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상관된 페이딩 채널에서 하이브리드 ARQ를 사용하는 V-BLAST 시스템의 수율

(Throughput of V-BLAST System using Hybrid ARQ in Correlated Fading Channels)

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요 약

본 논문에서는 H-ARQ를 위한 NACK 신호를 이용한 안테나 스위칭 방식을 제안하고 V-BLAST 시스템에서 분석하였다. 여기서 전송 안테나는 재전송시 번갈아 스위칭 되어 동작한다. 상관된 페이딩 채널에서 제안된 방식의 채널 용량을 해석적으로 분석함으로써, 채널 상관성의 악영향이 안테나 스위칭 방식으로 줄어듦을 보인다. 시뮬레이션 결과를 통해 상관된 페이딩 채널에서 평균 수율은 큰 복잡도의 증가 없이 개선되어질 수 있음을 보인다.

Abstract

In this paper, an antenna-switching scheme using negative acknowledgement for hybrid automatic repeat request (H-ARQ) is proposed and analyzed in the Vertical Bell Labs Layered Space-Time (V-BLAST) system, in which the transmit antenna is alternatively switched under retransmission. By analytically evaluating the channel capacity of the proposed scheme over correlated fading channels, it is shown that the adverse effect of the channel correlation is alleviated by the antenna switching scheme. Simulation results demonstrate that the average throughput may be improved in a correlated fading channel without adding much complexity to the process.

Keywords : V-BLAST, Negative Acknowledgement, Hybrid ARQ, Correlated fading channels

I. Introduction

A multi-input multi-output (MIMO) wireless channel has much higher capacity than a single-input single-output (SISO) wireless channel[1]. Vertical Bell Labs Layered Space-Time (V-BLAST) is known as an open-loop MIMO system which transmits independent data streams via each transmit antenna, and hence achieves high spectral efficiency, assuming the antenna element is subject to independent fading[2]. In reality, MIMO channels are not always independent, but exhibit channel correlation caused by narrow spacing between antennas and a finite number of scattering objects with limited angle spread[3]. Hence, the spectral efficiency is significantly reduced when the transmitted signals experience the fading correlation[4]. Therefore, an additional method is needed to reduce impact of the channel correlation and improve the overall system throughput. Hybrid automatic repeat request (H-ARQ) protocols, consisting of the joint use of the pure ARQ and forward error correction (FEC) schemes, were

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considered in order to overcome drawbacks such as the loose quality of service and increased delay[5]. For highly-reliable data transmissions, the applicability of negative acknowledgement (NACK) in a type I H-ARQ, which is completely blind and does not require any knowledge of the channel conditions, has also been investigated[6~7]. In this contribution, an antenna-switching scheme using NACK for H-ARQ is proposed in the V-BLAST system, where the transmit antenna is alternatively switched under retransmission and the adverse effect of the channel correlation is thus alleviated..

Ⅱ. Proposed scheme using NACK

We consider the V-BLAST system to have M transmit antennas and N receive antennas ($M \leq N$). We assume that each transmission channel from a transmit antenna to a receive antenna is frequency non-selective. Figure 1 shows the block diagram of the overall transmission scheme. The information symbol is channel-encoded and sent to a serial-to-parallel processor. For each parallel data stream, the transmit antenna is determined in an antenna switching block, depending on the result of a frame error check obtained on the receive side. The data for the k-th transmission (k=1: the first transmission, k>1: retransmissions) through the j-th transmit antenna is represented as

$$s_j^k = c_y, \quad j=1,\cdots,M, \quad k=1,\cdots,L+1. \qquad (1)$$

where cy is the y-th-encoded data stream (y=1, ⋯, M) where $y = f(j,k)$is a function of j and k which decides an integer value between 1 and M according to retransmission rule, and L is the maximum number of retransmissions. The received signal can be written in a vector form as

$$\begin{aligned} \mathbf{x}^k &= \mathbf{H}^k\mathbf{R}^H\mathbf{s}^k + \mathbf{n}^k = \mathbf{G}^k\mathbf{s}^k + \mathbf{n}^k \\ &= \left[\mathbf{g}_1^k, \mathbf{g}_2^k, \cdots, \mathbf{g}_M^k\right]\mathbf{s}^k + \mathbf{n}^k \end{aligned} \qquad (2)$$

Here, $\mathbf{x}^k = \left[x_1^k, \cdots, x_N^k\right]^T$ is Nx1 vector where x_i^k is the received data stream in the i-th receive antenna and []T is the transpose operation, Hk denotes the NxM channel response matrix at the k-th transmission, R is such a matrix that $\mathrm{R{\cdot}R}^H = \Gamma$ is the channel correlation matrix where ()H is the conjugate and the transpose operation, $\mathrm{G}^k = \mathrm{H}^k\mathrm{R}^\mathrm{H}$ is the overall channel matrix including the effect of the channel correlation whose column consists of $\mathrm{g}_\mathrm{j}^\mathrm{k}, \mathrm{j} = 1, \Lambda, \mathrm{M}$, $s^{k=}\left[c_{f(1,k)}, \Lambda, c_{f(M,k)}\right]^T$ is Mx1 data vector in the k-th transmission, and nk denotes the N-dimensional additive white Gaussian noise (AWGN) vector at the k-th transmission with covariance matrix σ^2I where σ^2 is the variance of each noise element and **I** is the NxN identity matrix. Assuming that chase combining is employed for the H-ARQ, the elements of s^k are the same for any values of k. The difference is the only change of the antennas in which the elements of $s^k$is transmitted. Therefore, we may say that the rows permutation in

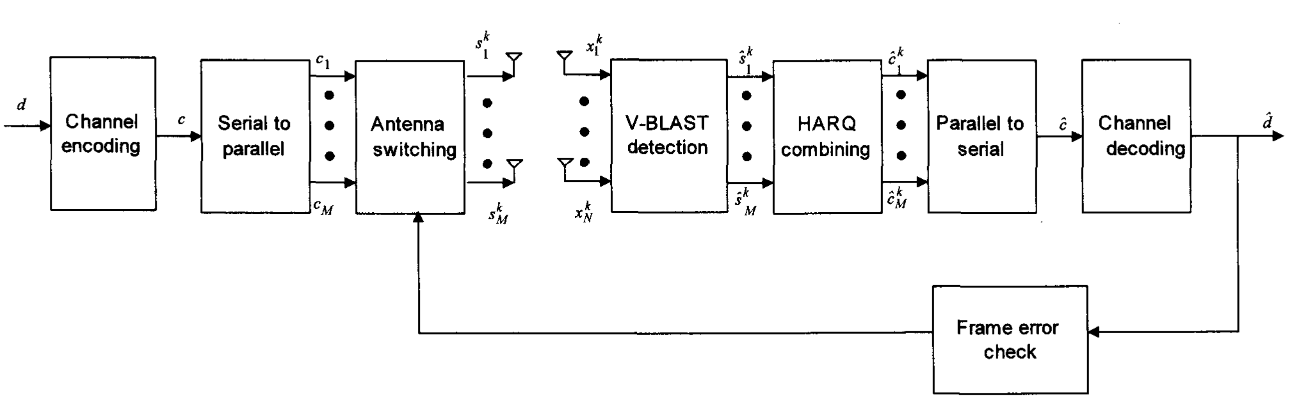


그림 1. 전체 전송 방식의 블록 다이아그램

Fig. 1. The block diagram of overall transmission scheme.

s^k by (1) is mathematically equivalent to the columns permutation in G^k. Now, when the data stream is assumed to be s^1 which is the data vector in the first transmission, the equivalent channel matrix, G^k, at the k-th transmission is as follows:

$$\mathbf{x}^k = \left[\mathbf{g}^k_{f(1,k)}, \mathbf{g}^k_{f(2,k)}, \cdots, \mathbf{g}^k_{f(M,k)}\right] \mathbf{s}^1 + \mathbf{n}^k = \mathbf{G}_k\, \mathbf{s}^1 + \mathbf{n}^k \tag{3}$$

where $\mathbf{s}^1 = [c_1, \cdots, c_M]^T$

By piling up the received signal vectors in (3) during k transmissions, we obtain the overall channel response.

$$\begin{bmatrix} \mathbf{x}^1 \\ \mathbf{x}^2 \\ \vdots \\ \mathbf{x}^k \end{bmatrix} = \begin{bmatrix} \mathbf{g}^1_{f(1,1)} & \mathbf{g}^1_{f(2,1)} & \cdots & \mathbf{g}^1_{f(M,1)} \\ \mathbf{g}^2_{f(1,2)} & \mathbf{g}^2_{f(2,2)} & \cdots & \mathbf{g}^2_{f(M,2)} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{g}^k_{f(1,k)} & \mathbf{g}^k_{f(2,k)} & \cdots & \mathbf{g}^k_{f(M,k)} \end{bmatrix} \mathbf{s}^1 + \begin{bmatrix} \mathbf{n}^1 \\ \mathbf{n}^2 \\ \vdots \\ \mathbf{n}^k \end{bmatrix}$$

$$= \begin{bmatrix} \mathbf{G}_1 \\ \mathbf{G}_2 \\ \vdots \\ \mathbf{G}_k \end{bmatrix} \mathbf{s}^1 + \begin{bmatrix} \mathbf{n}^1 \\ \mathbf{n}^2 \\ \vdots \\ \mathbf{n}^k \end{bmatrix} = \mathbf{G}\,\mathbf{s}^1 + \mathbf{n} \tag{4}$$

where $G = [G_1, \Lambda, G_k]^T$ and $n = [n^1, \Lambda, n^k]^T$. After the V-BLAST detection, the detected data stream is processed in the H-ARQ combining block. Finally, the data is recovered in the channel decoding block. If the recovered data is judged to be error-free in the frame error check block, then ACK signaling is delivered to the transmitter. Otherwise, NACK signaling is obtained and the transmitter repeatedly sends the data. Here, the transmit antenna for the retransmitted data stream is to be changed in order to mitigate the effect of the channel correlation. In this study, we assume the retransmission rule as follows.

$$y = f(j,k) = 1 + [(j+k-2) \bmod M] \tag{5}$$

For example, when the retransmission is allowed to be only once (k=1, 2), we get the overall channel response matrix $\mathbf{G} = \begin{bmatrix} \mathbf{g}^1_1 & \mathbf{g}^1_2 \\ \mathbf{g}^2_2 & \mathbf{g}^2_1 \end{bmatrix}$ *for* $M = N = 2$ and

$$\mathbf{G} = \begin{bmatrix} \mathbf{g}^1_1 & \mathbf{g}^1_2 & \mathbf{g}^1_3 & \mathbf{g}^1_4 \\ \mathbf{g}^2_2 & \mathbf{g}^2_3 & \mathbf{g}^2_4 & \mathbf{g}^2_1 \end{bmatrix} \quad \textit{for } M = N = 4 .$$

The capacity of the MIMO wireless channel without channel knowledge at the transmitter side is as follows [1]

$$C = \log_2 \det\left(\mathbf{I}_N + \frac{\text{SNR}}{M}\mathbf{G}\mathbf{G}^H\right). \tag{6}$$

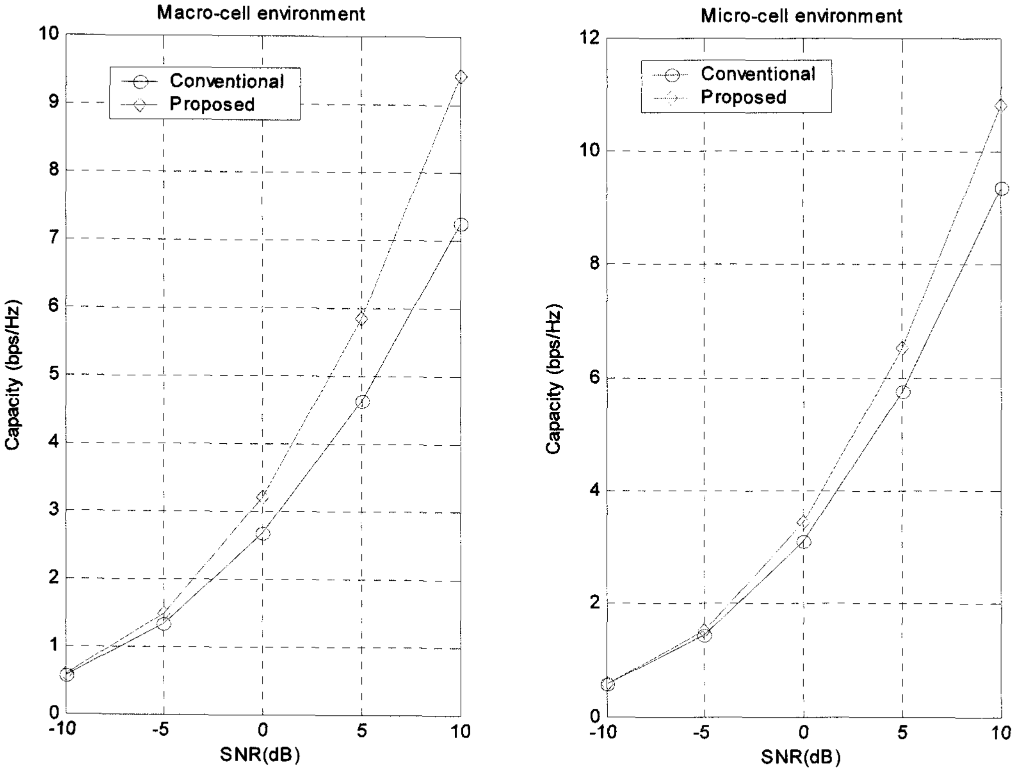
Also, we can find the equivalent formula as [1]

$$C = \sum_{p=1}^{r} \log_2\left(1 + \frac{\text{SNR}}{M}\lambda_p\right) \tag{7}$$

where r is the rank of the overall channel response matrix $\mathbf{G}\mathbf{G}^H$ and λ_p $(p = 1.2, \cdots, r)$ is the positive eigenvalue of $\mathbf{G}\mathbf{G}^H$.

III. Numerical results

First of all, we analytically evaluate the channel capacity of the proposed antenna switching scheme over correlated fading channels.. For the correlated fading channel, we consider two representative environments. One is a macro-cell environment where the angle of arrival (AOA) is assumed to be $20°$ and the angle spread (AS) is $5°$, and the other is a micro-cell environment where the AOA is $10°$ and the AS is $15°$. The distance between antennas in the base station is assumed to be half wavelength for antenna configuration. From these parameters, the channel correlation matrix is $\Gamma = \begin{pmatrix} 1 & a & b & c \\ a' & 1 & a & b \\ b' & c' & 1 & a \\ c' & b' & a' & 1 \end{pmatrix}$ for M=N=4 where $a = 0.4640 + 0.8449j$, $b = -0.4802 + 0.7452j$, and c = -0.7688+0.0349j for the macro-cell environment and $a = 0.3769 - 0.6866j$, b = -0.2687-0.3691j, and $c = -0.2627 + 0.0087j$ for the micro-cell environment [8], and ' is the conjugate operation. For comparison, we assume that the



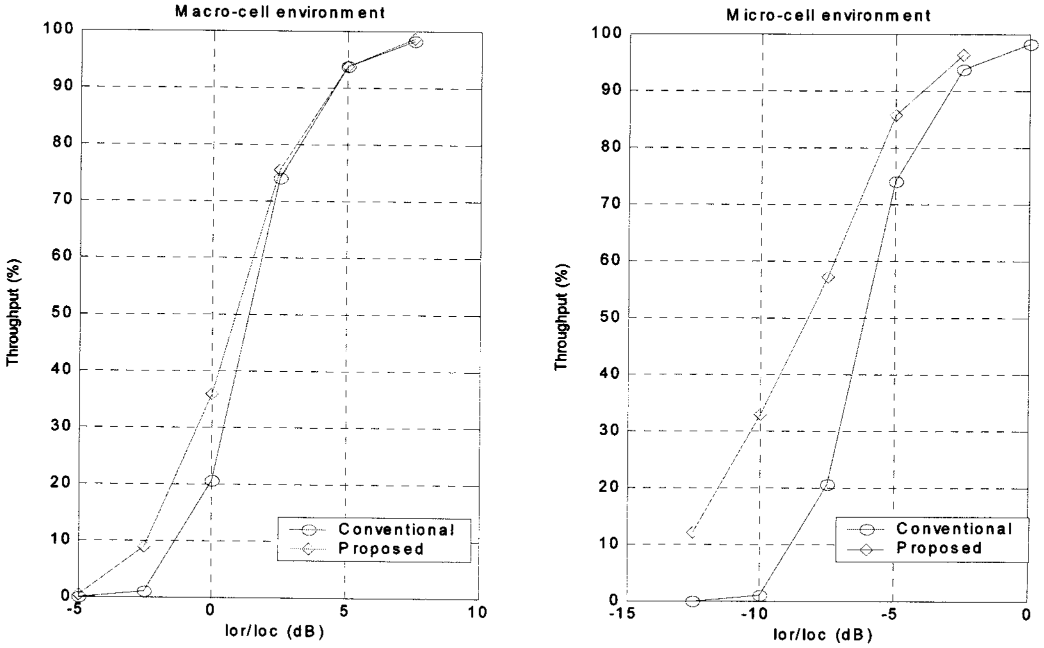
(a) (b)

그림 2. 수식7에 의해 계산된 제안된 안테나 스위칭이 존재하는 경우와 존재하지 않는 경우의 채널 용량 (a) 매크로셀 환경 (b) 마이크로셀 환경

Fig. 2. Channel capacity of both cases with and withoutthe proposed antenna switching scheme computed by Eq.7.. (a) Macro-cell environment and (b) Micro-cell environment

maximum number of retransmissions, L, is equal to one. The retransmission rule in Eq.(5) is considered. That is, $\mathbf{G}=\begin{bmatrix} \mathbf{g}_1^1 & \mathbf{g}_2^1 & \mathbf{g}_3^1 & \mathbf{g}_4^1 \\ \mathbf{g}_2^2 & \mathbf{g}_3^2 & \mathbf{g}_4^2 & \mathbf{g}_1^2 \end{bmatrix}$. Figures 2 show the capacity of the proposed scheme over correlated fading channel. From the figure, we can see that the antenna switching may increase the channel capacity. Therefore, we anticipate improved system throughput because the adverse effect of channel correlation may be mitigated with the transmit antenna switching.

The performance of the proposed antenna-switching scheme is confirmed in terms of the throughput by computer simulation . A frame size is assumed at 394 bits,and its duration 2 ms. Half-rate turbo code has a generator polynomial of $\left[1 \;\; \frac{1+D+D^3}{1+D^2+D^3}\right]$. The type I H-ARQ, so-called chase combining, is assumed. The maximum number of retransmissions, L, is set to one, and the retransmission delay is six frames. QPSK modulation is considered. The channel is assumed to be the frequency non-selective fading, and mobile speed is 3 km/h. On the receive side, perfect channel estimation is assumed. The throughput metric is defined as $\text{Throughput}\,(\%)=\frac{S-F}{T_{total}}\times 100$, where S is the number of total transmitted frames, F is the number of failed frames after L retransmissions, and T total is the total number of transmissions. Figure 3 shows the throughput performance of the proposed scheme for both macro-cell environment and micro-cell environment. From Fig. 3(a), we see that the throughput of the proposed scheme with antenna switching in the macro-cell environment is as high as about 15% at 0 dB of Ior/Ioc compared to that of



(a) (b)

그림 3. 시뮬레이션에 의해 계산된 제안된 안테나 스위칭이 존재하는 경우와 존재하지 않는 경우의 수율 성능 (a) 매크로셀 환경 (b) 마이크로셀 환경

Fig. 3. Throughput performances of both cases with and without the proposed antenna switching scheme evaluated by simulation. (a) Macro-cell environment. (b) Micro-cell environment.

the scheme without antenna switching. In Fig. 3(b), it is shown that the proposed scheme significantly improves the throughput performance in the micro-cell environment. At -10 dB of Ior/Ioc, throughput improvement of higher than 30% is achieved. Note that much higher throughput is achieved in the relatively low Ior/Ioc value range. With the proposed antenna switching, we can mitigate the adverse effect of channel correlation on the V-BLAST performance and then obtain the improved system throughput. To summarize, the average throughput may be improved in a correlated fading channel without adding much complexity to the process. As well, no additional information signaling is required because the retransmission rule is known to both the transmitter and receiver sides.

Ⅳ. Conclusion

In conclusion, this paper studied the novel antenna-switching scheme using NACK for H-ARQ in a V-BLAST system, where the transmit antenna is alternatively switched under retransmission, and the adverse effect of the channel correlation is thus alleviated. The results demonstrate that the average throughput may be improved in a correlated fading channel without adding much complexity. Consideration of the antenna-switching rule in the V-BLAST system with more than two antennas constitutes the topic of further research.

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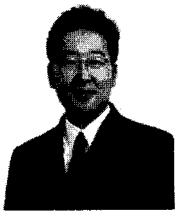

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