Build or Merge: Locational Decisions in Mobile Access Networks

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***Abstract*—Mergers between mobile network operators involve merging their respective networks. Though this may represent a chance to optimize the network structure, merging may not represent the cost-optimal solution. In this paper, we compare two different evolution paths, where the networks to be merged are separately upgraded to cover the whole traffic demand or a single network is optimized as the result of the merger (Build vs Merge). Our preliminary analyses show that the Merge approach may lead to 50% higher costs, due in particular to the high costs borne to switch off redundant access points. Any Build vs Merge decision should therefore consider the sunk costs due to the inherited networks, as well as the possible benefits associated to a merger.**

***Index Terms*—Cellular networks; Mobile networks; Mergers; Location optimization; Network consolidation**

I. Introduction

THE market of mobile network services is generally restricted to a few operators per country, with licenses typically assigned through competitive procedures (e.g. auctions). In Europe, according to the information provided by Wikipedia[1], the maximum number of operators per country is 5 (excluding Russia and Ukraine).

Though the markets are quite steady, mergers do take place [1], [2]. In Fig. 1 we see that in many cases the net balance between new entrants and mergers/closures is negative, ending with a reduction of operators. Recent examples of mergers are those between Telia and Telenor [3] and between Wind and Tre in Italy [4]. Mergers may be a natural way towards market consolidation (involving two operators of similar size), as an alternative to license acquisition on the secondary market [5], or as an opportunity for expanding operators to take over from weaker competitors [6].

Though the company consolidation associated to mergers may have its benefits, the resulting operator inherits both the networks set up by the merging companies. Excepting the special case where the customer basins of the two companies were geographically disjoint, the resulting network exhibits several duplications, i.e. same geographical areas served by two access points. A consolidation of networks is therefore needed to avoid running an economically inefficient network. The issues related to the costs of running a mobile access network are so relevant that infrastructure sharing has been proposed as a means of achieving cost reduction [7].

[1]https://en.wikipedia.org/wiki/List_of_mobile_network_operators_of_Europe

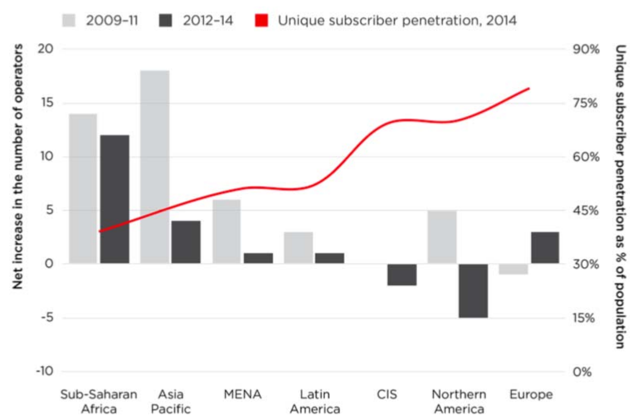

Fig. 1: Net additions of mobile network operators per region
Source: GSMA Intelligence

In this paper we deal with the problem of consolidating the access network infrastructure after a merger by minimizing the overall cost. We adopt an Integer Linear Programming approach and apply our procedure to a real dataset. After describing the problem of selecting access points locations in Section II and the costs involved in Section III, we describe the cost minimization procedure in Section IV and apply it to a real dataset in Section V, where we show that:

- as far as just access network costs are concerned, merging carries along an increase in costs by slightly more than 50%;
- OPEX are the dominant portion of costs, accounting for over 85% of total costs for the operators to be merged;
- CAPEX costs are represented just by switch-off costs for the after-merger network, which are anyway the

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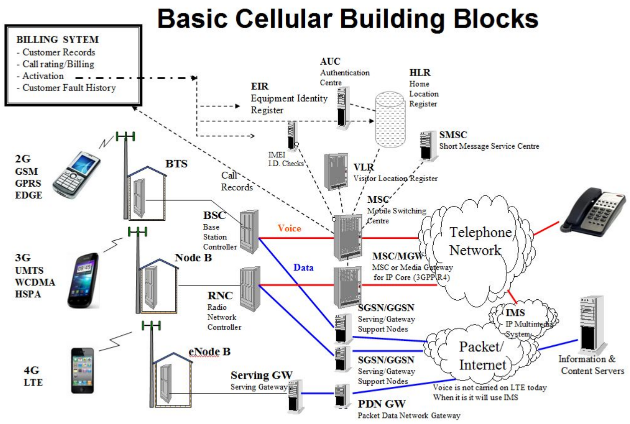

Fig. 2: Access network in GSM, UMTS, and LTE

prevalent cost (85-91% of CAPEX) for the operators to be merged;
- Rental cost is the most significant OPEX item, accounting for about 80%, with power costs being a negligible fraction of the overall OPEX.

II. The Location Problem in a Mobile Network Infrastructure

In this section we set the scenario where we apply our optimization procedure.

We consider a mobile operator that, in order to cover an area (e.g. a whole country, if it is a national operator), has to disseminate a number of access points (AP). These access points provide the customers' mobile terminals with the radio access to the network. The dissemination is done so that each AP covers an access area (a cell) and, hopefully, no area within the operator's basin remains unserviced.

Though the mobile network has undergone several technological advances (from GSM to UMTS and LTE) [8], the access structure has remained basically the same as shown in Fig. 2. We see that the AP in a GSM network is represented by the Base Transceiver Station (BTS), which serves a single cell (for the time being we neglect the practical issue of areas being served by more than one cell, for reliability purposes and to warrant a smooth location updating process). In UMTS the access network is named UTRAN (Universal Terrestrial Radio Access Network), and the AP is named Node B. Similarly, in the LTE (Long-Term Evolution) network, also known as 4G, the cellular structure involves a radio access network where the APs are named E-node B.

The similar structure of the access network in the three technologies considered here is such that our procedure applies to a general access network.

III. Network merging costs

When two mobile operators merge, their networks are to be merged as well. Both networks and the modifications implemented for their consolidation carry costs, which are to be considered to reach the maximum economic benefit. In this section, we describe the costs incurred during and after the consolidation process. In the following, we refer to the operators (and their networks) to be merged as Operator A and B, while the operator (and its network) resulting after the merger will be called Operator Z. In order to describe costs, we adopt the established classification into CAPEX (capital expenses) and OPEX (operating expenses). OPEX are evaluated on an annual basis.

Merging Network A and Network B leaves the resulting Operator Z with the following cost-carrying states:

- any AP remaining active after merging carries an annual operating cost;
- any new AP carries a one-off switch-on (set-up) cost plus an annual operating cost
- any AP being switched off carries a one-off dismantling (switch-off) cost;

The CAPEX comprise therefore the following cost items: (i) Set-up costs and (ii) Switch-off costs. The annual operating costs (OPEX) of the cell tower consist instead of the following components: (iii) Maintenance costs, (iv) Power costs, and (v) Site rental. In our model, power costs are also related to the location and service range of the access points (the cell towers). A rural AP serves a larger area than an urban one and needs therefore more power. Similarly, an AP serving a high-traffic area needs a larger number of transmit-receive module, hence consuming a higher power.

In this paper, we adopt a parametric view of costs, so that all the expenses are referred to the set-up costs conventionally set at a reference value (100). In Section V, we report the average values used in our experiments.

IV. Location Optimization

The network can be represented by a bipartite graph $G = (V = S \cup D, E)$. The set of nodes S contains the all possible sites for actual or potential location of the access points. In particular, in S we distinguish—with obvious notation—the sets of APs owned by the two companies as $A \subset S$ and $B \subset S$, with $A \cap B = \emptyset$ and let $O = A \cup B$. The remaining set $N = S \setminus O$ collects all potential new locations for additional APs.

Moreover, each node $v \in D$ is associated to a specific demand point (hereafter *centroid*) representative of an aggregated traffic demand for a specific portion of the territory [9]. In Section V-A we briefly sketch how such an aggregation procedure is performed in order to return centroids all with (roughly) the same amount of traffic demand.

The possibility for an AP at $u \in S$ to serve a client $v \in D$, depends on the configuration of the AP (which determines directly its capacity, i.e., the overall demand that can be allocated to it) and the power level which the AP is operating at. Assume, as it is usual in this setting, discretized sets of configurations, with increasing capabilities, $J = \{1, \dots, |J|\}$, and available (increasing) power levels $K = \{1, \dots, |K|\}$, for all APs. Labels are associated to each node $u \in V$ of the network to express the following relevant quantities when considering the locational decisions arising after the merging:

- One-off switch-on cost f_u of AP at $u \in N$;
- $a_u(j,k)$ annual operating cost with configuration $j \in J$ and power level k for AP at $u \in S$;
- One-off switch-off cost g_u of AP at $u \in S$;
- Finally, the upper limit on the traffic capacity of an AP $u \in S$ with configuration $j \in J$ can be expressed in terms of the maximum number $b_u(j)$ of centroids that u is able to serve (recall that all centroids express the same traffic demand.)

Thus an AP which is located in $u \in S$, with configuration $j \in J$, and operating at power level $k \in K$, might serve at most $b_u(j)$ centroids placed within a certain distance $r(k)$, where $b_u(j)$ and $r(k)$ are given quantities[2]. On these grounds, the set of potential links E in the network between access points and centroids actually depends on the configurations and working power levels of the APs. In our ILP model we use datum δ^k_{uv}, which is equal to 1 if the AP $u \in S$ operating at power level k is able to serve centroid $v \in D$, and 0 otherwise. Entries δ^k_{uv} are given for all $u \in S$, $v \in D$, $k \in K$.

It is important to observe that, in the locational decisions we are taking, for any $u \in O$ the corresponding AP may be left operative or it can be dismissed: In the first case, the company is bearing the associated operating costs for that facility while in the latter case the company would suffer from a switch-off price for its disposal. On the other hand, for all $u \in N$, it must be decided whether that location is left vacant, or an AP is made active there and in this case switch-on plus operating costs has to be paid.

In our ILP models, we make use of the following variables:

- For all $u \in S$, $k \in K$, variable $x_u(j,k) \in \{0,1\}$ is equal to 1 if and only if AP u is active, its configuration is j, and it operates at power level k.
- We also use, for all $u \in S$, a dependent variable $x_u \in \{0,1\}$ that indicates if AP u is switched on ($x_u = 1$) or no AP is located in point u in the network ($x_u = 0$). Because an AP can only operate at a single power level, we have that $x_u = \sum_{k \in K} \sum_{j \in J} x_u(j,k)$, however, hereafter, we keep using x_u for better clarity.
- Variable $y_{uv} \in \{0,1\}$, for all $u, v \in S \times D$, indicates if centroid v is served by an active AP located in u ($y_{uv} = 1$).

[2]We suppose J and K are ordered so that $b_u(j) < b_u(j+1)$ and $r(k) < r(k+1)$, i.e., the capabilities of the AP increase together with the configuration and power levels of the AP. Cost coefficients $a_u(j,k)$ in the objective function, increase accordingly.

Hence we may express the following variable-dependent cost items: $z_{\text{on}} = \sum_{u \in N} f_u x_u$ is the total cost for switching new facilities on, while the overall switch-off cost is given by $z_{\text{off}} = \sum_{u \in O} g_u(1 - x_u)$. (Note how the x_u variables are used in the two expressions.) Lastly, the operating costs are expressed by the quantity $z_{\text{loc}} = \sum_{u \in S} \sum_{j \in J} \sum_{k \in K} a_u(j,k) x_u(j,k)$.

Now, as we are interested in minimizing the overall penalty, we may write the ILP below:

$$\min z_{\text{Z}} = z_{\text{on}} + z_{\text{off}} + z_{\text{loc}} \quad (1)$$

$$\text{s.t. } y_{uv} \le \sum_{j \in J} \delta^k_{uv} x_u(j,k) \qquad u, v \in S \times D,\ k \in K; \quad (2)$$

$$\sum_{v \in D} y_{uv} \le \sum_{j \in J} b_u(j) x_u \qquad u \in S; \quad (3)$$

$$y_{uv} \le x_u \qquad u, v \in S \times D; \quad (4)$$

$$\sum_{u \in S} y_{uv} = 1 \qquad v \in D; \quad (5)$$

$$\sum_{j \in J} \sum_{k \in K} x_u(j,k) = x_u \qquad u \in S; \quad (6)$$

$$x_u, y_{uv}, x^k_u \in \{0,1\} \qquad u, v \in S \times D,\ k \in K. \quad (7)$$

Constraints (2) impose—through the indicator parameter δ—that a centroid $v \in D$ cannot be assigned to a facility $u \in S$ if its distance exceeds the covering radius allowed by the operating power level u is working at, and such a level is unique as established by Constraints (6). Constraints (3) guarantee that no more than $b_u(j)$ centroids are assigned to an active AP $u \in S$ with configuration j. Note also that Constraints (4) are implied by (2) and (3): We still keep them in our optimisation model since they reinforce our formulation and proved to be effective in terms of computation times. Finally, the assignment constraints (5) ensure that each centroid has an AP serving its demand.

So far, we proposed an optimization model to address the facility location problem arising when a company A is merging its infrastructure with that of another company B. Observe that the very same mathematical program can be of use to model the problem of a single company, say A, that faces a “build” (rather than a “merge”) decision. That is, the acquisition of additional capabilities is obtained through optimally locating *new facilities* when starting from the original set A of APs owned by the company A rather than from the union of A and B. In this case, by simply setting $O = A$ and $N = S \setminus A$ and minimizing the new objective $z_{\text{A}} = z_{\text{on}} + z_{\text{off}} + z_{\text{loc}}$ we may compute, through ILP (1)–(7), the optimal cost incurred by company A when extending its network. The cost z_{B} for B, when extending *its* network, can be clearly computed in a similar way. (Note that, in our model, the potential new sites of the new facilities for company A is given by the all possible points in the network, ignoring whether APs of company B are already there or not.

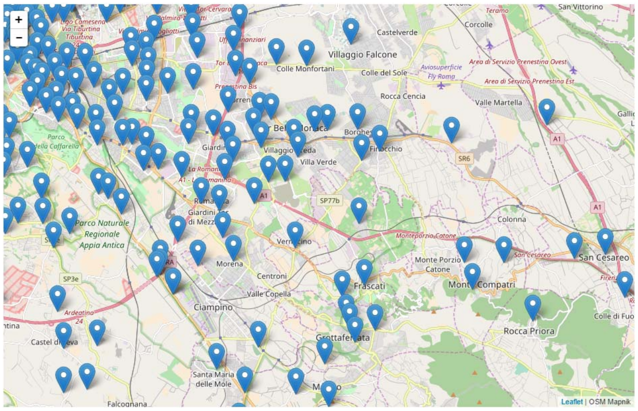

Fig. 3: Cell tower locations in South-East Rome

Moreover, the demand is assumed to remain the same in all the three models.)

V. Experiments

After describing the cost optimization procedure, in this section we describe an experimental set-up where we have applied the procedure.

Our test-bed comprises a set of real cell tower sites, located in a territory of around 400 square kilometres, located South-Est of the urban area of Rome, Italy. We extracted the geographical location of the sites from the website of Inwit (https://www.inwit.it/mappa-dei-siti), a company of the Telecom Italia Group that operates in Italy in the field of electronic communications infrastructure, and specifically those dedicated to hosting radio transmission equipment. The overall number of actual tower sites in the area is 52. In the experiments, we also considered around 30 extra locations, summing up to 85 APs that are assigned randomly among three groups, representing Operator A, Operator B (i.e. the two companies to be merged), and a group of potential extra sites that A an B can use to install additional new facilities. A map of the sites is shown in Fig. 3.

In our experiments, we use average parametric (cf. Sec. III) values for the various cost items. Though studies have been released concerning the cost of mobile networks (see, e.g., [10], [11], [12], they report aggregate data (or focus on a specific country), which can hardly be re-used. Here we limit ourselves to the access network, represented by the APs, and neglect all backbone costs, as well as the company costs (e.g. personnel). Our values have been set after interviews with technical staff members of several telecom companies. We considered the following average parametric values for the CAPEX:

- Set-up costs = 100;
- Switch-off costs = 70.

In our ILP described by Equations (1)–(7), the overall CAPEX equal the values taken by $z_{\text{on}} + z_{\text{off}}$.

The average annual (parametric) operating costs of the cell tower comprise instead the following components:

- Maintenance costs = 8;
- Power costs = 2;
- Site rental = 50.

In the ILP, OPEX are to be read in the quantity z_{loc}.

A. *Traffic demand*

As we mentioned above, teletraffic demand is modeled by adapting an algorithm proposed in [9]. The procedure is based on a geographic model which meets geographical and demographical factors yielding the demand for mobile communication services. The observed region is suitably partitioned into several districts each associated to a centroid or node $v \in D$. Centroids are representatives of the traffic demand of those areas the whole region is partitioned into. An important characteristic of the adopted procedure is that all the centroids express equal shares of the total demand of the region.

Hereafter we briefly sketch how the algorithm works (we directly refer to the test-bed region used in our experiments.) The basic steps of the algorithm, as reported in [9], are the following:

1) Estimation of traffic demand[3] depends on different factors related to population density, traffic of vehicles, orographic/morphological issues, income per capita. We used data available at the Geographical Information System of the Italian National Institute of Statistics [13] combining demographic and spatial analyses, with resolution of 27×15 Km^2, and basic cells sized at 1×1 Km^2. The output of this phase is a *spatial traffic intensity matrix* of the observed region.
2) Generation of the demand nodes D, i.e., the actual set D of centroids, is performed using a clustering method. The basic principle this method relies upon is to recursively bisect the region(s) until the demand associated to a tessellation piece is below a given threshold θ. Clearly, if we start from a rectangular-shaped input region, successive bisections produce clusters with rectangular shapes as well (in general, of different sizes). Eventually, a centroid is output (located in a barycentric position) for each one of the final clusters. Due to the particular stopping criterion, we are guaranteed that the traffic demand associated to any centroid $v \in D$ is at most θ.

In our case, running the algorithm with a value $\theta = 4015$ MBps/Km^2, we obtain $|D| = 118$ centroids.

B. *Results*

In our simulation experiments, we considered 30 different initial pseudo-randomly generated configurations for the

[3]In telephony, usually measured in Erlangs per area unit. In this study we use MB per second per square Kilometre.

sets A and B of the APs owned by the two companies. We distinguish three disjoint groups (C1, C2, and C3) of configurations whose characteristics are reported in Table I. The cardinality of the two sets A and B randomly varies in the three groups within the ranges indicated in columns 2 and 3 of Table I. However, the overall number of APs owned by the two companies remains constant in each group and equal to 40, 60, and 28 in C1, C2, and C3, respectively. For each initial configuration, three ILP have been run, thus

	$\|A\|$, $\|B\|$	$\|S \setminus (A \cup B)\|$
C1	16–24	45
C2	26–34	25
C3	10–18	57

TABLE I: Experiments: Initial configurations

evaluating the optimal merging cost z_Z, and the optimal buiding costs z_A, and z_B, together with the correponding CAPEX ($z_{on} + z_{off}$) and OPEX (z_{loc}) values.

The ILP have been implemented in AMPL [14] and solved by means of the CPLEX 12.5 solver [15] on a standard PC equipped with a Intel i5 processor, 2.7 GHz, 4GB RAM, under Windows 10 OS.

The first question we deal with is the impact of merging operations on costs. We can compare the costs of Operator Z to those of Operators A and B if the latter have to upgrade their network to cover the same customer basin and serve the same customer demand as Operator Z. We evaluate their costs by considering an operating lifetime of 5 years and computing the present values of OPEX (CAPEX are assumed to be borne at year 0) with a discount rate equal to 3%. In Fig. 4 we show the distribution of the ratio of the average costs of Operator Z compared to those incurred by a *single* Operator (which is indicated by Operator A/B). Actually, we show the kernel density estimate, using a Gaussian kernel. This means that for both operators the Build vs Merge dilemma is solved in favour of the Build options, as far as just access network costs are concerned.

In order to see what impacts more on the overall present costs, we report in Fig. 5 the weight of CAPEX and present OPEX for the three operators. The weight of CAPEX is much larger for the after-merger network (Operator Z). If we considered a longer interval, the larger weight of CAPEX would contribute to lower the gap between Operator Z and the operators to be merged. For example, raising the evaluation interval to 10 years would lower the average cost increase due to merging by 5.9%. Merging therefore carries along a reduction of overall network costs in the long run, though it remains by far the more costly alternative. It is however important to stress that our comparison only takes into account network OPEX and CAPEX, neglecting other important factors such as expected revenues from the resulting market shares, human resources, etc.

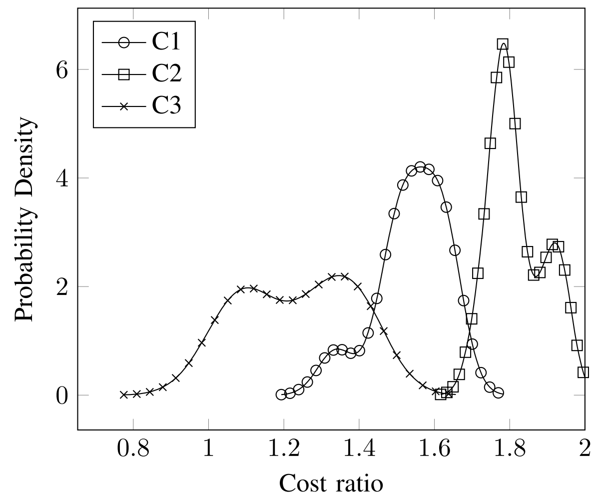

Fig. 4: Ratio of net present costs of Operator Z to Operator A/B

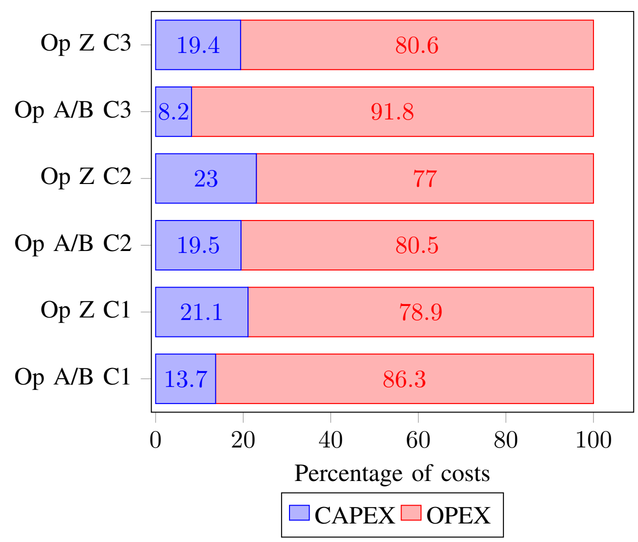

Fig. 5: Composition of costs

Delving deeper into what contributes to CAPEX, we analyse the relative impact of either CAPEX items: set-up and switch-off costs. In Fig. 6 we see a striking difference. For the operators to be merged, set-up costs are a low, but not marginal, portion of the overall CAPEX, but Operator Z's CAPEX are due to just switch-off costs. For networks serving the same basin, merging is accompanied by the need to switch off many APs. On the other hand, dominant switch-off costs for the operators to be merged also means that there are wide margins of cost optimization for an existing network, since the same basin can be served with a lower number of APs.

As to OPEX, we see in Fig. 7 that the largest contribution is by far due to rental costs, with power representing about

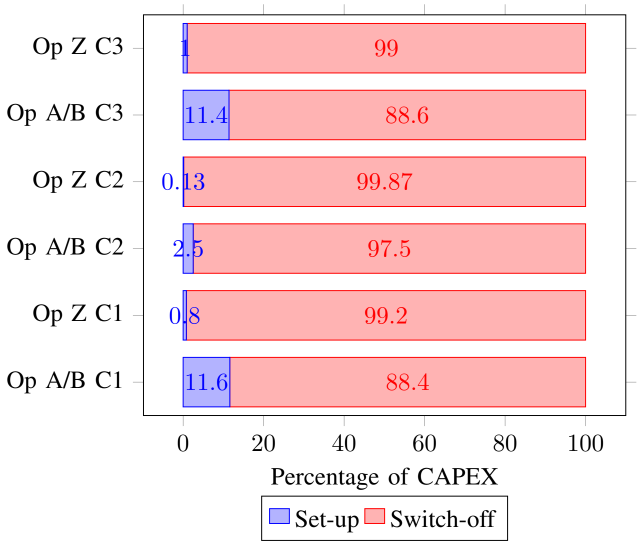

Fig. 6: Composition of CAPEX

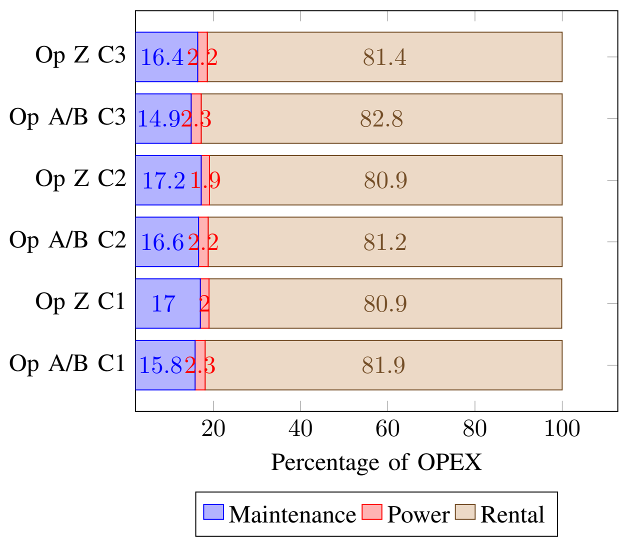

Fig. 7: Composition of OPEX

2% of the overall amount. Differences among the three networks are negligible.

VI. Conclusion

Though a merger may represent a good chance to consolidate the network, the actual cost of the network resulting after the merger must be carefully considered. Here we have compared the merger against the case where the networks to be merged may be separately upgraded to serve the same customer basin as the after-merger network. As far as just the access network costs are concerned, we have shown that the merger may result in a 50% cost increase.

This is largely due to the high cost incurred to switch off redundant access points. Though a merger may be desirable for other reasons and a higher view of costs and revenues should be considered, the merger costs should be reduced, e.g. through an alternative management of the access points to be dismissed, for it to be competitive against the Build option. Also, mixed approaches may be envisaged, where different choices are taken for different geographical areas. An interesting topic to be considered in this setting concerns fairness issues (see, e.g., [16], [17]), for instance how to manage setup/switch-off of AP facilities pertaining to the two merging operators.

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