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Asymptotic results for the Generalized Bin Packing Problem

Mauro Maria Baldi[a,*], Teodor Gabriel Crainic[b], Guido Perboli[a,b], Roberto Tadei[a]

[a]*Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino, Italy*
[b]*CIRRELT, 2920, Chemin de la Tour, Montreal, QC, H3T 1J4, Canada*

Abstract

We present a worst case analysis for the Generalized Bin Packing Problem, a novel packing problem arising in many Transportation and Logistics settings, characterized by multiple item and bin attributes and by the joint presence of both compulsory and non-compulsory items. The contribution of this paper is twofold: we conduct a worst case analysis applied to the much richer Generalized Bin Packing Problem of two outstanding bin packing algorithms (the First Fit Decreasing and the Best Fit Decreasing algorithms) arising in Transportation and Logistics, and we propose two semi-online algorithms also arising in the fields of Transportation and Logistics. We also show how knowing part of the instance or the whole instance is not enough for computing worst case ratio bounds.

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1. Introduction

Packing problems in Transportation and Logistics are often more complex than the ones traditionally present in the literature. In particular, it is quite normal to face situations where the nature of the problem cannot be reduced to a single packing problem. For this reason, in recent years the research community started to think to new multi-attribute and multidimensional extensions of packing problems, as already done in the VRP field (Crainic et al., 2008). One of the latest attempts in the direction of the generalization of packing problems is the so called Generalized Bin Packing Problem (GBPP). Given a set of containers, different in cost and volume, and a set of items, characterized by volume, profit and the compulsory attribute, i.e. the attribute stating if the model is obliged to load an item or whether it can decide according to an economic criterion, the GBPP aims to find the subset of bins and the subset of non-compulsory items such that all the items (all the compulsory and the chosen

* Corresponding author. Tel.: +39-011-090-7083; fax: +39-011-090-7099.
E-mail address: mauro.baldi@polito.it

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non-compulsory ones) are accommodated into the bins and the overall cost, given by the cost for using the bins minus the profit associated to the items is minimized.

As shown in Baldi et al. (2012a), the GBPP is able to describe new operational settings in Transportation and Logistics characterized by the joint optimization of company revenues and transportation costs and by the presence of different 3PL or container types. Moreover, in multi-modal and cross-continental transportation, freight is not shipped directly from origins to destinations but calls at intermediate platforms named transshipment facilities. At these facilities freight consolidation and handling operations are performed and, usually, freight is moved to another transportation vector. However, a portion of the freight might wait to proceed its journey to destination, depending on the overall trade-off between freight profits and shipping costs. The GBPP is the first packing problem able to model this setting. Additionally, the GBPP copes with the majority of the traditional packing problems, ranging from Knapsack to Bin Packing and to different variants of Multiple Knapsack and Cutting Stock problems.

Baldi et al. (2012a, b) proposed both bounds and exact and approximate methodologies in order to address this problem. Moreover, a preliminary worst case analysis has recently been proposed (Baldi et al., 2013). The GBPP is rooted on earlier bin packing problems which are the eldest Bin Packing Problem (BPP), the Variable Sized Bin Packing Problem (VSBPP), and the most recent Variable Cost and Size Bin Packing Problem (VCSBPP). We briefly recall here these problems.

The BPP was first investigated by Ullman (1971) and Garey et al. (1972). Johnson (1973) proposed the Next Fit (NF) algorithm and proved that its performance ratio is 2. Johnson et al. (1974) showed that the First Fit (FF) and the Best Fit (BF) algorithms have both performance ratios of 17/10. Moreover, they computed a worst case ratio bound for the First Fit Decreasing (FFD) and the Best Fit Decreasing (BFD) algorithms equal to 11/9. de la Vega & Lueker (1981) presented a polynomial time approximation scheme, Seiden (2002) studied the online variant, and Crainic et al. (2007a, b) introduced fast lower bounds and conducted an asymptotic worst case analysis on BPP lower bounds. Li & Chen (2006) studied the variant where all bins have the same capacity but are characterized by a non-decreasing concave cost function of the bin utilization. The VSBPP was introduced by Friesen & Langston (1986). The authors provided one online and two offline algorithms and proved that their worst case ratios are 2, 3/2, and 4/3, respectively. Murgolo (1987) presented an approximation scheme and Kang & Park (2003) provided two offline algorithms and showed that their asymptotic worst case ratio is equal to 3/2. Crainic et al. (2011) proposed accurate bounds for the VCSBPP. For this problem, Epstein & Levin (2008, 2012) provided an APTAS and an AFPTAS.

Although Baldi et al. (2013) performed a worst case analysis for the GBPP, this study is not complete because only online algorithms were considered. In this paper, we extend the work of Baldi et al. (2013) by also considering semi-online and offline settings. These two settings often arise in Transportation and Logistics where orders (i.e., the items) are not known a priori but arrive along time to a shipping company. In many circumstances, shipping companies do not immediately ship the already received freight (coming from customers and leading to final destinations) but decide to wait in order to receive more freight to dispatch with a unique shipment. The semi-online setting of the GBPP also arises in freight transportation, and in particular among freight forwarders and carriers, where freight is shipped through means of transport with cadenced departure times.

We show that, being the GBPP a richer setting due to the presence of multiple attributes and of both compulsory and non-compulsory items, it is impossible to guarantee a worst case ratio.

This paper is organized as follows. In Section 2, we present in a more formal way the problem and the nomenclature. In Section 3, we present our worst case analysis results, while conclusions and future developments are discussed in Section 4.