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THROUGHPUT OPTIMIZATION FOR MIMO SYSTEMS BASED ON CROSS-LAYER DESIGN

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ABSTRACT

Based on cross-layer design, an optimization method was proposed, which combined the adaptive modulation and coding with symbol rate at the physical layer, and the packet size and sub-packet number at the data link layer. The parameters were jointly optimized to maximize the MIMO system throughput in the Rayleigh fading channel. Numerical results reveal that the optimization method can be adapted to the time-varying wireless channel and greatly improve the throughput compared with separate layer design. Besides, under prescribed error performance constraint, the larger the maximum number of transmissions, the higher the throughput. A small number of transmissions can offer a desirable delay-throughput tradeoff in practice.

Keywords: *Cross-Layer Design, MIMO System, Throughput Optimization, Adaptive Technique*

1. INTRODUCTION

Wireless communications using multiple-input-multiple-output (MIMO) have recently emerged as one of the most important technologies. A key feature in MIMO systems is the ability to increase the data rates [1]. Adaptive modulation and coding (AMC) technology [2] chooses the best modulation and coding mode at the physical layer according to the current channel conditions. Automatic repeat request (ARQ) is a technology that the receiver requests the sender to retransmit the error packet. The traditional ARQ transmits fixed-length packets and the efficiency is low. Reference [3] proposed an adaptive packet size transmission algorithm. Reference [4] proposed a sub-packet transmission mechanism. Cross-layer design [5] is an advanced technology in the wireless communications field. The parameters in different layers are jointly combined to achieve optimal resource utilization of the system. References [6-13] have studied the cross-layer design in different fields, such as WiMax, cooperative relay networks, cognitive radio networks and so on. In this paper, we have proposed a cross-layer design using AMC and ARQ to maximize the MIMO system throughput. The rest of this paper is organized as follows. In section 2, the system model of cross-layer design for MIMO systems is described. In section 3, different parameters optimizations are presented. Then we analyze the performance of the systems and present numeric results in section 4. Finally, we draw conclusions in section 5.

2. SYSTEM MODEL

Consider a MIMO system with 2 transmitting and 2 receiving antennas. Two consecutive symbols are divided into a group, expressed as $[x_1, x_2]$. In the first interval, antenna 1 transmits the symbol x_1 and antenna 2 transmits the symbol x_2. In the second interval, antenna 1 transmits the $-x_2^*$ and antenna 2 transmits the x_1^*. Here x_1^* is the complex conjugate of x_1. The channel matrix is $H=(h_{ij})_{2\times2}$. h_{ij} is the channel coefficient between the j-th transmitting antenna and the i-th receiving antenna and it can be modeled as complex circular Gaussian random variable. $E(|h_{ij}|^2)=1$. The received signal-to-noise (SNR) of sub-channel is given by [1]

$$SNR'=\frac{1}{2}(|h_{11}|^2+|h_{12}|^2 + |h_{21}|^2+|h_{22}|^2)SNR \quad (1)$$

Figure 1 shows the system model of cross-layer design for MIMO systems. Each information block at the link layer contains L bits. After been segmented, it is divided into N sub-blocks, each contains k bits. Then every sub-block is added by L_H-bit headers and L_{CRC}-bit cyclic redundancy check (CRC). All sub-packets are then time-multiplexed into a whole packet with length L_{CB}.

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After modulated and coded with mode of b bits/symbol, the packet is mapped to a symbol-block containing L_S symbols and sent by the antennas. The receiver decodes the symbol-block. If no error is found by the CRC, an ACK packet is returned and the sender will begin a new packet transmission. Otherwise, a NACK packet is replied and the wrong sub-packet will be retransmitted.

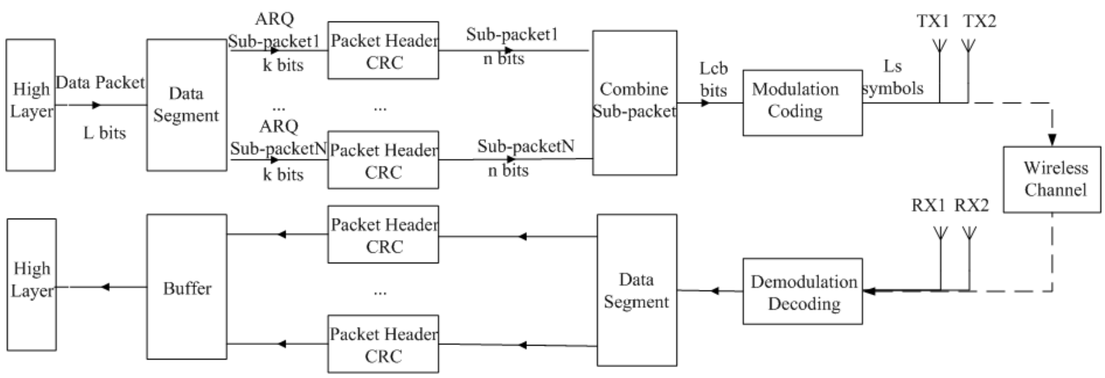

Figure 1 System model of cross-layer design for MIMO systems

3. PARAMETERS OPTIMIZATION

The throughput can be defined as the number of payload bits received correctly per second.

$$T = \frac{L_{CB} - N \times (L_H + L_{CRC})}{L_{CB}} \cdot bR_S(1 - P_{SP}) \quad (2)$$

Here, R_S is the symbol rate and P_{SP} is the sub-packet error rate. P_{SP} is given by [4]

$$P_{SP} \approx \frac{P_P}{N} . \quad (3)$$

Here, P_P is the frame error rate, which is the packet error rate when the sub-packet number is 1.

$$P_P = 1 - [1 - P_E(b, \gamma_S)]^{L_{CB}/b} . \quad (4)$$

P_E is the symbol error rate. The P_E of Multiple Quadrature Amplitude Modulation (MQAM) in a Rayleigh channel is given by [14]

$$P_E(b, \gamma_S) = 2(1 - 2^{-b/2}) \left(1 - \sqrt{\frac{3\gamma_S}{2(2^b - 1) + 3\gamma_S}}\right) . \quad (5)$$

$$\gamma_S = \frac{P_R}{N_O R_S} . \quad (6)$$

Here, P_R is the received power and N_O is the one-sided noise power spectral density.

$$SNR = \frac{P_R}{N_O W} . \quad (7)$$

Here, SNR is the received signal-to-noise ratio and W is the transmission bandwidth.

3.1 Optimization Of Modulation Mode At The Physical Layer

To simplify the analysis, we first assume b to take continuous values. We differentiate Eq. 2 with respect to b, set the resulting expression to zero and solve it to obtain the optimal b^*

$$P_{SP} + b^* \frac{\partial P_{SP}}{\partial b} |_{b=b^*} - 1 = 0 . \quad (8)$$

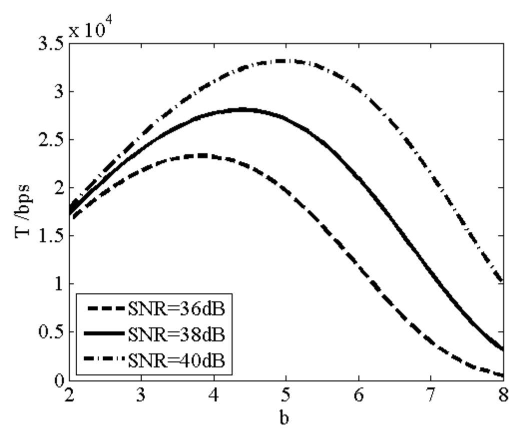

Figure 2 Throughput Versus Modulation Mode

In Figure 2, N=1, L_{CB}=512, R_S=10000. It shows the relationship between throughput and modulation

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mode. As b increases, the throughput first increases and then decreases. There exists a unique b^* to maximize the throughput. Besides, as SNR increases, the corresponding b^* will also increase.

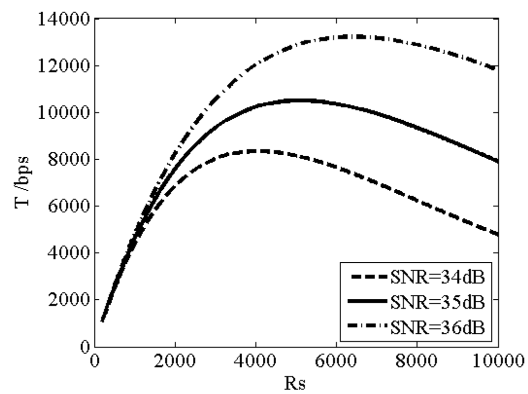

Figure 3 Throughput Versus Symbol Rate

3.2 Optimization Of Symbol Rate At The Physical Layer

Differentiate Eq. 2 with respect to R_S and solve it.

$$P_{SP} + R_S{}^* \frac{\partial P_{SP}}{\partial R_S}\Big|_{R_S = R_S{}^*} - 1 = 0 \quad . \qquad (9)$$

Figure 3 shows when R_S is small; the low resource utilization limits the system throughput. When R_S is large, the large error rate limits the throughput. Thus, there exists a unique optimal $R_S{}^*$.

3.3 Optimization Of Packet Size At The Data Link Layer

Do same operation as section 3.1 to obtain $L_{CB}{}^*$.

$$\frac{N(L_H + L_{CRC})}{L_{CB}{}^{*2}}(1 - P_{SP}) = [1 - \frac{N \times (L_H + L_{CRC})}{L_{CB}{}^*}]\frac{\partial P_{SP}}{\partial L_{CB}}\Big|_{L_{CB} = L_{CB}{}^*} \quad . \qquad (10)$$

Figure 4 shows when L_{CB} is small; the excessive packet headers limit the throughput. When L_{CB} is large, the large packet error rate limits the throughput. Thus, there exists a unique optimal $L_{CB}{}^*$.

3.4 Optimization Of Sub-Packet Number At The Data Link Layer

Do same operation as section 3.1 to obtain N*.

$$N^* = \sqrt{\frac{P_P L_{CB}}{L_H + L_{CRC}}} \quad . \qquad (11)$$

From Figure 5, we see that as N increases, the throughput increases and then decreases. There exists a unique N^*. Besides, we observe that as SNR increases, the corresponding N^* decreases.

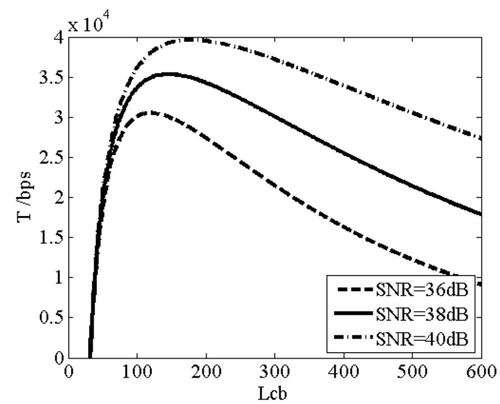

Figure 4 Throughput Versus Packet Size

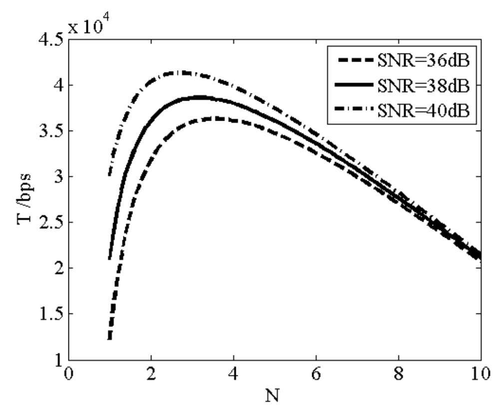

Figure 5 Throughput Versus Sub-Packet Number

3.5 Cross-Layer Design

The preceding analyses show that there exists a unique combination of the parameters to maximize the throughput. We can combine and solve the Eq. 8, 9, 10, 11.But simultaneously solving the four nonlinear equations can be quite challenging. So we can use the steepest descent algorithm [15].

3.6 Cross-Layer Design Under Prescribed Constraints

In the actual situations, the systems usually have strict restrictions on the packet error rate, delay and so on. We adopt the following two constraints.

(1) The maximum number of transmissions is M. Thus, the average number of transmissions is

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$$\bar{N}_T = 1 + P_{SP} + ... + P_{SP}^{M-1} = \frac{1-P_{SP}^{M}}{1-P_{SP}} . \quad (12)$$

(2) The probability of packet error after M transmissions is no larger than P_{LOSS}

$$P_{SP}^{M} \le P_{LOSS} . \quad (13)$$

This problem can be solved as follows. (1) Use the steepest descent method to solve the problem with no constraints. (2) If the solution satisfies the constraints, then this solution is the optimal solution. Otherwise, the optimal solution must be taken to the boundary constraints. We set

$$N = ceil(P_{LOSS}^{-1/M} [1-(1-P_E(b,\gamma_S))^{L_{CB}/b}]) . \quad (14)$$

Here, ceil is up rounded function. Then substitute Eq. 14 into Eq. 2, and re-solve it.

4. NUMERICAL RESULTS

We present numerical results in this section. Consider a MIMO system with 2 transmitting and 2 receiving antennas in a Rayleigh channel. The QAM is adopted and b can take values from 1 to 6. Both CRC and packet headers' length are 16. We set the maximum packet size 512 and the maximum sub-packet number 10. The bandwidth is 10 kHz.

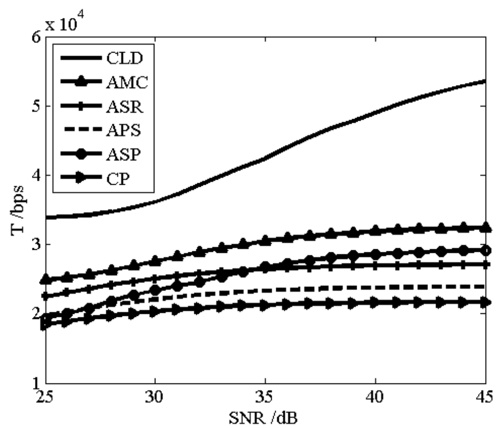

Figure 6 Throughput Comparisons Among Different Parameter Optimization Methods

In Figure 6, CLD represents the cross-layer design. CP represents the fixed parameters method with b=4, L_{CB}=400, N=4, R_S=8000. AMC represents the adaptive modulation and coding. Only b is optimized and other parameters are same with CP. ASR represents the adaptive symbol rate method and only R_S is optimized. APS represents the adaptive packet size method and ASP represents the adaptive sub-packet method. From Figure 6, we see that the CLD can automatically adjust the parameters according to the SNR. The resulting throughput is much larger than the separate layer design (AMC, ASR, APS, ASP). As the CP method is not able to adjust any network parameter, the throughput is the smallest. When SNR is 25 dB, the throughput of CLD improves 83.6%, 36.1%, 50.5%, 71.0%, 74.8% compared with CP, AMC, ASR, APS, ASP respectively. When SNR is 45 dB, the throughput of CLD improves 146.6%, 65.3%, 97.4%, 123.7%, 83.5% respectively. Therefore, the proposed cross-layer design can effectively work.

When constraints are considered, we set the maximum P_{LOSS}=0.005. M can take values 1, 2, 3. From Figure 7, we see that as M increases, the throughput increases. The throughput with M=3 is equal to the throughput with no constraint among all different SNR. When SNR>32 dB, the throughput with M=2 is also equal to the throughput with no constraint. Therefore, we conclude that in practical ARQ systems, a small transmissions number will be able to meet the requirements of packet error rate.

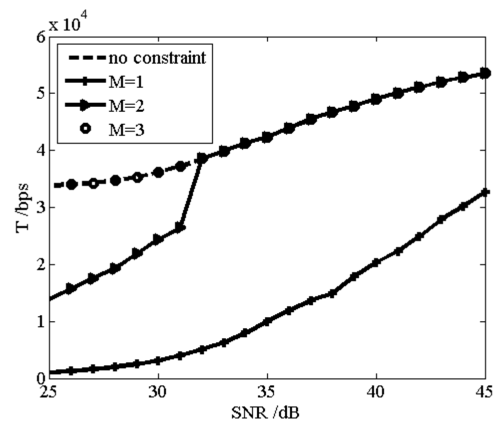

Figure 7 Throughput Comparisons With Different Number Of Transmissions

5. SUMMARY

In this paper, we have developed a cross-layer design to maximize the MIMO system throughput, which combines adaptive modulation mode and symbol rate at the physical layer, the packet size and sub-packet number at the data link layer. Both theoretical and numerical results show that our design can greatly improve the throughput. Besides, under prescribed error performance constraint, the larger the maximum number of transmissions, the higher the throughput. Just one or two

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retransmissions can offer a desirable delay-throughput tradeoff in practice. In this paper, we assume that perfect channel state information (CSI) is available at the receiver and the feedback channel has no delay and error. This may not always be true and one possible future direction is to analyze our cross-layer design with imperfect CSI. Besides, the cross-layer design in Ad Hoc network can also be analyzed in the future.

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