An Integrated Bandwidth Adaptation Scheme for Multimedia Wireless Networks and its Connection-Level Performance Analysis

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Abstract— **This paper presents an integrated bandwidth adaptation scheme for multimedia wireless networks using application utility functions. With the proposed scheme, each call in the network is assigned a utility function according to its adaptive characteristics. Depending on the network load the allocated bandwidth of ongoing calls are upgraded or degraded dynamically so that the achieved utility of the network is maximized. Appropriate call admission control and bandwidth reservation policies are also incorporated into the scheme to provide QoS guarantees to the new and handoff calls, respectively. Extensive simulation experiments have been conducted to evaluate the connection-level performance of the proposed scheme. Results show that our bandwidth adaptation scheme is effective in both increasing the utility and bandwidth utilization of wireless networks while keeping the call blocking and handoff dropping probabilities substantially low.**

Index Terms: **bandwidth adaptation, connection-level performance, multimedia wireless networks, QoS, utility function.**

I. Introduction

In recent years, there has been an explosive demand for multi-class traffic (voice, video, and data), especially bandwidth-intensive multimedia traffic in wireless networks. Different classes of traffic over networks require various amounts of bandwidth and it is important to provide QoS guarantees to the multi-class traffic according to their bandwidth needs. QoS provisioning has been extensively studied for wireline networks; however, due to the diverse application QoS requirements and the scarcity of wireless link bandwidth, the QoS issues in wireless networks are much more challenging than their wired counterpart. Thus efficient resource management becomes a key factor in enhancing the system performance of wireless networks.

Bandwidth adaptation is one of the most promising methods to provide QoS guarantees in wireless networks. In the traditional non-adaptive network environment, once a call is admitted its allocated bandwidth is fixed throughout its lifetime; when a new or handoff call requests a certain amount of bandwidth, the network rejects the call if there is no sufficient bandwidth available. However with adaptive bandwidth allocation, when a new or handoff call arrives to a congested network the allocated bandwidth of ongoing calls can be degraded to smaller values to accept the new or handoff call; thereby reducing call blocking and handoff dropping probabilities. On the other hand, when an ongoing call is terminated due to its completion or outgoing handoff, the released bandwidth can be used to increase the network bandwidth utilization by upgrading other ongoing calls which have not received their maximum bandwidth requirements.

A. Related Work

The concept of bandwidth adaptation was originally introduced in wired networks to overcome the problem of network congestion. More recently, some adaptive bandwidth management and QoS provisioning schemes for wireless networks have been reported in the literature [1, 3 – 6, 8 – 10]. Oliveira et al. [9] propose an admission control scheme based on adaptive bandwidth reservation to provide QoS guarantees for multimedia traffic in high-speed wireless cellular networks. The proposed scheme allocates bandwidth to a call in the cell where there is a new or handoff request and reserves bandwidth dynamically in all neighbouring cells according to the network conditions. Bandwidth reservation in all neighbouring cells guarantees QoS; however, it often results in underutilization of resources as the mobile user hands off to only one of the cells. Moreover the allocated bandwidth of the call is fixed during the stay in a cell and it can be changed only at a handoff. In the work of El-Kadi et al. [5], an effective rate-based borrowing scheme (RBBS) is provided for multimedia wireless networks. In the case of insufficient bandwidth, in order not to deny service to requesting calls, bandwidth can be borrowed on a temporary basis from existing calls to accept the new or handoff call. Although the scheme is adaptive, it does not include a quantitative measure (e.g. QoS satisfaction or revenue curve) to reflect the importance of different calls. In [1], Bharghavan et al. present the TIMELY adaptive resource management architecture and algorithms for resource reservation and

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adaptation in mobile computing environments. The architecture has four layers – link, reservation, adaptation and transport – all of which perform resource adaptation in a coordinated manner to solve the problems introduced by scarce and dynamic network resources. A revenue model for resource usage is introduced and a weighted version of the max-min fair rate adaptation algorithm is proposed to distribute resources among the adaptable flows in order to maximize revenue increase. However, the multi-layer feature has made the bandwidth adaptation work at the expense of high message overhead. Curescu et al. [4] introduces a utility-maximization bandwidth allocation scheme. Interestingly, the scheme takes into account the age of the connections to reflect the sensitivity of the connections to the bandwidth re-allocation by assuming that the duration of every connection can be estimated. However, the feasibility of estimating connection duration is doubtful in real-time wireless network environments since the connection duration is updated dynamically with bandwidth re-allocation. Another bandwidth adaptation scheme using quantitative QoS measure can be found in [10]. A revenue-based model is used to describe the bandwidth degradation process for both real-time and non-real-time traffic and an effective algorithm has been proposed to maximize the total network revenue. The scheme gives handoff calls higher priorities over new calls to provide them QoS guarantees. However, it does not reserve bandwidth for real-time handoff calls thus it risks an inability of meeting their QoS requirements when the network is heavily overloaded since real-time connections are sensitive to delays and the lack of bandwidth during handoff can cause them to be dropped.

B. Our Contributions

In this paper, we present an integrated bandwidth adaptation scheme for multimedia wireless networks using application utility functions. The objective of our scheme is to strike the balance among multiple connection-level QoS requirements of multimedia wireless networks under the constraints of limited and varying bandwidth resources. Within the proposed scheme, a call admission control policy is provided for the new calls, a bandwidth adaptation algorithm is proposed for the connected calls to maximize the network utility, and a bandwidth reservation mechanism is applied for real-time handoff calls to prevent them from being dropped.

Moreover, even though the revenue/utility function has been applied for the bandwidth allocation problems in [1, 3, 4, 6, 8, 10], none of these schemes provide explicit formulation of utility functions to capture the adaptive nature of the application. For example, reference [10] adopts the Sigmoid functions, reference [6] uses the linear and convex functions and reference [4] assigns utility functions using subjective values from the authors' experiments. This paper classifies the traffic into different classes and formulates the utility function for each traffic class according to their adaptive characteristics.

The rest of the paper is organized as follows. Section II describes the utility-based adaptive traffic model including the concept of utility function and the characteristics of the traffic classes used in our study. In Section III we give a detailed description and formulation of the bandwidth adaptation problem and propose a utility-maximization bandwidth adaptation algorithm. Section IV introduces the new call admission and handoff call management mechanisms. The simulation model and numerical results are presented in Section V. Finally Section VI gives the concluding remarks.

II. Utility-Based Adaptive Traffic Modeling

A. The Concept of Utility Function

Utility was originally used in economics and has been brought into networking research in recent years [3, 4, 8, 11, 12]. It represents the "level of satisfaction" of a user or the performance of an application. A utility function here is a curve mapping bandwidth received by the application to its performance as perceived by the user. It is monotonically non-decreasing; in other words, more bandwidth allocation should not lead to degraded application performance. The key advantage of the utility function is that it can inherently reflect the user's QoS requirements and quantify the adaptability of the application. The shape of the utility function varies according to the adaptive characteristics of the application.

B. Traffic Classes and Their Utility Functions

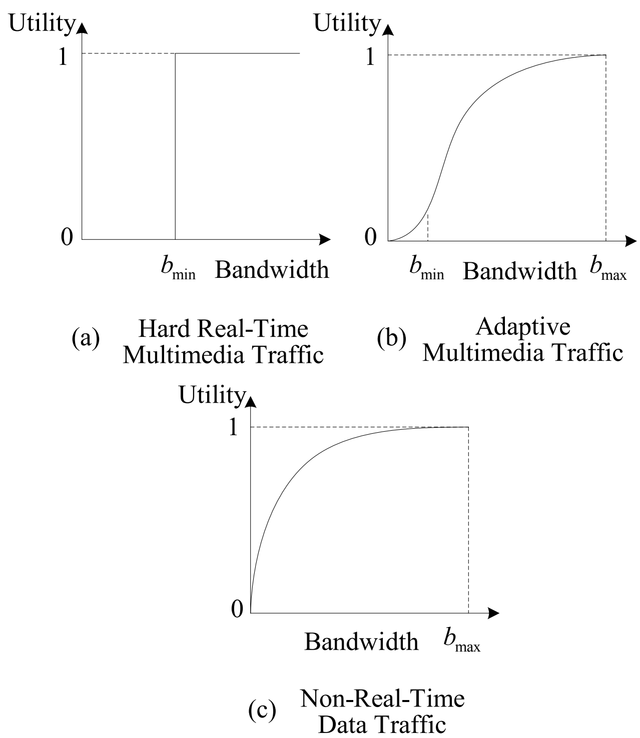

Fig. 1. Multi-class traffic utility functions

In this paper, the traffic offered to the network is assumed to belong to two classes:

- Class I – real-time multimedia traffic, and
- Class II – non-real-time data traffic.