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Heuristics for PON-Based 5G Backhaul Design

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1. INTRODUCTION

Small radio cells have been acknowledged as the only technically viable way to provide the individual 100 Mb/s – 1 Gb/s access rates promised by the future 5G[1] cellular networks. This small-cell approach faces a number of technological challenges when it comes to the design of an appropriate backhaul network [7]. However, not less importantly, it also poses a financial challenge for operators, given the high cost of deployment and maintenance of a large amount of active devices connected at gigabit speeds scattered over a metropolitan area.

To address this problem, it is generally agreed that PON (Passive Optical Networks) technologies can be the basis for a cost-effective way to reach 5G radio access nodes –eNodeB in LTE terminology–. The broadcast-and-select nature of PON entails a few advantages for seamless mobility [5] and also some disadvantages [2]. The winner PON technology is likely to be the one capable of deployment on street lamps with minimum fiber installation requirements, of flexible bandwidth allocation and of agile support to inter-access node communication –X2 interface between eNodeBs in LTE standard–. Before this technology is in place, it is possible to leverage the existing infrastructure deployed for residential FTTH services, and planning this secondary use of PON infrastructure in an optimal way is another interesting engineering problem recently addressed. Recent relevant work on this latter and less-studied technique gives very useful cost models and formulation as an ILP problem. In this paper we propose simple heuristic algorithms as less computationally complex alternatives to ILP-based optimization. Getting close to the optimum as obtained by means of an ILP solver with heuristic planning algorithms can be complicated and strongly dependent on the concrete data set. Thus it is interesting to know how much this is in practice in order to get quick estimations for big data sets. On the other hand a procedural heuristic lets you drive other design considerations (policies, preferences, capacity margins, differential treatment of areas due to differential geographic development of the city, *etc*.) that could be difficult to model with ILP if they cannot be represented as convex functions. Therefore it is also convenient to have a procedural algorithm where to establish priorities on policies not far from the optimum cost configuration.

2. DESIGN OF HEURISTICS

There are quite a few models for residential and WOBAN green-field modeling *e.g*. [4][6]. [1] is an excellent recent work to start from for massive deployment over existing fiber modeled as an ILP problem that we have taken as optimal design reference. Furthermore, its results give hints to algorithm design. We have studied two heuristic approaches that have an initialization and a consolidation phase.

Initialisation

The first step consists of assigning every ONT to its closest FAP (Fiber Access Point) as an initial default. This way we guarantee that no ONT will be left out without attachment and that we start from our design aim of having short distribution spans as their cost can be triple the feeder and requires an extra investment. Since the cost of installing the first splitter in a FAP is estimated to be double the cost of subsequent splitters (given the cost of the enclosure) during the optimization phase, ONTs may move around to other splitters for the sake of a lesser global cost. Alternatively, we can choose to start with the FAP for which the fiber cost of the full span is minimum.

Consolidation

The second phase deals with heuristic merging of splitters in order to get close to the optimum as obtained by ILP optimization. This can be done by making an arbitrary partition of the area based on densities, or by checking for cost saving in close enough splitter merging. In this latter approach, we only explore the r nodes in $V(m,r)$, defined as the r-vicinity of a FAP node m, i.e. the set made up by the r FAP nodes closest to m. Parameter r can be used to tune the quality of the optimization and execution time. The order in which we try to consolidate pairs of splitters at different FAPs is relevant. Our heuristic starts by the FAPs with the least number of ONTs and explores the vicinity of those nodes starting by the most loaded and in descending order. We may also try to compute and analyze all permutations of $|V(m, r)|!$ as a variant of the algorithm. We do not pay attention to the split ratio when consolidating because in this algorithm we prefer to minimize the number of FAP locations with splitters, as long as there is saving. Thus, unlike [1], our target design is not optimized for

[1] In this paper 5G refers to the next generation of cellular networks intended to succeed 3GPP's LTE advanced.

a given fixed split ratio. Once *S* is computed, it is possible to use either the best-fit split ratio for every FAP hosting splitters or a fixed one.

Preliminary simulation results show that the obtained cost is not far from the optimal obtained by ILP on a simple reference data set at low execution times. All models and heuristics can be further improved. Furthermore, this model only considers re-use of existing fiber as feeder and only new distribution fiber, always assuming sufficient fiber coverage all over the map. However this may be far from reality and the algorithm should recommend the deployment of new feeder fiber instead of multiple very long distribution fibers.

3. EXTENDING THE MODEL TO ALTERNATIVE PON TECHNOLOGIES FOR 5G

Extending the model and algorithms to other PON technologies should be relatively simple. WDM-PON technologies based on AWGs instead of splitters, like ITU-T G.698.3 have similar modelling. Athermal AWGs should be used or additional constraints will be necessary on AWGs location. On the other hand, the installation of active devices, such as switches instead of splitters, can get justified by the need for low latency ONT-ONT communication requirements of 4G (and very likely in 5G) [2]. This option will add constraints related to power supply proximity. TWDM technologies compatible with GPON and EPON splitter-based infrastructure are promising options for 5G. However, given the need for technologies supporting small-cell deployment along long streets, additional topologies for tap-and-continue operation can be expected to raise interest and complement the well-known uniform power splitting, and at the same time they may provide ONT-ONT inter-communication mechanisms. This will change the way the ILP model and heuristic algorithms are designed, from a Steiner's tree family of models/algorithms to a "travelling salesman" one, or a hybrid of both.

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