The hub location problem with stopovers in a tree topology

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1 Introduction

This research focuses on the study of a hub location problem (HLP), specifically immersed in a tree-shaped network. HLPs are a study field that looks to the best location of hub facilities, minimizing an objective function related to the transportation of commodities. Due to its complexity and potential applications to academic or real case scenarios, HLPs are still a challenging research topic. The goal of this work is to find the minimum cost tree network with three sets of nodes : (i) a set of selected hubs, (ii) a set of spokes that are allocated to a single hub, and (iii) a set of so-called stopovers that are intermediate nodes located on a path between two hubs. To locate stopovers, it is necessary to relax some assumptions of classical HLPs. The first one to violate is the assumption to have a complete graph of the hubs. In this work, the graph of hubs is a tree. Another assumption to relax is that the link between hubs may form a path traversing a set of stopovers.

2 Problem Settings

We study a HLP on a tree topology. This problem setting is related to the tree of hubs location problem (THLP) [1], which is a variant of the HLP. Our main contribution is to locate stopovers as intermediate nodes between located hubs. Stopovers are nodes used to load and unload commodities, but without the possibility to reload the unloaded commodities at stopovers to other transportation nodes. Accordingly, transshipment is not allowed between transportation modes at the stopovers. The introduction of the stopovers helps to reduce the number of transshipments and also reduces the length of the itineraries between some pairs of origin and destination nodes. Consequently, transportation costs can be reduced. We keep the classical role of the hubs, as their function is to consolidate and transship commodities between pairs of origin and destination nodes. This promotes the appearance of economies of scale by the consolidation of the flows in larger quantities when transferring between hubs.

The proposed topology in this work could be useful to link systems when the associated costs are too high ; e.g., waterways, rail networks and data distribution systems. An additional scenario to use the proposed topology is the design of physical internet networks, a new paradigm that takes advantage of the digital internet protocols. In such a network, the resources are used efficiently in highly collaborative and interconnected environments [3]. Another applications of stopovers can be appreciated in distribution systems in which the level of service turns out to be a determining factor to have a competitive advantage among service providers. With the use of stopovers, the level of service can be increased and at the same time take advantage of the use of shared resources such as hubs. The level of service is increased because it is focused on the specific requirements of customers, therefore, it can be an added value of the stopovers. Accordingly, we can also establish that stopovers can be relevant in collaborative or coopetitive environments, resulting in challenges not only from the perspective of mathematical modeling but also from the managerial perspective. We can also observe that the use of stopovers adds value to distribution systems in which the handling of commodities must be reduced due to their fragility or because they may represent a health risk. Thanks to the efficiency of operations generated by the use of stopovers, we can find that they can add value to business models in which ergonomic conditions are not the friendliest for logistics workers, the strategic location of stopovers and the addition of an automation component in loading and unloading operations will benefit employees, these considerations are also aligned in the context of the physical internet.

The strategic decisions taken in this work are 1) the location of hubs and stopovers and 2) the allocation of spokes to hubs, where spokes can be allocated to a single hub (i.e., single allocation assumption). The objective function to be minimized is the total cost related to the transportation of a set of commodities between different pairs of origin and destination nodes through the network. Figure 1 presents the graphical representation of a solution of classical HLP, with a complete network connecting the hubs (represented by squares). Under the single allocation assumption, each spoke (represented by a circle) is allocated to only a single hub. On the other hand, Figure 2 presents a network under tree topology, where stopovers are represented by empty gray squares. The set of hubs forms a tree, and stopovers can be located on the path between two hubs.

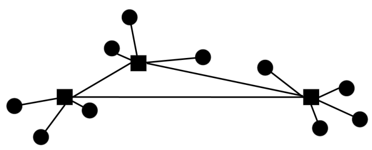

FIG. 1 – Classic representation of an HLP

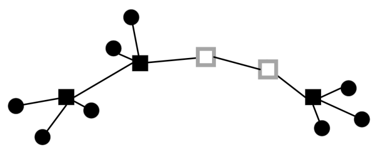

FIG. 2 – Tree-shaped HLP

3 Mathematical formulation and computational experiments

We present a mixed-integer linear programming (MILP) formulation for the HLP with stopovers on a tree topology. This formulation is an adaption of the HLP model proposed by [2]. Numerous computational experiments are performed to test the limits of the MILP formulation. Additionally, several valid inequalities are proposed to improve the LP bound of the original formulation. We finally present a case study relying on a real river network and explain how this work can be used in the context of waterborne Physical Internet ([3]).

Références

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