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Leaky Integration Weight Prediction for TDD Adaptive Antenna Base Station in Fast Time Selective Fading Channel

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1. Introduction

Recently there is an increasing interest in adaptive antenna technology since its capability of user tracking, co-channel interference reduction, and spatial diversity offer better coverage, capacity, multipath rejection, and power efficiency. Generally used adaptive algorithms such as directional constant modulus algorithm (DCMP), minimum mean square error (MMSE), and power inversion (PI), summarized in [1], are used to adjust the weights in adaptive antenna system to suppress interference signals while amplify desired signal.

The adaptive antenna technology is very useful in time division duplex (TDD) scheme. Because a frequency is used for uplink and downlink transmission commonly, then the same antenna beamforming for uplink channel can also be used for downlink channel considering a slow time selective fading channel. But as the user moves faster, the time selective fading, mainly caused by movement of user relative to the base station, reduces the performance of the system at the downlink period. Analysis of this performance degradation for TDD system is shown in [2] and [3] for specific systems.

There have been some researches for specific systems to deal with this issue by predicting the downlink channel, such as in [4] and [5]. They are generally based on the causal complex-valued Markov random field (CMRF) model. This paper proposes a modification of the conventional CMRF model by weighting the parameter of the CMRF in a time based manner, which is more suitable for continuously changing time selective fading channel. The simplest way to realize this type of channel prediction is to employ a leaky integration of Newton backward difference and Newton interpolation. The proposed method, adapted from [6], can be used generally for any TDD scheme using adaptive antenna.

2. Theory

TDD scheme uses only one frequency channel for uplink and downlink. The base station receives uplink signal and transmits downlink signal alternately in time. An adaptive antenna can be used to improve the performance of a TDD system by mitigating multipath interference. An adaptive antenna base station uses the signal received from the user in the uplink period to adjust parameters of the array antenna. In the downlink period, the same parameters can be used to transmit signal to the user because of the reciprocity of electromagnetic propagation. This conventional approach assumes that the user is not moving or moving slowly enough to cause only negligible change in the channel. When the user is moving faster, a predictive method is required to adjust the weights parameter of adaptive antenna in the downlink period without any received signal from user.

The general configuration of an adaptive antenna in a multipath environment is shown in Fig. 1. Signal received by antenna element $x_i(t)$ of the array antenna is the sum of all signals $s_{il}(t)$, where $s_{il}(t)$ is the signal propagating from a user to each antenna element i through each path l.

$$x_i(t) = \sum_{l=1}^{L} s_{il}(t) \quad \text{where} \quad s_{il}(t) = e^{jkr_{il}(t)} \tag{1}$$

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The phase of signal $s_{il}(t)$ depends on path length r_{il} and wavenumber k of the carrier. We ignore amplitude attenuation in this paper since its contribution to the time selective fading is small compared to the phase shift. Output of the array antenna is the linear combination of received signals $x_i(t)$ and complex weights $w_i(t)$ at each antenna element.

$$y(t) = \sum_{i=1}^{K} w_i(t) x_i(t) \tag{2}$$

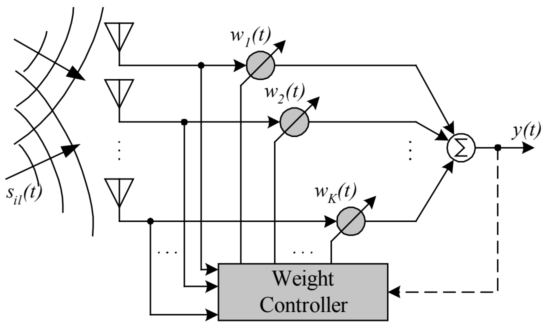


Figure 1: Basic bonfiguration of adaptive antenna system

In purpose to analyse how the weights change, we assumed that user-transmitted signal has constant phase and amplitude so that the change in the received signal is merely caused by user's movement. The weight controller algorithm continuously adjusts weights in order to maintain the output constant, hence cancels the time selective fading. When time derivative of equation (2) is zero, the derivative of the weights is a function of path lengths and carrier's wavenumber.

$$\frac{dy}{dt} = \sum_{i=1}^{K} \frac{dw_i}{dt}\left(\sum_{i=1}^{L} s_{il}\right) + \sum_{i=1}^{K} w_i \left(\sum_{l=1}^{L} \frac{ds_{il}}{dt}\right) = 0 \tag{3}$$

$$\frac{dw_i}{dt} = -\left(\sum_{l=1}^{L} e^{jkr_{il}}\right)^{-1} w_i \left(\sum_{l=1}^{L} jke^{jkr_{il}} \frac{dr_{il}}{dt}\right) \tag{4}$$

If the sampling period is very small, then path lengths r_{il} are almost constant for a short period of one TDD frame period. Therefore derivative of the weights simply related to the derivative of the length (speed) of all the paths, which is changing only slowly within the short sampling period. Based on this reason, we can roughly approximate each weight as a polynomial curve in time with a particular order, and then predict the weight when no input signal available for weight controller algorithm to calculate the weight.

We calculate the estimated derivatives of weights $\left(\tilde{\dot{w}}_i(t), \tilde{\ddot{w}}_i(t), ...\right)$ by measuring derivatives of the weights in the uplink period up to some order of derivatives using Newton backward difference. The derivatives are accumulated in time with a leaky integration controlled by constants $(K', K'', ...)$. This leaky integration weights the preceding values of derivatives exponentially, paying more attention to the latest values. This is important to capture the continuously changing characteristic of the channel.

$$\begin{aligned} &\tilde{\dot{w}}_i(t) = (1-K')\tilde{\dot{w}}_i(t) + K'[w_i(t) - w_i(t-\Delta t)] \\ &\tilde{\ddot{w}}_i(t) = (1-K'')\tilde{\ddot{w}}_i(t) + K''[\dot{w}_i(t) - \dot{w}_i(t-\Delta t)] \quad \text{where} \quad \dot{w}_i(t) = w_i(t) - w_i(t-\Delta t) \\ &\quad\vdots \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \vdots \end{aligned} \tag{5}$$

The weight prediction is described in equation (6), where the initial values of weights and their derivatives calculated from equation (5) are used to predict the weights $\tilde{w}_i(t+\Delta t)$ in the downlink period using Newton backward difference interpolation. The predicted weights are calculated every sampling period Δt after the uplink period.

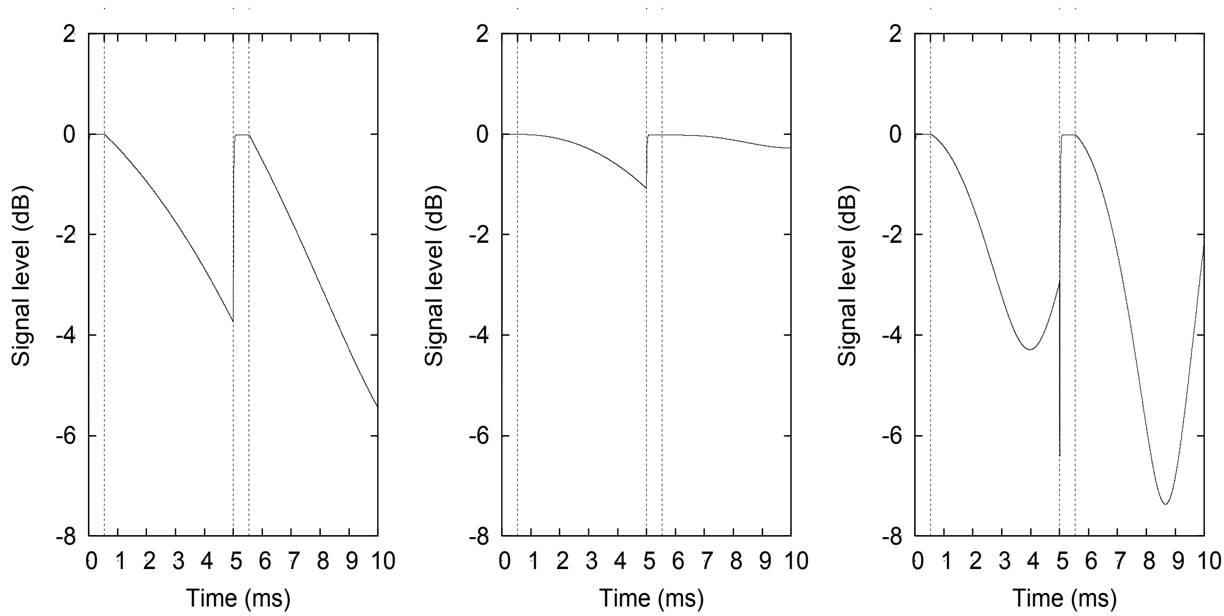
$$\begin{aligned}
\tilde{w}_i(t+\Delta t) &= \tilde{w}_i(t) + \dot{\tilde{w}}(t) + \ddot{\tilde{w}} + \ldots \\
\dot{\tilde{w}}_i(t+\Delta t) &= \dot{\tilde{w}}_i(t) + \ddot{\tilde{w}} + \ldots \\
\ddot{\tilde{w}}_i(t+\Delta t) &= \dddot{\tilde{w}} + \ldots \\
&\vdots
\end{aligned} \tag{6}$$

Equations (5) and (6) can be expanded easily to any order higher than two to predict more complex fluctuation of the weights.

3. Simulation

The base station array antenna consists of 12 monopole antenna elements in horizontal circular arrangement. The distance between any two adjacent antenna elements is half wavelength of the 2GHz carrier. Random positions of 7 reflectors create 8 signal paths from the omnidirectional signal transmitted by a user moving away from the antenna at 5 m/s. Asymmetric TDD scheme is considered with an uplink period of 0.5 ms and a downlink period of 4.5 ms. The MMSE algorithm is used to adjust weights in the uplink period. Weights prediction is simulated up to second order of derivatives.

Two TDD frames are simulated for a total of 10 ms. Typical output signal levels of the adaptive antenna are shown in Fig. 2. Each frame starts with a short uplink period in which the MMSE algorithm adapts the weights based on the received input signal. The boundaries between uplink and downlink periods are marked with dashed lines in fig. 2. We can see from these figures that the MMSE algorithm maintains the outputs constant for 0.5 ms at the beginning of each frame.



(a) without prediction (b) with Newton interpolation (proposed method) (c) with Lagrange interpolation (method described in [5])

Figure 2: Signal level comparison

Figure 2(a) shows the output signal level without weight prediction. The weights after uplink period are constant, equal to the last values calculated in the uplink period by the MMSE algorithm. However as the user keeps moving after that period, we can see in Fig. 2(a) that the output is gradually deflect away from 0 dB. We can also see sudden large correction of the output at the beginning of uplink period by the MMSE algorithm.

The output signal level with the proposed weight prediction is shown in Fig. 2(b), where the weights are kept changing following the latest trends in the previous uplink period. We can see that the deflections in the output are smaller compared to those in Fig. 2(a). The corrections at the beginning of each frame are also not as abrupt as those in Fig. 2(a).

As a comparison, the method proposed in [5] is adopted in the simulation. This method interpolates three values of weights in the uplink period using the second order Lagrange interpolation to predict the next weights. However, because it only depends on the three input weight values, just a small disturbance in those values tends to interpolate to a very steep parabolic curve of predicted weight values in the downlink period. Therefore, the resulting output signal level, shown in Fig. 2(c), also tends to have a very steep curve.

4. Conclusion

We have proposed a weight prediction method to improve the performance of TDD adaptive antenna system in the time selective fading channel. The method, based on causal CMRF with leaky integration using Newton's backward difference interpolation, has been simulated along with the MMSE adaptive algorithm and fast time selective fading. The proposed method can be implemented generally for any TDD adaptive antenna system to overcome fast time selective fading without complex implementation. It can also be expanded to higher order interpolation to predict more complex fluctuation of the weights. The simulation results showed the improvement in multipath interference rejection over the conventional system, which does not use prediction, as well as a system with conventional Lagrange method in a fast time selective fading channel.

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