Design and Mobile Tracking Performance of a Retro-Directive Array (RDA) Antenna System

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Abstract. Beamforming is one of the most important technologies for wireless communication systems. A beamforming antenna system can control the radiation beam pattern and thus can reduce power consumption, compared with an omni-direction antenna system. In general, the digital beamforming technology requires a complex control system. However, a digital RDA (retro-directive array) antenna system has very small calculation load and its configuration is quite simple as it transmits to a receiving direction without prior information, and simply needs to estimate the phase from an incident. Thus, a RDA antenna system can reduce the system complexity and power consumption, and improve system performance. In this paper, we describe the structure of a digital RDA system and investigate the beam tracking performance of a digital RDA system. It is shown through simulation results that a digital RDA system can effectively improve the beam tracking performance when a target receiver is moving. The mean beam tracking error can reach 1.9° when the SNR is 10 dB and 0.6° when the SNR is 20 dB.

Keywords: Retro-directive array · RDA · Beam tracking

1 Introduction

With the emergence of many moving-terminal applications, such as an unmanned aerial vehicle (UAV) cellular system [1], there is an increasing demand for tracking high-speed signals between a transmitter and a receiver. Beamforming is an effective technology for controlling the propagation direction and the receipt of RF signals. A beamforming antenna system can control the radiation beam pattern and thus can reduce power consumption, compared with an omni-direction antenna system. In general, the digital beamforming technology requires a complex control system. However, a digital RDA (retro-directive array) antenna system has very small calculation load and its configuration is quite simple as it transmits to a receiving direction without prior information, and simply needs to estimate the phase from an incident. Thus, an RDA antenna system can reduce the system complexity and power consumption, and improve system performance [2, 3]. Beamforming techniques can be divided into digital beamforming antenna techniques and analog beamforming antenna techniques. In general, digital beamforming can reduce the synchronization and power

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consumption problems and thus has received more attention [4, 5]. In this paper, we investigate the beam tracking performance of a digital RDA system based on simulation experiments. Through simulation results, we show that a digital RDA system can effectively improve the beam tracking performance when a target receiver is moving in terms of the mean beam tracking error.

The remainder of this paper is organized as follows. In Sect. 2, we introduce the structure of a digital RDA system. In Sect. 3, we describe the system model used in the simulation experiments. In Sect. 4, we show simulation results. In Sect. 5, we conclude this paper.

2 Digital RDA

An RDA (retro-directive array) system is based on a transmission technique that transmits a signal in a receiving direction with an incident angle without any prior direction information, which is quite different from the conventional beamforming techniques. Thus, an RDA system can have faster response with low latency than an omni-direction antenna, and has many other advantages, including battery life extension and so on.

Figure 1 shows an RDA element array. In the array, each antenna element transmits and receives a signal independently [6]. If each antenna transmits an incident signal that has an incident angle θ, the phase delay of the received signal will show $\Delta\varphi$. Thus, $\Delta\varphi$ can be written as

$$\Delta\phi = \frac{2\pi fd \sin\theta}{c} \tag{1}$$

where f denotes the frequency, θ denotes the angle of incidence, d denotes the distance between the antenna and another antenna, and c denotes the speed of light.

In an RDA system, random data are first generated and modulated. After modulation, data are divided into two antenna arrays and are transmitted. Then, the signal passes through an AWGN channel and adds phase delay by the angle of incidence and

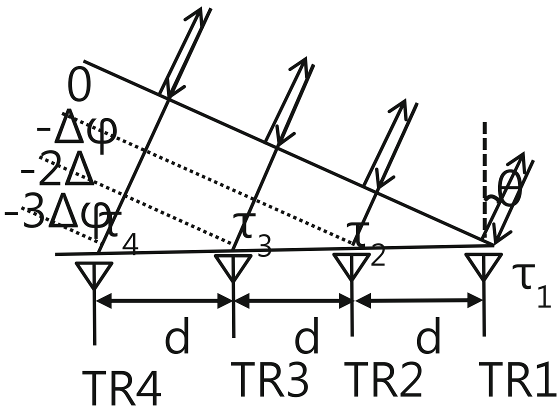

Fig. 1. Illustration of a retro-directive array antenna.

the distance between the antennas. After passing the channel, the phase detector estimates the phase delay and compensates the difference of the phase delay from the received signal. The estimated phase information is stabilized by digital PLL (phase lock loop).

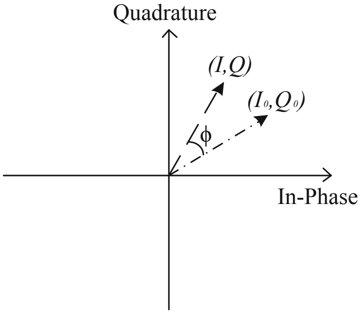

Fig. 2. Phase difference of a reference symbol and the received symbol.

When using the array antenna, the received phase delay is different for each array each antenna. A reverse directional antenna system is a system that returns to the original signal by 180° rotation of the phase delay by calculating the phase delay. Figure 2 illustrates how to handle the phase estimator to determine (I_0, Q_0) of a standard signal that is received the first element. The standard signal estimates the phase difference compared with the input signal. When using a modulation signal of 4-QAM or QPSK, the magnitude of the standard signal is 1.414 and can be expressed as

$$\begin{aligned} e^{j\varphi} &= \cos\varphi + j\sin\varphi = e^{j(\varphi' - \varphi_0)} \\ &= \frac{e^{j\varphi'}}{e^{j\varphi_0}} = \frac{\sqrt{I_0^2 + Q_0^2}}{\sqrt{I^2 + Q^2}} \cdot \frac{I + jQ}{I_0 + jQ_0} \\ &= \frac{\sqrt{2}}{\sqrt{I^2 + Q^2}} \cdot \frac{II_0 + QQ_0 + j(I_0Q - IQ_0)}{2} \end{aligned} \tag{2}$$

Generally, due to $|\varphi| \leq 20°$, φ can be approximated as follows

$$\varphi \approx \sin\varphi = \frac{1}{\sqrt{2(I^2 + Q^2)}} \cdot (I_0Q - IQ_0) \tag{3}$$

where $\frac{1}{\sqrt{2(I^2+Q^2)}}$ can compensate using AGC (Auto Gain Control). Thus, the phase delay can be approximated as

$$\varphi = I_0Q - IQ_0 \tag{4}$$

3 System Model for Simulation

To evaluate the beam tracking performance of a digital RDA system, we perform simulation experiments using a Simulink System.

Figure 3 shows the beamforming for a mobile user in a circle track and a line track, respectively, where V is constant velocity, L is the linear distance between a transmitter and a receiver, and θ is AOA (angle of arrival), which is the directivity angle of the bean in space. In the simulation experiments, with reference to the speed of the fastest high-speed train in Korea, V is set to 300 km/h. It is an environment which considers the Doppler frequency. The angle changes for the beamforming to a target user in the circle track and the line track are, respectively, given by

$$\theta = (\frac{360}{2\pi L} Vt) \tag{5}$$

$$\theta = \tan(\frac{Vt}{L} - \tan\theta_0) \tag{6}$$

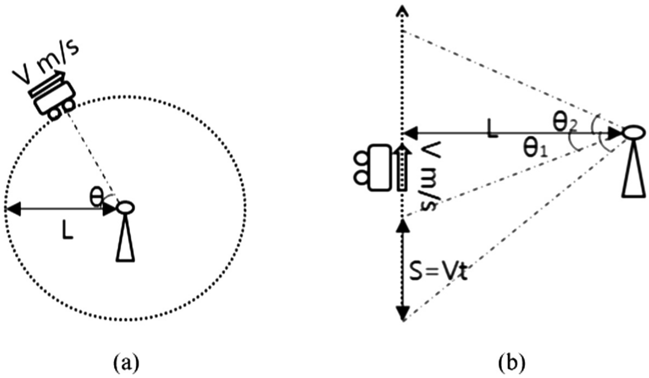

Fig. 3. Beamforming for a mobile user in circle and line tracks.

Figure 4 shows a block diagram constructed on the basis of the Simulink simulator software. The theta box, AOA changes along the moving path is generated from the Tracking model box, which determines the phase delay of the receiving antenna. RDA system configuration, and this time, insert it in the channel Doppler frequency is considered. At this time, to compare or track better AOA generated in the tracking model, the phase and RDA system is tracked.

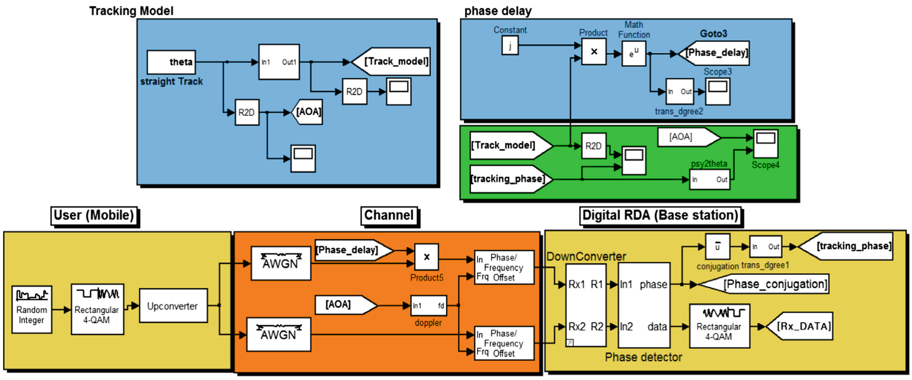

Fig. 4. The block diagram on the basis of the Simulink simulator software.

4 Simulation Results

In the experiments, it is assumed that fast-moving objects move in a straight line. In this case, when a mobile user moves in a straight line track, the expression changes can be each AOA to arrive or each of the received signals of θ.

Figures 5 and 6 show the beam tracking performance of the digital RDA system at each SNR 10 dB and 20 dB, respectively. It is seen that the mean beam tracking error is 1.9° when SNR is 10 dB and 0.6° when SNR is 20 dB.

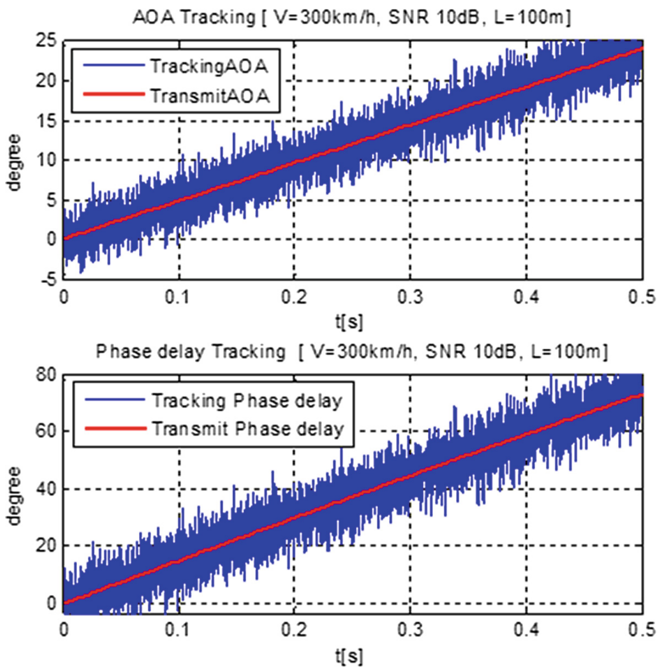

Fig. 5. Comparison of fast tracking performance at SNR = 10 dB.

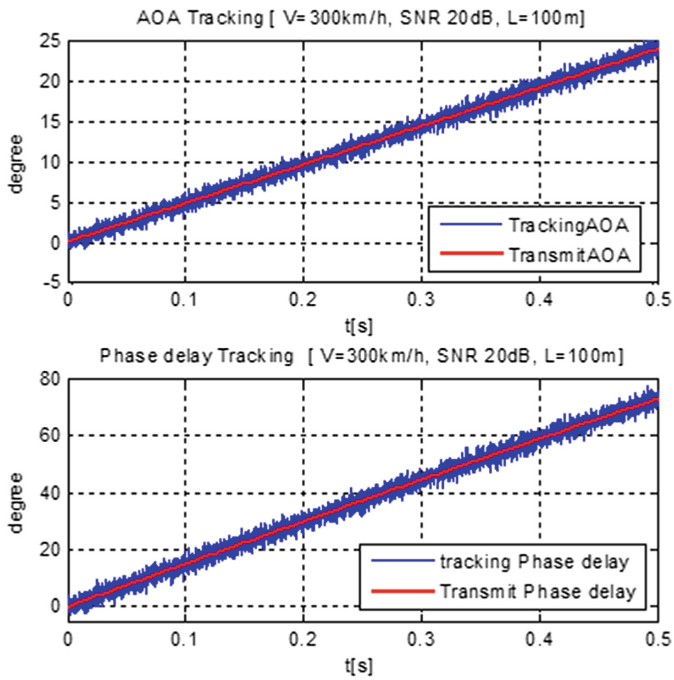

Fig. 6. Comparison of fast tracking performance in multipath environment at SNR = 20 dB.

5 Simulation Results

In this paper, we investigated the high-speed beam tracking performance of a digital RDA system based on simulation experiments. Depending on the number of array antennas and SNR requirement, the range of an error changes and is adjustable to the tolerable limit. It is shown that a digital RDA system can effectively improve the beam tracking performance when a target receiver is moving in terms of the mean beam tracking error. The error of AOA is 0.6° when SNR is 20 dB and the number of array antenna is 8. Even though these are the simulation results by Simulink, we can observe that the digital RDA system is of high-speed tracking performance in real time with acceptable accuracy tolerance. Moreover, an RDA system may become an promising technology in future high capacity communication and high speed mobile communication.

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