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Robust Digital Retrodirective Beamforming Technique for Multipath Channel Environment

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Abstract

In this paper, we describe the effect of temporal and spatial focusing obtained by using the digital retrodirective beamforming (DRDB) system and analyze BER performance of DRDB in multipath channel. There is a problem with reception performance degraded due to inter symbol interference (ISI) in multipath channel. In order to reduce ISI, the existing communication system use complex equalizer. In order to reduce ISI, we propose a DRDB system which can retransmit data information toward direction as the received signal without any prior information. Also, we explain ISI mitigation by temporal and spatial focusing of the proposed system. Simulation results show that the proposed system has better BER performance than that without DRDB because of ISI mitigation effect in multipath channel environment.

Keywords: Digital retrodirective beamforming; Retrodirective antenna; DRDB; Multipath channel

1. Introduction

Recently, the demand for high quality and large-capacity transmission is rapidly increasing in high speed mobile environment. As a result, recently, there are many researches on a new communication system enabling high-speed beam tracking and beamforming[1-3]. Retrodirective beamforming technique receives a lot of attention from as possible technology for high speed beam tracking and beam-forming.

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Analogue retrodirective beamforming has a merit that it can make beamforming without any prior location information[4-5]. Analogue retrodirective beamforming technique is able to do fast beam tracking because it does not require complex signal processing unlike smart antenna[6]. But, retrodirective beamforming technique is difficult to get additional signal processing gain and to system upgrade and modified because analogue retrodirective beamforming scheme is only configured using the passive elements. To solve these problems, digital retrodirective beam-forming technique is proposed[7]. Digital retrodirective techniques use simple digital signal processing method for phase conjugation. Reception performance is degraded caused by inter symbol interference (ISI) due to multipath channel effect. Therefore, research for reception performance enhancement is needed in multipath channel environment. Generally, Equalizer is used for ISI elimination in single carrier system[8]. But, complexity of communication system increases. Thus researches on receive performance improvements without equalizer in multipath channel environment are noted.

Many experiments have shown that retrodirective beamforming techniques can obtain improved reception performance in multipath channel[9,10]. Retrodirective beamforming can retransmit data information toward direction of the received signal without location information.

In this paper, we analyze the spatial and temporal focusing effect of DRDB in a multipath channel environment. Also, we discuss on reception gain by DRDB in the multipath environment. We explain the digital retrodirective beamforming and multipath channel environment in chapter 2 and 3. Then, chapter 4 shows theoretical analysis of the benefits by using DRDB under multipath channel. Simulation and conclusion is in chapter 5 and 6.

2. Digital Retrodirective Beamforming

Figure 1 shows principle of retrodirective antenna. Phase delay φ_1 occurs by time delay τ_1 between first element and second element when incident angle is θ. If the distance d between each of elements is same, phase delay of adjacent element is given by

$$\triangle \quad \frac{d}{c}\sin\theta \tag{1}$$

where f_c is carrier frequency, c is light speed, θ is incident angle. Retrodirective beamforming must estimate the phase delay $\Delta\varphi$. It set phase conjugation as $-\Delta\varphi$ for retransmission steering into source.

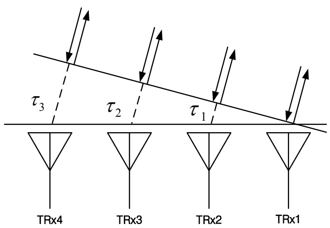

Fig. 1. Principle of retrodirective antenna.

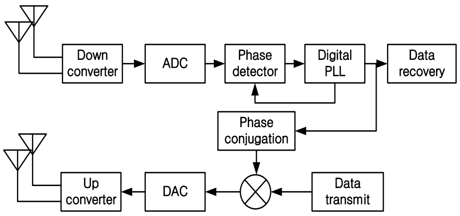

Fig. 2. Digital retrodirective beamforming.

Fig. 2 shows block diagram of DRDB system. Digital retrodirective beamforming technique set phase detection and phase conjugation by using digital signal processing. Digital PLL (phase lock loop) is used for constantly fixed to 0 degrees to the phase of the received signal through a first element.

3. Multipath Channel

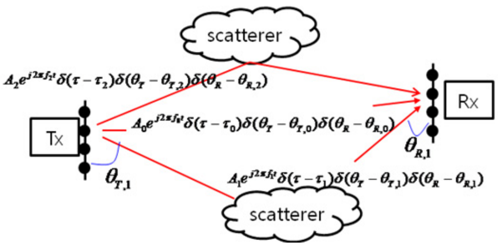

Fig. 3. Multipath channel environment.

Fig. 3 is multipath channel environment. A_i is path attenuation coefficient, τ_i is path delay, f_i is Doppler frequency, $\theta_{T,i}$ and $\theta_{R,i}$ are transmission and reception angle of transceiver in Fig. 3. In wireless communications, multipath channel is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths. The ISI due to multipath channel can result for errors and affect the quality of communications. ISI due to multipath channel effect worsens the quality of the reception performance.

3.1. Uncorrelated channel

The channel coefficient H in multiple array antennas with M-th transmitter and N-th receiver is given by

$$H = \Theta_R^{1/2} A_{iid} \Theta_T^{1/2} \tag{2}$$

where $\Theta_R^{1/2}$ is correlation matrix between the receiver antennas, $\Theta_T^{1/2}$ is correlation matrix between the transmitter antennas, A_{iid} is independent identically distributed Rayleigh channel. We assume that correlation matrix of transceiver can be divided when the spacing between elements is sufficiently smaller than distance from transmitter to receiver. The correlation channel H between M-th transmitter and N-th receiver is M x N matrix.

3.2. Correlated channel

The coefficient of correlated channel can be obtained by multiplying the uncorrelated channel as the following equation.

$$\tilde{A} = \sqrt{P_l C a_l} \tag{3}$$

where P_l is average power of l -th path, C is spatial correlation matrix, and uncorrelated channel vector is $a_l = [a_1^{(l)}, a_2^{(l)}, \cdots$ $\overset{r}{}_{MN\times 1}$. At this time, $E[| a_x^l |^2]$ is 1.

Correlation matrix of channel is given by

$$R \begin{cases} R_{TX} \otimes R_{RX} \\ R_{RX} \otimes R_{TX} \end{cases} \tag{4}$$

where $\otimes$ is Kronecker product, root power correlation matrix T using R is given by

$$\Gamma = \begin{cases} \sqrt{R}, \textit{for field type} \\ R, \textit{for complex type} \end{cases} \tag{5}$$

$\tilde{A}$ is correlated fading channel coefficients as following equation.

$$\tilde{A} = [a_{11}^{l}, a_{21}^{l}, \cdots \quad {}_{N}]_{MN}^{1} \tag{6}$$

4. Digital Retrodirective Beamforming in Multipath Channel

When the transmitter sent data signal s_n, received signal y_n at the DRDB is given by

$$y_n(t) = h(z)s(t) + n(t) \tag{7}$$

where $h(z) = \sum_{k=0}^{L-1} h_k \delta(z-k)$ is impulse response, h_k is channel coefficient as k-th path, s(t) is transmission signal, and n(t) is additive white Gaussian noise (AWGN).

If tap delay L of channel is 3, received signal at the DRDB is given by

$$y_n = h_0 s_n + h_1 s_{n-1} + h_2 s_{n-2} \tag{8}$$

where h_0, h_1, h_2 is the first, second, and third complex channel gain respectively. Channel coefficients have Rayleigh distribution, and $\sum_{l=0}^{L-1} E[|h|^2] = 1$.

After phase conjugation at the DRDB, DRDB retransmit to source. Retransmission data y_n^* is transmitted to source.

Received signal at the source is given by

$$\begin{aligned} z_n &= h_0 y_{n-2}^* + h_1 y_{n-1}^* + h_2 y_n^* \\ &= R(0)s_{n-2}^* + R(1)s_{n-1}^* + R(1)^* s_{n-3}^* + R(2)s_n^* + R^*(2)s_{n-4}^* \end{aligned} \tag{9}$$

where $R(\tau)$ is instantaneous correlation function (ICF).
After pass through DRDB, retransmission signal $y_{n-2}^*, y_{n-1}^*, y_n^*$ take effect of conjugation and time reversal effect. ICF is given by

$$R(\tau) = h_i h_{i-\tau} \tag{10}$$

If channel delay L is 3,

$$\begin{aligned} R(0) &= |h_0|^2 + |h_1|^2 + |h_2|^2 \\ R(1) &= h_1 h_0^* + h_2 h_1^* \\ R(2) &= h_2 h_0^* \end{aligned} \tag{11}$$

Convolution and time reversal in the time domain is represented by the multiplication and phase conjugation in frequency domain. Therefore, we will get the temporal and spatially focusing because time reversal and conjugation is generated by the DRDB system. The retransmission signal from retrodirective antenna to source will be concentrated in the direction of the source in space.

5. Simulation Results

In this paper, we analyze ISI mitigation by DRDB technique in multipath channel environment. We assume that channel coefficient is not change during round trip.

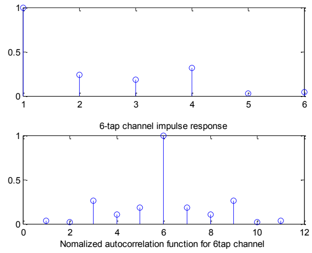

Fig. 4. Channel coefficient and autocorrelation.

Fig. 4 shows channel impulse response and autocorrelation of channel. When data signal is retransmitted using DRDB to the source, channel effect at the source like the autocorrelation of the channel response. These characteristics are obtained as retrodirective beamforming technique with time reversal and conjugation.

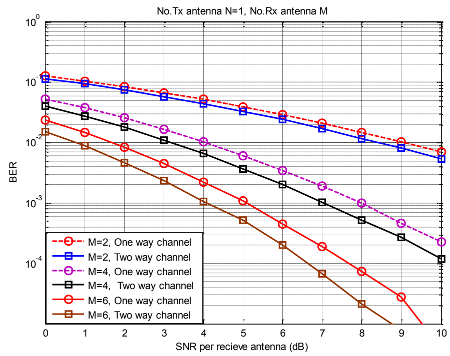

Fig. 5. Comparison of BER performance in uncorrelated channel.

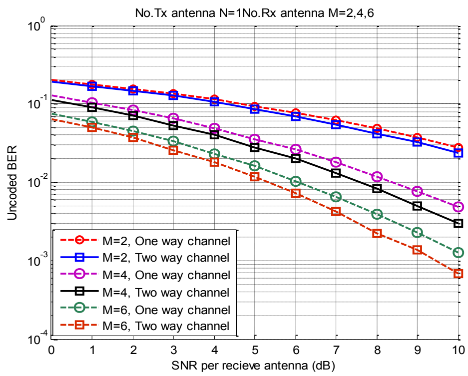

Fig. 6. Comparison of BER performance in correlated channel.

Fig. 5 shows comparison of bit error rate (BER) performance in uncorrelated channel. One way channel is from source to DRDB. The two way channel is round trip from source through DRDB to source. We confirm that reception performance is improved as the number of receiver elements increases because of the array gain. DRDB system has a reception performance like maximum ratio combine at the source without complexity signal processing. The proposed system is possible to concentrate signal spatially by retransmit a signal toward source. These effects are similar to path diversity. As a result, the two way channel has a better BER performance than one way channel because of temporal focusing DRDB.

Fig. 6 shows comparison of BER performance in correlated channel. We have changed the MIMO channel environment using the SUI channel model. Since spatial correlation coefficients p are real number, we can be obtained C using square root decomposition. Antenna correlation is [p=0.7/0.5/0.4/0.3/0.5/0.3]. We confirm that system has better BER performance in uncorrelated channel than that in correlated channel. BER performance is degraded in correlated fading channel. We show that BER performance is improved when the number of antenna elements is increase. The two way channel has better BER performance than one way channel because digital retrodirective beam-forming system has ISI mitigation effect.

6. Conclusions

In this paper, we analyze the ISI mitigation effect using digital retrodirective beamforming in multipath channel environment. Retrodirective beamforming system send data signal to concentrate as spatially and temporally. When the signal is received by using DRDB technique, return channel has autocorrelation characteristics of channel. ISI is mitigated due to autocorrelation characteristics of channel. When digital retrodirective beamforming system uses, we can get the reception performance improvement without equalizer because of reduction of ISI effect. Also, DRDB has characteristic of temporal and spatial focusing.

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