A Use Case of Shared 5G Backhaul Segment Planning in an Urban Area

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ABSTRACT

This work presents a case study for the network planning of a 5G backhaul in a dense urban area. The study is fed by estimated population density data and real geographical layout coming from a Spanish city (Cartagena, around 220,000 population). The layout includes current locations of 4G base stations, which are assumed to place also new 5G macrocells, and real positions of lamp posts. The study assumes (i) an agreement among mobile operators to share the 5G network infrastructure, and (ii) a hypothetical agreement with the city hall, where the 5G deployment can be done by using city lamp posts for installing microcells, covering the city with a broadband 5G network outdoor access. An algorithm has been implemented to solve the dimensioning problem, as an Integer Linear Programming (ILP) technique. The deployment cost is proportional to the number of microcells to be installed in the study scenario. Results in terms of total number of microcells to be installed and traffic per microcell for different ratios of traffic demanded vs. traffic carried are also analysed. The results can help mobile network operators to drive their strategic investment decisions.

Keywords: 5G, backhaul, network planning, Net2Plan, GIS.

1. INTRODUCTION

Mobile Network Operators (MNOs) are in a race against time to upgrade and expand their infrastructure to face the new and future mobile broadband services. 5G is in the nucleus of this network evolution, that promises an Internet of Everything (IoE) world with high data rates and low latency. In dense urban areas, one of the key approaches to target such requirements is network densification, placing 5G access cells closer to the users [1].

The economic impact behind the deployment of the 5G infrastructure is not easy to dimension. Since 5G is not yet commercialized, there are some uncertainties around technical and economic aspects, and the rollout strategies that MNOs will carry out. Some contributions have addressed this aspect, providing quantitative deployment evaluations of the 5G architecture [2]-[5]. Furthermore, the 5G deployment in the access is significantly affected by the radio propagation limitations. In previous works like in [6][7], the 5G dimensioning in dense urban areas has been evaluated, reporting the spectral efficiency, reflections, scattering and propagation loses, etc., at the frequency bands considered for 5G. These results motivate an approach (i.e. neutral hosting) for 5G deployment, where domestic and commercial venue owners have WiFi hotspots, picocells or femtocells in their own facilities, while outdoor microcells installed by telecom operators (e.g. building facades or lamp posts) should mostly cover outside users, and users in the vehicles. In this line, the present work focuses on the massive deployment of microcells to cover a medium size city (≈220,000 population), Cartagena (Spain). We assume that an agreement is made among MNOs to share the microcell deployment (multi tenancy). In addition, we assume that microcells can be placed at lamp posts, taking benefit of a hypothetical agreement between the city hall and the MNOs alliance (neutral host model). A Net2Plan [8] algorithm has been implemented to solve the dimensioning problem, modelled as an Integer Linear Programing (ILP) problem using the Java Optimization Modeler (JOM) [9]. This study explores the cost vs. city coverage trade-off in a real city layout and reports relevant performances, like the number of microcells to install, and the traffic that each microcell will carry out. The results of this work can give light to 5G roll out decisions and may help MNOs in their strategic investment.

The rest of the paper is organized as follows: Section 2 explains 5G backhaul physical architecture. Section 3 describes the 5G dimensioning problem addressed and Section 4 presents the ILP developed to solve it. Section 5 shows the results of the ILP under different scenarios. Finally, Section 6 concludes the paper.

2. 5G BACKHAUL PHYSICAL ARCHITECTURE

Figure 1 illustrates the assumed 5G network, with optical and wireless technologies. In the backhaul, microcells can be wireless connected to a macrocell or wired connected to the wavelength division multiplexing passive optical network (WDM-PON). WDM-PON delivers a wavelength-based point-to-point connectivity between macrocells and microcells, and the Central Office (CO). This point-to-point connection requires an optical network unit (ONU) installation in the cell. Each ONU operates on a dedicated optical channel of at least 10 Gbps, and multiple ONUs could be installed in a single macrocell to serve the aggregated capacity. If the total

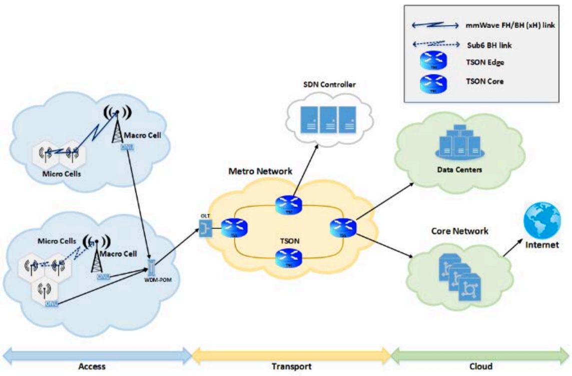


Figure 1. Illustration of 5G physical network architecture.

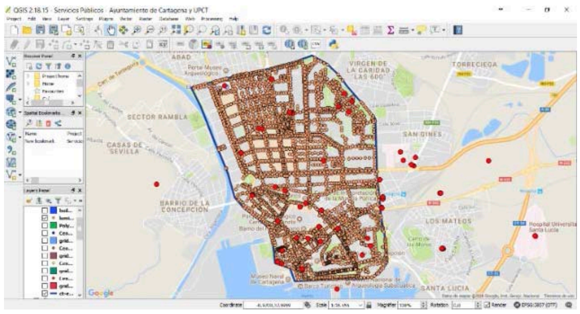


Figure 2. Snapshot of QGIS tool with GIS data of Cartagena downtown.

ingress traffic in a macrocell is lower than 10 Gbps, the connectivity between microcells and the macrocell is considered as wireless connection. Multiple radio equipment can aggregate the traffic from several microcells on the ONU in the macrocell, by using a 10G Ethernet switch. If microcells are wirelessly connected, two wireless transport technologies are considered for 5G backhaul: Sub 6-GHz or mm Wave [4].

3. DIMENSIONING 5G BACKHAUL SEGMENT IN A DENSE URBAN AREA. PROBLEM DESCRIPTION

The problem addressed in this work consists of solving the tentative dimensioning of a non-virtualized 5G backhaul segment in the city of Cartagena, in Spain. Cartagena has a population of 220.00 inhabitants. The area under study is Cartagena downtown: 6.45 km2 and 49.353 inhabitants [10]. We assume all inhabitants are potential users of mobile broadband services. The 5G network will serve those users on the streets.

We assume 5G macrocells will be placed in the same location as current 4G antennas. Current COs in Cartagena providing fixed broadband access will be also reused to serve as 5G CO, connecting the 5G backhaul and fronthaul infrastructure. The way these are connected is out of the scope of this work.

Lamp posts in streets are the candidate locations for placing microcells. The geolocation data of these have been obtained from Geographic Information System (GIS) database of Cartagena city, provided by the City Hall [11]. The set of locations of buildings has been imported from Open Street Maps [12] and the set of locations where 4G antennas are installed has been extracted from [13]. Figure 2 shows a snapshot of Cartagena downtown in QGIS tool. Brown circles are the street lamps (5686 candidates to allocate a microcell) and red circles are the 4G antennas (77 antennas in total). After solving the dimensioning problem, the resulting set of microcells to be installed will be connected to their nearest macrocell. For the sake of simplicity, we leave out of this study how microcells are connected to the core CO, assuming the microcells could be wirelessly connected to a macrocell or wired connected to the CO as Section 2 describes. We also leave out of this study how the physical factors affect to the microcells coverage range, assuming all microcells have 16 meters distance. The capacity of microcells to serve users is set to 1 Gbps. These values are in line with other deployment studies [4],[5]. Finally, since the 5G network infrastructure required is expected to be cost full, one way to overcome this is to have 'open' deployments of neutral networks serving users of any service provider. Then, we consider all MNOs share the 5G infrastructure.

With the previous assumptions, the dimensioning problem is simplified and the optimal network planning problem is to obtain the number of microcells needed to satisfy the traffic user demand, with a set of geographic and capacity constraints in a 5G environment.

4. ALGORITHM FOR OPTIMAL NETWORK PLANNING OF 5G BACKHAUL SEGMENT

An Integer Linear Programing (ILP) problem has been implemented as a Net2plan algorithm [8] to solve the dimensioning 5G backhaul segment. Some data of the infrastructures are taken as input: a set of locations where lamp posts are placed (potential locations where the microcells can be installed) and a set of locations where 4G antennas are placed (location of 5G macrocells).

The area under study is divided into a four cells grid, where each one is a square of 1500×1500 m (2.25 km^2) and is associated to a specific population density [14]. The upper left quadrant is quadrant 1 (U1), with a density of 24644 people. The lower left one is quadrant 2 (U2), with a population density 5751. On the right side, the upper quadrant is quadrant 3 (U3), with 12778 people, and finally the lower one is quadrant 4 (U4), with 6180 people. The sum of all of them is the total of inhabitants (U) of the area under study, that is, 49.353 inhabitants.

$$U = \sum_{q=1}^{q=4} U_q = 49353 \qquad (1)$$

Since we are assuming that microcells should cover users outside the buildings, we filter-out those cells overlapping with buildings, and identify their corresponding quadrant. We denote as C_q the number of cells in quadrant q. In each cell c the traffic demand t_c is computed as follows:

$$t_c = t_u \cdot R_u \cdot \frac{U_q}{C_q} \tag{2}$$

being t_u the traffic demand expected per user, R_u the percentage of users on the streets during the busy hour and U_q the total number of inhabitants in the quadrant under study.

We denote L the set of all lamp posts, M the capacity of microcells and R_{oc} the target coverage ratio (total traffic served over total traffic demanded) that operators intend to guarantee.

The ILP is shown in the set of equations (3). The decision variables x_{cl} mean the amount of traffic in each cell c served by the microcell installed in lamp l. Note that the traffic demanded in a cell is only carried by those microcells installed in lamps in range with the cell. A cell c is in range of l if the distance between the geographic center of c and the location of l (both set as a point in the map) are less than the coverage range of microcells. The decision variables z_l are set to 1 if a lamp post l allocates a microcell, 0 otherwise. The objective function (3.1) seeks to minimize the deployment cost, given by the number of microcells installed. Constraints in (3.2) limit the traffic carried by microcells to their capacity. Constraint in (3.3) forces the total carried traffic being equal to the traffic demanded multiplied by R_{oc}. Constraints in (3.4) ensure the traffic demanded by cells to be equal or higher to the traffic carried.

$$\text{minimize}\left(\sum_l z_l\right) \tag{3.1}$$

subject to:

$$\sum_c x_{cl} \leq M \cdot z_l \qquad \forall\, l \in L \tag{3.2}$$

$$\sum_c \sum_l x_{cl} \geq R_{oc} \cdot \sum_c t_c \tag{3.3}$$

$$\sum_l x_{cl} \leq t_c \qquad \forall c \in C \tag{3.4}$$

5. RESULTS

Net2Plan-GIS [11] is used to solve the 5G network dimensioning problem described in Section 4, which is an open source extension of Net2Plan planning tool [15][8] that permits importing data of different layers from GIS databases to solve network planning problems. A snapshot of Net2Plan-GIS with the scenario under studio is shown in Fig. 3.

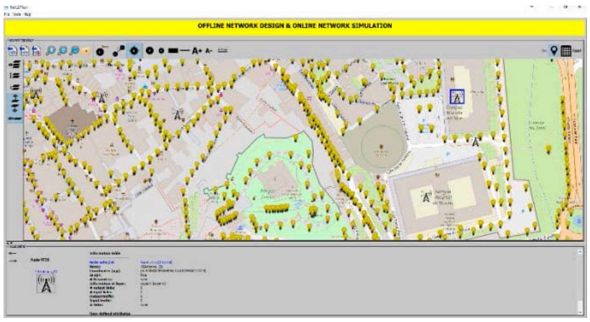
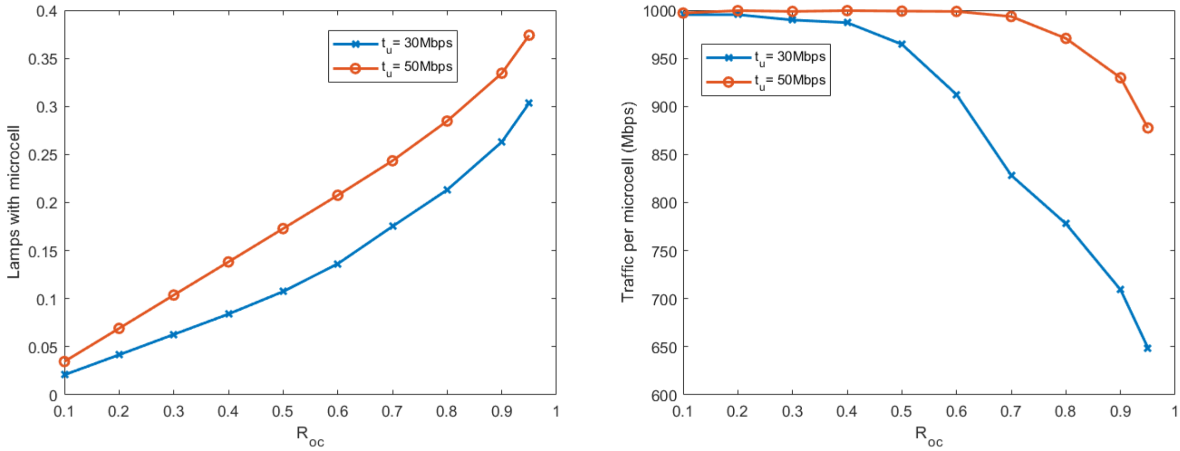


Figure 3. Snapshot of Net2Plan-GIS with lamp post and 4G antennas plotted in the area under studio.

The area is managed as a grid of cells of 20×20 meters. 9296 cells are plotted, and 5815 of them are non-overlapping building cells. In line with previous studies [3], we consider two network loads, assuming 30 Mbps and 50 Mbps per network user in the busy hour (t_u ={30 Mbps, 50 Mbps}). As we stated before U is 49.353 and R_u is set to 0.8, that is, we assume 80% inhabitants on the streets in busy hour. R_{oc} has been set from 0.1 to 0.95 to study the effect of setting a threshold of maximum traffic carried over traffic demanded (coverage ratio).

Figure 4(a) shows the ratio of microcells installed and lamp posts for the two user traffic demands and different values of R_{oc}. As it can be seen, as the ratio of traffic served over traffic demanded increases, the ratio of microcells installed grows for both t_u values, but the ratio grows faster when t_u = 50 Mbps. If MNOs need to carry 50% of traffic demanded, with 50 Mbps of user traffic demand, they should install microcells in 17% of lamp posts. If t_u = 30 Mbps, this percentage decreases up to 10%. However, if MNOs want to serve 90% of traffic with t_u = 50 Mbps, they should install microcells in 33% of lamp posts, whereas this percentage decreases up to 25% if t_u = 30 Mbps. Figure 4(b) represents the traffic carried per microcell in Mbps. The values are consistent with the number of microcells installed and R_{oc}: the greater the number of microcells deployed, the lower the average amount of traffic each microcell carries. When R_{oc} = [0.1, 0.6] and t_u = 50 Mbps, microcells occupation is 100% and, when R_{oc} = 0.7 or higher, the occupation decreases as R_{oc} increases.



(a) (b)

Figure 4: (a) Ratio of microcells installed and lamp posts for different coverage ratio; (b)Traffic per microcell (Mbps) for different coverage ratio.

6. CONCLUSION

This work has provided the optimal network planning of 5G backhaul network for ultrafast mobile broadband in a dense urban area. An ILP algorithm has been implemented to solve the dimensioning problem as an ILP problem using JOM. The algorithm is fed by population density data geographical info about the infrastructures of the city under studio: location of lamp posts (tentative location of microcells), 4G antennas (tentative location of macrocells) and buildings. The algorithm solves the optimal deployment minimizing the cost, giving by the number of microcells. The number of microcells to deploy and total traffic served is also derived from the results. Our results show up a deployment profile where ≈1700 (≈ 2600) microcells would almost entirely cover (95%) our target scenario for a traffic per user in the busy hour of 30 Mbps (50 Mbps), with an occupation per microcell of 65% (90%), a fairly acceptable and economically efficient utilization of the infrastructure in the access context. The results of this work can help MNOs to drive their strategic investment decisions.

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