# BEAM-SPACE ADAPTIVE ARRAY ANTENNA FOR SUPPRESSING THE DOPPLER SPREAD IN OFDM MOBILE RECEPTION

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## 1. INTRODUCTION

OFDM (Orthogonal Frequency Division Multiplexing) has been successfully applied to a wide variety of digital communication applications over the past few years. One of the principle disadvantages of OFDM, however, is sensitivity to frequency offset. Significant frequency offset could appear in mobile video links as a result of Doppler effect, which would lead to Doppler frequency spread. Doppler spread causes a number of impairments including inter-channel interference (ICI)[1].

A number of methods have been proposed to reduce this sensitivity to frequency offset, including windowing of the transmitted signal [2], and space domain interpolation [3].

In this paper we introduce a receiving scheme, which uses Beam-Space Adaptive Array Antenna to suppress the Doppler spread. Further we have evaluated and verified the performance of the proposed scheme by computer simulation. In particular, it was certified that it is possible to suppress the Doppler spread efficiently for every incident angle by using eight-element beam-space array antenna with element spacing of $(3/8)\lambda$.

## 2. ICI DUE TO DOPPLER SPREAD

The base band signal at the output of a basic OFDM transmitter can be given by

$$S(i) = \sum_{n=0}^{N-1} d_n \cdot \exp(j2\pi ni / N) \quad , \quad i = 0,1,2,...,N-1 \tag{1}$$

where $N$ denotes the number of sub-carriers and $d_0, d_1,..., d_{N-1}$ are the complex original data symbols (e.g. PSK), which modulate the sub-carriers of the OFDM symbol.

If the transmitter or the receiver is moving at a speed of $v$ (Fig.1), the Doppler frequency shift of the received signal can be given by

$$f_d = (v/\lambda)\cos(\theta) \tag{2}$$



Fig.1 Doppler shift due to moving of receiver

where $\theta$ and $\lambda$ denote the incident angle and carrier wavelength. Therefore the Doppler shifted OFDM symbol can be given by

$$S^{'}(i) = \sum_{n=0}^{N-1} d_n \cdot \exp(j2\pi(\frac{n}{NT} + f_d)iT) \quad , \quad i = 0,1,2,...,N-1 \tag{3}$$

where $T$ denotes the original data symbol duration. When demodulating the received signal using a basic OFDM demodulator, received complex value of the $k^{th}$ sub-carrier, $d^{'}_k$ can be obtained as

$$d^{'}_k = \frac{1}{N} \sum_{i=0}^{N-1} \sum_{n=0}^{N-1} \left\{ d_n \exp(j2\pi \left[ \frac{n}{NT} + f_d - \frac{k}{NT} \right] iT \right\} \tag{4}$$

Here we can see that, $d'_k$ consist of ingredients of all the $N$ complex values, which modulate all the $N$ sub-carriers of the OFDM symbol, when $f_d$ is considerably large.
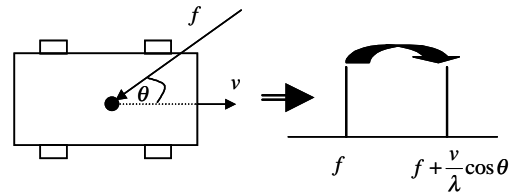
This verifies that the Doppler frequency shift leads to Inter Channel Interference (ICI). But if the moving speed of the receiver and the incident direction of the signal are known, it is possible to estimate and cancel the Doppler frequency shift.

On the other hand, under a multi-path propagation condition, Doppler frequency shift of each path differs from each other and it causes Doppler spread. Therefore, to realize high quality reception in such an environment, it is required to separate these multi-path signals on their incident directions and correct their frequency shifts individually.

## 3. PROPOSED SCHEME
### 3.1 Basic configurations

Fig.2 shows the configuration of the proposed receiving scheme at a mobile terminal in OFDM system. The scheme will be applicable to mobile reception of terrestrial digital television broadcasting. Followings are the step-by-step procedure of the proposed scheme.

Step1: Separate the multi-path signals on their incident directions to number of groups (beams), using Beam-Space Array Antenna.



Fig.2 Proposed scheme for OFDM mobile reception

Step2: Correct the frequency shift due to Doppler effect of each beam considering its beam direction.

Step3: Convert the serial data stream into a parallel data stream and demodulate the corrected signals of each beam by performing Discrete Furrier Transformation (DFT).

Step4: Combine the demodulated beam signals using Maximal Ratio Combiner (MRC).

Step5: Convert the parallel data stream back into a serial data stream.
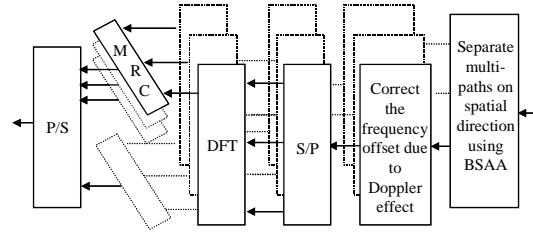
### 3.2 Beam-Space Array Antenna (Multi-beam formation)

In the proposed scheme, we have suggested using a linear array antenna consisting of $M$ components in the mobile terminal (Fig.3(a)), to separate multi-path signals on their incident directions. The received signal of the array antenna can be given by

$$\mathbf{R} = R_0 \left[ 1, \exp(-j2\frac{\pi}{\lambda}d\cos\theta), \exp(-j4\frac{\pi}{\lambda}d\cos\theta),...., \exp(-j2(M-1)\frac{\pi}{\lambda}d\cos\theta) \right]^T \qquad (5)$$

where $d$, $\theta$, and $R_0$ denote the inter-element space, the incident direction of the signal and the received signal complex amplitude of the first element of the array antenna. Then we formed a multi-beam pattern by performing DFT in space domain. The received signal by the $m^{th}$ beam pattern is given by

$$B_m = \sum_{i=0}^{M-1} R_i \cdot \exp(-j2\pi im/M) \qquad , \quad m = 0,1,2,...,M-1 \qquad (6)$$

Here $R_i$ denotes the received signal complex amplitude of the $i^{th}$ element of the array antenna. Fig.3(b) illustrates the multi-beam pattern of eight-element beam-space array, where inter-element space $d$ is $\lambda/2$. As shown in the figure, beam number 4 receives signals from the front and rear sides of the vehicle, where Doppler frequency shifts are $v/\lambda$ and $-v/\lambda$, respectively. Therefore beam4 receives signals with two different Doppler shifts.

Let's consider the other beams, for example beam number 6. The beam6 receives both signals in the direction of $\theta = \left| \cos^{-1}(2/3) \right|$ and $\theta = -\left| \cos^{-1}(2/3) \right|$. But it should be noted that the Doppler frequency shift for both directions are the same. This signifies that the beams except beam4, only contain signals with similar frequency shift.

By setting the inter-element space to $(3/8)\lambda$ in eight-element array, we can direct beam5 to the moving direction of the vehicle and beam3 to opposite of the moving direction (Fig.3(c)). Therefore, we can receive signals from all the directions only with other beams except beam4. In four-element array, this can be done when the inter-element space set to $\lambda/4$.

### 3.3 Despreading the Doppler frequency spread

In each beam, signals having nearly the same frequency shift are received. Accordingly,

by compensating each Doppler shift beam-by-beam, despreading of Doppler spread can be performed.

If $\lambda$ and $v$ are known factors, we can calculate the degree of Doppler frequency shift for each beam direction. Calculated Doppler shift canceling vector for eight-element array receiver is given by

$$\mathbf{P} = \left[ \begin{array}{c} \exp(-j2\pi \dfrac{v}{\lambda} \cos\theta_0), \exp(-j2\pi \dfrac{v}{\lambda} \cos\theta_1),. \\ ...., \exp(-j2\pi \dfrac{v}{\lambda} \cos\theta_{M-2}) \end{array} \right]^{T} \quad (7)$$

here $\theta_m$ denotes the beam direction of the $m^{th}$ beam. Then the despread beam signal vector, $\mathbf{X}$ can be given by

$$\mathbf{X} = diag\left[\mathbf{B}\right] \cdot \mathbf{P} \quad (8)$$

where $\mathbf{B}$ denotes the multi-beam signal vector given by

$$\mathbf{B} = \left[ B_0, B_1, \cdots, B_{\frac{M}{2}-1}, B_{\frac{M}{2}+1}, \cdots, B_{M-1} \right] \quad (9)$$

## 3.4 Maximal Ratio Combining (MRC)

After correcting the Doppler frequency shift of each beam signal, we demodulate and combine them using Maximal Ratio Combiner (MRC), independently for each sub-channel (Fig.2), to maximize the SN ratio of the combined signal.



(a)

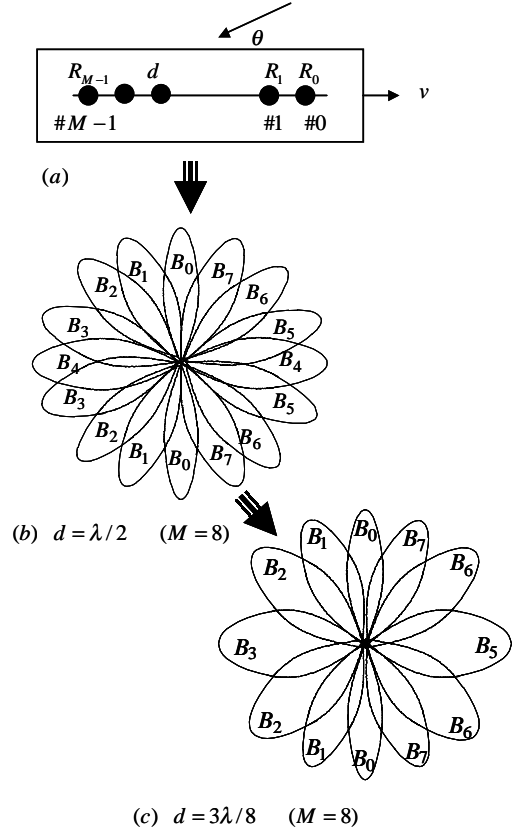(b) $d = \lambda/2$ $(M = 8)$

(c) $d = 3\lambda/8$ $(M = 8)$

Fig.3 Beam-Space Array Antenna in the mobile terminal (a) antenna arrangement (b) multi-beam pattern for $d = \lambda/2$, $M = 8$ (c) multi-beam pattern for $d = 3\lambda/8$, $M = 8$

When calculating the correlation matrix among the beam output signals for each sub-channel, we have taken the sliding average of past $Q$ samples in each sub-channel. Correlation matrix for $k^{th}$ sub-channel can be given by

$$\mathbf{R}_{xx}^{(k)}(t) = \frac{1}{Q} \sum_{i=0}^{Q-1} \mathbf{X}^{(k)}(t - iT_s)\mathbf{X}^{(k)H}(t - iT_s) \quad (10)$$

where $T_s$ denotes the OFDM symbol duration, and $\mathbf{X}^{(k)}(t - iT_s)$ denotes the $k^{th}$ sub-channel signal of past $i^{th}$ OFDM symbol of every beam and given by

$$\mathbf{X}^{(k)}(t - iT_s) = \left[ X_{(0)}^{(k)}(t - iT_s), X_{(1)}^{(k)}(t - iT_s), ...., X_{(M-2)}^{(k)}(t - iT_s) \right]^{T} \quad (11)$$

Then we carried out MRC by using the eigen vector $\mathbf{e}_{max}^{(k)}(t)$, for the maximum eigen value $\lambda_{max}^{(k)}(t)$, of the $\mathbf{R}_{xx}^{(k)}(t)$ as the weight vector for the $k^{th}$ sub-channel.

$$\mathbf{w}^{(k)}(t) = \mathbf{e}_{max}^{(k)}(t) \quad (12)$$

## 4. SIMULATION CONDITIONS AND RESULTS

We set the system parameters as shown in Table 1 and carried out the simulation to evaluate the performances of the proposed scheme. Table 2 shows the propagation environment assumed here. The performance is evaluated as a function of the number of elements and the number of past data considered when calculating $\mathbf{R}_{xx}^{(k)}(t)$. As a reference, we also have a result for simply adding multi-beam output without MRC.

Table 1 System parameters

| No. of bits transmitted | 100,000 |
|---|---|
| No. of sub-carriers $(N)$ | 128 |
| Symbol period $(T_s)$ | 1 ms |
| Modulation system | DQPSK |
| Guard interval | $4T$ |
| No. of elements of linear array antenna $(M)$ | 1,4,8 |

Fig. 4 shows how the bit error rate (BER) varies as a function of normalized Doppler frequency shift for various $Q$ and $M = 8$. The BER attains its least at $Q = 3$. It is noted that once BER declines with the addition of past data concerned, and then again BER increases with increasing the value of $Q$.

Table 2 Propagation environment

| path | angle | amplitude | SNR(dB) | delay |
|------|-------|-----------|---------|-------|
| 1 | 30° | 1.0 | 20.0 | 1$T$ |
| 2 | 45° | 1.0 | 20.0 | 2$T$ |
| 3 | 120° | 1.0 | 20.0 | 3$T$ |
| 4 | 235° | 1.0 | 20.0 | 5$T$ |
| 5 | 290° | 1.0 | 20.0 | 7$T$ |

Fig. 5 shows how the bit error rate varies as a function of normalized Doppler frequency shift for $M$ of 1,4 and 8, for both the systems where MRC ($Q = 3$) and simply adding is performed when combining the beam signals. Here we can see that the BER improves with the increasing of $M$. This signifies the possibility of beam-space array antenna to suppress the BER due to Doppler frequency spread. Further it is noted that applying of MRC improves the BER sharply.
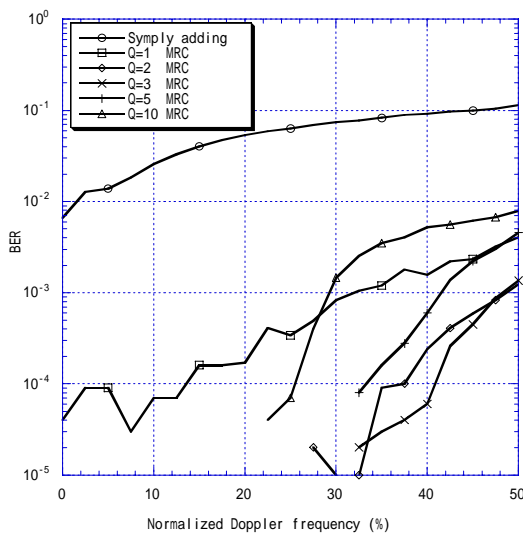


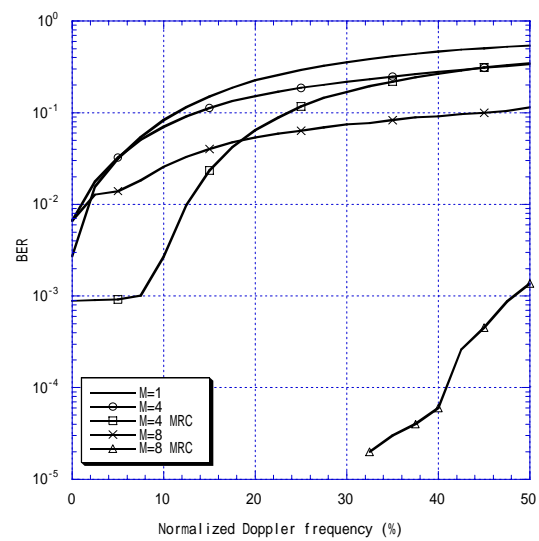Fig.4 BER as a function of normalized Doppler frequency shift for various $Q$ ($M = 8$)



Fig.5 BER as a function of normalized Doppler frequency for $M = 1,4,8$ and $Q = 3$

## 5. CONCLUTIONS

In this paper we have proposed to use beam-space array antenna for OFDM mobile reception. It was verified by computer simulation that the proposed system performs excellently to suppress the inter channel interference (ICI) due to the Doppler spread.

In the performance evaluation, we assumed a propagation condition around a mobile station where a number of multi-path waves come from omni-directional angles and have delay spreading, and adopted eight-element beam-space array antenna with element spacing of $(3/8)\lambda$.

Finally, we could gain a visible performance improvement in the system by implementing Maximal Ratio Combiner (MRC) to combine beam-spaced signals.

## REFERENCES
[1] T.Pollet, M. van Bladel, and M.Moeneclay, "BER sensitivity of OFDM systems to carrier frequency offset and Wiener phase noice," IEEE Trans. Communication, vol.43, pp.191-193, Feb./Mar./Apr. 1995.
[2] C. Muschallik, "Improving an OFDM reception using an adaptive Nyquist windowing," IEEE Trans. Consumer Electron, vol. 42, Aug. 1996.
[3] T. Wada, M. Okada, H. Yamamoto, "Adaptive Modulation with Fast Fading Compensation Using Space-Domain Interpolation Filtered Array Antenna," Technical report of IEICE, RCS 2000-158, Oct. 2000.