Available online at www.sciencedirect.com
ScienceDirect
Computers & Operations Research 35 (2008) 2482–2496
computers & operations research
www.elsevier.com/locate/cor

Queues in DOCSIS cable modem networks

J. Lambert*, B. Van Houdt, C. Blondia

Department of Mathematics and Computer Science, Performance Analysis of Telecommunication Systems Research Group, University of Antwerp, Middelheimlaan, 1, B-2020 Antwerp, Belgium

Available online 29 January 2007

Abstract

In this paper we determine the optimal fraction c^* of the uplink channel capacity that should be dedicated to the contention channel in a DOCSIS cable network in order to minimize its mean response time. For this purpose, we have developed an open queueing network with a non-standard form of blocking consisting of tens to hundreds of nodes. The network contains several types of customers that enter the network at various points according to a Markovian arrival process with marked customers. One of the main building blocks of the model exists in capturing the behavior of the conflict resolution algorithm by means of a single processor sharing queue. To assess the performance characteristics of this open queueing network we rely on an advanced decomposition technique that is specifically designed to deal with the Markovian nature of the arrival pattern. Several simulations are run to confirm the accuracy of the decomposition technique. We also explore the impact of a variety of systems parameters, e.g., the number of cable modems, the initial backoff window size, the correlation structure of the arrival process, the mean packet sizes, etc., on the optimal fraction c^*.

Keywords: DOCSIS cable networks; Contention channel; Performance evaluation; Queueing networks; Decomposition algorithm

1. Introduction

Recently, the rapid growth of the number of residential Internet users and the increased bandwidth requirements of multimedia applications have necessitated the introduction of an access network that can support the demand of such services. The data over cable service interface specifications (DOCSIS) [1] are the dominant specifications for carrying data over cable TV distribution (CATV) networks and have been developed by CableLabs and MCNS (multimedia cable networks systems), which is a group of major cable companies, to support IP flows over hybrid fiber coaxial (HFC) networks. DOCSIS defines the modulation schemes and protocols for high speed bi-directional data transmissions over cable systems. It has been accepted by most major vendors and is now a widely used specification to provide high-speed residential access. DOCSIS specifies a set of interface protocols between the cable modem (CM) customer side and the termination network side.

The media access control (MAC) protocol defined in the DOCSIS RFIv1.1 is based on time division multiple access (TDMA). It uses MAC management messages, referred to as MAP messages, to describe the usage of the uplink channel (that is, from the end-user to the network). A given MAP message, broadcasted on the downlink channel (that is, from the network to the end-users), indicates the upstream bandwidth allocation over the next MAP time, termed the

* Corresponding author. Tel.: +32 3 265 38 75; fax: +32 3 265 37 77.
E-mail addresses: joke.lambert@ua.ac.be (J. Lambert), benny.vanhoudt@ua.ac.be (B. Van Houdt), chris.blondia@ua.ac.be (C. Blondia).

0305-0548/$ - see front matter
doi:10.1016/j.cor.2006.12.004

MAP length. The MAP assigns part of the uplink minislots to particular CMs to transmit data, other slots are available as contention slots to request bandwidth. This is one of the critical components of the DOCSIS MAC layer and the DOCSIS specification purposely does not specify these bandwidth allocation algorithms so that vendors are able to develop their own competitive solutions. In this paper, we develop an open queueing network with blocking, whose performance determines the optimal ratio between the number of contention slots and reservation slots during a single MAP length.

For this purpose, we have developed an open queueing network with a non-standard form of blocking consisting of tens to hundreds of nodes. The model will consist of a single queue for each CM and two additional queues: one to reflect the behavior of the reservation channel and one to capture the activity on the contention channel. The CM queues will be FIFO queues with independent Markovian input streams that hold different types of customers, while the reservation and contention queues are processor sharing (PS) queues. Blocking occurs as there can be at most one customer in either the reservation or contention queue that originated from the same CM. To solve this queueing network, a decomposition technique splits the network into two subsystems: the first being a BCMP network with a finite number of customers and multiple customer types [2], the second an MMAP[C]/M[C]/1 queue [3]. By repeatedly solving these two subsystems, while exchanging a number of system parameters until convergence occurs, we capture the interaction between the two subsystems. The work presented in this paper is in the same spirit as [4] which was limited to the special case of Poisson arrival streams at the CM, this greatly simplified the decomposition technique as both subsystems were much easier to solve and the exchange of only a single parameter was needed.

An overview of earlier work on DOCSIS and the performance evaluation of DOCSIS networks can be found in [5] and the references therein. This prior work typically relied on simulations, whereas we propose an analytical method to determine the performance of a DOCSIS CM network.

Due to the strong similarity between 802.16 and DOCSIS, it seems quite probable that the techniques, described in this paper and used to asses the performance of a DOCSIS CM network, can be adapt for 802.16 networks.

The paper is structured as follows. Section 2 presents a general description of the cable network considered. The contention resolution algorithm (CRA) specified by the DOCSIS standard is discussed in Section 3. Section 4 provides some general information about the Markovian arrival process with marked customers, which is the arrival process used in this paper. The queueing network model together with the decomposition techniques used to assess its performance is introduced in Section 5, whereas Section 6 validates this model. Finally, we numerically explore the influence of several system parameters in Section 7. We end this paper with some conclusions in Section 8.

2. The DOCSIS cable network

The DOCSIS CM network considered in this paper is shown in Fig. 1 and consists of a single cable modem termination system (CMTS), located in the head-end of a cable operator or service provider and a number of CMs that are installed at the end-users. At initialization time each CM registers itself with the CMTS and at least two service flows are created for each CM: one in the downstream and one in the upstream direction. Since the head-end is the only transmitter in the downstream channel, no downstream MAC mechanism is needed. The upstream channel, on the other hand, is shared by all CMs and transports signals from the CMs to the head-end. The available bandwidth is divided into fixed length allocation units, called minislots, and the DOCSIS specify a reservation-based, centralized approach for distributing these minislots among the CMs.

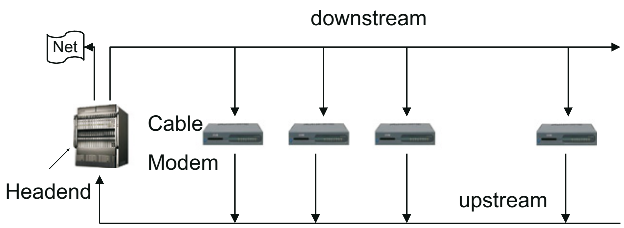

Fig. 1. Logical topology of a cable modem network.