Pilot Design Based on Distributed Transmit Antennas in V-BLAST for Full Frequency Reuse

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Abstract. Spectrum resources are very valuable. This paper presents a pilot design for full frequency reuse system in the vertical Bell Labs layered space-time with distributed transmit antennas. In this system, the transmit antennas are placed distributed and the pilot symbols of adjacent 9 antennas are placed at different times or on different subcarriers. A simulation is carried out under the condition of three transmit and three received antennas, multipath Rayleigh fading channel, and antenna spacing of 500 meters. The simulation results show that, at the area averaged mean square error of 5×10^{-2}, the propose method is superior by about 2dB to the traditional method in bit signal-to-noise ratio.

Keywords: full frequency reuse, distributed transmit antennas, V-BLAST.

1 Introduction

In order to fully utilize the scarce spectrum resources, future cellular networks are expected to be full frequency reuse (FFR). For achieving FFR, distributed antenna systems (DAS) are attractive technique over traditional co-located antenna systems (CAS) due to its power and capacity advantages [1]. The power saving and capacity increase of DAS are significantly influenced by antenna placement and channel estimation, which is typically achieved by pilot symbols placed at different times or on different subcarriers [2].

There are challenges for pilot-assisted channel estimation in the traditional co-located antenna systems (CAS): (a). severe co-channel interference (CCI) in the cell boundary may be produced if simply applying FFR; (b). the predicted gains can not be achieved due to spatial correlation in CAS; (c). the effective data transfer rate is reduced in vehicle environments with fast pilot insertion.

Studies on pilot design generally focus on orthogonal pilot design in either time domain or frequency domain [3], without utilizing the antenna placement of DAS. Recently, the work in [4] investigates a four-antenna based structure in DAS with directional antennas for capacity improvement. And the work in [5] the work in proposes pilot coordination in DAS to combat CCI, combined with interference cancellation on the terminal side. Yet, the advantages of distributed transmit antennas

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need to be further exploited. In this paper, we investigate on how to achieve FFR for pilot-assisted channel estimation in DAS, where V-BLAST and OFDM are employed.

2 System Setup

2.1 Transmitter

The system model is presented in Fig. 1. In traditional regular hexagonal cell, the topology of placement for base station (BS) is equilateral triangle [6]. To maintain such topology in the distributed MIMO model we investigated, only a single transmit antenna are located at the vertex of the triangle. In a large region, these transmit antennas are connected to a single BS by fiber optic or coax cables, where the processing/control functions are realized at the BS. Each antenna transmits signals using the same carrier frequency. In addition, assume a mobile station (MS) is uniformly distributed over a triangle cell. The MS with M_r received antennas is served by M_t transmit antennas nearby.

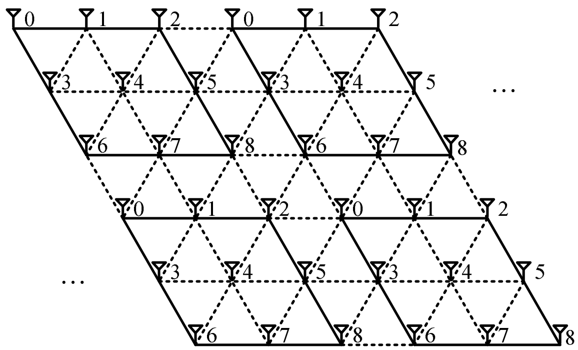

Fig. 1. System model of distributed transmit antennas. Solid lines present that the placements of the adjacent 9 antennas constitute a regular shape.

In CAS, 3 transmit antennas are located at BS centrally, and assume that the pilots of 9 transmit antennas for adjacent 3 cells at least are orthogonal. To maintain this pilot overhead in DAS, assume the pilot symbols of adjacent 9 antennas are orthogonal, i.e. they are placed at different times or on different subcarriers. The placements of these antennas constitute a regular shape, which can cover the entire region without overlap or gap.

We consider a downlink single frequency reuse V-BLAST OFDM with M_t transmit antennas and M_r receive antennas. System bandwidth B is divided into N subcarriers. A cyclic prefix (CP) with N_{cp} subcarriers is added in front of the OFDM symbol. Note that in the scenario with DAS, the CP length must equal to or greater than the sum of the maximum multipath delay and the maximum relative propagation delay caused by the different distances between the receiver and transmit antennas.

2.2 Receiver

The received signal for *k*-th subcarrier and *t*-th time of *j*-th received antenna $R_j(k,t)$ can be expressed as [6]

$$R_j(k,t)=\sum_{i=0}^{M_t-1}H_{ji}(k,t)X_i(k,t)+W_j(k,t)+V_j(k,t) \tag{1}$$

where $H_{ji}(k,t)$ denotes the fading channel coefficient from the *i*-th transmit antenna to the *j*-th received antenna $X_i(k,t)$ is the transmitted symbol for the *i*-th transmit antenna, $W_j(k,t)=\sum_{i=0}^{M_t-1}\sum_{m=0}^{M_\mathrm{I}-1}H_{ji}^{(m)}(k,t)X_i^{(m)}(k,t)$ denotes the received M_I signals of co-channel interference (CCI), $V_j(k,t)$ is assumed to be independent and identically distributed complex Gaussian with zero-mean and variance σ_V^2.

2.3 Channel

Consider the effect of path loss and time-variant multipath Rayleigh fading. $H_{ji}(k,t)$ can be expressed as [6]

$$H_{ji}(k,t)=\sqrt{\xi_{ji}}\sum_{n=0}^{L-1}h_{ji}(n,t)e^{\mathrm{j}\pi f_{D_n}T}\frac{\sin\left(\pi f_{D_n}T\right)}{\pi f_{D_n}T}W_N^{k\tau_n} \tag{2}$$

where ξ_{ji} is path loss, L is the total number of propagation paths, $h_{ji}(n,t)$ is the complex impulse response of the *n*-th path $(n=0,1,\cdots,L-1)$, f_{D_n} is the *n*-th path Doppler shift which causes intercarrier interference (ICI), and τ_n is the *n*-th path delay time, $W_N=e^{-\mathrm{j}2\pi/N}$, $\mathrm{j}=\sqrt{-1}$. Channel Energy is normalized, namely $\sum_{n=0}^{L-1}E\left\{\left|h_{ji}(n,t)\right|^2\right\}=\sum_{n=0}^{L-1}\sigma_{h,n}^2=1$.

The path loss ξ_{ji} can be simplified to ξ_i, since the receive antennas are centrally located. We model ξ_i as [6]

$$\xi_i=\begin{cases}\left(\dfrac{\lambda}{4\pi}\right)^2 d_i^{-2}\,,\ d_i\le\Upsilon\\ \left(h_b h_s\right)^2 d_i^{-4}\,,\ d_i>\Upsilon\end{cases} \tag{3}$$

where λ is the wavelength, h_b is the transmit antenna height, h_s is the mobile station (MS) antenna height, d_i is the distance between the i-th transmit antenna and the j-th received antenna of MS, and $\Upsilon = 4\pi h_s h_b / \lambda$ is the break point.

3 Channel Estimation

To estimate the channel frequency response, N_p pilot tones are inserted into the useful subcarriers. Let D_f and D_t present the pilot spacing in time domain and frequency domain, respectively. Then, the pilot spacing D_f satisfy $D_f = N/N_p$. The pilot tone labels for the i-th transmit antenna is $k' = i, D_f + i, \cdots, N - D_f + i$, where $i = \mathrm{mod}\left(m, D_f\right)$, after modulo operation, $m = 0, \cdots, M_p - 1$. Hence, the received signal at pilot tones (k', t') for the j-th received antenna is

$$R_j\left(k',t'\right) = H_{ji}\left(k',t'\right) X_i\left(k',t'\right) + W_j\left(k',t'\right) + V_j\left(k',t'\right) \tag{4}$$

The DFT-based channel estimation can be in the following steps [7]: Firstly, the channel coefficient $\hat{H}_{ji}\left(k',t'\right)$ at the pilot tones obtained by using LS channel estimation are given by

$$\hat{H}_{ji}\left(k',t'\right) = \frac{R_j\left(k',t'\right)}{X_i\left(k',t'\right)} \tag{5}$$

Secondly, by the N_p-point IDFT operation, we transform $\hat{H}_{ji}\left(k',t'\right)$ into the time domain, that is

$$\hat{h}_{ji}\left(n,t'\right) = \frac{1}{N_p} \sum_{m=0}^{N_p-1} \hat{H}_{ji}\left(i + mD_f, t'\right) W_{N_p}^{-mn} \tag{6}$$

Lastly, the time domain signal is in zero-padding operation as following

$$\tilde{h}_{ji}\left(n,t'\right) = \begin{cases} \hat{h}_{ji}\left(n,t'\right), & n = 0,1,\cdots,N_p - 1 \\ 0, & n = N_p, N_p + 1, N - 1 \end{cases} \tag{7}$$

By the N-point DFT operation for $\tilde{h}_{ji}\left(n,t'\right)$, the channel frequency response $\tilde{H}_{ji}\left(k,t'\right)$ is

$$\tilde{H}_{ji}\left(k,t'\right) = \sum_{n=0}^{N-1} \tilde{h}_{ji}\left(n,t'\right) W_N^{nk}, \qquad k = 0,1,\cdots N-1 \tag{8}$$

Lastly, after linear difference between $\tilde{H}_{ji}(k,t')$ and $\tilde{H}_{ji}(k,t'+D_t)$, the channel frequency response is given by

$$\tilde{H}_{ji}(k,t)=\left(1-\frac{t-t'}{D_t}\right)\tilde{H}_{ji}(k,t')+\frac{t-t'}{D_t}\tilde{H}_{ji}(k,t'+D_t) \tag{9}$$

where $t'<t<t'+D_t$.

The channel estimation mean square error (MSE) is

$$\text{MSE}=\sum_{j=0}^{M_r-1}\sum_{i=0}^{M_t-1}\sum_{t=0}^{T-1}\sum_{k=0}^{N-1}\frac{E\left\{\left|\tilde{H}_{ji}(k,t)-H_{ji}(k,t)\right|^2\right\}}{\xi_i} \tag{10}$$

where $E\{\cdot\}$ represents expectation.

4 Simulation Results

We demonstrate the performance of the proposed scheme through computer simulation. According to 3GPP TS 36.101 [8], the simulation parameters are assumed as follows: M_t=3, M_r=3; B=30MHz, N=2048, N_{cp}=160; quadrature phase shift keying (QPSK) modulation; LTE Extended Typical Urban (ETU) channel model; vehicle speed of 350km/h and carrier frequency of 1GHz, which result in $f_{D\max}$=324Hz. From parameters above, we can choose D_f=4, D_t=6. Assume the transmit correlation factor ρ=0 in DAS due to the large antenna spacing, and ρ=0.1, 0.5 and 0.9 in CAS according to 3GPP TR 25.996 [9]. Regardless of the effect of the receive correlation. The CCI from last layer antennas are considered in both methods. Finally, Eb/N0 is defined as a ratio of received bit energy to the power spectral density of noise, i.e. Eb/N0= $\sigma_p^2\sum_{i=0}^{M_t-1}\xi_i \big/ M_t\sigma_v^2$.

Simulation results of the proposed DAS method and the traditional CAS method are compared based on the area averaged mean square error (AAMSE) and the area averaged bit error probability (AABEP), respectively. The AAMSE and AABEP are derived by averaging the mean square error (MSE) and the bit error probability (BEP) over the cell, respectively.

Fig. 2 shows the AAMSE performance for V-BLAST OFDM systems. From Fig. 2 we can see that, at AAMSE of 5×10^{-2}, the proposed method is 2dB to the traditional method in Eb/N0. With the increase of Eb/N0, the two methods tend to different error platforms of channel estimation. Since the proposed method utilizes the advantages of DAS, the error platform in DAS is lower than that in CAS.

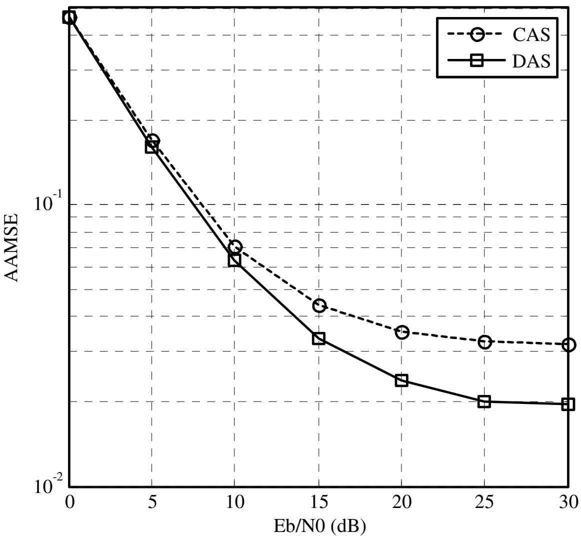

Fig. 2. AAMSE performance for V-BLAST OFDM systems. (M_t=3, M_r=3, $f_{D\max}$=324Hz, ρ=0, antenna spacing of 500m).

Fig. 3 shows the AABEP performance for V-BLAST OFDM systems with a variable correlation of transmit antennas ρ. From Fig. 3 we can see that, at AABEP of 4×10^{-2}, relative to the case with ρ=0.1 and 0.5 in CAS, the performance is getting better by 0.7dB and 2dB, respectively. For the case with ρ=0.9 in CAS, the performance is getting deterioration.

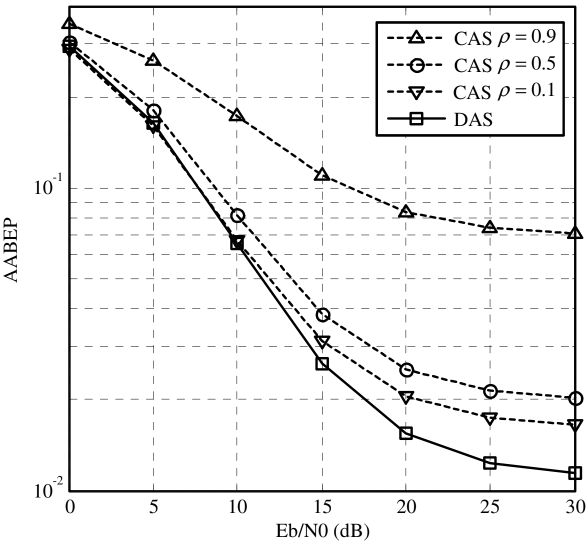

Fig. 3. Example of a figure caption. (M_t=3, M_r=3, QPSK modulation $f_{D\max}$=324Hz, antenna spacing of 500m).

5 Conclusions

This letter presents a method of pilot arrangement for distributed V-BLAST OFDM with FFR. The pilot symbols of any antenna and its adjacent antennas are placed at different times or on different subcarriers. Simulation results show that the impact of CCI and transmit correlation in proposed DAS is lower than that in CAS for achieving FFR. Furthermore, the pilot overhead of proposed method will not increase in vehicle environments.

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