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Broadband Access Network Planning through Hierarchical FLP

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Abstract

The broadband access networks consists of various layer 2 and layer 3 devices, e.g., ethernet switches and routers. To deploy broadband access networks, how to locate devices appropriately is an important issue. The device location problem could be treated as a hierarchical facility location problem (FLP). The basic solution for the hierarchical FLP is to optimize the devices of layer 2 and layer 3 individually. However, such solution ignores the correlation between the locations of layer 2 and layer 3 devices and only derives semi-optimized results. Another solution adopts non-linear model to illustrate the correlation, but the computation complexity is increased greatly. While the capital expenditure (CAPEX) of the network deployment is a critical concern for the telecommunication operators, a fully optimized model is getting important.

In this work, we propose a detailed mathematical model for the FLP problem encountered in broadband access networks planning. A linear model for hierarchical FLP is presented and could obtain the feasible solution easily. As compared with previous models, the proposed scheme is fast and optimum.

Keywords: Broadband access network,

facility location problem, linear programming.

1 Introduction

The main purpose of the network planning is to optimize the network investments in a unified way to meet customers' requirements. Network planners should be armed with scientific tools for solving various problems involved in the network deployment. The broadband access network planning is completely different from conventional telecommunication network planning due to its hierarchical deployment. A sample network topology is shown in Fig. 1. In the telecom networks, the equipments (e.g., PSTN switches) have identical functions and thus form a flat topology.

To provide broadband accesses in NGNs, the required equipments are different to those in the conventional networks. These equipments could be separated as layer 2 and layer 3 devices. The layer 2 devices include DSLAMs, ethernet switches and ATM edge switches and the layer 3 devices indicate core routers. Figure 2 illustrates the broadband access networks from Fig. 1. Each exchange will be installed the DSLAMs and some of them will be equipped with edge switches and core routers. To simplify the planning complexity, the set of ex-

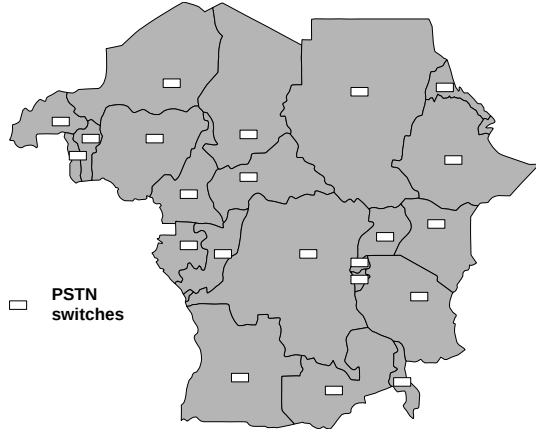


Figure 1. The Location of the Exchanges.

changes with core routers is a subset of exchanges with edge switches. This is also a reasonable configuration since co-location of layer 2/3 devices could eliminate the cost of links. Since the locations of the layer 2 devices (except DSLAMs) are unknown, the model for the locations of layer 3 devices thus becomes to a non-linear one.

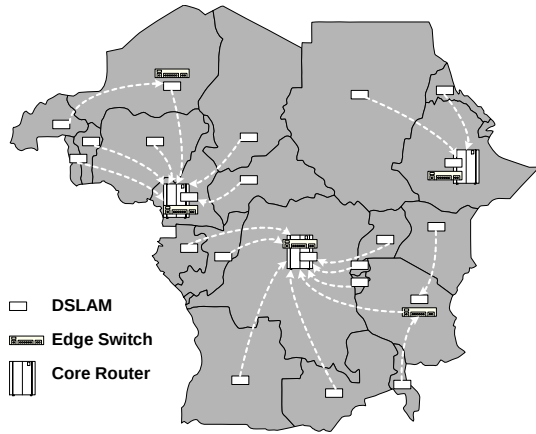


Figure 2. The Hierarchical Results of the Edge Switches and Core Routers.

For an estimated traffic, basic network planning are to determine the locations of switching nodes and link capacities between selected nodes. These problems are called the facility location problem (FLP) [2,4] and dimensioning problem [3], respectively. The FLP for broadband access networks can be modelled by a capacitated p -median problem. The dimensioning problem is simpli-

fied by only considering the number of requirements.

In this work, we propose a fully optimized model for the FLP of broadband access networks. This new model is linear and could obtain a feasible solution easily. As compared with previous models, the proposed scheme is much fast and optimum. The rest of the paper is organized as follows. Section 2 introduces previous models. Section 3 describes the proposed model. Section 4 presents the experimental setup and results. Finally, Section 5 summarizes the work.

2 Previous Models

The FLP of layer 2 and layer 3 devices in existing buildings could be formulated as follows:

- Input data

N : the set of exchanges

L_{ij} : the per link cost between (i, j) ,
 $i, j \in N$

H_{ij} : the hop count between (i, j) ,
 $i, j \in N$

R_i : the requirements of node i , $i \in N$

C_s : the cost of edge switch

C_r : the cost of core router

CA_s : the capacity of edge switch

CA_r : the capacity of core router

CA_l : the capacity of link

δ_s : the maximum allowable hop count
between exchange and edge switch

δ_r : the maximum allowable hop count
between edge switch and core
router

- Decision variables ($i, j \in N$ hereafter)

x_{ij} : the number of links between ex-
changes i and edge switches at j

y_{ij} : the number of links between edge
switches at i and core routers at j

c_i^s : the number of edge switches at i

c_i^r : the number of core routers at i

- Temporary variables ($i, j \in N$ hereafter)

x'_{ij} : the binary variables indicating links between exchanges i and edge switches at j are selected

y'_{ij} : the binary variables indicating links between edge switches at i and core routers at j are selected

c_i^s : the binary variables indicating whether there is edge switch at i

c_i^r : the binary variables indicating whether there is core routers at i

- Mathematical model

$$\begin{aligned} \text{Minimize } & \sum_{j \in N} \sum_{i \in N} (L_{ij}x_{ij} + L_{ij}y_{ij}) \\ & + \sum_{j \in N} (C_s c_j^s + C_r c_j^s) \end{aligned} \quad (1)$$

subject to

$$\sum_{j \in N} x'_{ij} = 1, \forall i \in N \quad (2)$$

$$\sum_{j \in N} y'_{ij} = c_i^s, \forall i \in N \quad (3)$$

$$x'_{ij} \leq c_i^s, \forall i, j \in N \quad (4)$$

$$y'_{ij} \leq c_i^s, y'_{ij} \leq c_i^r, \forall i, j \in N \quad (5)$$

$$x'_{ii} = c_i^s, \forall i \in N \quad (6)$$

$$c_i^r \leq c_i^s, y'_{ii} = c_i^r, \forall i \in N \quad (7)$$

$$x_{ij} = \lceil \frac{x'_{ij} \times R_i}{CA_l} \rceil \quad (8)$$

$$y_{ij} = \lceil \frac{y'_{ij} \times \sum_{j \in N} R_j x'_{ji}}{CA_l} \rceil \quad (9)$$

$$c_i^s = \lceil \frac{\sum_{j \in N} R_j x'_{ji}}{CA_s} \rceil \quad (10)$$

$$c_i^r = \lceil \frac{\sum_{k \in N} [\sum_{j \in N} R_j x'_{jk}] y'_{ki}}{CA_r} \rceil \quad (11)$$

$$x'_{ij} = 0, \text{ where } H_{ij} > \delta_s \quad (12)$$

$$y'_{ij} = 0, \text{ where } H_{ij} > \delta_r \quad (13)$$

$$x_{ij}, y_{ij}, c_s, c_r \in \text{integer} \quad (14)$$

$$x'_{ij}, y'_{ij}, c_i^s, c_i^r \in \{0, 1\} \quad (15)$$

This model is a generalized version of the p -median problem and we call it a capacitated hierarchical p -median problem. The

objective function this model consists of two parts. The first term represents the link cost of connecting exchange i and edge switch j or edge switch i and core router j . The last term is the cost of installing edge switches and core routers. The temporary variables indicate the topology information required in the calculation. The constraint (2) requires that each exchange connects to edge switch and (3) shows that each edge switch connects to core router. The link between (i, j) must satisfy that i is an exchange (edge switch) and j is an edge switch (core router), as shown in constraints (4)-(7). In constraint (8) and (8), the required links is calculates according to the requirements. Constraint (10) and (11) calculates the required edge switches and core routers, respectively. The hop count limitation for links of different types are illustrated in (12) and (13). The constraint (14) represents the binary property of variables and (15) shows the integer property.

The hierarchical p -median problem could be solved by non-linear programming. However, the calculation time for non-linear programming is time consuming as compared with linear programming. Therefore, some heuristics are required to solve the FLP model [1]. A simplest one is to calculate the locations and numbers of edge switches. In the following, the required core routers and their locations are derived by taking the results of previous calculation as input. However, such solution ignores the correlation between the locations of edge switches and core routers and only derives semi-optimized results. Accordingly, a improved model is presented in next section.

3 Proposed Model for FLP

In the previous model, the location of the core router is related to that of the edge switch. To solve the hierarchical FLP with linear programming, it is necessary to represent their relationship in the model. A new temporary variable, P_{ijk} , is introduced to replace x'_{ij} and y'_{jk} . The different con-

straints in the new model are shown as below.

$$\sum_{k \in N} \sum_{j \in N} P_{ijk} = 1, \forall i \in N \quad (16)$$

$$P_{ijk} \leq c_j^s, \forall i, j, k \in N \quad (17)$$

$$P_{ijk} \leq c_k^r, \forall i, j, k \in N \quad (18)$$

$$\sum_{k \in N} P_{iik} = c_i^s, \forall i \in N \quad (19)$$

$$P_{iii} = c_i^r, \forall i \in N \quad (20)$$

$$x_{ij} = \lceil \frac{P_{ijk} \times R_i}{CA_l} \rceil \quad (21)$$

$$y_{jk} = \lceil \frac{\sum_{i \in N} P_{ijk} R_i}{CA_l} \rceil \quad (22)$$

$$c_j^s = \lceil \frac{\sum_{i \in N} R_i P_{ijk}}{CA_s} \rceil \quad (23)$$

$$c_k^r = \lceil \frac{\sum_{j \in N} \sum_{i \in N} R_i P_{ijk}}{CA_r} \rceil \quad (24)$$

$$P_{ijk} = 0, \text{ where } H_{ij} > \delta_s \quad (25)$$

$$P_{ijk} = 0, \text{ where } H_{jk} > \delta_r \quad (26)$$

$$P_{ijk} \in \{0, 1\} \quad (27)$$

The constraints in (12)-(15) which are related x'_{ij} and y'_{jk} are rewrote with the new variable P_{ijk} . P_{ijk} is a binary variable which indicates a path from exchange i through edge switch j to core router k . Thus each exchange i must has a selected path to edge switch j and core router k (16)-(18). The constraint (19) and (20) show the path for exchanges which also equip with edge switch and core router. The number of required links, edge switches and core routers are represented in the constraints (21)-(24). The hop count limitation for links are illustrated in (25) and (26). The constraint (27) represents the binary property.

In the new model, the locations of edge switches and core routers are implied by P_{ijk} . The hierarchical p -median problem is thus reduced to path assignment problem with $|N|$ flows. Therefore, the model could be solved by linear programming, which is much faster than non-linear programming. A major concern for adopting new variables is the increased variables for P_{ijk} ($|N|^3$), while the generated variables in the original model is $2|N|^2$.

Several extra constraints could eliminate the calculated variables. For example, the degree limitation of each exchange could be used to prune unfeasible exchange since the exchange with higher degree is usually more important than the exchange with lower degree in telecommunication network. The unfeasible paths, e.g. looped paths, should be pruned. A tighter limitation to hop counts is also helpful. In the next section, the experimental results would demonstrate that the proposed model is much fast and accurate than the previous one.

4 Performance Evaluation

In this section, we evaluate the performance of three models: original, heuristic and the proposed model. The original model is non-linear programming while the rest are linear. The heuristic model consists of two programs, which the first one calculates the locations of edge switches and the second derives the locations of core routers. The models are implemented on Lingo v7.5 [8], which is a tool for utilizing the power of linear and nonlinear optimization to formulate and solve large problems concisely. A IBM PC with Pentium IV 1.7G Hz CPU is used to execute the programs. Two real networks including the existing requirements with 32 and 42 exchanges are used in our experiments. Also, the limitations of degrees and hop counts are carefully defined.

The performance metrics include the number of variables and constraints, the optimized cost, the execution time, and the number of iterations and taken branches to optimality. Since the heuristic model includes two programs, the performance metrics for both are listed and separated by slash.

The experimental results for the small network are presented first. The required memory represents scale of the model. The original model requires least storage while the proposed model needs most. Also, the original model requires the least variables, but longest execution time. Apparently, the

Table 1. Performance Comparisons for 32-node Network

Metrics	Original Model	Heuristic Model	Proposed Model
Variables	456	1,380/190	672
Linear Constraints	513	495/275	1,069
Nonlinear Constraints	42	0/0	0
Iterations	1,261,396	86/0	4,642
Branches	1,621	0/0	84
Execution Time (second)	1,683	2/1	7
Optimized Cost	0.3826965E+09	0.4308626E+09	0.3826965E+09
Required Memory	232K	285K/385K	320K

Table 2. Performance Comparisons for 42-node Network

Metrics	Original Model	Heuristic Model	Proposed Model
Variables	977	2,208/627	1,785
Linear Constraints	1,294	644/930	3,039
Nonlinear Constraints	246	0/0	0
Iterations	1,834,733	79/382	8,545,728
Branches	1,050	0/6	126,988
Execution Time (second)	29,286	1/1	2,056
Optimized Cost	0.1665237E+10	0.1901787E+10	0.1580357E+10
Required Memory	450K	451K/720K	737K

model complexity could not be reflected by the required storage and the number of variables, but the linearity of the models. Both heuristic model and the proposed one generate no nonlinear constraints, thus could be solved by fast linear programming. The heuristic model could derive the optimization within minimal iterations since the two-step solution deals with two simpler sub-problem. However, such solution also incurs about 13% higher deployment cost than the proposed scheme. The original model could obtain a optimal solution but with more iterations/branches and longer execution time. Therefore, the proposed scheme is more practical for network planning than the previous ones.

For the large network, the execution speed of the original model is severely slowed down. Due to the complex calculation of the non-linear programming, the execution time for each iteration is increased exponentially as the model getting larger. Also, the resulted cost is higher than that

of proposed model. It is because of the non-linear solver only calculate the local optimum. That is, a solution for which no better feasible solutions can be found in the immediate neighborhood of the given solution. Although better solutions can't be found in the immediate neighborhood of the local optimum, additional local optimums may exist some distance away from the current solution. These additional locally optimal points may have objective values substantially better than the solver's current local optimum. Hence the non-linear model is not scalable, neither optimal. The cost from the heuristic model is even worse, though it is the fastest model. Only the proposed model could reach the optimality for the hierarchical FLP within reasonable time.

5 Conclusion

In this work, the issue of broadband access network planning is addressed. Unlike the traditional telecommunication networks, the new networks are hierarchical,

and the network planning is complicated due to its nonlinearity. The heuristic model solves the complexity by adopting two-step calculation, but such solution would incur extra cost because of the loose information between both steps. The proposed scheme is a linear model and could solve the hierarchical FLP in one step. The new model introduces the concept of path and could derive the optimality fast. From the experimental results based on real networks, the new model outperforms the previous ones in either deployment cost or execution time. Therefore, the proposed scheme is suitable for broadband access network planning.

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