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Optimal Telecommunication Facility Planning Under Uncertainty

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Introduction:

In this paper, we address an important telecommunication network design issue through a new approach that incorporates significant uncertainty in the input data. In particular, we focus on locating communication hubs in a star-star network with both demand and cost uncertainties. The research model determines 1) the number of hubs to be employed, 2) the location of hubs within a given set of pre-determined sites, and 3) the assignment of end-user nodes to these communication hubs without violating their line capacities. The total system cost includes the fixed costs of installing hubs, and the variable costs of connecting end-user nodes to selected hubs. It is assumed that the demand imposed by any end-user node is not known a priori. Furthermore, each end-user node imposes a variable cost that depends on both the processing demand and a time-varying communication charge. The incorporation of uncertainty in end-user demands, and hence the communication costs, adds a new dimension to network management and facility planning.

Research Review, Motivation and Impacts: Our research is an extension to the conventional '**C**apacitated **C**oncentrator **L**ocation **P**roblem' **(CCLP)**, a well known research issue in telecommunications [Gavish 1989; Pirkul 1987]**.** While the conventional CCLP considers only deterministic input in its model, it has been proven NP-complete [Mirzaian and Steiglitz 1981]. As commonly criticized by practitioners, deterministic models fail when uncertainties are involved in the decision making process. In this paper, a pioneering attempt is made to explicitly incorporate both demand and cost uncertainties into our final CCLP model, hereinafter referred to as the **C**apacitated **C**oncentrator **L**ocation **P**roblem under **U** ncertainty **(CCLPU)**. In specific, our model addresses a decision making environment in which more than one decision case (termed "scenario" in subsequent sections) is considered for searching optimal solution. This model extension will ensure the robustness of the final solution since all possible scenarios are considered during the optimization process. Our research is motivated by the fact that telecommunication traffic involves significant uncertainty that should be captured by the planning model.

Robust Optimization:

A new approach known as robust optimization is used to solve CCLPU. The traditional deterministic approach is inappropriate for CCLPU due to its limitation in addressing input data uncertainty. In contrast to stochastic modeling, robust optimization requires less information (for e.g., robust optimization does not require information on estimated probabilities, probability distributions), and hence renders itself a greater implementation appeal. Our use of the term robustness is consistent with the notion introduced by earlier researchers [Gupta and Rosenhead 1972; Sengupta 1991].

The robustness approach to CCLPU helps design a cost efficient network that is relatively insensitive (robust) to the potential changes in the processing demands of the end-user nodes and the time-varying costs. To parameterize the robustness approach, a set of possible demand and cost scenarios are identified. The objective is to obtain a robust network design that has the best worst-case performance among all realizable scenarios.

Mathematical Model:

NOTATION:

I index set of end-user nodes

J index set of potential sites for hub location

S index set of scenarios

T index set of time zones

dsij demand imposed by end-user i **I** on hub at site j **J**, in scenario s **S**

cij cost of assigning end-user i **I** to hub at site j **J** (e.g. cable cost)

cst cost associated with scenario s **S** in time zone t **T**

Fj fixed set up cost of installing a hub at site j **J**

Zs* optimal solution for scenario s **S**

Decision variables:

xij takes the value one if end-user node i is assigned to hub at site j and takes the value zero otherwise.

yj takes the value one if a hub is located at site j and takes the value zero otherwise.

Define **the objective function for scenario s** as**:**

$$Z_s = \sum_{i \in I} \sum_{j \in J} (c_{ij} + c^s_t d^s_{ij})\, x_{ij} + \sum_{j \in J} F_j y_j$$

Using the above notation, the mathematical model is formulated below:

$$\textbf{Min Max}_{s \in S} (Z_s - Z_s^*) \qquad (1)$$

subject to:

$$\sum_{j \in J} x_{ij} = 1 \qquad \forall\, i \in I \qquad (2)$$

$$\sum_{i \in I} d^s_{ij} x_{ij} \leq p_j \qquad \forall\, j \in J \qquad (3)$$

$$x_{ij} \leq y_j \qquad \forall\, i \in I \quad \forall\, j \in J \qquad (4)$$

Note that the objective function (1) is to minimize the maximum deviation between the robust solution and the optimal solution of each scenario. Constraints (2) are to ensure each end-user node is assigned to one and only one concentrator. Constraints (3) are to ensure that the processing capacity of each concentrator will not be violated by the total processing demands imposed by the assigned end-user nodes. While a more general model should also consider the total number of ports associated with each concentrator, this additional capacity constraint will be explicitly addressed in our future research.

Solution Methodology:

The solution algorithm involves the parallel development of branch and bound trees for each scenario and is similar to the one discussed by Gutierrez [1993]. A node in a tree *corresponds* to a node in another tree if these two nodes have identical positions in their respective branch and bound trees. The parallel development of scenario trees implies that whenever a node in a tree is branched to create two child nodes, the same corresponding node must be branched in all scenario trees. This rule also applies to those nodes that are fathomed. Branching from a node is done by setting the value of one of the integer variables yj to either zero or one. Each robust solution is required to be within '***p*** ' percent of the optimal solution of each scenario. An outline of the algorithm to generate the N best robust solutions for CCLPU is presented below. The algorithm outline proposed below may serve as a general solution methodology for any scenario-based robust optimization problems.

Algorithm Outline:

- **Step 0**: Initialization
- **Step 1**: Find optimal solution for each scenario
- **Step 2**: Find lower bound for each scenario
- **Step 3**: Define a root node for each scenario
- **Step 4: a)** Select the scenario tree with the lowest lower bound

b) Select a variable to branch and create two new descendent nodes for each scenario

c) Stop if no variables to branch or all nodes are fathomed

- **Step 5**: Compute lower bounds for all new nodes in each scenario tree
- **Step 6**: Fathom new nodes if fathom tests fail

Go to Step 4 if all new nodes are fathomed

- **Step 7**: Find a solution for each unfathomed node

If solution is not feasible go to Step 4

- **Step 8**: If robust solution is not within ***p*** % of the current scenario's optimal solution, then go to Step 4
- **Step 9**: Add solution to the robust solution list; go to Step 4.

Preliminary results and Concluding remarks:

The robust algorithm has been successfully implemented on a small test problem. The test problem considers two different scenarios and uses randomly generated data. Currently we are implementing the robust algorithm to solve larger sized problems by including more scenarios. We intend to compare the performance of different branching procedures. This includes different branching criteria for selecting 1) the branching scenario tree and 2) the branching variable. Extensive computational results will be reported.

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