Chapter XVIII
Cross-Layer Performance of Scheduling and Power Control Schemes in Space-Time Block Coded Downlink Packet Systems

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ABSTRACT

In this chapter, we consider a cellular downlink packet data system employing the space-time block coded (STBC) multiple-input-multiple-output (MIMO) scheme. Taking the CDMA high data rate (HDR) system for example, we evaluate the cross-layer performance of typical scheduling algorithms and a point-to-point power control scheme over a time division multiplexing (TDM)-based shared MIMO channel. Our evaluation focuses on the role of those schemes in multi-user diversity gain, and their impacts on medium access control (MAC) and physical layer performance metrics for delay-tolerant data services, such as throughput, fairness, and bit or frame error rate. The cross-layer evaluation shows that the multi-user diversity gain, which comes from opportunistic scheduling schemes exploiting independent channel oscillations among multiple users, can increase the aggregate throughput and reduce the transmission error rate. It also shows that STBC/MIMO and one-bit and multi-bit power control can indeed help the physical and MAC layer performance but only at a risk of limiting the multiuser diversity gain or the potential throughput of schedulers for delay-tolerant bursty data services.

INTRODUCTION

Very high rate physical-layer transmission and scheduling schemes have recently drawn significant attentions for the design of the next-generation wireless cellular system. The downlink transmission and throughput are in particular considered to be a primary bottleneck in the current system design. In anticipation of the high demand for wireless data service, two solutions of downlink data systems come out by utilizing existing CDMA systems for high rate data transmission. Both support high-rate packet data services on a shared channel. One of them is High Data Rate (HDR) system which is based on the techniques of cdma2000 (3GPP2, 2002), while the other is High Speed Data Packet Access (HSDPA) which is based on the WCDMA systems (3GPP, 2001). In these two standards, multiple active data users access the downlink channel in a time-division multiple accessing (TDMA) manner with certain scheduling scheme (Bender, 2000). Based on the channel state information (CSI), the scheduler at the base station (BS) selects a user to transmit according to certain scheduling criterion that should use transmission capacity efficiently to achieve high throughput. In this chapter, we take multiple-input-multiple-output (MIMO) HDR systems for an example, but our study applies to MIMO HSDPA systems as well.

MIMO techniques have been studied extensively in the recent past. Various MIMO schemes could be distinguished by different design goals (Alamouti, 1998; Foschini, 1996; Telatar, 1999). Among them the orthogonal space-time block coding (STBC) aiming at full transmitter-diversity was recently adopted for implementation as one of the transmit diversity modes of 3G wireless networks. The STBC schemes, originally proposed by Alamouti (1998) and Tarokh et al. (1999), introduce a simple and elegant mechanism with spatial or antenna diversity that improves the spectral efficiency over wireless channels. In this chapter, the STBC/MIMO systems are considered to support delay-tolerant bursty data services over a TDM-based downlink shared channel.

Focusing on MAC-layer throughput and fairness, we consider several typical scheduling algorithms for the delay-tolerant data services. Among them, the ``greedy'' or maximum carrier-to-interference ratio (Max-C/I) scheduling (Knopp and Humblet, 1995) routes each transmission time slot to the user with the best instantaneous channel conditions. This scheduling scheme explores independent channel dynamics of multiple users, the so called ``multiuser diversity'' (Viswanath et al., 2002). Another scheduling algorithm, the Proportional Fair (PF) scheduling (Jalali et al., 2000), balances between instantaneous channel status and long-term throughput performance of different users, i.e., it balances between the transmission rate and the fairness among users. The third scheduling scheme we consider is the Round-Robin (RR) that picks the user for transmission purely randomly. Note that the HDR systems has 11 channel states, which thus renders invalid the following scheduling schemes: Wireless Fluid Fair Queueing (WFFQ) and its packet-level approximation Idealized Wireless Fair Queueing (IWFQ) (Lu et al., 1999), and Channel-condition Independent Packet Fair Queueing (CIF-Q) (Ng et al., 1998), both are variants of wired scheduling schemes based on the over-simplified On-Off channel model. We refer readers to the references (Fattah and Leung, 2002; Cao and Li, 2001) for further information.

Our study shows that the performance of the three scheduling algorithms over STBC/MIMO differs significantly in throughput and multiuser diversity gain, while the STBC/MIMO channel may have inherent statistical limitations to support high-rate data services. This reveals that the global spectral efficiency in a single cellular data system depends on efficient cross-layer collaborations or an integral design of transmission and scheduling algorithms.

To see the above point more clearly, we also study a simple power control scheme given multi-fold multi-user diversity by channel-dependent scheduling schemes. Given the feedback knowledge of channel statistics and diversity gain, we derive the 1-bit and multi-bit power control scheme to minimize the frame/bit error rate (FER/BER). A numerical approach is given to obtain the optimal power level. We compare performance with and without the power control scheme in the CDMA/HDR STBC/MIMO systems. The results shows that although the power control scheme provides certain FER gain at the physical layer, it degrades the multiuser diversity gain at the scheduling layer. Therefore, its application in STBC/MIMO systems has dual impacts that may offset each other. Again we see the necessity of a cross-layer design and evaluation in designing such systems.

SYSTEM DESCRIPTIONS

We consider a downlink high-speed data service system with space-time block coding using n_T transmit antennas and n_R receive antennas, as shown in Fig. 1. The channel is time slotted. Infinite data from different users are buffered and will be selected by the scheduler. The output data bits are QPSK modulated, then time multiplexed with pilot signal. The data sequences are then STBC coded and transmitted. At the receiver, the signals are received from n_R receive antennas. After matched filtering and symbol-rate sampling, the received discrete-time signal at the kth terminal is modeled by

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