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Transmit Beamforming with DOA Estimation in Fast Fading Channels with AOA Spread

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Abstract – **This paper shows performance of a transmit beamforming with DOA estimation in fast time selective fading channels with angle of arrival spread. The performance is confirmed by simulation where carrier frequency is assumed to be 20GHz and a linear array antenna is introduced. The unitary ESPRIT is applied for the DOA estimation. The beamfoming gain can be kept high as far as the maximum Doppler frequency f_D is less than 10^4 in the fading channel.**

Index Terms — **Transmit Beamforming, DOA, Doppler frequency, AOA spread.**

I. INTRODUCTION

Wireless access systems are going to be allocated in higher frequency bands than current systems such as the LTE (long term evolution) cellular system and IEEE 802.11ac. If higher frequency bands, e.g., 20GHz and 60GHz, are utilized in wireless communications, transmit signals are attenuated more severely in the channels, and Doppler frequency becomes higher. Multiantenna approach, such as transmit beamforming, is a well-known technique to compensate for the signal attenuation[1]. Even if exact CSI can be obtained with received signals in the uplink at the base station[2], however, transmit beamforming with CSI is easily degraded in fast time selective fading channels, because the CSI is outdated during time interval between the transmit slot and the receive slot. Beamforming with direction of arrival (DOA) estimation has been proposed to mitigate the degradation[3]. While CSI varies very quickly to movement of the terminal, the DOA changes relatively slowly. Therefore, transmit beamforming with DOA is expected to achieve more gain than that with CSI.

This paper shows robustness in a beamforming gain of a transmit beamforming with the unitary ESPRIT[4,5], one of DOA estimation techniques, in fast time selective fading channels. Carrier frequency is assumed to be 20GHz. Angular spread of the received signals is taken into account in order to verify the performance of the beamforming in realistic channels.

II. SYSTEM MODEL

We assume that the number of antennas at a terminal is only one and a linear array antenna with L elements is installed on a base station. The terminal is located in the antenna boresight of the linear array antenna on the base station at time $t = 0$. Signal $x(t)$ transmitted from the terminal is travelling in a time-selective fading channel and received at the base station with the linear array antenna. The received signals $y_i(t)$ at the ith antenna is written in a vector form, i.e., $Y(t)=[\ y_0(t)\ y_1(t)\ ..\ y_{N-1}(t)]^{\mathrm{T}}$, where superscript T represents transpose of a vector.

$$Y(t)=\sum_{i=0}^{M-1} H(\theta_i(t))x(t)+N(t). \tag{1}$$

In (1), $N(t)$ and M denote the white Gaussian noise vector and the number of the arrivals. In addition, $H(\theta_{\mathrm{i}}(t))$ represents the channel vector of the ith arrival coming along with the direction of $\theta_{\mathrm{i}}(t)$, which is defined as,

$$H(\theta_i(t))=\frac{g_i(t)\mathrm{e}^{\mathrm{j}\phi_i}}{\sqrt{L}}\begin{pmatrix} 1 & \mathrm{e}^{\mathrm{j}2\pi\frac{d}{\lambda}\sin\theta_i(t)} & \cdots & \mathrm{e}^{\mathrm{j}2\pi\frac{d}{\lambda}(L-1)\sin\theta_i(t)} \end{pmatrix}^{\mathrm{T}}. \tag{2}$$

$g_i(\mathrm{t})$, ϕ_{i}, λ, and d denote a norm of the channel vector, a phase of the ith arrival, a wavelength of the carrier, and spacing of the array antenna, respectively. The probability density function (PDF) of the norm with respect to angle of arrival (AOA) is defined as follows.

$$P(g_i(t))=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{|g_i-\varphi(t)|^2}{2\sigma^2}} \tag{3}$$

σ^2 and $\varphi(t)$ is variance and a direction to the terminal at time t, respectively. In the paper, we assume that the terminal starts moving on a line along with the direction perpendicular to the antenna boresight at time t=0. Let v denote the velocity of the terminal, $\varphi(t)$ can be defined as,

$$\varphi(t)=\arctan\left(\frac{vt}{D}\right), \tag{4}$$

where D denotes the distance between the terminal and the base station at t=0. Correlation of the phase between the nth and mth arrivals is set as

$$\mathrm{E}\left[\mathrm{e}^{\mathrm{j}(\varphi_n-\varphi_m)}\right]=\mathrm{e}^{-|\sigma\sin(\varphi_n-\varphi_m)|^2}\ , \tag{4}$$

where $\mathrm{E}[\alpha]$ represents an ensemble average of α. As the PDF of the AOA defined in (3) becomes wider, the correlation of the phase decreases.

III. TRANSMIT BEAMFORMING WITH UNITARY ESPRIT

A. Configuration

The received signal vector $Y(t)$ is fed to the unitary ESPRIT to estimate the direction of the terminal, $\phi(t)$. The weight vector for the transmit beam forming with the unitary ESPRIT is written as follows.

$$W = \frac{1}{\sqrt{L}} \begin{pmatrix} 1 & e^{j2\pi \frac{d}{\lambda} \sin\bar{\varphi}} & \cdots & e^{j2\pi \frac{d}{\lambda}(L-1)\sin\bar{\varphi}} \end{pmatrix}^{\mathrm{T}} , \qquad (5)$$

where $\hat{\phi}$ denotes an estimated direction by the unitary ESPRIT. Even though the M waves arrive at the base station, only one direction is estimated in the unitary ESPRIT.

B. Beam gain

While the direction is estimated at time $\underline{t}$, the transmit beamforming is performed at time $t+T$ where T denote a time interval between the receive signal slot and the transmit signal slot. Hence, a gain given by the transmit beamforming can be defined as,

$$G = W^{\mathrm{H}} \left(\sum_{i=0}^{M-1} H\left(\theta_i\left(t+T\right)\right) \right). \qquad (1)$$

Superscript H denotes the Hermit transpose.

IV. SIMULATION

A linear array antenna with a half wavelength of the spacing, i.e., $d=\lambda/2$ is applied. The number of the elements is set to 13 to compensate for the attenuation in the 20GHz band, while one antenna is placed on the terminal. The total least square technique is used for the unitary ESPRIT. The time interval T is 10msec and the distance D is 1km. The AOA is distributed with the Gaussian distribution. Since we assume that scattering, reflection and so on, happen around the terminal, the root mean square AOA spread is at most 0.2 [rad]. Therefore, the Jakes model[6] is applied for the channel through which all the waves path, even though the channel vector is defined in (2),

Fig.1 shows the DOA estimation performance with respect to the maximum Doppler frequency f_{D}. The transmit beamforming with FFT-based DOA is added as a reference. The two transmit beamforming with DOA keeps high estimation performance as far as the maximum Doppler frequency is less than 10^4. Obviously, the transmit beamforming with the unitary ESPRIT achieves better performance than that with the FFT-based DOA.

Fig.2 shows the loss of the beam gain with respect to the maximum Doppler frequency f_{D}. If the maximum Doppler frequency is less than 10^4, the transmit beamforming achieves the same performance despite of f_{D}. The transmit beamforming with the unitary ESPRIT achieves by about 8dB better performance than that with the FFT based DOA.

V. CONCLUSION

This paper shows robustness in a beamforming gain of a transmit beamforming with the unitary ESPRIT. Actually, the beamforming achieves superior performance as far as the maximum Doppler frequency is less than 10^4, which happens in 20GHz band when a vehicle runs at 540km/h. It is shown that the transmit beamforming with DOA can be applied for mobile communications in higher frequency bands, e.g., 20GHz.

REFERENCES

[1] J. Litva and T. K.-Y. Lo, "Digital Beamforming in Wireless Communications," Artech House, 1996.

[2] L. P. Withers, R. M. Taylor, and D. M. Warme, "Echo-MIMO: A two-way channel training method for matched cooperative beamforming," *IEEE Trans. Signal, Process.*, vol. 56, no.9, pp. 4419-4432, 2008.

[3] A. Kuchar, M. Tangemann, and E. Boneck, "A real-time DOA-based smart antenna processor," *IEEE Trans. Veh. Technol.*, vol.51, No.6, 2002.

[4] R. Roy and T. Kailath, "ESPRIT-Estimation of signal parameters via rotational invariance techniques," *IEEE Trans. Acoustics, Speech, Signal Process.*, vol. 37, no.7, pp. 984-995, 1989.

[5] M. Haardt and J. A. Nossek, "Unitary ESPRIT: How to obtain increased estimation accuracy with a reduced computational burden," *IEEE Trans. Signal, Process.*, vol. 43, no.5, pp. 1232-1242, 1995.

[6] W. C. Jakes, "Microwave mobile communications," IEEE press, 1994.

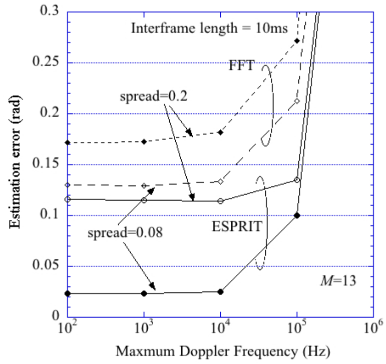

Fig. 1. Estimation performance vs. Doppler frequency.

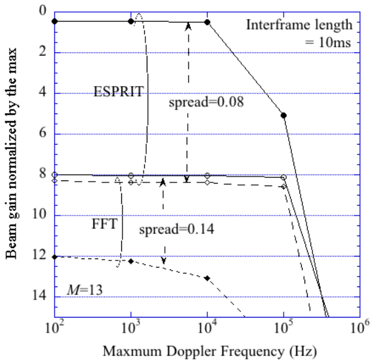

Fig. 2. Loss in beamgain vs. Doppler frequency