

Adaptive Transmission for MIMO systems with Integrated Voice/Data Traffics *

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Abstract. Multimedia traffic has different quality of service (QoS) requirements. For example, voice traffic has tight delay constraint at low data rate, while data traffic requires a higher data rate with less severe delay constrains. This paper proposes an adaptive transmission scheme for MIMO systems with multimedia traffic, which provides different bit error rate and transmission rate. The adaptive transmission scheme allocates substreams, rate and power jointly according to the feedback information to satisfy the different QoS requirements of the multimedia traffic. Furthermore, a sub optimal search algorithm with low complexity is proposed for practical implementation. Simulation results show that the proposed scheme improves the spectral efficiency while guarantees the QoS requirements of multimedia traffic. Moreover, the proposed sub optimal search achieves close optimal performance with great complexity reduction.

Keywords: Adaptive transmission, MIMO systems, Voice/Data Traffics

1 Introduction

Multiple-input multiple-output (MIMO) communication system has recently been emerging as one of the most significant breakthroughs in wireless communications [1]-[3]. Spatial Multiplexing is a promising technique to achieve the theoretical capacity of MIMO systems [4] [5]. It obtains high spectral efficiency by dividing the incoming data into multiple substreams and transmitting each substream by different transmit antennas after independent channel coding and modulation. The substreams are then separated at the receiver by means of signal processing techniques.

Meanwhile, link adaptation techniques, in which transmission parameters such as modulation rate, coding rate, and power are dynamically adapted to the channel state, have been used in combination with MIMO techniques to achieve higher spectral efficiency

* This paper has been partially supported by NSFC Project (60272021).

and better transmission quality [6]-[10]. Extended Vertical Bell Labs Layered Space-Time (V-BLAST), which is proposed in [7] [8], allocates rate and power of each substream to maximize the system capacity and has been shown to be able to achieve theoretical capacity of MIMO systems. For given transmit rate, [9] proposes a transmit power allocation scheme to improve the bit error rate (BER) performance, while [10] proposes transmit power, rate and antenna subset joint allocation to minimize either BER or the total transmit power. However, the work above does not support multimedia traffic that has different quality of service (QoS) requirements. For example, the voice traffic requires a real time service with tight delay constraint at low data rate, while the data traffic requires a higher data rate with less severe delay constraints. In addition, the voice usually tolerates higher BER but the data is sensitive to BER. Adaptive nonuniform phase shift keying is proposed in [11] to transmit two types of traffic in a stream, while adaptive hybrid binary phase shift keying (BPSK)/ M-amplitude modulation (AM) is used in [12]. In order to improve the spectral efficiency, [13] proposes a method that employs adaptive M-ary quadrature amplitude modulation (QAM) for both data and voice.

The previous work does not consider MIMO systems with multimedia traffic, which can be quite common in future wireless networks. In this paper, we propose an adaptive transmission scheme that supports real-time (RT) and non real-time (NRT) traffic, e.g., voice and data, to be transmitted simultaneously in MIMO systems. Transmit power, rate and antenna subset are jointly selected to obtain fixed data rate for RT traffic and maximal data rate for NRT traffic. In addition, two types of traffic have different BER requirement. After that, a sub optimal algorithm is then proposed to reduce the computation complexity for practical implementation.

In Section 2 the system model is set up, and in Section 3 the proposed adaptive transmission scheme is presented. Then numerical examples are given in Section 4, while Section 5 contains our conclusions and future work.

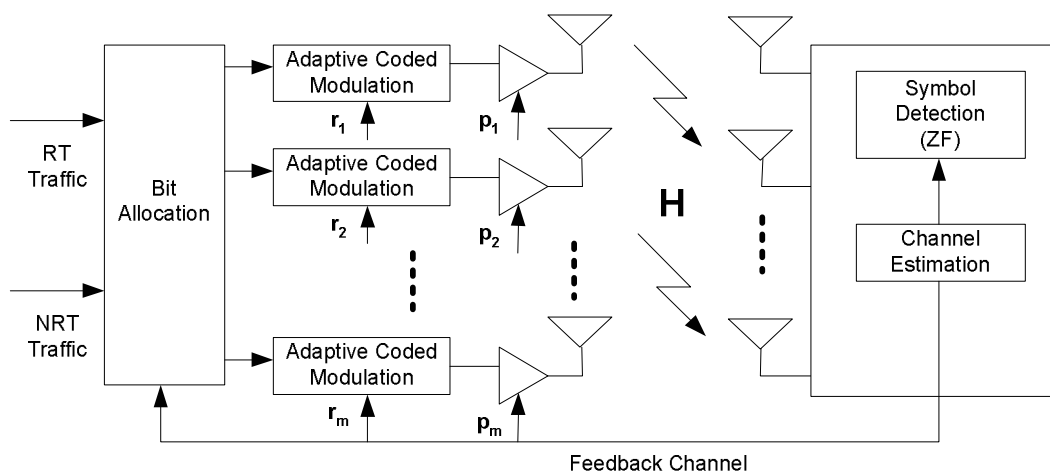


Fig. 1. Block diagram of the proposed adaptive system

2 System Model

We consider a spatial multiplexing system with m transmit antennas and n receive antennas. The channels are assumed to be quasi-static³ flat fading and denoted by \mathbf{H} , where the (i, j) th element of \mathbf{H} , h_{ij} , is defined as the channel gain from the i th transmit antenna to the j th receive antenna. The receiver knows the channel state perfectly, and the transmitter obtains channel state information by feedback channel, which is assumed to be error-free and zero-delay. Denoting the signal transmitted from the i th transmit antenna by s_i , the transmit signal vector \mathbf{s} is $(s_1, \dots, s_m)^T$.⁴ Denoting the receive signal from the j th receive antenna by y_j , the receive signal vector $\mathbf{y} = (y_1, \dots, y_n)^T$ is

$$\mathbf{y} = \mathbf{H}\mathbf{s} + \mathbf{n}, \quad (1)$$

where \mathbf{n} denotes the AWGN term which are modelled as i.i.d. zero mean complex Gaussian random variables with unitary variance. The transmit signal vector is assumed to satisfy

$$E(\mathbf{s}^*\mathbf{s}) = \begin{pmatrix} p_1 & 0 & \dots & 0 \\ 0 & p_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & p_m \end{pmatrix}, \quad (2)$$

where $E(\cdot)$ and p_i represents expectation operator and transmit power for the i th substream respectively. The total transmit power is denoted by P_t and

$$\sum_{i=1}^m p_i \leq P_t. \quad (3)$$

Linear receiver uses a linear filter to separate the transmitted data substreams and then decodes each substream independently. For Zero Forcing (ZF) receiver, the receive signals are processed by a linear filter, \mathbf{H}^\dagger , which is pseudo inverse of \mathbf{H} . The post-processed SNR of the i th substream ρ_i is

$$\rho_i = \frac{p_i}{[\mathbf{H}^\dagger \mathbf{H}^{\dagger*}]_{kk}} = p_i g_i, \quad (4)$$

where $[H^\dagger H^{\dagger*}]_{kk}$ represents the (k, k) th element of $H^\dagger H^{\dagger*}$, and g_i is defined as the gain of the i th substream.

3 Proposed Adaptive Transmission Scheme

The block diagram of the proposed adaptive transmission scheme is illustrated in Fig. 1. The RT and NRT traffic are first allocated to different substreams, which are then coded and modulated separately. The set of substreams for RT traffic is denoted by \mathcal{A} , while the set of substreams for NRT traffic is denoted by \mathcal{B} . The transmit rate and power for

³ Quasi-static means that the channel are constant over a frame length and changed independently between different frames.

⁴ We use $(\cdot)^T$ and $(\cdot)^*$ to denote the transpose and conjugate transpose operation respectively.

the i^{th} substream are r_i and p_i respectively. The receiver estimates the channel state and searches the proper transmission mode, which is then feed back to the transmitter. At the transmitter, the bits, rate and power allocation are based on the feedback information.

In order to satisfy QoS requirements of RT and NRT traffic, the substreams in \mathcal{A} and \mathcal{B} provide BER requirement of RT traffic, which is denoted by BER_v , and BER requirement of NRT traffic, which is denoted by BER_d , respectively. Moreover, due to the characteristic of the RT and NRT traffic, the total transmit rate for RT traffic should be a constant, r_v , while the total transmit rate for NRT traffic should be maximized according to channel states. Thus the problem is formulated as

$$\text{Maximize} \quad \sum_{i \in \mathcal{B}} r_i \quad (5)$$

$$\text{Subject to} \quad \sum_{i=1}^m p_i \leq P_t, \quad (6)$$

$$f(\rho_i, r_i) \leq \text{BER}_v, i \in \mathcal{A}, \quad (7)$$

$$f(\rho_i, r_i) \leq \text{BER}_d, i \in \mathcal{B}, \quad (8)$$

$$\sum_{i \in \mathcal{A}} r_i = r_v, \quad (9)$$

$$p_i, r_i \geq 0, \quad (10)$$

where $f(\rho_i, r_i)$ is BER of the i^{th} substream with transmit rate r_i . For simplicity, in this paper no channel coding is assumed and the modulation is assumed to be 2^{r_i} QAM. It is well know that BER for 2^{r_i} QAM with gray coding is upper bounded by [14]

$$f(\rho_i, r_i) \leq 0.2e^{-\frac{1.5\rho_i}{2^{r_i}-1}}. \quad (11)$$

However, the solution of this problem is not close-form. Therefore, we first assume the given \mathcal{A} and \mathcal{B} , resulting in the problem above divided into two problems,

Problem 1

$$\text{Minimize} \quad \sum_{i \in \mathcal{A}} p_i \quad (12)$$

$$\text{Subject to} \quad f(\rho_i, r_i) \leq \text{BER}_v, i \in \mathcal{A}, \quad (13)$$

$$\sum_{i \in \mathcal{A}} r_i = r_v, \quad (14)$$

$$p_i, r_i \geq 0, \quad i \in \mathcal{A}, \quad (15)$$

and

Problem 2

$$\text{Maximize} \quad \sum_{i \in \mathcal{B}} r_i \quad (16)$$

$$\text{Subject to} \quad \sum_{i \in \mathcal{A}} p_i \leq P_t - P_v, \quad (17)$$

$$f(\rho_i, r_i) \leq \text{BER}_d, i \in \mathcal{B}, \quad (18)$$

$$p_i, r_i \geq 0, \quad i \in \mathcal{B}, \quad (19)$$

where $P_v = \sum_{i \in \mathcal{A}} p_i$ and $0 < P_v \leq P_t$.

By K-T conditions, the solution of Problem 1 is

$$r_i = \frac{r_v}{|\mathcal{A}|} + \frac{1}{|\mathcal{A}|} \log_2 \frac{g_i^{|\mathcal{A}|}}{\prod_{i \in \mathcal{A}} g_i}, \quad i \in \mathcal{A}, \quad (20)$$

$$p_i = \frac{2^{r_i} - 1}{1.5g_i} \ln \frac{1}{5\text{BER}_v}, \quad i \in \mathcal{A}, \quad (21)$$

where $|\mathcal{A}|$ is the number of substreams in \mathcal{A} . When $P_v > P_t$, the solution is infeasible. That is to say, the transmit rate of the RT traffic under transmit power constraint can not be supported, which is named outage event. After that, the solution of Problem 2 is

$$r_i = \log_2 g_i C, \quad i \in \mathcal{B}, \quad (22)$$

$$p_i = \frac{2^{r_i} - 1}{1.5g_i} \ln \frac{1}{5\text{BER}_d}, \quad i \in \mathcal{B}, \quad (23)$$

where C is

$$C = \left(\frac{1}{\ln \frac{1}{5\text{BER}_d}} (P_t - P_v) + \sum_{i \in \mathcal{B}} \frac{1}{1.5g_i} \right) \frac{1.5}{|\mathcal{B}|}, \quad (24)$$

where $|\mathcal{B}|$ is the number of substreams in \mathcal{B} . The sum of the transmit rate of the NRT traffic is

$$\sum_{i \in \mathcal{B}} r_i = \log_2 \left(\prod_{i \in \mathcal{B}} C g_i \right). \quad (25)$$

Thus the optimal solution can be found by exhausted search of all possible \mathcal{A} and \mathcal{B} . For given \mathcal{A} and \mathcal{B} , (20)-(24) are used to allocate the rate and power of each substream. After that, the substreams allocation which achieves maximal transmit rate of NRT traffic is selected. Since each substream could be used for RT or NRT traffic or neither, there are 3^m possible substreams allocation, resulting in unacceptable complexity for practical implementation. Hence, it is necessary to find a sub optimal method with low complexity.

The sub optimal search method separates the exhausted search into two steps. Generally, RT traffic has stringer delay constraint, which requires as low outage probability as possible. For this reason, the sub optimal search selects the substreams for RT traffic first. When the receive Signal-to-Noise Ratio (SNR) is low, i.e. P_t is low, the system can not support high transmit rate, even the transmit rate of the RT traffic. In this case, the substreams with the largest gain are allocated for RT traffic to reduce the outage probability. On the other hand, when SNR is high, i.e. $P_t \rightarrow +\infty$, (25) becomes

$$\sum_{i \in \mathcal{B}} r_i \approx \log_2 \left(\prod_{i \in \mathcal{B}} \frac{1.5P_t}{|\mathcal{B}| \ln \frac{1}{5\text{BER}_d}} g_i \right). \quad (26)$$

In this case, $\sum_{i \in \mathcal{B}} r_i$ increases as g_i ($i \in \mathcal{B}$) increases. Thus allocating the substreams with the largest gain to NRT traffic can improve the performance. That is to say, when the transmit rate of RT traffic is guaranteed, the substreams with large gain should be allocated to NRT traffic. Thus the procedure of the sub optimal search is listed as follow.

1. $k = 1$.
2. find the subset of substreams, which supports transmit rate r_v/k with equal power allocation, $\mathcal{D} = \{i | f(g_i P_t / m, r_v / k) \leq \text{BER}_v\}$.
3. **if** $|\mathcal{D}| \geq k$,
then k substreams in \mathcal{D} are selected by ascending order of corresponding gain to \mathcal{A} ,
else k substreams are selected by descending order of corresponding gain from all possible substreams to \mathcal{A} .

4. $\mathcal{B} = \{i|i \notin \mathcal{A}\}$.
5. By (20)-(24), compute $\sum_{i \in \mathcal{B}} r_i$.
6. $\mathcal{B} = \mathcal{B} - \{i|i = \arg \min_{i \in \mathcal{B}} g_i\}$.
7. Repeat 4) until $\mathcal{B} = \emptyset$.
8. Repeat 2) until $k = m + 1$.
9. The substreams allocation \mathcal{A} and \mathcal{B} with maximal $\sum_{i \in \mathcal{B}} r_i$ is then selected.

Obviously, the sub optimal search has $\sum_{i=1}^{m-1} i = \frac{m^2-m}{2}$ loops, which is greatly reduced in comparison to the exhausted search. Moreover, since the RT traffic has higher priority, the outage probability of the sub optimal search is the same as the optimal exhausted search.

4 Numerical Examples

We consider an uncoded system with four transmit antennas and six receive antennas. ZF detection is used at the receiver. The BER requirement of RT and NRT traffic are assumed to be 10^{-2} and 10^{-4} . The possible modulation schemes are 4QAM, 16QAM, 64QAM and 256QAM. Thus the possible transmit rate of each substream are 2,4,6,8 bps/Hz. The transmit rate requirement of the RT traffic is assumed to be 4 bps/Hz. For comparison purposes, the performance of a traditional adaptive system, which has unitary BER requirement (10^{-4}) for all the substreams and maximize the total transmit rate, is also presented. Uncoded BER is obtained by averaging 10000 samples of channel realizations. Moreover, we use the transmit antenna correlation model in [15] in the simulations. Linear arrangement of the antenna array is assumed with the distance between the neighboring antennas being 4λ , where λ is the wavelength. We also assume the “broadside” case as defined in [15], and the angle spread is 5° .

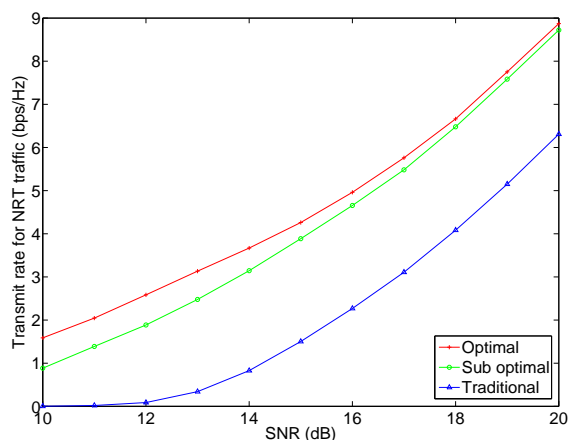


Fig. 2. Transmit rate for NRT traffic of different schemes under independent fading channels

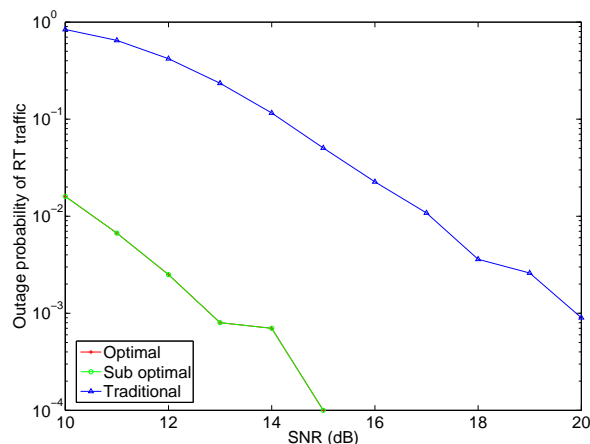


Fig. 3. Outage probability of RT traffic of different schemes under independent fading channels

Fig. 2 plots the transmit rate for NRT traffic of different scheme under independent Rayleigh fading channels. In comparison to the traditional adaptive scheme, the proposed

scheme achieves higher spectral efficiency. The reason is that when the BER requirements of RT traffic and NRT traffic are different, the proposed scheme saves the transmit power of the substreams with less BER requirements and therefore supports higher spectral efficiency. Moreover, the sub optimal scheme achieves close performance of the optimal scheme, especially for high SNR. Since the sub optimal allocates the substreams with best channel state to the RT traffic at low SNR, the spectral efficiency for NRT traffic is reduced in comparison to the optimal scheme.

The outage probability of RT traffic of different schemes under independent Rayleigh fading channels are given in Fig. 3. The proposed scheme achieves great improvement in comparison to the traditional scheme. The outage probability of the sub optimal scheme is the same as the optimal scheme, which means that the QoS of RT traffic is optimized by the sub optimal scheme.

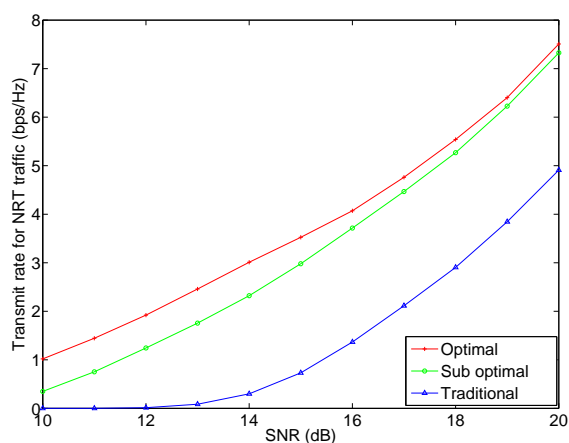


Fig. 4. Transmit rate for NRT traffic of different schemes under correlated fading channels

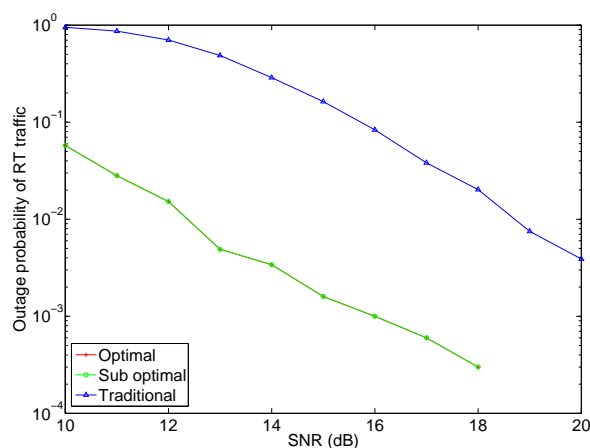


Fig. 5. Outage probability of RT traffic of different schemes under correlated fading channels

Fig. 4 and Fig. 5 plot the the transmit rate for NRT traffic and the outage probability of RT traffic of different schemes under correlated fading channels. The results show that the proposed scheme is also effective under correlated fading channels, which is inevitable in practical systems due to lack of scatters and spacing between antennas.

5 Conclusion & Future Work

This paper has proposed an adaptive transmission scheme for MIMO systems with multimedia traffic. Joint substreams, rate and power allocation has been used at the transmitter to provide different QoS requirements of RT and NRT traffic. A sub optimal scheme with low complexity and close optimal performance has also been presented. The simulation results has shown that the proposed adaptive transmission scheme achieves higher spectral efficiency than the traditional scheme with single QoS requirement under independent or correlated Rayleigh fading channels. Furthermore, the sub optimal scheme has been shown to have close optimal performance for NRT traffic and optimal performance for RT traffic in comparison to the optimal scheme.

However, this paper only considers the ZF receiver. Extending the adaptive transmission scheme to the other receiver, such as ZF successive interference cancellation (ZF-SIC) receiver, is an interesting topic for future study.

Acknowledgement

The authors would like to express their sincere thanks to Hitachi R&D Headquarter for the continuous supports.

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