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Performance analysis for voice and data integration in hybrid fiber/coax networks

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Abstract

This paper examines the performance for the integrated voice and data services in hybrid fiber/coax (HFC) networks through mathematical analysis. Our objective is to obtain the feasible region (FR) for the integrated services subjected to their packet level quality-of-service (QoS) requirements. The analysis is focused on the upstream channel and the performance of the system is evaluated in terms of voice packet loss probability and the mean data message delay. Two different service classes are provided for voice. The voice packet loss probability is independent of data traffic and an elaborate discrete-time Markov chain model is developed. The data traffic is modeled as a batch Poisson arrival model. Two schemes are considered for data: with or without bandwidth reservation. The integrated voice and data systems are analyzed using the matrix-analytic method. Numerical examples are presented to demonstrate the performance of such a proposed integrated voice and data system. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Hybrid fiber/coax; Upstream transmission; Feasible region; Discrete-time Markov chain; Matrix-analytic method

1. Introduction

Within the last few years, there has been large interest in hybrid fiber/coax (HFC) networks due to their large excess bandwidth and high penetration to the home. It is widely believed that the HFC network will play an important role in introducing integrated services into the home. An HFC network is characterized as a tree-and-branch topology, with the head–end (H/E) as a central controller and the stations distributed at different distances away from the H/E. The entire frequency spectrum is divided into channels for information or video delivery. An upstream channel (from the stations to the H/E) generally has a programmable bandwidth and occupies the band from 5 to 42 MHz. A downstream channel (from the H/E to the stations) occupies the higher frequency band having a bandwidth of either 6 or 8 MHz. Currently, two working groups, the IEEE 802.14 and the Multimedia Cable Network System (MCNS) are developing the specifications of media

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access control (MAC) protocols for HFC networks [10,17]. Their work and most of the research work in the literature focuses on the design and performance evaluation of the MAC protocols, see [8,11,14,15] for some examples. Generally, these efforts focus on supporting data traffic and only best effort service is considered. However, in the near future, the applications supported by HFC networks are expected to have various traffic characteristics and quality-of-service (QoS) requirements. In order to provide different levels of QoS guarantees to these applications while achieving high network utilization, HFC networks must control and manage both the upstream and the downstream bandwidth efficiently. To our best knowledge, only a few works intending to solve this problem have been reported [3,22], and both working groups are likely to leave the QoS provision issues to be defined by the individual vendors.

Generally, applications are categorized into realtime (voice and video) and non-realtime (data) traffic. Although QoS performance metrics used may vary from one application to another, they can be generally classified into packet level and connection level QoS. Packet level QoS is measured using packet loss ratio, packet delay and packet delay variation, while connection level QoS is measured using the call blocking probability. In a practical system, scheduling algorithms and connection admission control (CAC) algorithms are used to control the congestion at the packet level and the connection level, respectively. Scheduling aims to satisfy the packet level QoS requirements for all connections by controlling the service order of each packet, while CAC tries to maximize the network utilization subject to the connection level QoS requirements by controlling the acceptance or rejection of new connections during connection setup. In order to make CAC work independently from the scheduling algorithm used, the concept of feasible region (FR) is used [1,9]. FR is the set of connection configurations (the number of connections of each class) for which the packet level QoS requirements of all the connections are satisfied and can be used as the concise information needed by the H/E to perform CAC at the connection level.

In this paper, we investigate the performance of integrated voice and data services in HFC networks. As shown in Fig. 1, we consider a logical MAC network consisting of a collection of downstream channels, associated upstream channels, and a H/E controller. Each downstream channel is a broadcast channel, while each upstream channel is a multiple access shared medium. The H/E controller is responsible for the bandwidth allocation of both the upstream and downstream channels. Although there can be multiple upstream and downstream channels in a logical MAC network, we assume that a pair of upstream and downstream channel is used to provide voice telephony. The unused bandwidths left by the voice are used for data transmission. Generally, voice telephony requires equal bandwidths in both directions. Since the upstream data is transmitting over a hostile noisy environment, low spectral efficiency modulation technique is used and hence bandwidths available for transmission are relatively scarce compared to the downstream channel. Therefore, the QoS in the upstream direction is generally more critical and our analysis will focus on upstream channel.

Generally, voice traffic which requires timely delivery of packets, normally has stringent bandwidth and delay requirements, but they can tolerate a small amount of packet loss. On the other hand, data traffic has much looser delay requirements but generally cannot tolerate any packet loss. Therefore, we assume that those voice packets which experience a delay larger than a prespecified value are discarded in this paper and the packet loss probability is the main QoS metric considered for voice. For data traffic, mean message delay is examined.

We consider three service classes. In class 1, voices without speech activity detectors (SAD) are

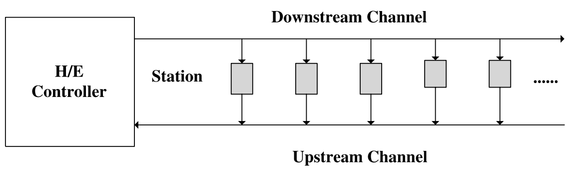

Fig. 1. The logical MAC network.