Chapter 8
Energy-Efficient Power Allocation for HARQ Systems

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ABSTRACT

Reliability of data transmission is a fundamental problem in wireless communications. Fading in wireless channels causes the signal strength to vary at the receiver and this results in loss of data packets. To improve the reliability, automatic repeat request (ARQ) schemes were introduced. However these ARQ schemes suffer from a reduction in the throughput. To address the throughput reduction, conventional ARQ schemes were combined with forward error correction (FEC) schemes to develop hybrid-ARQ (HARQ) schemes. For improving the reliability of data transmission, HARQ schemes are included in the wireless standards like LTE, LTE-Advanced and WiMAX. Conventional HARQ systems use the same transmission power in different ARQ rounds. However this is not optimal in terms of minimizing the average energy spent for successful transmission of a data packet. In this book chapter, the recent research results related to HARQ systems are reviewed first. Next, optimal resource allocation in HARQ systems with a limit on the maximum number of allowed transmissions for a data packet is considered in the next part. Specifically, the problem of minimizing the rate-outage probability under a constraint on average energy consumption per data packet for both incremental redundancy (IR)-based and Chase combining (CC)-based HARQ systems is considered. Towards solving the optimization problems, the expressions for rate-outage probability of both IR-HARQ and CC-HARQ systems in i.i.d. Rayleigh fading channels is provided. Methods to solve the optimization problems using nonlinear optimization techniques are discussed. To reduce the complexity of finding a solution, the rate-outage probability expressions are approximated, using which, the non-convex optimization problems are converted into geometric programming problems (GPPs), for which the closed-form solutions are derived. Illustrative and analytical results show that the proposed power allocation provides significant gains in energy savings over the traditional equal power allocation transmission, and the closed-form GPP solution can provide a performance close to that of the exact method for smaller values of rate-outage probability.

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INTRODUCTION

There is a rapid increase in the number of devices communicating using different wireless technologies. It is predicted that there will be about 50 billion connected devices by the year 2020. To support this rapid growth, ideally more radio resources are needed. However, the radio resources like frequency spectrum and transmit power available for wireless communication are limited like any other natural resource. Hence it is becoming increasingly important to efficiently utilize the available radio resources. Another important aspect of communication over wireless networks is the reliability of the data. Often, reliability over wireless networks is affected by fading, which causes the signal strength to vary at the receiver and this results in a loss of data packets.

One way to overcome the reliability problem in wireless systems is by employing adaptive transmission techniques. These techniques will also be a fundamental feature for future generation wireless systems. An important factor in facilitating the adaptive transmission schemes is the channel state information (CSI) feedback from the receiver to the transmitter. In the presence of CSI at the transmitter, a common adaptive transmission technique used at the physical layer is dynamic link adaptation. In link adaptation, the transmitter dynamically adapts the modulation order, coding rate and/or other signal transmission parameters (Goldsmith, 2007; Goldsmith, & Chua, 1998). Commonly used link adaptation strategy in practical wireless systems is adaptive modulation and coding (AMC). The basic idea of AMC is to exploit the good channel conditions by transmitting with higher order modulation and coding scheme (MCS), and if the channel quality degrades, the transmitter switches to a lower MCS level to maintain a fixed target error probability. By selecting the best MCS level for a given channel quality, the link adaptation results in higher average throughput performance compared to the non-adaptive systems (Catreux, Erceg, Gesbert, & Heath, 2002). However the errors in the channel estimation, quantization of channel state information, and non-ideal feedback channel lead to degradation in performance even in the presence of link adaptation. To further improve the robustness of the wireless systems against the link adaptation inaccuracies, hybrid automatic repeat request (HARQ) schemes are adopted at the medium access control (MAC) layer in systems like LTE and LTE-advanced (Dalhman, Parkvall, & Sköld, 2011). Moreover, for the emerging small-cell systems, HARQ schemes can be seen as a fast retransmission mechanism to improve reliability without causing significant delays.

In HARQ schemes, forward-error correction (FEC) schemes are combined with automatic repeat request (ARQ) schemes (Lin, & Costello, 2004). If a data packet is received in error, the transmitter re-sends the information about the erroneous packet to the receiver. Upon receiving additional information about the erroneous packet, the receiver makes another try to decode the erroneous packet, and it may or may not combine the information received across different transmissions of the same data packet. HARQ systems use acknowledgment (ACK) and negative acknowledgment (NACK) signal feedback to determine whether retransmission of a data packet is required or not. Although retransmission schemes consume additional radio resources in terms of channel uses and transmission power, they are necessary to improve the transmission reliability in fading channels. There are many different HARQ schemes proposed in the literature, and they are mainly classified into two types (Lin, Costello, & Miller, 1984). In type-I HARQ schemes, the receiver does not combine the information across different (re)transmissions. By way of contrast, in type-II HARQ schemes, the receiver combines the information from different (re)transmissions to decode the packet. These type-II HARQ schemes are further classified into:

Chase Combining (CC) Schemes: These are type-II HARQ schemes in which all the retrans-

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