Chapter II
Cross-Layer Resource Allocation and Scheduling for Wireless Systems

Dimitris Toumpakaris
University of Patras, Greece

Jungwon Lee
Marvell Semiconductor Inc., USA

ABSTRACT

This chapter presents an introduction to cross-layer scheduling and resource allocation for wireless systems and an overview of some of the approaches and proposed algorithms. The use of scheduling is motivated by first considering the fading Gaussian channel. Then, the focus shifts to scheduling and resource allocation for cellular systems. Existing approaches for the uplink and the downlink are discussed, as well as research results relating to the fading Multiple Access and the fading Broadcast Channel. Schemes for OFDMA and CDMA systems as well as systems using multiple antenna transmission are also presented. It is hoped that this survey will affirm the improvement in performance that can be achieved by use of cross-layer approaches in the design of Next-Generation Networks.

INTRODUCTION

Next-Generation Networks will be expected to deliver high data rates to a large number of different users in diverse environments. Moreover, they should be able to accommodate different user needs in terms of Quality of Service (QoS) and, in the same time, guarantee fairness. As the networks expand, energy efficiency will also be required, especially for wireless systems where battery life and radiation levels are major concerns. In order to meet successfully these demands, improved and new system designs are being developed. The designs encompass all system aspects, from smaller, faster and more energy-efficient circuits to sophisticated applications allowing seamless user connectivity and mobility.

Traditionally, system design has been greatly facilitated by following a layered approach where each layer of the network is designed and optimized separately. As an example, the link layer can be optimized by viewing the physical layer as a bit pipe with given capacity and bit-error rate. Historically, systems have greatly benefited from this level of abstraction. However, this view is suboptimal. In order for future networks to achieve the required performance gains and exploit the available resources to the fullest possible extent, more than one layer should be considered jointly when designing the system and when making scheduling and resource allocation decisions. In many cases the attained performance gains (and the associated financial revenue) may justify the increased complexity in the system design and implementation.

This survey focuses on cross-layer resource allocation and scheduling policies for cellular wireless systems. As will be described in the following, these policies consider not only the channel condition (state), but also some utility function that depends, in general, on QoS and fairness criteria. Moreover, because user traffic appears randomly, in order to guarantee stability and increase the achievable rates, the number of bits (or packets) waiting for transmission in the user or node queues often needs to be taken into account. Unlike earlier approaches, the physical layer does not decide on the rate and the modulation scheme independently. Rather, a cross-layer controller schedules users that are allowed to transmit during a given interval and allocates the usage of the resources of the channel at the physical layer based on the traffic needs of higher layers. In general, the controller also implements scheduling, allocation and routing policies at higher layers. However, the focus of this survey is on joint physical and link/network layer adaptation.

Several reviews on cross-layer resource allocation and scheduling have appeared recently, an evidence of the increased research interest in the area. In (Lin, Shroff & Srikant, 2006) a survey of policies for both single-hop and multiple-hop networks is given. For single-hop networks it is assumed that only one user can transmit (or receive) at any given time. While this is generally true in systems using time division and the model can also apply to frequency and code division with appropriate changes, from an information-theoretic point of view it may be optimal to transmit to more than one user simultaneously. In (Berry & Yeh, 2004) the authors focus on techniques for fading multiple access (MAC) and fading broadcast (BC) channels and examine policies that allocate a vector of powers and rates to more than one users, in general. Finally, (Chiang et al., 2007) reviews the current status of the "layering as optimization decomposition" effort to develop a mathematical framework for future networks where an appropriate vertical layer topology is first defined, and each layer is then optimized horizontally.

The aim of the present survey is to provide the reasons and the motivation for the use of cross-layer techniques in Next-Generation Networks, and to give a brief overview of some interesting results that have been obtained from the current research in the area. Therefore, for the details on each particular scenario and policy, the reader is encouraged to consult the references that are provided at the end of this chapter. First, it is explained why the particular nature of the wireless channel creates a need for cross-layer policies if one wants to exploit efficiently the available resources. Cross-layer scheduling is first motivated using the fading Gaussian channel paradigm where the tradeoff between the transmit energy and the packet delay is discussed. Next, a summary of the cross-layer framework and major results for multiple user channels is given assuming orthogonal multiplexing. A transition is then made to the more general case where users are allowed to transmit simultaneously in the uplink and the Base Station is allowed to transmit simultaneously to more than one user in the downlink. The survey concludes with a review of some cross-layer policies for OFDMA and CDMA, as well as a brief discussion on cross-layer scheduling and resource allocation for multiple antenna systems. It should be mentioned that this chapter focuses exclusively on single-hop cellular networks and does not deal with the very interesting problem of cross-layer design for multi-hop networks and the associated issues (such as joint congestion control and routing).

CROSS-LAYER SCHEDULING AND RESOURCE ALLOCATION: A NECESSITY AND AN OPPORTUNITY FOR FUTURE WIRELESS SYSTEMS.

Although wireless systems share many common characteristics and are based on the same principles as other communications systems (such as wire-line, optical, and magnetic) their special nature also calls for modified and/or new design approaches. One important characteristic of wireless systems is their *variability*. This refers to the varying channel in a system where the transmitter and the receiver are fixed (e.g. a WiFi connection where