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O.R. Applications

Bandwidth packing with priority classes

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Abstract

The bandwidth packing problem is defined as the selection and routing of messages from a given list of messages with prespecified requirements on demand for bandwidth. The messages have to be routed over a network with given topology so that the generated revenue is maximized. Messages to be routed are classified into two priority classes. An integer programming based formulation of this problem is proposed and a Lagrangean relaxation based methodology is described for solving this problem. A general purpose heuristic is then developed for generating feasible solutions of good quality. Several numerical experiments are conducted using a number of problem parameters such as number of messages, ratio of messages for lower and higher priority classes, capacity of links, and demand distribution of messages belonging to different classes and high quality solutions to the priority bandwidth packing problem are generated under the different situations.

Keywords: OR in telecommunications; Bandwidth packing; Integer programming; Lagrangean relaxation; Priority classes

1. Introduction

Networks of today often suffer from congestion problems due to the tremendous increase in traffic in recent times as well as irrational allocation of bandwidth to support this increased traffic. One of the fundamental problems related to design of networks is determination of which messages to route among a given list of messages and determination of the routes to be used for delivering messages between communicating nodes so that the revenue generated from routing these messages is maximized. This is known as the bandwidth packing problem. The objective of this research is to use an optimization based approach for solving the bandwidth packing problem for messages belonging to multiple service classes. This will involve selection of a target group of messages from a list of messages provided by the users, and determination of the best paths for routing these messages. Usually the topology of the network, the capacities of the links, the revenues to be generated by routing the messages, and the demand requirements of the messages are specified prior to the start of network design. The messages are listed in the form of a message table and are prioritized based on the demand requirements. Since the network capacity is usually insufficient to route all messages, a selected group of messages are routed during a given period of time. This is known as the static bandwidth packing problem (as opposed to dynamic bandwidth packing where the demand requirements of the messages change over time) and is studied in this paper. My goal in this paper is to find an appropriate message selection and routing scheme that provides an efficient resource allocation mechanism and maximizes the revenue generated from the usage of the network.

The problem addressed in this research is important since many telecommunication companies have invested heavily in building networks that will be used for carrying multimedia traffic. As more delay sensitive applications (e.g., interactive

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television, real-time virtual simulations, collaborative computing, online interactive gaming, telemedicine) become common in the future, the routing issues for networks will become very important. As bandwidth becomes scarce for such networks, there will be an increasing need to develop intelligent message selection and routing schemes that will maximize the generated revenue for the company. Technology Futures Inc. has forecasted that the percentage of households in US that will demand high definition IP video will increase from 20% in 2010 to 80% in 2020 (Vanston and Hodges, 2004). The analytical model that I propose is a close representation of the present networks that use connection oriented protocols for routing of messages. It gives significant insights about the various operational issues which are of importance to network service providers, network designers, and network users. This paper aims to help network operators maximize the generated revenue by providing design guidelines about various network operating parameters that can help them meet the service requirements of the different classes of messages.

Various versions of the bandwidth packing problem have been studied in the past. This includes research published by Cox et al. (1991), Anderson et al. (1993), Laguna and Glover (1993), Parker and Ryan (1993), Park et al. (1996), Rolland et al. (1999), Amiri et al. (1999), Amiri and Barkhi (2000) and Amiri (2003, 2005). Most of these papers strive to maximize the revenue earned by routing the messages subject to some service related constraints. A notable exception is the paper by Amiri et al. (1999) where the objective is to maximize revenue as well as minimize the delay cost associated with the use of the network. An extension to the basic bandwidth packing problem that considers multi-hour traffic is provided by Amiri and Barkhi (2000) and a further extension that solves the multi-hour bandwidth packing problem with delay guarantees is described in the paper by Amiri (2003). Also, a new version of the bandwidth packing problem which involves scheduling the messages within a prespecified time window is discussed in the recent paper by Amiri (2005). Various methods are used in these papers including tabu search (Anderson et al., 1993; Laguna and Glover, 1993), genetic algorithms (Cox et al., 1991), column generation (Parker and Ryan, 1993), and Lagrangean relaxation (Rolland et al., 1999; Amiri et al., 1999; Amiri and Barkhi, 2000; Amiri, 2003; Amiri, 2005). On a different vein, an interesting paper by Dantzer et al. (2000) studies the stability properties of the bandwidth packing algorithm. However, the available research on bandwidth packing considers only a single message class. This assumption is not realistic as users use the networks for running different applications. Some of these applications are delay sensitive but others are not. So it is more appropriate to model the bandwidth packing problem in the presence of multiple priority classes. To the best of my knowledge, this is the first paper that addresses the priority bandwidth packing problem. As opposed to the existing literature this problem is considerably more difficult because exact analytical expressions for the average delay of the priority classes are difficult to obtain and this is turn complicates the formulation of the problem.

The remainder of this paper is organized as follows. In Section 2, an integer programming based formulation of the bandwidth packing problem with multiple classes is presented. In Section 3, a Lagrangean relaxation of the original problem is obtained by dualizing a subset of the constraints and the relaxed problem is decomposed into two solvable sub-problems. An analytical solution of the sub-problems is proposed. A heuristic to obtain a feasible solution to the problem is described in Section 4. The different numerical results obtained using various choices of problem parameters are detailed in the next section. Section 6 concludes the paper with a summary and discussion of directions for future research.

2. Problem formulation

In this section I provide a mathematical representation of the bandwidth packing problem. A network with a known topology is used for transmission of messages (that belong to two different priority classes) between several origin and destination pair of nodes. The messages belonging to the higher priority class are shorter in length, generate more revenue, and are more demand intensive compared to the messages belonging to the lower priority class. The objective of the network manager is to select and route the messages through the network in such a way that the revenue generated from the process is maximized. At the same time, the number of messages in the network belonging to the higher and the lower priority classes must not exceed some predetermined bounds and the bandwidth consumed by all the messages routed on any link of the network must be less than the available capacity of the link. I introduce the following notation for developing an integer programming model for the priority bandwidth packing problem:

N set of nodes in the network
E set of undirected links in the network
M set of messages
M_1 set of messages of lower priority
M_2 set of messages of higher priority
$1/\mu_1$ average length of messages of lower priority
$1/\mu_2$ average length of messages of higher priority
d^{m_1} demand for message $m_1 \in M_1$
d^{m_2} demand for message $m_2 \in M_2$
r^m revenue generated by routing message $m \in M$