A Study on Reactively Steered Adaptive Array in OFDM Systems

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Abstract-We propose a new scheme to introduce the **RE**actively **S**teered **A**daptive **A**rray (RESAA) technique into an orthogonal frequency-division multiplexing (OFDM) system, taking advantage of the OFDM-transmission-data-frame format characteristics. Using computer simulation, we evaluate the performance of the proposed RESAA system in suppressing a signal with a delay time exceeding the guard interval as interference under the IEEE802.11a system format. The results show that the proposed scheme provides a significantly faster convergence and a better output signal-to-interference ratio (SIR) compared to the conventional scheme.

1. Introduction

In a next-generation wireless communication environment, where a variety of systems and services coexist adjacently with respect to carrier frequency, an adaptive array antenna for mobile terminals is required in order to achieve high-quality, high-speed data transmission by suppressing not only intersymbol and intercarrier interferences but also other system interferences.

The **RE**actively **S**teered **A**daptive **A**rray (RESAA) technique using parasitic elements facilitates implementation of beam- and/or null-steering in mobile terminals because of its significantly low power consumption and sufficiently small size for practical use. Although primary research on RESAA goes back to the 1970's [1][2], it has only recently been reinvestigated as a means of beam forming for ad-hoc networking [3].The reason is that commercial hardware implementation has been enabled by recent semiconductor advances in varactor devices and digital signal processor technologies.

Orthogonal frequency-division multiplexing (OFDM) transmission have recently been applied to commercial use for terrestrial digital broadcasting and wireless LAN services such as systems based on IEEE802.11a/g. It has also been investigated for next-generation cellular systems, mainly because of its robustness with respect to signal delay spread. However, techniques for suppressing intersymbol interference whose delay time exceeds the guard interval (GI) are still in demand to enable easy deployment of high-reliability systems. A digital array processing scheme for OFDM systems proposed previously [4] improved system performance under interference, by utilizing the channel impulse response (CIR) within the GI and signal powers on no-date-sent carriers where interference signals appear.

In this paper, we apply the previous scheme [4] in order to introduce RESAA into an OFDM system.Using computer simulation, we have evaluated the performance of RESAA schemes to suppress signals with delay time exceeding the GI, under the IEEE802.11a system format. Our results show that one of the proposed algorithms achieves significantly faster convergence and a better output signal-to-interference ratio (SIR) compared to the conventional scheme.

2. Proposed RESAA System in OFDM receiver

Figure 1 shows a block diagram of the proposed RESAA system in an OFDM receiver. Each antenna part consists of one element connected by a transmission line to the receiver and a set of closely coupled M-parasitic elements, each terminated by a variable reactance (varactor).

2.1 Signal Model

We now introduce the signal model for RESAA in an OFDM system. The output of RESAA can be expressed as

$$y(t) \quad = \quad \mathbf{w}^T \int_{-\pi}^{\pi} \int_{-\infty}^{\infty} \mathbf{a}(\theta) h(\tau, \theta) s(t-\tau) d\tau d\theta + n(t) \tag{1}$$

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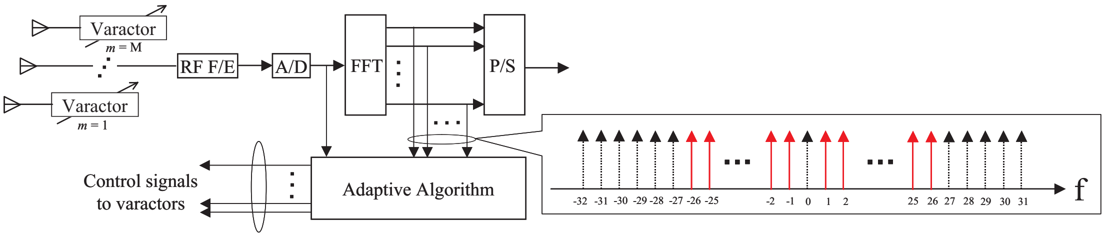

Figure 1: Proposed RESAA scheme for OFDM systems

$$\mathbf{w} = \left[w_1,\ w_2,\ \cdots,w_{M+1}\right]^T \tag{2}$$

$$\mathbf{a}(\theta) = \left[a_1(\theta),\ a_2(\theta),\ \cdots,a_{M+1}(\theta)\right]^T, \tag{3}$$

where $\mathbf{w}$ is the equivalent weight vector [3], $\mathbf{a}(\theta)$ is the array response vector of RESAA at the point of the azimuth angle θ, and $h(\tau,\theta)$ is the complex channel impulse response (CIR).$\tau, n(t)$ and superscript T indicate the delay time, the complex-valued additive white Gaussian noise (AWGN) at time t, and the transpose of the vector or matrix, respectively.

2.2 Proposed Adaptive Algorithms

According to IEEE802.11a [5], data is sent on the 52 subcarriers from -26 to -1 and from 1 to 26.No signal is sent on the other 12 subcarriers, i.e., from -32 to -27, 0, and from 27 to 31. We call the latter 12 subcarriers "virtual subcarriers." Our proposed algorithms utilize two repetitions of a "long training sequence" on the 52 subcarriers and signal powers on the virtual subcarriers, as references for training. The powers of the interference signals appear on the virtual subcarriers. Then, by controlling the varactors to minimize the signal powers on the virtual subcarriers, excessively long-delayed signals and other system signals are suppressed as interferences. We are now ready to describe the algorithms of RESAA. The update value of the reactance vector $\mathbf{X}(n+1)$ at the $(n+1)$-th update is computed by using a simple recursive relation with the descent algorithm expressed as

$$\mathbf{X}(n+1) = \mathbf{X}(n) - \mu\nabla\mathbf{J}(n) \tag{4}$$

$$\mathbf{X}(n) = \left[x_1(n),\ x_2(n),\ \cdots,x_M(n)\right]^T \tag{5}$$

$$\nabla\mathbf{J}(n) = \left[\nabla J_1(n), \nabla J_2(n),\ \cdots,\ \nabla J_M(n)\right]^T \tag{6}$$

$$\nabla J_m(n) \simeq \frac{J(n)\Big|_{x_m(n)=x_m(n)+\Delta x} - J(n)\Big|_{x_m(n)=x_m(n)}}{\Delta x}, \tag{7}$$

where μ is the step-size controling the convergence speed and $\nabla J_m(n)$ is the gradient vector of the cost function $J(n)$ when the m-th reactance changes from $x_m(n)$ to $x_m(n)+\Delta x$ with perturbation size Δx.

- Algorithm 1:
  The cost function for algorithm 1 is expressed as

  $$J^{(1)}(n) = \frac{1}{12}\sum_{i_{vs}}\left|\sum_{k=0}^{63} y\left(k\Delta T_s, n\right)e^{-j2\pi i_{vs}\Delta f\frac{k}{64}\Delta T_s}\right|, \tag{8}$$

  where $y(t,n)$ is the equivalent lowpass signal of the analog-to-digital converter (ADC) output during the long training sequence period at the n-th update. i_{vs}, ΔT_s, and Δf denote the index number of the virtual subcarriers, the sampling duration and the frequency separation between subcarriers, respectively. The power of the interference signals appears on the virtual subcarriers. Thus algorithm 1 suppresses signal powers on the virtual subcarriers, i.e., min $J^{(1)}(n)$. It can provide only null steering to the inteference signals including those from other systems. Additionally, algorithm 1 does not require reference signals.

- Algorithm 2 (conventional):
  The cost function for algorithm 2 is expressed as

$$J^{(2)}(n) = 1 - \frac{\left|\sum_{i=-32}^{31} Y_m(i\Delta f, n) R^*(i\Delta f)\right|}{\sqrt{\sum_{i=-32}^{31} Y_m(i\Delta f, n) Y_m^*(i\Delta f, n)}\sqrt{\sum_{i=-32}^{31} R(i\Delta f) R^*(i\Delta f)}} \quad (9)$$

$$Y_m(i\Delta f, n) = \sum_{k=0}^{63} y(k\Delta T_s, n) e^{-j2\pi i\Delta f \frac{k}{64}\Delta T_s}, \quad (10)$$

  where $R(f)$ is the "long training sequence" known at the receiver. The superscript * indicates the complex conjugate. Algorithm 2 utilizes the reference sequence and provides beam steering to the first arrival signal as desired by using the cross-correlation coefficient between the reference and the received signal, in the frequency domain. The cost function for controlling RESAA in this manner was investigated [3].

- Algorithm 3:
  The cost function for algorithm 3 is expressed as

$$J^{(3)}(n) = \frac{\alpha(n)}{\alpha(n)+\beta(n)}\eta(n) + \frac{\beta(n)}{\alpha(n)+\beta(n)}\xi(n) \quad (11)$$

$$\eta(n) = \alpha(n) = J^{(1)}(n) \quad (12)$$

$$\xi(n) = 1 - \frac{\left|\sum_{i=-32}^{31} Y_m(i\Delta f, n) R_h^*(i\Delta f, n)\right|}{\sqrt{\sum_{i=-32}^{31} Y_m(i\Delta f, n) Y_m^*(i\Delta f, n)}\sqrt{\sum_{i=-32}^{31} R_h(i\Delta f, n) R_h^*(i\Delta f, n)}} \quad (13)$$

$$\beta(n) = \frac{1}{52}\sum_{i_{ds}}\left|\sum_{k=0}^{63} y(k\Delta T_s, n) e^{-j2\pi i_{ds}\Delta f \frac{k}{64}\Delta T_s}\right| \quad (14)$$

$$R_h(f, n) = H(f, n)R(f), \quad (15)$$

  where i_{ds} denotes the index number of the data subcarrier, and $\alpha(n)$ and $\beta(n)$ are the average absolute amplitude of the virtual subcarriers and the data subcarriers, respectively. $H(f, n)$ is defined as the frequency response of the CIR $h(\tau, \theta)$ within the GI. Algorithm 3 utilizes the replica $R_h(f, n)$ calculated from $H(f, n)$ and $R(f)$.

3. Simulation Results

The simulation parameters are indicated in table 1. The CIR estimation, timing, and carrier synchronization are assumed ideal. Here we treat a signal with delay exceeding the GI as an interference signal. The Angle of arrival (AOA) for the three interested paths are 0^o, 100^o, and 300^o respectively, and that for the interference path is 200^o. The angular spread is zero and the powers are all equal. The delay times for the interested and interference paths are 0, 0.25, 0.5, and 2.0 μsec, respectively. Figure 2 illustrates the convergence properties of the algorithms. The convergence speed for algorithm 1 is lower and less stable than those of the other algorithms, because it is susceptible to noise on the virtual subcarriers. In contrast, algorithm 3 provides a significantly faster and more stable convergence property than the other algorithms do, because it makes it easy to suppress the interference, (i.e., a path with delay time exceeding the GI) by utilizing the CIR within GI and the leakage power of the interference on the virtual subcarriers. Figure 3 shows antenna patterns for each algorithms after 1000 iterations. Algorithm 1 null-forms to the interference, but it dose not beam-form to the interested paths. Algorithm 2 dose not null-form only to the interference but also to the delayed paths, so it beam-form only to the first arrival paths. Thus algorithm 2 is useless for a scattered rich environment. On the other hand, algorithm 3 null-forms only to the interference and beam-forms to all interested paths that lead to an output-SIR increase.

Table 1: Simulation parameters

Number of parastic elements	6
Configulation of parastic elements	Uniform circular array
Element spacing	$\lambda/4$ in radius
Step size μ	5, 10 and 10 for algorithm 1, 2 and 3
Delay time [μsec]	0, 0.25 and 0.5 for interested paths/ 2.0 for interference
Angle of Arrival [degree]	0, 100 and 300 for interested paths/ 200 for inteference
SNR[dB]	30

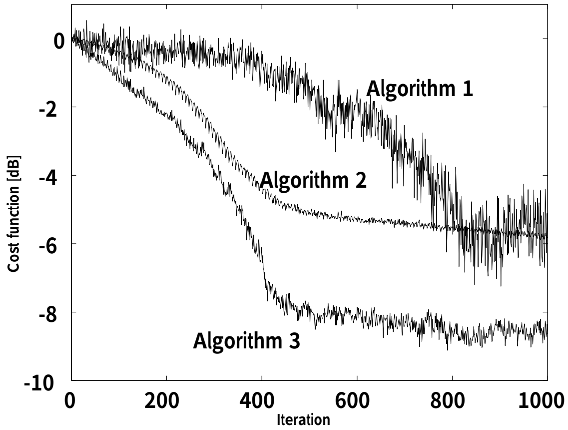

Figure 2: Convergence properties

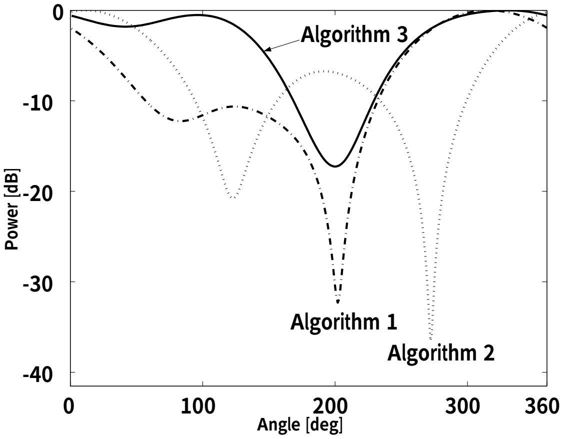

Figure 3: Antenna patterns by computer simulation

4. Conlusion

We have proposed RESAA systems and controlling algorithms for OFDM transmission. The proposed RESAA systems utilized the power of interference signals on virtual subcarriers and the CIR within the GI to provide null-forming only to interference paths and beam-forming to all interested paths. Simulation results have shown that the proposed algorithm provided a significantly faster and more stable convergence property and also improved the output-SIR, compared to the conventional algorithm.

References

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