Performance Assessment of Adaptive AF Relay with Active Antenna System and Angle Estimation Strategy

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***Abstract*—The adaptive AF relay combined with the active antenna system (AAS) and angle estimation strategy is studied in this paper. To improve the system performance, we introduce the AAS scheme into AF relay. Meanwhile, we also propose a joint AAS relay (JAR) angle estimation strategy to obtain the useful horizontal angle information. Results show that, in the temporary cover or emergency communication scene, the adaptive AF relay with AAS helps to improve the system performance gain effectively and also enhance the robustness stably.**

Keywords*—*Adaptive AF Relay; Active Antenna System; Angle Estimation Strategy

I. INTRODUCTION

Fixed relay system is an effective solution to enlarge the coverage of system and it's already widely used to improve the quality of communication. However, in the temporary cover or emergency communication scene, the position of relay may change constantly and it takes a big challenge for fixed relay system. In these dynamic cases, the constant change of angle results in that operators can't fix the relay antennas for maximum gain. Although omni-directional antenna radiate and receive signal equally in all directions(360°), it also limits spectral efficiency and frequency reuse [1]. And it's also found that Active Antenna System (AAS) is a good solution to solve the limitation of omni-directional antennas[1]. AAS is such a smart directional antenna system for wireless networks that it transmits and receives signals in an adaptive manner [1][2]. Because AAS automatically changes the direction of transmit/receive beam pattern, it is always used to control the antenna pattern actively due to the real angle.

Currently, some relevant researches on this promising technology are carried out, and also there is a certain outcome in this field. The performance of active antenna arrays for mobile communication base stations are analyzed in [3] and the accuracy of their system can be good enough to fulfill the required accuracy to build active antenna arrays. Design of a VHF/UHF/L-Band low-power active antenna for mobile handsets is also achieved in [4]. [5] studies the impact of both vertical and horizontal beamforming on LTE system performance using AAS, and [6] shows the performance evaluation on coexistence of LTE with AAS. All of these results point that it's feasible to use AAS for the communication networks and AAS can improve the direct link system performance such as BER, capacity etc effectively. However, they just assess the performance of direct link system between BS and MS by using the AAS technology. In the field of relay system it is seldom studied. Actually, on one hand, it costs much more money and time to deploy AAS for the existed BS and MS than RS. On the other hand, in the temporary cover or emergency communication scene, because the angle information change constantly, the adaptive relay system with AAS plays much greater role than the direct link communication system in the real networks. Thus, in order to improve the performance of communication system effectively, operators prefer to adopt the adaptive relay with AAS due to its low cost and high flexibility. Therefore, it's necessary to study the adaptive relay with AAS, and it's also valuable to assess the performance of adaptive relay with AAS.

In order to solve the problems in the temporary cover or emergency communication scene, we propose an adaptive relay system combined the adaptive AAS scheme and the real-time angle estimation algorithm in this paper. We first analyze the effect of angle information on communication system, so that we find a feasible model contained both the relay networks and antenna angle information. And then based on the AF relay model with angle information, we propose a joint AAS relay (JAR) angle estimation strategy to obtain the useful angle information. Finally, according to this proposed relay system and the model of antenna array, we make a comparative analysis on the performance gain in a few different systems and prove that in the dynamic environment, the relay with AAS not only adaptively selects the direction of maximum antenna gain, but also improves the communication performance effectively.

The rest of this paper is organized as follows. In Section II, the model of AF relay with horizontal angle information is introduced. In Section III, we investigate the improved estimation strategy to obtain the angle information. Based on the model of antenna pattern and the control of maximum

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antenna array gain, simulation results are presented in Section IV. And the paper concludes with Section V.

II. AF Relay Model with Antenna Angle Information

According to the antenna pattern, as the horizontal angle is different, both the transmitted and received antenna gain are apparently different. Fig. 1 illustrates the simplest possible relay network with different horizontal angle information. The rings represent the antenna pattern and the arrows stand for the horizontal direction of maximum gain.

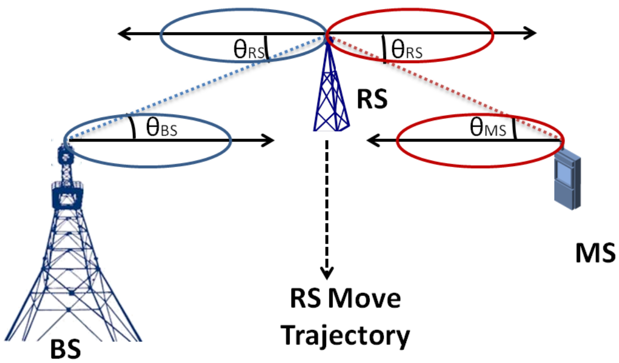


Fig. 1. the Model of Relay with Antenna Angle Information

The BS transmits the signal x and the received signal $y_{RS}(t)$ at the RS is

$$y_{BS-RS}(t) = \sqrt{P_{BS}} h_{BS-RS}(t) x + n_R \quad (1)$$

where P_{BS} denotes the average signal energy from BS and h_{BS-RS} is the radio channel between BS and RS. n_R is the additive white Gaussian noise at the relay with zero mean and variance $\sigma_{n_R}^2$.

In amplify and forward mode, the RS amplifies the received signal and forwards it to the MS. The received signal $y_{MS}(t)$ at the MS is

$$y_{MS}(t) = \sqrt{P_{BS}} h_{BS-MS}(t) x + \alpha_{amp} h_{RS-MS}(t) y_{BS-RS}(t) + n_D \quad (2)$$

where α_{amp} denotes the amplification factor by AF RS and h_{BS-MS}, h_{RS-MS} represents the radio channel between BS and MS, RS and MS respectively. n_D is the additive white Gaussian noise at the relay with zero mean and variance $\sigma_{n_D}^2$.

According to the Clause 5.4 and Clause 5.5.3 in [7] (pages: 22-27), we just take large scale fading into consideration without MIMO and multipath. So that we can analyze the effect of antenna angle on relay performance effectively. And we can obtain the channel coefficients from BS to MS, BS to RS, and RS to MS respectively.

$$h_{BS-MS}(t) = \sigma_{SF}\left(\sqrt{G_{BS}(\theta_{BS})}\sqrt{G_{MS}(\theta_{MS})}\exp(\Phi_{LOS})\exp(jk\|v\|\cos(\theta_{MS}-\theta_v))\right) \quad (3)$$

$$h_{BS-RS}(t) = \sigma_{SF}\left(\sqrt{G_{BS}(\theta_{BS})}\sqrt{G_{RS}(\theta_{RS})}\exp(\Phi_{LOS})\exp(jk\|v\|\cos(\theta_{RS}-\theta_v))\right) \quad (4)$$

$$h_{RS-MS}(t) = \sigma_{SF}\left(\sqrt{G_{RS}(\theta_{RS})}\sqrt{G_{MS}(\theta_{MS})}\exp(\Phi_{LOS})\exp(jk\|v\|\cos(\theta_{MS}-\theta_v))\right) \quad (5)$$

where θ_{BS}, θ_{RS}, θ_{MS} are the useful angle information as shown in Fig.1. And G_{BS}, G_{RS}, G_{MS} are the horizontal antenna patterns impacted by angle information.

σ_{SF} is the lognormal shadow fading.

Φ_{LOS} is the phase of the LOS component.

v is velocity vector.

θ_v is the angle of the velocity vector with respect to the broadside.

All of these above are the basic theory to generate the relay model with horizontal antenna angle information. Therefore they guide us to analyze and assess the performance gain of adaptive AF relay with AAS.

III. The Strategy of Obtaining Angle Information

In section II, we obtain the model of AF relay with the horizontal angle information. However, another problem comes to us that is how we can obtain the useful horizontal angle information effectively in real-time.

In fact, we can get the horizontal angle information by the angle of arrival (AoA) estimation. [8] studies that the fast beam pattern switching-time is on the order of ns in the high frequency band. That's the premise of most AoA estimation algorithms.

Based on the power measurement of the pilot tone, [9][10][11] propose some AoA algorithms for direct link system with some special switched-beam directional antenna. But angle estimation strategy for AAS relay system with antenna array units is not studied yet. Therefore, in the paper, we propose a simple joint AAS relay (JAR) angle estimation strategy to obtain the angle information.

A. *Some Concepts of Strategy*

Before we describe the strategy, let us define some concept in the strategy.

Position tone is the pilot tone with position information in the head of each frame.

A cycle is the period consisted of 100 frames (as an example).

Threshold power P_{th} is the basic level to keep the system performance.

Omni-tracking represents that AAS tracks for the target in all direction (360 degree) as shown in Fig. 2.

Area-tracking represents that AAS just tracks for the target in the limited direction as shown in Fig. 3.

Lost-tracking represents that the target power is lower than the threshold power.

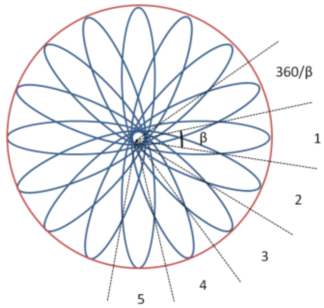


Fig. 2. Onmi-tracking

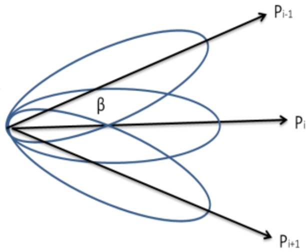


Fig.3. Area-tracking

B. *Description of Strategy*

Assuming the synchronous state is achieved among BS, MS and RS, in the first frame head of each cycle period, the AAS at RS tracks the position tone in all direction and find the maximum power as the target direction.

As shown in Fig. 2， because the beam pattern switching-time is on the order of ns[8], during the period of position tone, we have enough time to switch beam pattern in 360 degree and track for the maximum power. The beam pattern is switched β degree each time and $\beta \le \theta_{3dB}$. θ_{3dB} is the 3dB beamwidth in degrees.

If this maximum power is higher than the threshold, in next frame head, AAS enters into area-tracking. Otherwise, it changes into lost-tracking in this frame and then keep omni-tracking in the next frame.

TABLE 1. Angle Estimation Strategy

(1) Start with M=1, P= P_{th}， θ=0: *Here M is the frame number in one cycle, and θ is the original target direction.* (2) Frame-detection: *if M==1or M==100* *M<=1;* *go to (3);* *else* *go to (4);* *end if;* (3) Onmi-tracking: *for* $step = 1{:}1{:}360^0/\beta$ *if p(step)>P* *p<=p(step);* $\theta <= \beta \times step$; *end if;* *end;* *go to (5);*	(4) Area-tracking: $\rho = (P_{i-1} - P_i) - (P_{i+1} + P_i)$; *if* $\rho > 0$ $\theta <= \theta - \beta$; *else if* $\rho < 0$ $\theta <= \theta + \beta$; *else* $\theta <= \theta$; *end if;* *go to (5);* (5) Power-judgement *if P< P_{th}* *M<=1;* *else* *M<=M+1;* *end if;* *return to (2);*

Except omni-tracking and lost-tracking, in the rest of this cycle period, the AAS at RS just tracks the position tone in the limited area direction as area-tracking.

As shown in Fig. 3, due to the accurate position of onmi-tracking, since the RS is mobile, the next target position should be near the last position. Therefore, it’s not necessary to track in all direction. Just tracking around the limited area near the last target position, it’s highly effective and efficient. Here, we define a parameter ρ

$$\rho = (P_{i-1} - P_i) - (P_{i+1} + P_i) \tag{6}$$

If $\rho < 0$, the target position is the direction of P_{i+1}.

If $\rho = 0$, the target position doesn’t change.

If $\rho > 0$, the target position is the direction of P_{i-1}.

Finally, if the received power is lower than threshold, this cycle finishes and next cycle starts instead. And then, AAS at RS follows this algorithm again as shown in TABEL 1.

IV. Simulation and Analysis Results

After the horizontal angle information is obtained, we investigate the way to establish the antenna model and try to obtain the maximum antenna gain. Then, according to the target horizontal angle information, by controlling the direction of maximum antenna gain, we assess the performance of adaptive AF relay with AAS. Simulation is based on BPSK for the line-of-sight (LOS) model in the urban micro scenario. Analysis and results are about the comparison among different system performance with or without AAS.

A. *Establishing the Model of Antenna*

We establish the model of antenna with the help of mesh generator in matlab PDE tools or we use the Delaunay function in matlab to construct antenna by triangulation as the examples [12][13]. This method of antenna model is called RWG (Rao-Wilton-Glisson).

Loading the model of antenna, we obtain the electric field equation and the magnetic field equation [14] (pages: 134-135) as

$$\vec{E}(\vec{r}) = \sum_{m=1}^{M} \vec{E}_m [\vec{r} - \frac{1}{2}(\vec{r}_m^{\,c+} + \vec{r}_m^{\,c-})] \tag{7}$$

$$\vec{H}(\vec{r}) = \sum_{m=1}^{M} \vec{H}_m [\vec{r} - \frac{1}{2}(\vec{r}_m^{\,c+} + \vec{r}_m^{\,c-})] \tag{8}$$

Thus, the average radiation power at a certain point in a given unit of area is the Poynting vector [14] (pages: 35-37) as

$$\vec{W}(\vec{r}) = \frac{1}{2}\mathrm{Re}(\vec{E}(r) \times \vec{H}^*(r)) \tag{9}$$

With Eq. (9), we get the radiation intensity [14] (pages: 38) as

$$U = r^2 W \tag{10}$$

And the normalization factor is

$$U_0 = \frac{P_{rad}}{4\pi} \tag{11}$$

where P_{rad} is the total radiation power.

Antenna gain [14] (pages: 58-60) is obtained as

$$G = 10\log_{10}\frac{\max(U)}{U_0} \tag{12}$$

B. Controlling the Direction of Antenna Arrays

According to the theory of basic antenna, when the size of antenna is much larger than wavelength, we get strong radiation direction. Obviously, it's very expensive to manufacture this kind of antenna, and the deployment of antenna is too hard. Therefore, a better solution is to use the arrays with some small simple units like dipoles or monopoles. With appropriate distribution and feed, antenna arrays obtain the strong direction. Meanwhile, it's much more convenient and more accurate to control the maximum antenna pattern gain than traditional mechanical orientation.

There are four main factors to improve the antenna gain. First is the geometric structure of antenna arrays. In this paper, we use the line arrays model. Second is the number of the antenna units. With the increase of unit number, the antenna gain increases but the 3dB beam width decreases. To obtain the nearly ideal degree range for 3dB beam width, we establish antenna arrays consisted of 4 dipoles. Third is the distance among antenna units. The general rule[15] points that the distance among units should be shorter than half wavelength to avoid side lobe. Last is the phase of voltage feed. According to the theory of phased(scanning) array[16], when

$$\psi = kd\cos\varphi_0 + \delta = 0 \tag{13}$$

we get the maximum gain of antenna array.

where $k = \frac{2\pi}{\lambda}$, and

d is the distance between two adjacent units.

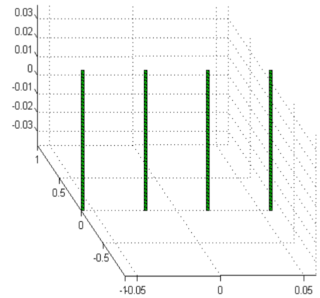
φ_0 is the expected direction of maximum gain.

δ is the step phase difference between two adjacent units.

Supposing the angle information φ_0 is known at RS, we just control the step phase difference δ between every two adjacent units, so that we can make the maximum gain in the direction φ_0 we expect. Therefore, the step phase difference is

$$\delta = -kd\cos\varphi_0 \tag{14}$$

By controlling the step phase difference δ, we obtain the expected direction of maximum antenna gain.



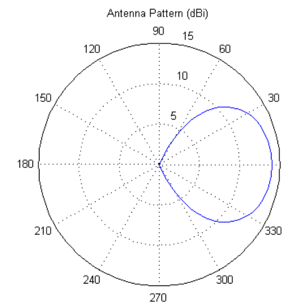


Fig. 4. Antenna Array   Fig. 5. Antenna Pattern

Though the above steps, with matlab, the model of antenna array is shown in Fig. 4 and the antenna pattern is Fig. 5.

C. Analysis and Results

According to [7] (pages: 8-11), the antenna pattern $A(\theta)$ is specified by

$$A(\theta) = -\min(12(\frac{\theta}{\theta_{3dB}})^2, A_m) \tag{15}$$

where $-180^0 < \theta < +180^0$, and

θ is defined as the angle between the direction of interest and the boresight of the antenna.

θ_{3dB} is the 3dB beamwidth in degrees.

A_m is the maximum attenuation.

According to the steps of Part B., we establish the model of antenna array and obtain the antenna pattern as shown in Fig. 6.

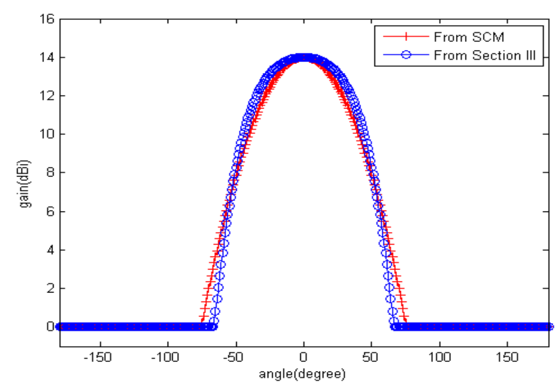


Fig. 6. the Antenna Pattern of Arrays

Compared to the antenna pattern from Eq. (15), it's proved that our antenna array model fits the spatial channel model mentioned in section II.

In the communication system, we assume that the position of BS is at the origin point. Suppose East is the 0 degrees azimuth and it's also the direction of maximum antenna gain. North is the -90 degrees. RS moves from -60 degree to 0 degree.

Based on Monte Carlo approach, combining with the AF relay model of angle information and the array model of antenna pattern, we simulate the performance of some typical communication system in the scenario of large scale fading and LOS. Some important parameters are shown as Table 2.

TABLE 2. Some Parameters of Simulation

Parameter	Value
Channel Model	SCM ,Urban Macro
Carrier frequency	2000MHz
BS transmit power	47dBm
Maximum Antenna Gain	14dBi
Noise figure at MS	7dB
Modulation	BPSK
Distance between BS and MS	200m

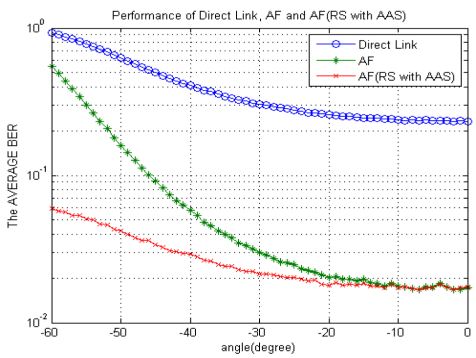


Fig. 7. Average BER of Direct Link, AF and AF with RS-AAS

As shown in Fig. 7, in the scenario of mobile RS, as the angle changes from -60 degree to 0 degree, the average BER of direct link system rises. The AF is certainly better than direct link system, but the angle information still affects the average BER of AF. Without AAS in system, the larger the angle is, the worse the performance is. However, the performance of AF with AAS maintains more stable in this whole process and the average BER is much lower than traditional AF. When the angle approaches to 0 degree, the performance of AF is almost as the same as the performance of AF with AAS.

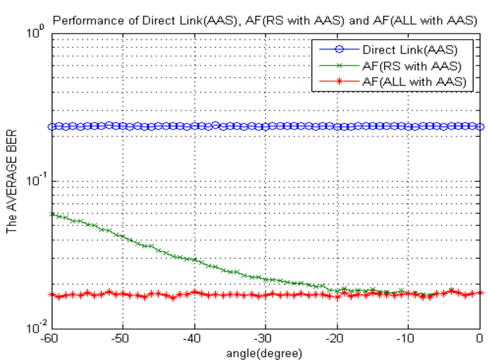


Fig. 8. Average BER of Direct Link with AAS, AF with RS-AAS and AF with All-AAS

Suppose that the deployment of AAS can also implement in BS and MS with low cost. In Fig. 8, it shows that in any scenario of communication system with AAS, the average BER keeps smooth, especially when the whole communication system use AAS. And the performance of AF with All-AAS is certainly better than the one of AF with RS-AAS only.

V. CONCLUSIONS

In order to solve the problems caused by switched angle information in the temporary cover or emergency communication scene, we propose an adaptive relay system combined the AAS scheme and the real-time angle estimation strategy. On one hand, we introduce the AAS scheme into the AF relay to improve the performance. Results show that with the help of AAS, the AF system is greatly improved and the performance keeps stable in dynamic environment. On the other hand, we propose a joint AAS relay (JAR) angle estimation strategy. It helps to obtain useful angle information for relay with AAS.

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