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# Joint Planning of MEC and Fiber Deployment in Sparsely Populated Areas

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***Abstract*—The planning of multi-access edge computing (MEC) systems does not only consist in distributing MEC servers among the base stations (BSs) but also in designing the network to interconnect BSs, MEC resources and the wide area network (WAN) gateway. Due to their high bandwidth, fiber links are the best option for those connections in 5G environments. In contrast to previous works, which only solve the server placement problem, in this paper, an integer linear programming (ILP) formulation is proposed for solving both problems while reducing the installation cost (servers and fibers). The fiber deployment cost is especially important in sparsely populated areas as the distance between BSs are much longer than in urban environments. The model was tested using real BSs locations and population data showing that the formulation considerably reduces the installation cost.**

***Keywords*— Multi-Access Edge Computing (MEC), ILP formulation, servers, optical networks, resource optimization.**

## I. INTRODUCTION

Multi-access edge computing (MEC) [1] enables the transfer of computing functionalities from the cloud to the edge of networks. Therefore, since a large amount of data do not trespass the edge, latency is considerably reduced, as well as the congestion of the backhaul network. This paper focuses on MEC and network planning, proposing a method to determine the location and amount of MEC servers to be deployed, together with the design of the optical fiber network to interconnect BSs, MEC resources and the WAN gateway. The problem of MEC server placement has been analyzed in different works. Spinelli and Mancuso [1] present a survey and analyze the required density of MEC hosts and its cost depending on user density. Shao *et al.* [2] propose a learning-based framework which integrates stochastic simulation, a neural network and a genetic algorithm in order to determine the optimal locations for edge servers with uncertain BSs demands. Cao *et al.* [3] place heterogeneous edge servers optimizing the expected response time using an ILP formulation for server placement. The goal of the work by Lahderanta *et al.* [4] is to minimize the sum of distances between the edge servers and the access points (APs) they cater for, while taking into consideration the workload of each AP and the capacity constraints of each server. Zeng *et al.* address in [5] the problems of server placement and task assignment minimizing the number of MEC servers, and APs with MEC servers, while ensuring QoS requirements. The work proposed by Wang *et al.* in [6], minimizes the access delay between base stations and edge servers while balancing their workload.

Previous proposals, to the best of our knowledge, have not jointly designed the fiber network required to interconnect BS, MEC servers and WAN gateway. MEC location and fiber connectivity are clearly related, both in brownfield and, especially, in greenfield scenarios. While this omission may be more permissible in urban areas, it is not in sparsely populated areas (i.e., outside cities) as the long distances between BSs makes the cost of fiber deployment the main contributor to the CAPEX of the system. This work presents a new ILP formulation to solve the joint problem of MEC server placement and fiber network design, minimizing the cost of system considering both aspects (MEC servers an fiber costs). The evaluation of different scenarios based on real BS locations and population data will demonstrate that the installation cost of MEC servers and fiber can be reduced using the proposed ILP formulation.

## II. MEC AND FIBER DESIGN FORMULATION

In this section, we present the problem of placing MEC servers and the deployment of a fiber-based network. The following assumptions are made:

- MEC servers are placed in BSs. No other locations are allowed. A BS may host several MEC servers.
- There are no previously deployed fiber connections nor MEC servers.
- All the servers can serve the same maximum number of

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simultaneous MEC users.

- All the traffic from a BS is served by MEC servers located in a single BS connected using a point-to-point fiber cable.
- If a BS is equipped with MEC servers, its associated users will be served by the servers located in that BS.
- All BSs equipped with MEC servers will be connected to a WAN gateway by a point-to-point fiber cable.
- A single fiber cable is assumed to have enough capacity to transport all the incoming/outcoming traffic of the BS.
- Only point-to-point fiber links have been considered.

Table 1 summarizes the notation used in the model. All symbols correspond to known values, except for the last two set of variables ($x_{ij}$ and $y_i$), which are the solutions of the problem. $y_i$ is the number of servers located in $\mathrm{BS}_i$ and $x_{ij}$ is a binary variable that takes value one when the traffic (requiring edge computing) from $\mathrm{BS}_i$ is served by the MEC servers located in $\mathrm{BS}_j$. Therefore, if $x_{ij}$ is one, an optical fiber cable must be laid between those two BSs. Similarly, if $x_{ii}$ is one (which happens when $y_i$ is greater than zero) an optical fiber cable connecting $\mathrm{BS}_i$ and the WAN Gateway must be deployed.

TABLE 1. Model notations

| Symbol | Meaning |
|---|---|
| $S_{\max}$ | Maximum number of MEC servers in the network. It can be set to a huge value if there is no restriction on the number of servers |
| $S_{\min}$ | Theoretical minimum number of MEC servers required |
| $B$ | Number of BSs in the network |
| $U_{\max}$ | Maximum number of simultaneous users (requiring MEC) that can be served by a MEC server (e.g., using the model in [1]) |
| $d_{ij}$ | Distance in km between $\mathrm{BS}_i$ and $\mathrm{BS}_j$ |
| $D_i$ | Distance in km between $\mathrm{BS}_i$ and the WAN gateway |
| $P_i$ | Population associated with $\mathrm{BS}_i$ |
| $\alpha_i$ | Fraction of population connected to $\mathrm{BS}_i$ which simultaneously requires MEC services, $\alpha_i \in [0,1]$ |
| $C_{\mathrm{F}}$ | Cost of the installation of one km of fiber cable |
| $C_{\mathrm{S}}$ | Cost of one MEC server |
| $x_{ij}$ | Binary variable. $x_{ij}=1$ if the traffic from $\mathrm{BS}_i$ requiring edge computing is served by servers located in $\mathrm{BS}_j$, else 0 |
| $y_i$ | Integer variable. Number of servers located in $\mathrm{BS}_i$.<br>$y_i \in [0, S_{\max}]$ |

The minimum number of servers is estimated based on real population data and assuming that a certain fraction, $\alpha_i$, of the total population associated to $\mathrm{BS}_i$ is simultaneously using MEC services. The minimum of servers required is determined by (1):

$$S_{\min} = \left\lceil \frac{1}{U_{\max}} \sum_{i=1}^{B} \alpha_i P_i \right\rceil . \tag{1}$$

The objective function (2) minimizes the total cost, which is given by the sum of the fiber deployment cost and the cost of MEC servers. We have only considered CAPEX (capital expenditures), leaving OPEX (operational expenditures) for future works. The total cost of fiber deployment is calculated as the multiplication of the cost per kilometer of optical cable by the total length to be deployed. Fiber deployment includes connections between BSs where traffic is originated and where servers are located (i.e., if $x_{ij} = 1$), and the connection from BSs with MEC servers to the WAN gateway (i.e, BSs where $x_{ii} = 1$). Transceiver costs have not been included, although their consideration would be straightforward. The total cost of the MEC servers is obtained by multiplying the cost of a MEC server by the total number of servers in the network.

$$\text{minimize} \left( C_{\mathrm{F}} \cdot \left( \sum_{i=1}^{B} \sum_{j=1}^{B} x_{ij} d_{ij} + \sum_{i=1}^{B} x_{ii} D_i \right) + C_{\mathrm{S}} \sum_{i=1}^{B} y_i \right) \tag{2}$$

subject to:

*1)* The maximum number of servers cannot be exceeded.

$$\sum_{i=1}^{B} y_i \leq S_{\max} \tag{3}$$

*2)* The traffic from any base station requiring MEC is only served by the MEC servers of one base station.

$$\sum_{j=1}^{B} x_{ij} = 1, \quad \forall i \in [1,B] \tag{4}$$

*3)* The workload assigned by all BSs to the servers in $\mathrm{BS}_j$ cannot surpass the total capacity of the servers located in $\mathrm{BS}_j$.

$$\sum_{i=1}^{B} \alpha_i P_i x_{ij} \leqslant U_{\max}\, y_j, \quad \forall j \in [1,B] \tag{5}$$

*4)* If a base station is equipped with MEC servers, the traffic of that base station will be served by that base station.

$$\frac{y_i}{S_{\max}} \leqslant x_{ii}\,, \quad \forall i \in [1,B] \tag{6}$$

## III. CASE STUDY: DEPLOYMENT IN VALLADOLID PROVINCE

The model has been evaluated using real data of the province of Valladolid, Spain, including the population of cities and villages [7] and the location of BSs [8]. For the sake of simplicity, we have only considered BSs of one mobile operator (Telefónica) and at most one BS per city/village. The model presented in Section II is independent of these assumptions, but the ILP formulation does not scale well as the number of BSs increases. Ongoing work includes the development of a heuristic to address this drawback. Following [1], we estimate the workload of each BS considering its amount of connected population and assuming a mixed traffic profile composed by a 70% of video traffic, 15% of car traffic, 10% of smart factory and 5% of augmented/virtual reality. All MEC servers have the same configuration as those used in [1]: a server is composed by 16 machines of 4 cores at 3.4 GHz. The cost of one server ($C_{\mathrm{S}}$) is 30,000 € (based on the current cost of 16 Dell R340 machines with that configuration). According to [1], the mentioned MEC server can serve up to 75 simultaneous users ($U_{\max} = 75$) with the mixed traffic profile described above. Regarding the fraction of population requiring MEC, we assume uniform scenarios, i.e., $\alpha_i = \alpha, \forall i$, and analyze the impact of that parameter. $C_{\mathrm{F}}$, the deployment cost of one kilometer of cable (materials plus installation) is estimated in 15,000 € [9]. To implement and test the model, we used the Python-based Pyomo optimization tool, with the GNU Linear Programming Kit (glpk) optimizer. We have implemented and analyzed the following scenarios:

*1) Set of BSs:* In each scenario, 25 out of 106 have been selected. We considered three options: (a) to select the 25 BSs closest to the WAN gateway, (b) to select the farthest 25, and (c) to select 25 BSs randomly, generating 100 random scenarios and averaging results. The WAN gateway is placed at Valladolid, capital of the province.

*2) Network Design Methods:* We compare the ILP formulation against a star topology, which directly connects each BS to the WAN gateway. The latter option does not get benefit from sharing MEC resources, as will be demostrated below.

Fig. 1 shows an example of the topology obtained when solving the ILP formulation for 25 randomly selected BSs, the connections between them (blue lines), and the connections from those BSs with MEC servers (red dots) to the WAN gateway (red lines). The figure also shows the number of MEC servers installed in each BS. Most of MEC servers are placed at the WAN gateway due to the fact that it is located at the most populated city, and according to *(6)* all of its traffic must be served locally.

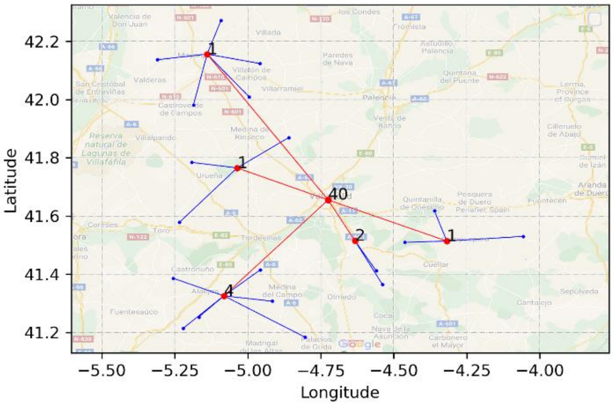

Fig. 1: Example of connections and servers' placement ($\alpha = 1\%$)

**¡Error! No se encuentra el origen de la referencia.** compares the costs for ILP solution and star topology. To obtain these results, 100 tests were made selecting 25 different sets of random BSs and saving the results of each experiment. Then, the mean of those results was computed as well as the 95% confidence interval (these intervals correspond to the small lines in the plots). We can compare the associated costs of deploying the optical fiber connections and of MEC servers. The x-axis corresponds to $\alpha$ in Table 1 (expressed in %).

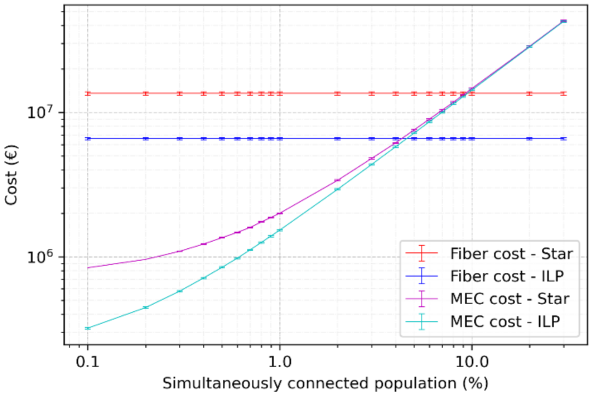

Fig. 2: Costs of MEC servers and fiber deployment

**¡Error! No se encuentra el origen de la referencia.** shows that the costs of the ILP design are lower than those of star topology for both components: the cost of fiber deployment and the cost of MEC servers. The cost of fiber deployment is almost constant for all values of $\alpha$ in both topologies because a fiber connection to a BS hosting servers must exist, regardless of the population.

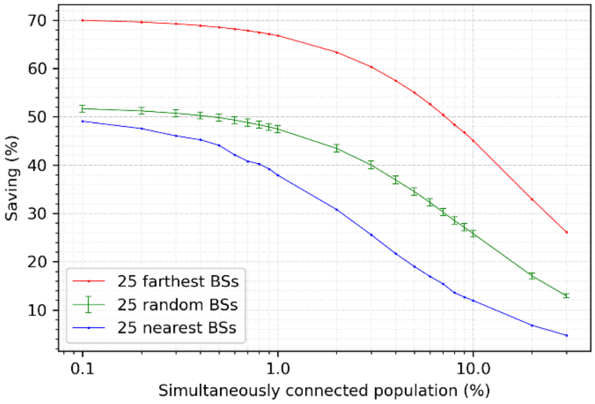

Fig. 3: Saving of ILP design vs star topology for different scenarios

The cost of MEC servers in **¡Error! No se encuentra el origen de la referencia.** increases when $\alpha$ grows, because each server can serve a limited number of simultaneous users. Notice that **¡Error! No se encuentra el origen de la referencia.** is in log-log scale, so the difference in fiber costs is greater.

Fig. 3 shows the cost savings when using the ILP design instead of the star topology for farthest BSs, nearest BSs, and average results of 100 experiments selecting 25 random BSs. The formulation brings significant cost savings, especially for the first scenario. This is because when distances are greater, any change in connections implies a larger difference in the cost of fiber. Moreover, the savings decrease as $\alpha$ grows due to the cost of MEC servers, which increases for higher connected population values.

## IV. CONCLUSION

An optimal MEC placement and connection planning implies considerable differences in network deployment cost. In this paper we have proposed, implemented, and tested an ILP-based optimization scheme that obtains the placement of both MEC servers and fiber connections, to minimize the network cost due to optical cabling and MEC server's deployment. The implementation of the ILP design results in considerable cost savings compared to a centralized star topology. Furthermore, the savings of the ILP design are higher in scenarios where the distances to interconnect are larger and the connected population requiring MEC services is small, which suggest that these implementations are particularly suitable in sparsely populated areas with long distances between BSs. Since the ILP formulation does not scale well as the number of BSs increases, ongoing work includes the development of a heuristic to address this drawback.

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