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A Cross Layer Optimization Based on Variable-Power AMC and ARQ for MIMO Systems

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Abstract

To improve spectrum efficiency (SE), the adaptive modulation and coding (AMC) and automatic repeat request (ARQ) scheme have been combined for MIMO systems. In this paper, we add variable power subject to power constraint in each AMC mode. We use KKT optimization algorithm to get the optimal transmit power and AMC mode boundaries. The numerical results show that the average SE is increased by about 0.5 bps/Hz for 2 × 2 MIMO systems with Nakagami fading with parameter $m = 2$ when SNR is around 15 dB and the ARQ retransmission is twice.

Keywords: Transmitter Power Control, Spectrum Efficiency

1. Introduction

The demand for high data rate and quality of service (QoS) in wireless networks requires cross layer approach [1]. The adaptive modulation and coding (AMC) are already considered for implementation in many wireless system standards. In order to improve the average spectrum efficiency (SE), a combining constant-power AMC scheme in physical layer and truncated automatic repeat request (ARQ) protocol which provides a trade-off between the average coding rate and the probability of undetected error at the data link layer (DLL) in single-input single-output (SISO) system [2].

In this paper, we add power adaptation proposed in [3] to the constant-power AMC and ARQ in MIMO systems in [4]. In the proposed adaptive-power AMC and ARQ in MIMO systems, the power can be changed to increase average SE. The packet error rate (PER) in [2,3] which is much smaller than the target PER, so we are motivated to increase the PER, make PER as close to the target PER as possible. In this way, the switching SNR level of each rate boundary of each rate shift left in the SNR axis and we move to higher mode earlier as using higher order modulation, or higher code rate and the average SE can be improved. However the leftmost part of one each SNR region can have PER exceed limit, so we need adaptive power to compensate it. In [4] the Lagrangian multipliers λ is only one. In the propose method, the Lagrangian multipliers λ is different according to each AMC mode.

Numerical results indicates that the proposed optimization algorithm which combine adaptive power AMC scheme at physical layer and truncated ARQ protocol at data link layer can increase the average SE.

This paper is organized as follows: Section 2 describes the system model. Section 3 presented our proposed scheme with adaptive power. Numerical results are presented in Section 4, and our conclusion is in Section 5.

2. System Model

We consider a SISO system which combining the AMC scheme with power control at the physical layer and the truncated ARQ module at the data link layer, as shown in **Figure 1**.

We assume channel gains remain invariant during a packet, but vary from packet to packet. Let R_n be the rate of the mode. $\overline{S}$ denotes the average transmit power, γ denotes the pre-adaptation received SNR which the receiver feed back to the transmitter, and $S_n(\gamma)$ denotes the allocated power in the AMC mode n. The AMC is performed by dividing the range of the channel SNR into $N + 1$ non-overlapping consecutive interval, denoted by $[\gamma_n, \gamma_{n+1}), n = 0,1,..., N, \quad \gamma_0 = -\infty, \quad \gamma_{N+1} = \infty$ and N is the number of AMC modes. No data is sent at $[\gamma_0, \gamma_1)$ SNR range which corresponds to the outage mode. Consider of power adaptation, we modify the PER expression in the mode n [2,3] as follows:

$$PER_n(\gamma) = \begin{cases} 1, & 0 \le \gamma < \gamma_{pn} \\ a_n \exp\left(-g_n \frac{S_n(\gamma)}{\bar{S}}\gamma\right), & \gamma \ge \gamma_{pn} \end{cases} \quad (1)$$

The mode dependent parameters $\{a_n, g_n, \gamma_{pn}\}$ are given in **Table 1**. The mode-switching SNR values in [2,3] (without power adaptation) can be found by assuming $S_n(\gamma)/\bar{S} = 1$ and $PER_n(\gamma) = P_t$ where P_t is the target PER (0.01 usually) in (1). If considering adaptation power, we have two unknown elements, $S_n(\gamma)$ is the adaptive power inside the mode n and γ is the switching SNR to mode n. So we need to solve adaptive power under each mode first, then we can look for the mode-switching SNR values.

3. Adaptive-Power AMC

Because the AMC algorithm is the same for all SISO sub-channel, so we only discuss the AMC scheme with truncated ARQ protocol in the *i*th sub-channel in this section.

Here, we propose adaptive-power AMC to find the optimal SNR switching level that maximize SE under the PER constraint. The instantaneous PER is smaller than target PER, $PER_n^i(\gamma) \le P_t$, $\gamma_n^i \le \gamma \le \gamma_{n+1}^i$; $\forall n = 1,...,N$, where P_t denotes the target PER, so average PER will lower than target PER, too. We now propose that, $PER_n^i(\gamma) = P_t$, and add power factor to make the average SE larger. From (1), we can find the power adaptation with PER constraint in mode n is

$$\frac{S_n^i(\gamma)}{\bar{S}} = \frac{1}{g_n\gamma}\ln\left(\frac{a_n}{P_t}\right) \quad \gamma_n^i \le \gamma \le \gamma_{n+1}^i \quad (2)$$

Using (2), we now have the PER constraint as follows

$$\frac{1}{g_n}\ln\left(\frac{a_n}{P_t}\right)\int_{\gamma_n^i}^{\gamma_{n+1}^i}\frac{1}{\gamma}p_\gamma(\gamma)d\gamma \le \Pr(n) \quad (3)$$

We want to find the close form of the above equation, so we first find the close form of the following: (difference from traditional, addition $1/\gamma$ factor)

$$\Pr_{pow}^i(n) \equiv \int_{\gamma_n^i}^{\gamma_{n+1}^i}\frac{1}{\gamma}p_\gamma(\gamma)d\gamma = \begin{cases} \frac{1}{\bar{\gamma}}\left(Ei\left(\frac{-\gamma_{n+1}^i}{\bar{\gamma}}\right) - Ei\left(\frac{-\gamma_n^i}{\bar{\gamma}}\right)\right), & m = 1 \\ \frac{m}{\bar{\gamma}}\left(\frac{\Gamma\left(m, \frac{m\gamma_n^i}{\bar{\gamma}}\right) - \Gamma\left(m, \frac{m\gamma_{n+1}^i}{\bar{\gamma}}\right)}{\Gamma(m)}\right), & m \ge 2 \end{cases} \quad (4)$$

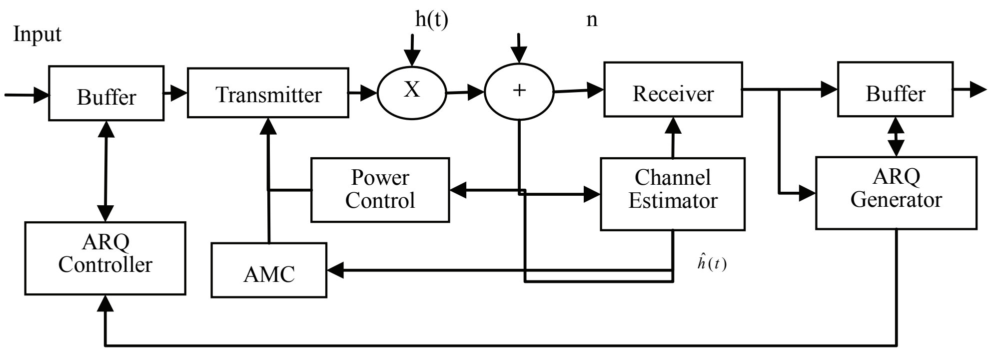

Figure 1. System model.

Table 1. Transmission modes in TM2 AMC scheme with convolutional coded M-QAM modulation.

	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6
Modulation	BPSK	QPSK	QPSK	16-QAM	16-QAM	64-QAM
Coding rate	1/2	1/2	3/4	9/16	3/4	3/4
R_n **(bit/sym.)**	0.5	1	1.5	2.25	3	4.5
a_n	274.72	90.25	67.62	50.122	53.399	35.351
g_n	7.9932	3.4998	1.6883	0.6644	0.3756	0.09
γ_{pn} **(dB)**	-1.533	1.094	3.972	7.702	10.249	15.978
Con-Power	1.0677	4.1537	7.1797	11.0799	13.5891	19.5801
Adapt-Power	-1.2437	1.6448	5.8601	9.5942	11.9965	16.8863

when $Ei(x) = -\int_{-x}^{\infty} e^{-t} / t dt$ is the exponential integral function, and has no close form. The optimization program can be formulated as

$$\begin{aligned} &\text{Maximize} \quad \sum_{n=1}^{N} R_n \Pr(n) \\ &\textit{subject to} \quad \sum_{n=1}^{N} \frac{1}{g_n} \ln(\frac{a_n}{P_t}) * \Pr^i_{pow}(n) \le \sum_{n=1}^{N} \Pr(n) \end{aligned} \tag{5}$$

The constraint in (5) is from (3) and (4). Using the KKT solution to solve , we got that:

$$\begin{aligned} &L(\gamma_1^i, \ldots, \gamma_n^i, \lambda) = \\ &\sum_{n=1}^{N} R_n \Pr(n) + (\sum_{n=1}^{N} \frac{1}{g_n} \ln(\frac{a_n}{P_t}) \lambda_n (\Pr^i_{pow}(n) - \Pr(n)) \end{aligned} \tag{6}$$

where λ are the Lagrangian multipliers. The optimal solution $(\gamma_1^{i*}, \gamma_2^{i*}, ..., \gamma_N^{i*})$ and the corresponding Lagrangian multipliers, λ_n^* must satisfy the following conditions:

1) $\quad \frac{\partial L}{\partial \gamma_n}(\gamma_1^{i*}, \ldots, \gamma_n^{i*}, \lambda_1^*, ..., \lambda_N^*) = 0, n = 1, 2, \ldots, N$

2) $\quad \sum_{n=1}^{N} \frac{1}{g_n} \ln(\frac{a_n}{P_t}) \Pr^i_{pow}(n) \le \sum_{n=1}^{N} \Pr(n)$

3) $\quad \sum_{n=1}^{N} \int_{\gamma_N^i}^{\gamma_{N+1}^i} S_n^i(\gamma) p_\gamma(\gamma) d\gamma \le \overline{S}$

4) $\quad \lambda_n^* \le 0$

5) $\quad \gamma_n^{i*} \ge \gamma_{pn}, n = 1, 2, \ldots, N \qquad (7)$

so that he optimal SNR switching level, $(\gamma_1^{i*}, \gamma_2^{i*}, ..., \gamma_N^{i*})$ will larger than the bound point constraint, γ_{pn}. The general form of the optimal mode switching levels can be written as

$$\begin{aligned} \gamma_1^{i*} &= -\frac{\ln(a_1 / P_1)}{g_1(\lambda_1^* - R_1)} \lambda_1^*, \\ \gamma_n^{i*} &= -\frac{\lambda_{n-1}^* g_n \ln(a_{n-1} / P_1) - \lambda_n^* g_{n-1} \ln(a_n / P_1)}{g_n g_{n-1}(R_n - R_{n-1} + \lambda_n^* - \lambda_{n-1}^*)}, n = 2, ..., N \end{aligned} \tag{8}$$

we have the optimal mode switching levels, checking the switching levels, $(\gamma_1^{i*}, \gamma_2^{i*}, ..., \gamma_N^{i*})$ satisfy the constraint in (5), and the optimal mode switching levels. Finally, the proposed algorithm is summarized in **Figure 2**.

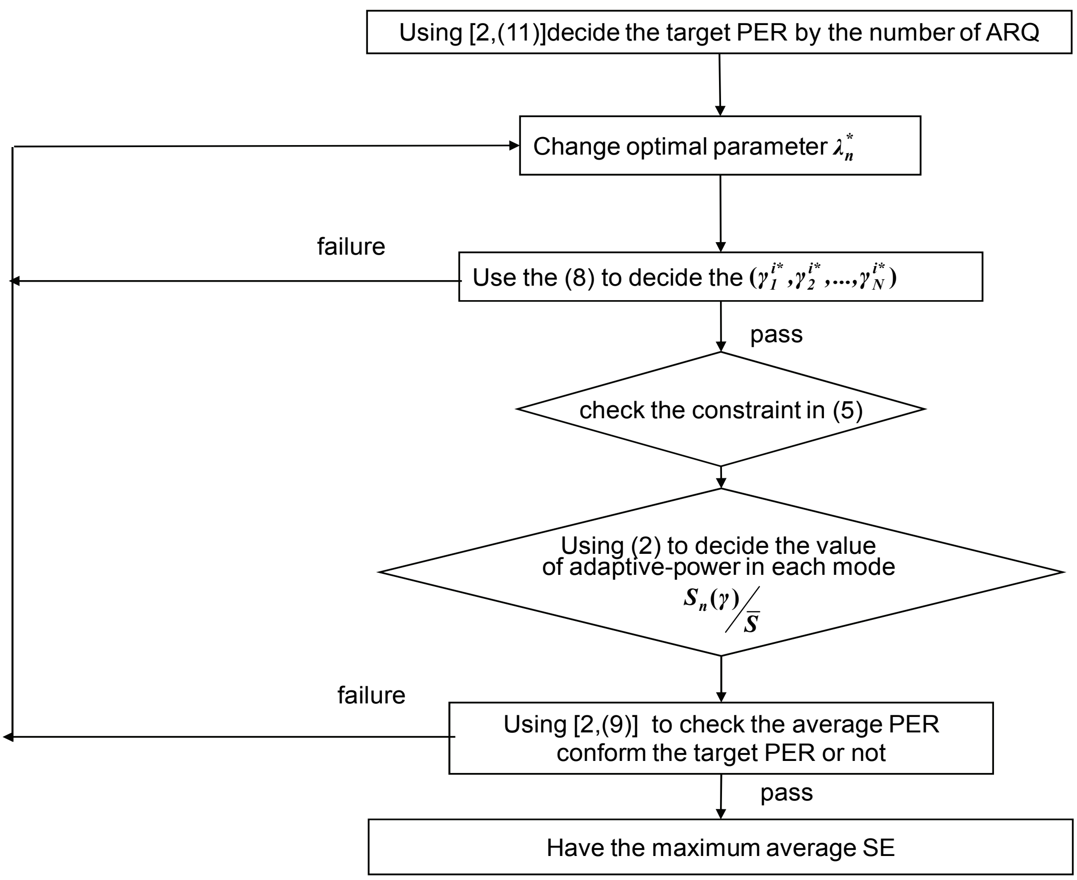

Figure 2. Flowchart.

4. Numerical Results

Here, we present numerical results for average spectral efficiency, power adaptation and PER using the optimal solution. We find the constraint in (5) when Nakagami channel $m = 1$ is a special case that $Ei(x)$ in (4) has no close-form and can't give the value of constraint in (5). So we use Nakagami channel fading parameter with m = 2 instead. We use the parameters of AMC scheme that is listed in **Table 1** from [5]. In **Figure 3**, we can see power switching in each mode and the leftmost power in each AMC mode is largest that make the average PER to conform PER constraint in each AMC mode. **Figure 2** shows the flowchart of optimal search algorithm. We use a Nakagami fading with parameter $m = 2$ 2 × 2 MIMO channel model, and assume a target PLR of $P_{loss} = 0.01$. In **Figure 4**, depict the average spectral efficiency for TM2 AMC scheme in **Table 1**, and we observed that using the truncated ARQ protocol helps increase the system SE ($N_{ARQ} = 2$ vs. $N_{ARQ} = 0$). Also in **Figure 4**, we can observe that our proposed scheme SE of $N_r = 0$ has a significant SE improvement over the one of $N_{ARQ} = 2$ in [2].

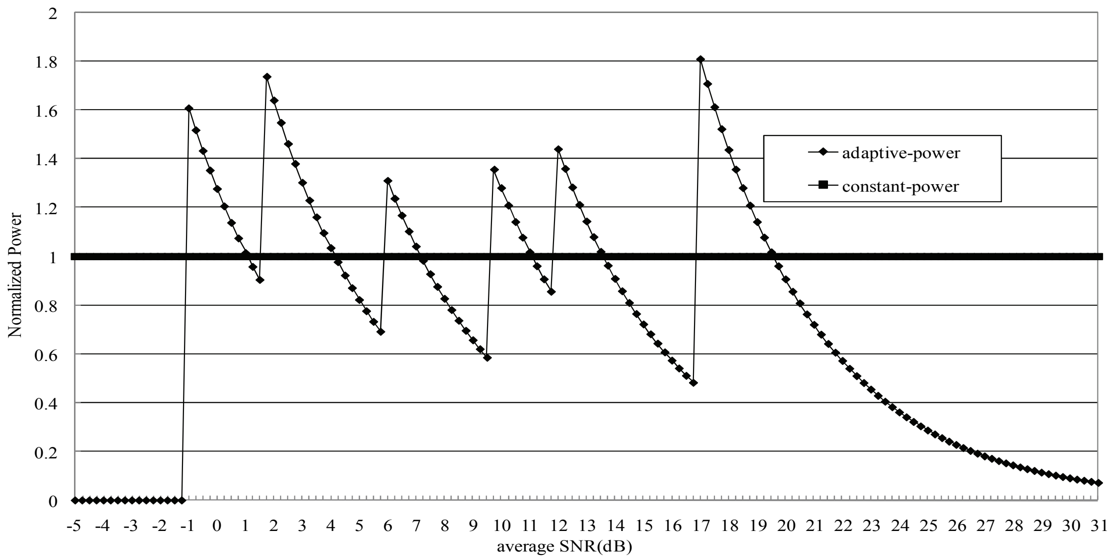

Figure 3. Adaptive power in each mode for Table 1 AMC scheme for sub-channel, target PER = 0.01.

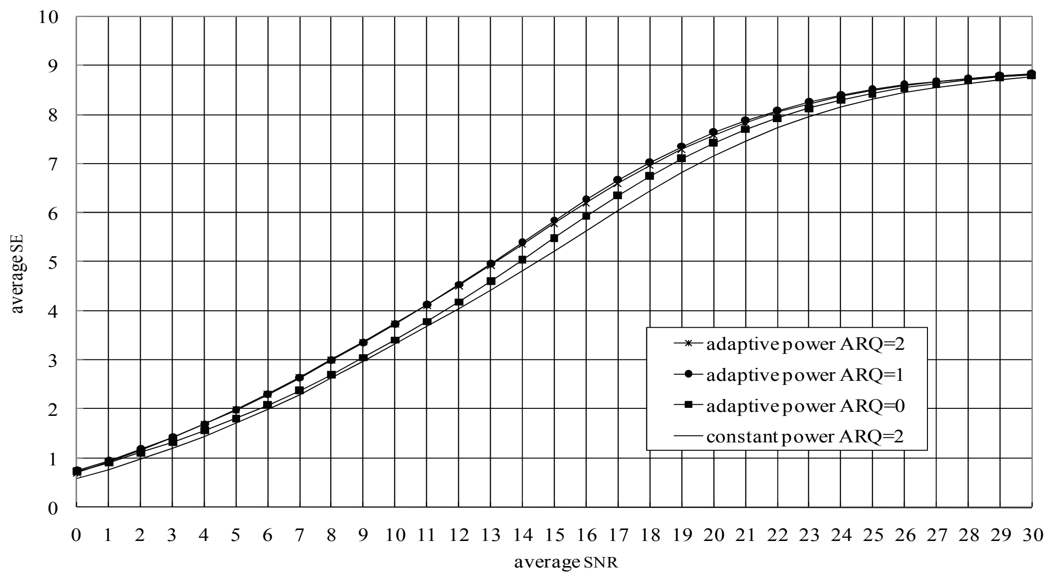

Figure 4. Table 1 AMC scheme 2 × 2 MIMO channel, target PER = 0.01.

But the maximum N_{ARQ} not always bring the best average SE, $11 \le SNR \le 21$ in **Figure 4**, we can see the average SE in 2 × 2 MIMO channel at N_{ARQ} = 2 is smaller than N_{ARQ} = 1. Because increasing N_{ARQ}, we alleviate the error bound to improve the average SE, but retransmission the same packet too many times will also degrade the average SE, so we try to balance N_r with target PER, such as $N_{ARQ} = 1$ in $P_t = 0.01$, and have the maximum average SE in our proposed system.

In **Figure 5**, we show the different combinations of two sub-channel for different SNRs in bar diagrams to the ARQ. We consider these 8 combinations and map them to integer numbers on x-axis [3]:

$$\{1=(c_1=0,c_2=0),2=(c_1=1,c_2=1),3=(c_1=2,c_2=1)\\ 4=(c_1=1,c_2=2),5=(c_1=2,c_2=2),6=(c_1=3,c_2=2)\\ 7=(c_1=2,c_2=3),8=(c_1=3,c_2=3)\}$$

where c_i is the i sub-channel.

In **Figure 5**, we can see the case 2 which have better SE than the other cases. This is consistent with the conclusions of the **Figure 4**.

Figure 6 compares the PER in [2] and the PER of our proposed scheme. We can see we increase the PER to the maximum (target PER = 0.01) at the left most of the SNR axis.

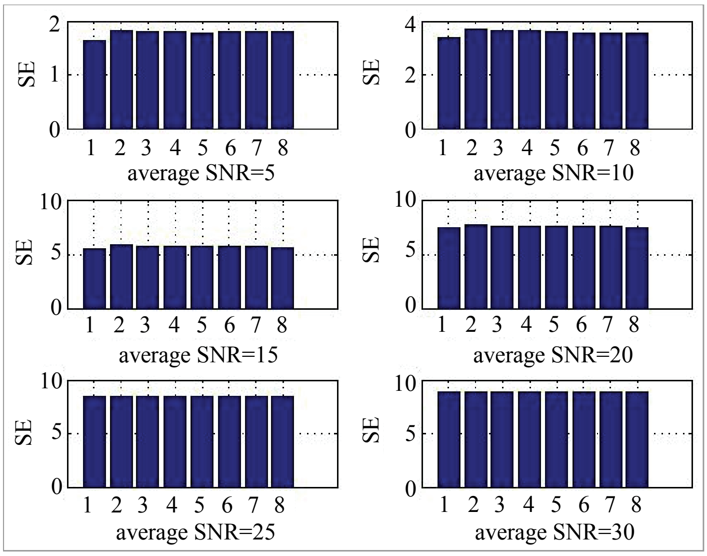

Figure 5. Different combinations of two sub-channel for different average SNRs.

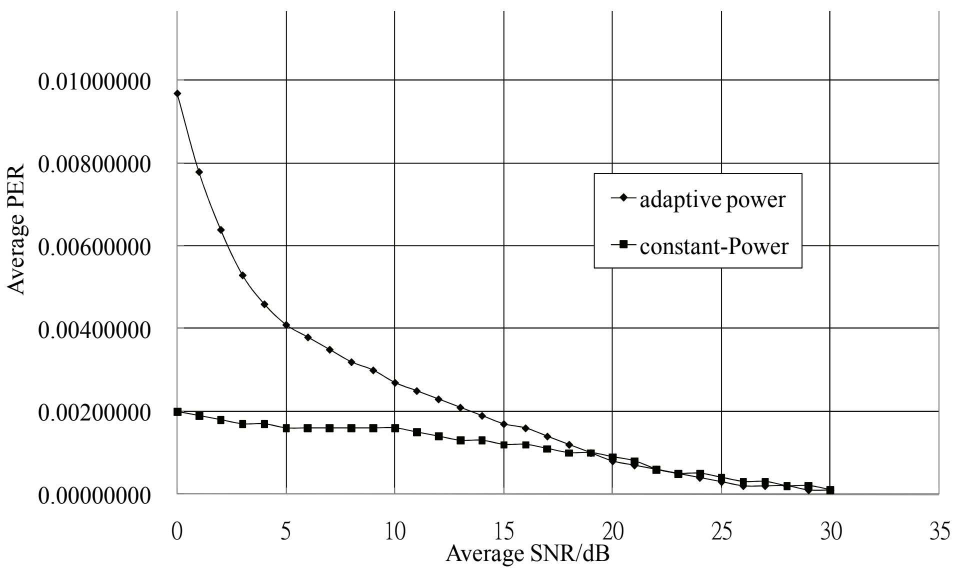

Figure 6. PER for Table 1 AMC scheme with adaptive power.

5. Conclusions

In this paper, we considered optimized rate and power adaptation at the physical layer aiming at maximizing the average SE, while satisfying a target PER constraint at the data link layer in MIMO channel. We proposed that increasing the PER makes it approach PER constraint, and the optimal mode switching level of each rate will shift to the left in the SNR axis, so we can use the higher order modulation to improve the average SE. The numerical results shows that the adaptation power within each SNR mode can improve the average spectrum efficiency by 0.4 ~ 0.7 (bits/symbol) in mid-SNR range for 2 × 2 MIMO systems, and ARQ $N_{ARQ} = 1$ is optimal for target PER = 0.01 to have the maximum average SE. We also show that each transmit antenna can have different maximum retransmission number due to independence of the sub-channels.

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7. References

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