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Finding stable flows in multi-agent networks under an equal-sharing policy

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Abstract

A Multi-Agent network flow problem is addressed in this paper where a set of transportation-agents can control the capacities of a set of routes. Each agent incurs a cost proportional to the chosen capacity. A third-party agent, a customer, is interesting in maximizing the product flow transshipped from a source to a sink node through the network. He offers a reward proportional to the flow value, which is shared equally among the transportation-agents. We address the problem of finding a stable strategy (i.e., a Nash Equilibrium) that maximizes the network flow. In this paper, we present a Mixed Integer Linear Program (MILP) to model and solve this problem.

Keywords: Multi-Agent Network flow, Nash Equilibria, Equal-sharing Policy.

1 Introduction

Multi-agent network games have become a promising interdisciplinary research area with important links to many application fields such as transportation networks, supply chain management, web services, production management, etc [1], [2]. This paper stands at the crossroad of two disciplines, namely multi-agent systems and social networks. To the best of our knowledge, the

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research presented here is an original way of presenting a transportation problem using multi-agent network flow with controllable arcs capacities. One important application is the expansion of transportation network capacity (railway, roads, pipelines, etc.) to meet current peak demand or to absorb future increase in the transportation demands. In this paper, we consider a particular multi-agent network flows problem involving a set of self-interested transportation-agents, each of them managing his proper set of network roads. Every agent is able to increase the capacity of his arcs by gathering extra resources, at a given cost. A customer-agent is interested in increasing the flow circulating in the network. He offers a reward, to be equally-shared among the agents, for each additional unit of flow delivered through the transportation network. The contribution of this paper is to propose a MILP to find a Nash equilibria maximizing the flow, assuming a given sharing policy of the reward. The paper is organized as follows: Section 2 defines formally the problem and recalls previous results. In Section 3 a MILP formulation is proposed. Thereafter, Section 4 provides experimental results.

2 Problem Statement

2.1 Notations and Definitions

The Multi-Agent Network-Flow with Controllable Capacities (MA-NFCC) can be defined as a tuple $< G, \mathcal{A}, \underline{\mathcal{Q}}, \overline{\mathcal{Q}}, \mathcal{C}, \pi, \mathcal{W} >$ where:

- $G = (\mathcal{V}, \mathcal{E})$ is a network flow. $\mathcal{V}$ is the set of nodes and $\mathcal{E}$ is the set of arcs, each one having its capacity and receiving a flow.
- $\mathcal{A} = \{A_1, \ldots, A_u, \ldots, A_m\}$ is a set of m transportation-agents. Arcs are distributed among the agents. An agent A_u owns a set of m_u arcs, denoted $\mathcal{E}_u$. Each arc (i, j) belongs to exactly one transportation-agent and $\mathcal{E}_u$ represents the subset of arcs for agent A_u.
- $\underline{\mathcal{Q}} = (\underline{q}_{i,j})$ (resp. $\overline{\mathcal{Q}} = (\overline{q}_{i,j})$) represents the vector of normal capacity (resp. maximum capacity) for the agent A_u such that $(i, j) \in \mathcal{E}_u$.
- $\mathcal{C} = (c_{i,j})$ is the vector of unitary costs incurred by the agent A_u for increasing the capacity of $(i, j) \in \mathcal{E}_u$ by one unit beyond the minimal capacity.
- π is the reward given by the customer proportionally to the additional flow.
- $\mathcal{W} = \{w_u\}$ defines the sharing policy of rewards among the agents.

Assumptions. In this paper, for sake of simplicity, it is assumed that the minimal capacities are equal to 0 ($\underline{q}_{i,j} = 0$) and that the reward is shared

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