Timing Acquisition with Cooperation of Two Distributed Receive Antennas over Flat-Fading Channels

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Abstract—**In the flat Rayleigh channels of linear cell, two distributed receive antennas are employed to receive the signal transmitted from the mobile station (MS) with a single antenna. We exploit the false alarm probability at the central processor to guarantee that the false alarm probability at each distributed antenna does not exceed the pre-defined probability of false alarm. Based on the exploited probability of false alarm at the central processor, a cooperative detection threshold of each antenna is derived for threshold detection. According to the threshold detection, a maximum-likelihood (ML)-based timing acquisition method is proposed for distributed antenna systems (DAS). Without increasing the pre-defined probability of false alarm, the analysis and simulation results show that the correct acquisition probability and the missed detection probability for each distributed antenna can be improved with the proposed method wherever the MS is located.**

Keywords- cooperative timing acquisition; distributed antenna systems; maximum-likelihood; threshold detection; linear cell; flat-fading channel

I. INTRODUCTION

Multi-antenna system can achieve higher data rates and better coverage than their single antenna counterparts without requiring additional power or bandwidth consumption [1]. However, the potential advantages of using multiple antennas cannot realize for centralized antenna systems (CAS) due to the co-located placement of antennas [1][2]. Relative to the CAS, the distributed antenna systems (DAS) presents many advantages, e.g., expanding coverage and increasing sum rates by having distributed antenna ports throughout a cell [2]–[4]. As the key technology of the next generation wireless system, the DAS has been attracting worldwide research interests [5][6].

Meanwhile, the inaccuracies of timing acquisition degrade the performance of wireless communication systems [7]–[9]. For DAS, the performance of timing acquisition is particularly important due to the different placement locations of the distributed antennas. To improve the performance of timing acquisition, some methods are proposed in [10]–[14]. However, the cooperative processing among distributed receive antennas is not exploited for timing acquisition in [10]–[12]. Although the cooperative processing is employed in [13] and [14], the transmitted signal from mobile station (MS) is assumed always exists,

thus the distributed receive antennas do not detect the existence of the transmitted signal. This assumption in [13] and [14] is too ideal to be adopted for the engineering application.

To enhance the adaptability of the method in [13] and [14], a cooperative timing acquisition method, which is based on threshold detection, is proposed in this paper. For simplifying the research, two distributed receive antennas, which are placed in the flat-fading channels of linear cell [15], are employed to receive the signal transmitted from the MS with a single antenna. The false alarm probability at the central processor is exploited to guarantee that the false alarm probability at each distributed antenna does not exceed the pre-defined probability of false alarm. With the exploited probability of false alarm at the central processor, we derive a cooperative detection threshold for the two receive antennas. According to the threshold detection, a maximum-likelihood (ML)-based timing acquisition method is proposed. Through Monte Carlo simulations, we show the probability of correct acquisition and the missed detection probability for each distributed receive antenna can be improved without increasing the pre-defined probability of false alarm wherever the MS is located.

The rest of this paper is organized as follows. In the next section, we describe the system model. In Section III, we present the ML timing acquisition method. Some numerical results are given in Section IV. Finally, Section V concludes this paper.

II. SYSTEM MODEL

Figure 1. shows the system model, where the receive antennas DRX_1 and DRX_2 are assumed to receive the signal transmitted from the MS with a single antenna in the linear cell. x ($x \in [0, R]$), 0 and R are respectively denoted the locations of MS, DRX_1 and DRX_2. The heights of MS, DRX_1 and DRX_2 are h_{MS}, h_1 and h_2, respectively.

We denote $c(t) = \sum_{j=0}^{L-1} c_j g(t - jT_c)$ as the pulse train, where $\{c_j\}$ denotes the training sequence of period L. $g(t)$ is a unit rectangular pulse function of duration T centered at $T/2$. The transmitted baseband signal from the

MS is $s(t)$. The baseband form of the received signal at DRX$_1$ and DRX$_2$, i.e., $r_1(t)$ and $r_2(t)$, can be given by

$$\begin{cases} r_1(t) = \sqrt{\xi_1} h_1 s(t - \tau_1 T) + n_1(t) \\ r_2(t) = \sqrt{\xi_2} h_2 s(t - \tau_2 T) + n_2(t) \end{cases} \quad (1)$$

where $h_i \ (i=1,2)$ is a zero-mean complex Gaussian random variable with unit variance. $\sqrt{\xi_i} \ (i=1,2)$ is a power gain factor that captures the effects of mean path loss and log-normal shadow fading [16]. $n_1(t)$ and $n_2(t)$ are additive white Gaussian noise with noise power σ_i^2. $\tau_1 T$ and $\tau_2 T$ are respectively the time-delays from MS to DRX$_1$ and DRX$_2$. $\tau_i \ (i=1,2)$ is the time-delay normalized to the period T.
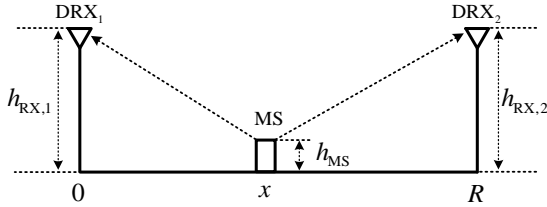

Figure 1.   System model

III.   TIMING ACQUISITION

A.   Detection Threshold

At DRX$_i$, we denote $C_i(\tau_i), i=1,2$ as the cross-correlation between the known training sequence and the received signal. According to the traditional method of timing acquisition in [17], we have

$$C_i(\tau_i) = \int_0^{T_0} r_i^*(t) s(t - \tau_i T) dt, i = 1,2 \quad (2)$$

where $T_0 = LT$.

Based on the researches in [13], [14] and [17], the estimation of $\tau_i, i=1,2$, i.e., $\hat{\tau}_i$ can be given by

$$\hat{\tau}_i = \arg\max_{\tau_i} \left\{ |C_i(\tau_i)|^2 \geq T_{h,i} \right\}, i = 1,2 \quad (3)$$

where $0 < \tau_i \leq L-1$, $T_{h,i}, i=1,2$ is the detection threshold of DRX$_i$. In (3), we consider the DRX$_i$ can pass the threshold detection only if $\max_{\tau_i} |C_i(\tau_i)|^2 \geq T_{h,i}$ is satisfied. Otherwise, the missed detection occurs at DRX$_i$ or none of signals transmitted from MS.

Denote P_{FA} as the pre-defined probability of false alarm for DRX$_1$ and DRX$_2$, According to the reference [18], $T_{h,i}, i=1,2$ can be expressed as

$$T_{h,i} = -2L\sigma_i^2 \ln(P_{FA}) \quad (4)$$

In (4), the detection threshold is derived without the cooperation of DRX$_1$ and DRX$_2$. In fact, the false alarm

probability at the central processor is generally more lower than the pre-defined P_{FA} if DRX$_1$ and DRX$_2$ all can reach the detection threshold $T_{h,i}$ according to the "data fusion rule" in [19]. Thus, the false alarm probability at the central processor can guarantee that the false alarm probability at DRX$_i$ is not higher than the pre-defined P_{FA}. Then, a lower detection threshold $\tilde{T}_{h,i}$, i.e., $\tilde{T}_{h,i} \leq T_{h,i}$, can be exploited for DRX$_i$ without increasing the pre-defined false alarm probability (i.e., P_{FA}) at DRX$_i$. In this paper, we call $\tilde{T}_{h,i}$ as cooperative detection threshold.

To derive the cooperative detection threshold $\tilde{T}_{h,i}$, the false alarm probability at DRX$_1$ and DRX$_2$ are respectively assumed as $P_{FA,1}$ and $P_{FA,2}$. Without loss of generality, we assume $P_{FA,1} = P_{FA,2}$ to meet the same demands of false alarm at DRX$_1$ and DRX$_2$. Then the false alarm probability at the central processor, i.e., P_{FA}^C, can be obtained according to the "data fusion rule" in [19]

$$P_{FA}^C = P_{FA,1} \times P_{FA,2} = P_{FA,1}^2 = P_{FA,2}^2 \leq P_{FA} \quad (5)$$

Replacing P_{FA} in (4) by the maximum of $P_{FA,1}$ or $P_{FA,2}$, i.e., $P_{FA,1} = P_{FA,2} = \sqrt{P_{FA}}$, the cooperative detection threshold $\tilde{T}_{h,i}$ can be given by

$$\tilde{T}_{h,i} = -L\sigma_i^2 \ln(P_{FA}) \quad (6)$$

In this paper, we discuss the timing acquisition with cooperation according to the detection threshold given in (4) and (6).

B.   Timing Acquisition

Denote $\hat{\mathbf{\Gamma}}_{ML} = (\hat{\tau}_1, \ \hat{\tau}_2)^T$ as the maximum-likelihood (ML) estimation of $(\tau_1, \tau_2)^T$. On the basis of [13] and [14], we have

$$\begin{cases} \hat{\mathbf{\Gamma}}_{ML} = \arg\max_{\{\tau_1, \tau_2\}} \left\{ |C_1(\tau_1)|^2 + |C_2(\tau_2)|^2 \right\} \\ s.t. |C_1(\hat{\tau}_1)|^2 \geq \tilde{T}_{h,1}, |C_2(\hat{\tau}_2)|^2 \geq \tilde{T}_{h,2} \end{cases} \quad (7)$$

where $\tilde{T}_{h,i}$ is given in (6).

When $|C_1(\hat{\tau}_1)|^2 \geq \tilde{T}_{h,1}$ and $|C_2(\hat{\tau}_2)|^2 \geq \tilde{T}_{h,2}$ cannot simultaneously be satisfied, the DRX$_i$, which can reach the detection threshold $\tilde{T}_{h,1}$, must be verified to ensure the false alarm probability at DRX$_i$ is not higher than the pre-defined P_{FA}. Assuming DRX$_j$, $j=1$ or 2 can only reach the detection threshold $\tilde{T}_{h,j}$, the estimation $\hat{\tau}_j$ can be given by

$$\begin{cases} \hat{\tau}_j = \arg\max_{\tau_j}\left\{\left|C_j\left(\tau_j\right)\right|^2\right\}, \ j=1 \text{ or } 2 \\ s.t. \left|C_j\left(\hat{\tau}_j\right)\right|^2 \geq T_{h,j} \end{cases} \qquad (8)$$

where $T_{h,j}$ can be obtained from (4).

IV. NUMERICAL AND SIMULATION RESULTS

To confirm the effectiveness of the proposed method, computer simulation results are presented in this section. Some basic simulation approaches and parameters are as follows: R=500m, $h_1 = h_2 = 6$m, $h_{MS} = 1$m, the probability of pre-defined false alarm $P_{FA} = 10^{-6}$, the training sequence is Zadoff-Chu sequence [20], which is also adopted by the 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE) standard. $L = 1024$, $T = 1/1.5\,\mu$s, $\sigma_1^2 \approx \sigma_2^2$, the detection threshold is set according to (4) and (6). From reference [21], we consider the path loss and shadowing model, i.e.,

$$\left(\frac{P_{r,i}}{P_t}\right)_{dB} = 10\lg K - 10\gamma\lg\left(\frac{d_i}{d_0}\right) - \varphi_{dB}, \ i=1,2 \qquad (9)$$

where P_t is the transmitted power of MS, $P_{r,i}$ is the received power of DRX_i, $K = \left(\lambda/4\pi d_0\right)^2$ (where λ is wavelength of carrier wave and d_0 is a reference distance for the antenna far-field), γ is the path loss exponent, φ_{dB} is a Gauss distributed random variable with mean zero and variance $\sigma_{\varphi_{dB}}^2$, d_i is the distance from MS to DRX_i, which can be expressed as

$$\begin{cases} d_1 = \sqrt{\left(h_{RX,1} - h_{MS}\right)^2 + x^2} \\ d_2 = \sqrt{\left(h_{RX,2} - h_{MS}\right)^2 + \left(R-x\right)^2} \end{cases} \qquad (10)$$

From [21], we set $\gamma = 3$, $d_0 = 1$m, $\sigma_{\varphi_{dB}} = 3.7$, $\lambda = 0.15$m (i.e., the carrier frequency is 2GHz). The noise power at DRX_i is set as -100dBm and the transmitted power of MS is $P_t = -20$dBm. Assume the transmitted power of MS keeps unchanged wherever the MS is located in the linear cell (i.e., $x \in [0, R]$).
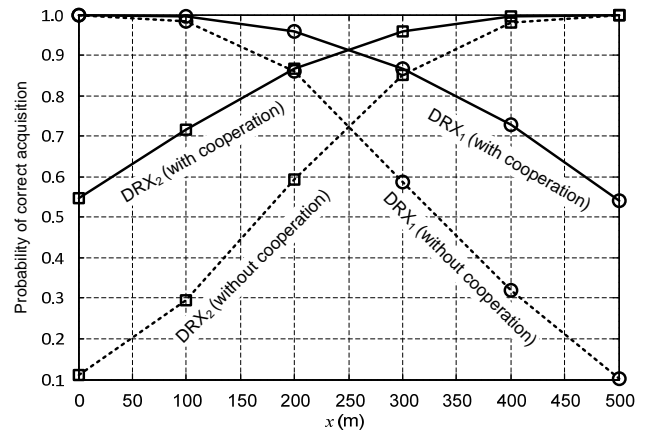

Figure 2. The probability of correct acquisition versus MS location x ($P_t = -20$dBm)

Figure 2. gives the correct acquisition probability versus MS location x when $P_t = -20$dBm. From Figure 2. the probability of correct acquisition for each antenna is improved with their cooperation. For the case that the location of MS is $x = 250$ m, the correct acquisition probability of DRX_1 and DRX_2 is only 72% without cooperation, while it increase to 91% with the cooperation of DRX_1 and DRX_2.

In Figure 2. , when $x = 0$ m (or $x = 500$ m), i.e., the MS is close to DRX_1 (or DRX_2) and far away from DRX_2 (or DRX_1), the probability of correct acquisition for DRX_1 (or DRX_2) keeps it nearly 100%. Thus, the proposed method has its robustness.
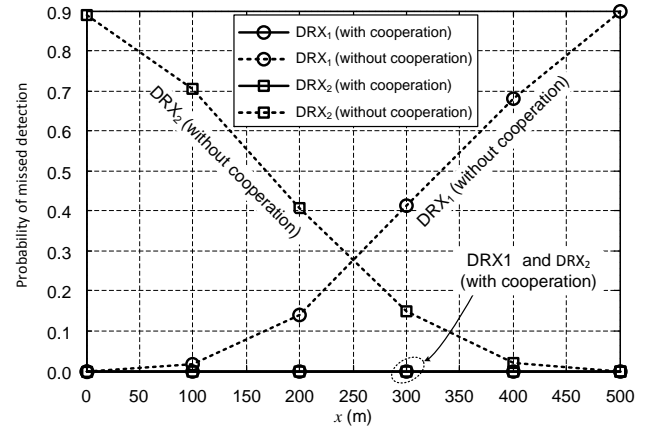

Figure 3. The probability of missed detection versus MS location x ($P_t = -20$dBm)

Figure 3. plots the missed detection probability versus MS location x. From Figure 3. , the missed detection probability is decrease dramatically with the cooperation of DRX_1 and DRX_2. With the cooperation between the two receive antennas, i.e., DRX_1 and DRX_2, the missed detection probability of DRX_1 and DRX_2 all can decrease

to far below 10%, while the missed detection probability of DRX_2 (or DRX_1) reaches 90% without the cooperation of DRX_1 (or DRX_2) when $x = 0$ m (or $x = 500$ m). Relative to the cases without cooperation, the simulation results in Figure 3. show that the missed detection probability is almost always improved.

V. CONCLUSION

We have investigated a timing acquisition method for distributed antenna systems to enhance the adaptability of the existing methods of cooperative timing acquisition. In the flat Rayleigh channels of linear cell, the false alarm probability at the central processor is exploited to guarantee the false alarm probability at each distributed antenna does not exceed the pre-defined probability of false alarm. Based on the exploited probability of false alarm at the central processor, a cooperative detection threshold for each antenna is derived for threshold detection. According to the threshold detection, a maximum-likelihood (ML)-based timing acquisition method is proposed. Without increasing the pre-defined probability of false alarm, the Monte Carlo simulations results show that the correct acquisition probability and the missed detection probability for each distributed antenna can be improved with the proposed method wherever the MS is located.

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