capable of handling this load, but the irruption of the 5G breakthroughs, expected to be at full operation by 2020, is visible. However, 5G technologies may come along with a considerable power consumption if they are not devised properly. As a consequence, a key issue in the developing of these networks is to make them energetically sustainable. In this work, a preliminary study of the optimization of various aspects of the 5G system is presented. It addresses the configuration of the different basic parameters of the system and optimizes the power transmitted by the base stations to obtain simultaneous improvements in system capacity and its power consumption for a massive connections scenario. To the best of our knowledge, this is the very first time this type of 5G scenario is optimized with these two performance criteria.

**Keywords**—IoT, massive connections, 5G networks, optimization.

## I. INTRODUCTION

In recent years, the world has experimented the evolution towards the second, third and fourth generation of wireless networks [1, 2]. This progress responds to the capacity demand of new technologies and applications, like high quality video streaming, online gaming, or e-healthcare. However, the new era of communications is still in its infancy. New use cases such as augmented reality, 3D visualization, tactile Internet, remote monitoring, road safety or real-time control place poses new challenges that have driven the development of the fifth generation (5G) mobile networks.

Moreover, the Internet of Things (IoT) adds an additional dimension to connectivity [3], increasing considerably the number of agents in the network. Intelligent "common objects" and accessories like smart wearable devices (e.g., bracelets, glasses, watches), smart home appliances, autonomous cars, etc. will be enabled in this new scenario, generating a hyper-connected smart world. Predictions estimate that users may download terabytes of data annually. Furthermore, future services like the ones introduced above require hundreds of Mbps each, summing up more than 1

Gbps per User Equipment. Considering such significant future traffic demands, the industry aims to increase today's networks capacity by a factor up to 1000x. In fact, in early 2012 ITU-R initiated the definition and research of 5G with the development of IMT-2020 systems. In order to improve network capacity, an increase of the spectrum, spectral efficiency, and spatial reuse are presented as the main three existing paradigms.

This new vision of the network and its requirements have also a big impact on the system architecture, that is facing new challenges and opportunities [4]. Apart from reusing and/or renovating old 4G technologies, future 5G networks will introduce a few changes in the network architecture. The two major ones are, on the one hand, the division of the 4G evolved packed core (EPC) into new core and MEC and, on the other hand, the introduction of a new structure with a central unit (CU) and a distributed unit (DU). However, the exigency of the new 5G features and requirements configures a broader range of more complex challenges and enablers. According to experts [5], there are at least six challenges that are not sufficiently addressed by Long Term Evolution-Advanced (LTE-A) networks. Some of these challenges and enablers are discussed in below:

- **System Capacity and Data Rate:** Current trends forecast a huge increase in data rates, also at high mobility and crowded areas [6]. This capacity-demanding not only in the radio access network, but also in the front- and backhaul, and the back bone.
- **End-to-End Latency:** New agents and scenarios like remote controlled robots or drones require real-time applications and rapid feedback control cycles. This is also critical for some applications like augmented and virtual reality as well as for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications. For enabling all these technologies, an improvement in the E2E latency is needed. An illustrative target value has been proposed in [7]: 1ms. Other techniques like well-tailored NAS protocols or NAS-access stratum (AS) integration could help to reduce the E2E latency.
- **Massive Number of Connections:** New 5G technologies suppose a considerable increase in the number of connections. For example, an actual deployment of IoT

implies providing connectivity to thousands of devices [8]. But the challenge goes even further if we consider the enormous diversity of service requirements and device types that should be supported in an efficient and scalable manner.

- **Cost:** As it has been motivated above, capacity and data rate are two of the main challenges to address in 5G deployments. However, some of the most suitable enablers for that, like network densification, increase the infrastructure costs reasonably.
- **QoE:** 5G network traffic will be dominated by challenging video applications like ultra-high-definition (UHD) [9]. In order to handle that, demanding user- and application-specific requirements have to be met by adopting Quality of Experience.

In this work, two studies of 5G network optimization are presented. In the first one, several parameters of the 5G system are optimized: system capacity, power consumption, and signalling costs. It aims at showing the influence of different assignments between users and base stations. Based on these results, a second study is undertaken for massive connection scenarios which would be the future scenario for IoT.

The structure of this paper is as follows. Section II presents the configuration of the system, detailing the different models used to compute the signal power, capacities and costs of the different elements. Also, in Section II, the different association strategies for assigning users to bases stations are described. In Sections IV and V, the two optimization studies are shown, respectively. Finally, Section VI provides the reader with conclusions drawn in the work.

## II. SYSTEM MODEL

This section aims to describe the underlying modelling on which all optimization and experimentations undertaken are based. It is important to remark that this is just a basic model, which has been taken from a previous work by Valenzuela *et al.* [10]. The main characteristics of the considered scenario are the following. The working area is a terrain of 500x500 m<sup>2</sup>. Both the base stations (BSs) and the users equipments (UEs) are randomly deployed on the scenario, but the users are not static: they move using a random waypoint model. Different types of base stations are used. Their characteristics (macro, micro or femto) are depicted in Table 1. With the aim of modelling different propagation conditions, ten different regions have been defined in the following way: each region is defined by an attraction point (i.e., a given coordinates) that is further used by a Voronoi tessellation. On each region, the propagation parameters are generated randomly (the path loss and the channel type).

Table 1: Specifications of the different types of base stations

	<i>Macro</i>	<i>Micro</i>	<i>Femto</i>
<b>Frequency (GHz)</b>	2	5	28
<b>BW (MHz)</b>	10	25	140
<b>Gain (dBi)</b>	15	5	5
<b>Max Power (dBm)</b>	46	25	20
<b>PIRE (dBm)</b>	61	30	25
<b>Heigh (m)</b>	25	10	6

### A. Received power

In order to compute the received power at each point ( $P_{rx}$ ), the following formula has been used:

$$P_{RX}[dBm] = P_{TX}[dBm] + G[dB] - L_{PATH LOSS}[dB] \quad (1)$$

where  $P_{rx}$  and  $P_{tx}$  are the received and transmitted power (in dBm). The signal losses depend on the propagation region and are represented as  $L_{PATH LOSS}[dB]$ . They are computed as:

$$L_{PATH LOSS}[dB] = L_{SPACE}[dB] + L_{SHADOW FADING}[dB]$$

where  $L_{SPACE}$  is the signal loss due to the distance between the base station and the user, and decays following an attenuation exponent.  $L_{SHADOW FADING}$  is the variation in attenuation due to multiple variables such as multipath propagation, the distribution of which follows a log-normal distribution. These transmission path losses have been modeled in six different ways following three transmission models [11], UMi (Urban Microcells), UMa (Urban Macrocells), RMa (Rural Macrocells) for two possible cases, LOS (Line-Of-Sight) and NLOS (Non-Line-Of-Sight).

### B. Signal to interference plus noise ratio (SINR)

The signal to interference plus noise ratio (SINR) for UE  $k$ , is calculated as follows:

$$SINR_k = \frac{S}{N} = \frac{P_{rx,j,k}(mW)}{(\sum_{n=1, n \neq j}^M P_{rx,n,k}(mW)) + P_{N_0}(mW)}$$

In this calculation, the power received by the UE  $k$  from the BS  $j$  is denoted by  $P_{rx,j,k}$ .

The summation in the denominator is the total received power by the UE  $k$  from all the BSs that operate at the frequency that the BS  $j$  does, except the BS $j$ . Finally, the noise power is denoted by  $P_{NO}$ , computed as:

$$P_{NO} = 174 + 10 \log_{10} BW_j$$

being  $BW_j$  the bandwidth assigned to the BS  $j$ . For assigning the bandwidth of the different stations, the criteria followed is to define it as the 5% of the operating frequency that depends on the cell type.

### C. System Capacity

Once the SINR has been calculated, the capacity of the system will be calculated using the well-known formula for MIMO systems:

$$C_{rxt} = \log_2 \left( \det \left( I_R + \frac{SNR}{t} \times H_{rxt} \times H_{rxt}^H \right) \right)$$

where  $R$  is the number of the receiver antennas,  $t$  is the number of antennas in the receiver,  $I_R$  is the identity matrix of  $R \times R$  dims and  $H$  is the matrix of the channel. In this work we have used a randomly generated Rayleigh matrix.

### D. Power Consumption

This work uses an model that takes into account both the consumption between the UE and the BS, and the consumption between the BS and the access router [12-13]. The regular power consumption of an BS, which we will denote as  $P_{bc}$ , can be expressed as:

$$Pbc = \alpha * P + \beta + \delta * S$$

where  $P$  represents the transmitted or radiated power of each BS. The coefficient  $\alpha$  denotes the power transmission efficiency due to an RF amplifier and feeder losses, while  $\beta$  represents the power dissipated due to signal processing,  $\delta$  is a constant denoting a dynamic energy consumption per unit of data, and  $S$  is the data rate.

The transmitted power is the sum of the powers of the different transmitters plus the energy consumed by the backhaul (PBH) that needs to be included [14], which is defined as:

$$P_t = \sum Pbc + PBH$$

### E. BS-UE Pairments

Once the configuration of the system parameters are modeled, as well as the subsequent computation of the different network measures, we proceed to detail two strategies for pairing UEs and BSs, that is, planning the assignments of UEs to BSs.

They are presented from the simpler case to the more complex one, both of them having as the goal of maximizing the SINR. These association could have considered other objectives, such as minimizing the distance or maximizing the received power between UEs and BSs, but the chosen one (maximization of the SINR) is what allows us to obtain the best results in terms of system capacity, providing the user with higher connection speeds to the network. Two different strategies are used:

Planning 1: the UE is paired with the BS that provides the highest SINR among all those available in the scenario.

Planning 2: Avoids the continuous jump between BSs. To do this, it pairs the UE with the BS that provides the highest SINR among all those available in the scenario whenever the change causes an improvement in the SINR above a certain threshold.

## III. MULTILAYER OPTIMIZATION

In this first approach to optimization of a 5G system, the parameter to be configured is the transmission power of the different BSs, i.e., the maximum transmitted power reflected in Table 1. The Matlab multi-objective toolbox has been used as the optimization engine, where different objectives have been set.

The number of BSs and UEs are deployed with three possible configurations each: is 20, 40 and 50 UEs and 5, 14 and 20 BSs, respectively. Regarding the connections of these UEs, they follow a Poisson process with an average arrival ratio of  $\lambda=0.2$ , and the duration of a session follows an exponential distribution with an average of  $\mu=10$  s. In this scenario, BSs are connected to an access network where routers offer IPv6 connectivity to mobile users.

First the experiment conducted has considered 2 objectives: the total capacity of the system and the power consumed, when using the two different UE-BS association strategies, i.e., Planning 1 (red) and Planning 2 (blue). Figure 1 shows the different Pareto fronts obtained. The set of non-dominated solutions shows different compromise solutions (points). It can be seen how Planning 1 obtains much better results as much higher capacities are obtained with the same consumed power. This is due to the fact that, by using a power

threshold to minimize the signaling, and thus lowering the number of handovers, the SINR decreases and therefore the capacity decreases. Figure 2 shows the bits per Joule obtained for this same set of solutions. Now, the solutions obtained for Planning 1 are very similar to the solutions obtained by Planning 2. It is also clearly shown how in the chosen bit/w metric in Planning 1 is much better than that of Planning 2.

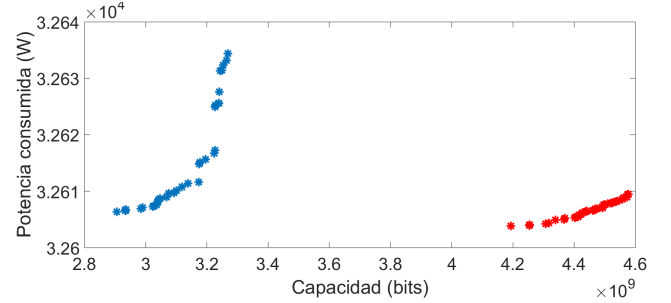


Figure 1: Pareto front obtained for this optimization of the configuration 2 with the Plannings 1 and 2.

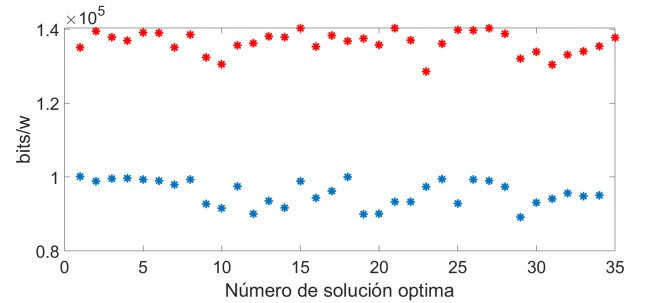


Figure 2: Different features of the solutions obtained for the solutions in Figure 1.

In a second experiment, a multi-objective optimization is carried out with three different objectives: power consumption, total system capacity, and mobility costs. This optimization is undertaken for Configuration 1 and Planning 1. Figure 3 shows the trade-off solutions obtained by the algorithm in a 3d graph, where the z-axis is the power consumption, the x-axis is the mobility costs and the y-axis is capacity of the system. The different solutions have been displayed according to the level of power consumed (from lowest to highest red, light blue, green, purple, yellow and black) for better identification. It can be seen that there are many solutions with low power and to improve in one of the parameters it is necessary to worsen in one of the other two. Figure 4 displays the bit/w metric of the previous solutions, and how they show that the costs of mobility and the quality of the solutions has a fairly different impact.

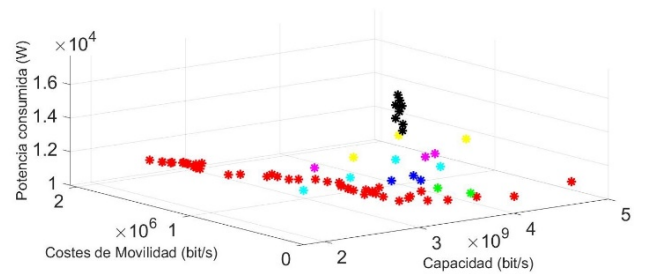


Figure 3: Solutions obtained for optimization with 3 objectives of Configuration 1 and Planning 1.

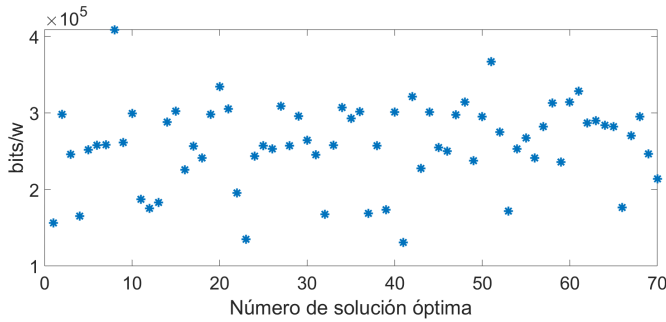


Figure 4: Different features of the solutions obtained for the solutions in figure 2.

#### IV. MASSIVE CONNECTIONS OPTIMIZATION

#### V. CONCLUSIONS

In this work, the optimization of a 5G system with different configuration parameters has been proposed. Two different multi-objective problems have been formulated that account for the network consumption, its capacity and the cost of signaling due to the handover induced by UE mobility. In these preliminary optimizations it is shown how to improve one parameter it is necessary to harm another, but efficient, compromise solutions of valuable impact for the network designer can be reached. Future work is on the line of developing new planning algorithms that maximize efficiency of the system.

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