Chapter 17

Cross-Layer Design, Analysis, and Optimization of QoS-Constrained AMC/ARQ-Based Wireless Networks

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ABSTRACT

In order to provide heterogeneous quality of service guarantees to applications, most wireless communications standards combine the error-correcting capability of (hybrid) automatic repeat request protocols at the data link control layer with the adjustment ability of adaptive modulation and coding strategies at the physical layer. In this chapter, a cross-layer multidimensional discrete-time Markov chain based queuing model is developed to jointly exploit the capabilities of (hybrid) automatic repeat request protocols and adaptive modulation and coding. Based on the stationary state probability distribution of this multidimensional discrete-time Markov chain, closed-form analytical expressions for performance metrics such as throughput, average packet delay, and packet loss rate are derived. Furthermore, the proposed analytical framework is used to formulate multidimensional and simplified two-dimensional constrained cross-layer optimization problems aiming at maximizing the system throughput under prescribed quality of service constraints.

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INTRODUCTION

Context

In the last decade, an explosive development of wireless services and applications has taken place fuelled by the users’ ever-increasing demands in terms of throughput and mobility. In such networks, the time and frequency selective nature of wireless fading channels poses a great challenge when designing solutions to support the Quality of Service (QoS) requirements, such as packet error rate and delay deadlines, for current and envisaged heterogeneous mobile applications.

In order to counteract the impact of wireless fading on the performance of the system, many transmission and reception strategies have been developed to improve the spectral and/or power efficiency of the Physical (PHY) layer. Among them, Adaptive Modulation and Coding (AMC) schemes have been intensely researched resulting in their adoption in most state-of-the-art wireless communications standards.

To guarantee the QoS constraints of new applications, powerful schemes to sustain or enhance link reliability are required. To that end, the use of error control strategies at the Data Link Control (DLC) layer, also called Medium Access Control (MAC) layer, has become an integral part in the design of modern communication systems. There are two categories of techniques for controlling transmission errors: the Forward Error Correction (FEC) scheme and the Automatic Repeat Request (ARQ) scheme. In an FEC system, an error-correction code is used. When a received codeword is detected in error and the number of errors is within the designed error-correcting capabilities of the code, the errors are corrected. In an ARQ system, a code with good error-detection capability is used. If a codeword is erroneously received, the transmitter is instructed, through the return channel, to retransmit the same codeword. In order to achieve the advantages of both strategies, most state-of-the-art wireless communications standards use combinations of ARQ and FEC.

Following the spirit of cross-layer design, in contrast to a local optimization of each of the layers, a joint optimization of different layers has been widely considered in order to improve the whole system performance. In this case, parameters and algorithms of different layers are jointly considered. For example, when the queuing model is taken into account, the throughput at the MAC layer is lower than that achieved at the PHY layer. The reasons for this loss are the buffer overflow due to finite-length queues, which may cause the drop of arriving packets, and the absence of packets waiting for transmission even if the channel is in good quality. Many recent cross-layer proposals coincide in combining AMC at the PHY layer with an ARQ protocol at the DLC layer, taking into consideration the queuing effects induced by both processes.

Adaptive Modulation and Coding

Adaptive modulation is a method to improve the spectral efficiency of a radio link for a given maximum required quality (error probability) by adapting the modulation and coding to the channel conditions (see, e.g., Svensson, 2007 and references therein). Since all practical wireless channels perturb the transmitted waveforms, the detection process is never free from errors thus making mandatory the use of error correction/detection techniques. Depending on the severity of the fading, different degrees of information protection are required. The basic premise is to estimate the channel at the receiver and feed this estimate back to the transmitter, so that the transmission scheme can be adapted relative to the channel characteristics. Modulation and coding techniques that do not adapt to fading conditions require a fixed link margin to maintain acceptable performance when the channel quality is poor. Thus, these systems are effectively designed for the worst-case channel conditions. Consequently,