Dual-Adaptive Linear Prediction for Radio Channel with Abrupt Change

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***Abstract*—A dual-adaptive linear prediction (DALP) method is presented to predict radio channel with abrupt change caused by appearance or disappearance of scattered components (SCs), based on the idea that the prediction error of classical adaptive linear prediction (CALP) method can also be predicted when the channel changes abruptly. The proposed predictor consists of a CALP and a linear predictor for error of CALP. It is just a simple combination of two linear predictors, but it is useful for the prediction of radio channel with abrupt change. As is verified through simulations on a simplified channel model, it can significantly speed the convergence process and maintain the accuracy of prediction at the cost of a little higher computational complexity compared with CALP.**

***Index Terms*—Abrupt change, channel model, channel prediction, dual-adaptive method, error prediction.**

I. Introduction

In recent years, radio channel prediction has been studied to develop many key technologies for higher spectral efficiency, e.g., adaptive transmission [1], [2]. Because of the effects of SCs and Doppler frequency shift, the channel rapidly varies and it is difficult to be predicted. Most of the existing radio channel prediction methods can be divided into two classical categories, the sinusoidal parameters estimation (SPE) methods [3], [4] and the linear prediction (LP) techniques [5], [6]. It is a fundamental problem for both classical methods to investigate robust prediction algorithms appropriate for most of the channel variety.

The channel variety can be classified as slow change and abrupt change [6]. The previous one is caused by the parameters variety of each multipath, while the latter one is caused by the appearance or disappearance of SCs. Many efficient techniques have been proposed to track the slow change of radio channel. Adaptive method of SPE focuses on the complex amplitude and frequency of each scattered component (SC) [7], [8], while the adaptive LP measures for the fading behavior of the channel [1]. Because all SCs just exist during a certain period [9], the aforementioned methods are effective only for a time span. The abrupt change becomes the key factor that restrict the accurate prediction of channel. As far as we know, few literatures are about the prediction of abrupt change. By our observation, the CALP method can track the abrupt change, but it will take a relative long convergence time. Although the convergence time can be reduced by a big step-size, it is still not fast enough, let alone that it is not a practical approach to this problems owing to the big excess mean-square error caused by big step-size [10].

Motivated by the reasons above, this paper analyze the CALP for radio channel with abrupt change and then proposes a robust DALP method. Firstly, the proposed predictor operates as the CALP method does. Then the prediction error of CALP is predicted by another low order adaptive linear process. Further, the final result of prediction is obtained through the combination of the two adaptive LPs.

The rest of this paper is organized as follows. Section II describes the channel model. Section III presents the proposed DALP method. Section IV illustrates the performance evaluation, while section V is the conclusion.

II. Channel Model

This paper focuses on the prediction of radio channel with abrupt change due to the appearance or disappearance of SCs in narrowband communication system. Thus, the slow change caused by the parameters variety of each SC is not discussed in this essay. In literature [9], the proposed channel modeling method assumes that some new SCs appear suddenly at a given time according to Poisson-distribution. However, our focus is on the adaptive prediction after the occurrence of abrupt change, rather than how and when it occurs, so the time-varying channel model can be simplified from [9] as

$$c(t) = \sum_{n=1}^{N} A_n e^{j2\pi f_n t} + u(t_0) \sum_{m=1}^{M} A_m^{'} e^{j2\pi f_m^{'} t} \tag{1}$$

where $\sum_{n=1}^{N} A_n e^{j2\pi f_n t}$ is the deterministic component based on the Jakes channel model [11] and N is the number of SCs in the deterministic component; $\sum_{m=1}^{M} A_m^{'} e^{j2\pi f_m^{'} t}$ represents the appearance of some new SCs or the disappearance of existing SCs and M is the number of SCs in the abruptly changed component; $u(t_0)$ is the unit step function. It means that some SCs are added into a deterministic process at t_0.

Suppose the received signal for channel prediction is sampled at the rate of f_s [2], that is

$$y_n = c_n x_n + z_n \tag{2}$$

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where c_n, x_n, and z_n are the samples of channel model in (1), the transmitted symbols, and the additive white Gaussian noise with variance σ^2 respectively. In this paper, the transmitted symbols is set as a constant $x_n = 1$. The lowest sampling rate f_s that will permit accurate reconstruction of sampled channel is the Nyquist rate given by double of the maximum Doppler shift frequency f_{dm}, which is much lower than the data rate.

III. Dual-Adaptive Linear Prediction Method

A. Error Analysis of CALP

The CALP method for radio channel is introduced firstly. Then the idea that the prediction error of CALP can also be predicted is derived. Moreover, a modified method (DALP) is proposed in this section.

The CALP method based on autoregressive (AR) model can be expressed by

$$\begin{aligned} \hat{y}_n &= \sum_{j=1}^{p} d_j^y(n) y_{n-j} \\ &= \underline{d}^y(n) \underline{y}_n^T \end{aligned} \tag{3}$$

where $\hat{y}_n$ is the prediction of the future channel sample, p is the order of AR model, $\underline{y}_n = [y_{n-1}, y_{n-2}, \cdots, y_{n-p}]$ are previous estimated channel samples, and $\underline{d}^y(n) = [d_1^y(n), d_2^y(n), \cdots, d_p^y(n)]$ are the AR coefficients for channel prediction. The initial value of the AR coefficients are determined by the minimum mean square error (MMSE) principle. Due to the slow change of the scattering environments, adaptive tracking of $\underline{d}^y(n)$ has been investigated

$$\underline{d}^y(n+1) = \underline{d}^y(n) + \eta e_n^y \underline{y}_n^* \tag{4}$$

where $e_n^y = y_n - \hat{y}_n$ is the channel prediction error, and η is the step-size.

Over a short interval after the occurrence of abrupt change in radio channel (1), the vector of channel samples ($\underline{y}_n$) is non-stationary for the new SC is not continuous, but the weight changes in this stage can be ignored as the step-size (η) is small and the non-stationary stage is not long. The CALP method uses (3) to predict the radio channel. We define that the optimal weight vector after the abrupt change occurs is $\underline{d}^{opt}$, then if the white noise in (2) is zero, the channel can be accurately predicted as

$$y_n = \underline{d}^{opt} \underline{y}_n^T. \tag{5}$$

Accordingly, the prediction error of CALP can be expressed as

$$\begin{aligned} e_n &= \hat{y}_n - y_n \\ &= \left[\underline{d}^y(n) - \underline{d}^{opt}\right] \underline{y}_n^T. \end{aligned} \tag{6}$$

According to equation (6), it is obvious that the prediction error of CALP can also be represented by an adaptive linear AR process during the transitional period, and the AR coefficients are $[\underline{d}^y(n) - \underline{d}^{opt}]$ which change with the CALP coefficients $\underline{d}^y(n)$. Besides, the value of M in (1) is small in actual situation, so a lower-order linear process is used to describe the error propagation according to [5].

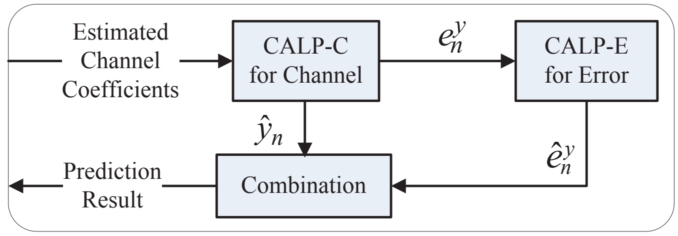

Fig. 1. Generic structure of proposed DALP method.

B. The Proposed DALP Method

Based on the analysis above, we propose a dual-adaptive linear predictor for the radio channel with abrupt change.The structure of DALP method is shown in Fig. 1. The channel predictor uses the estimated channel coefficients to predict future coefficients. The DALP consists of a CALP for radio channel, another CALP for error and the combination of them. The proposed method is just a combination of two linear predictors, but it is derived from the idea that the prediction error of CALP can also be predicted. Hence, this method is effective and appropriate. The details are described as follows.

1) The CALP for Channel: The CALP method has been introduced before. The results can be obtained as (3) and (4), and the details are in the context.

2) The CALP for Error: The prediction error $e_{n-1}^y, e_{n-2}^y, \cdots$ can be obtained in part A. In this part, the prediction error is modeled as another linear process when abrupt change of radio channel occurs. The prediction method is the same as in Part A, that is

$$\begin{aligned} \hat{e}_n^y &= \sum_{j=1}^{q} d_j^e(n) e_{n-j}^y \\ &= \underline{d}^e(n) [\underline{e}_n^y]^T \end{aligned} \tag{7}$$

where $\hat{e}_n^y$ is the future error to be predicted, q is the order of AR model ($q \ll p$), $\underline{e}_n^y = [e_{n-1}^y, e_{n-2}^y, \cdots, e_{n-q}^y]$ are the previous prediction errors, and $\underline{d}^e(n) = [d_1^e(n), d_2^e(n), \cdots, d_q^e(n)]$ are the AR coefficients for error prediction. The initial value of the AR coefficients are also computed using MMSE principle. The corresponding adaptive algorithm is as follows

$$\underline{d}^e(n+1) = \underline{d}^e(n) + \mu e_n^e [\underline{e}_n^y]^* \tag{8}$$

where $e_n^e = e_n^y - \hat{e}_n^y$ is the channel prediction error and μ is the step-size.

3) The Combination of predictors for Channel and Error: The result of CALP is obtained in (3), and as is presented in (7), the prediction error of CALP is also modeled as a linear adaptive process. Therefore, the prediction result of CALP, $\hat{y}_n$, can be revised through the combination with prediction error $\hat{e}_n^y$ as

$$\tilde{y}_n = \hat{y}_n + \hat{e}_n^y \tag{9}$$

where $\tilde{y}_n$ is the final result of channel prediction.

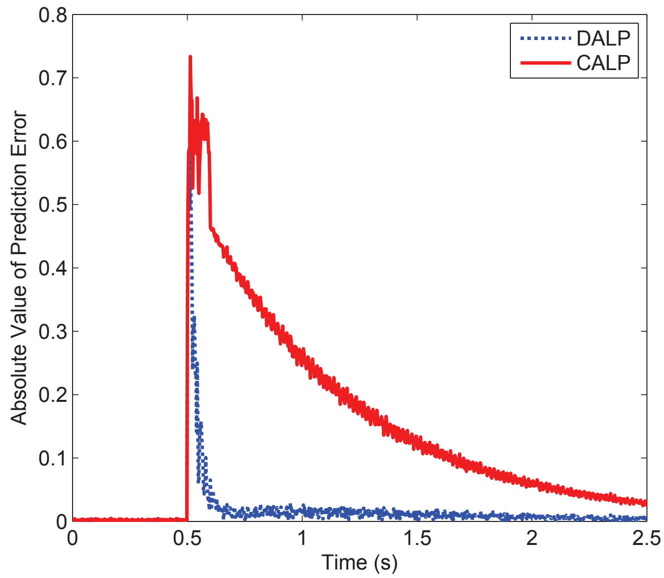

Fig. 2. Absolute value of prediction error for CALP and DALP. In this simulation, a new component with a different Doppler shift and a relative small amplitude is added into Jakes channel model at $t_0 = 0.5s$.

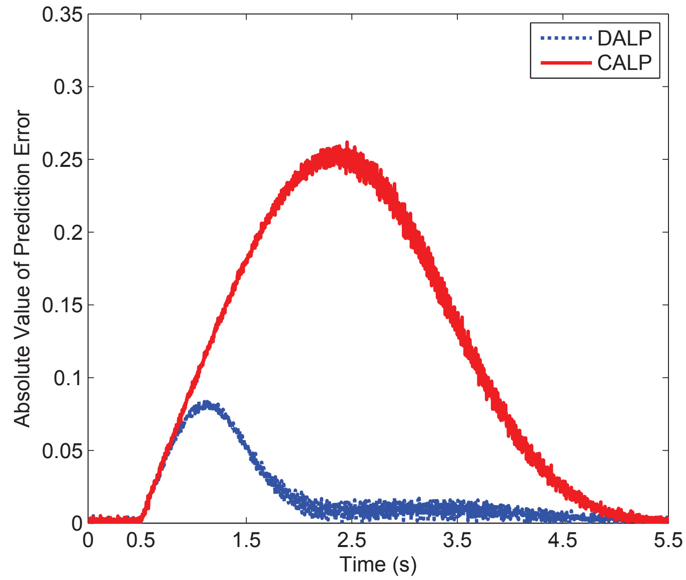

Fig. 3. Absolute value of prediction error for CALP and DALP. In this simulation, a new component with a different Doppler shift and a gradually increased amplitude (increased from zero at the rate of 0.1/s) is added into Jakes channel model at $t_0 = 0.5s$.

IV. Performance Evaluation

A. Simulation Description

The performance of the proposed DALP is evaluated based on the channel model in part II. The value of N in (1) is set as 16, the variance of the Jakes channel coefficients as 1 and the receiver travels at a speed of 100km/h which leads to a maximum Doppler shift of about 92.6Hz (the carrier frequency is 1GHz). Further, we assume that only one SC ($M = 1$) changes abruptly in (1) as its performance is similar to the case with several SCs, and only take the appearance of SCs as an example. The Doppler shift of the new SC is different from that of the 16 SCs of the Jakes model (the scatter of the new SC is different from that of Jakes model). Two circumstances about the appearance of the new SC are considered, including abrupt appearance with a fixed amplitude (the shadowed scatter far from the receiver appears abruptly as the receiver moves) and gradual appearance with the amplitude increased from zero (the receiver approaches the scatter slowly).

Also, we assume that the power of the white noise is set as $\sigma^2 = -50dB$, and the sample rate is $f_s = 400Hz$. The orders of CALP for channel and CALP for error are $p = 40$ and $q = 4$ respectively. The step-sizes are set as $\eta = 0.001$ and $\mu = 0.05$ respectively. The Burg method is used as an initial estimation of AR coefficients.

B. Prediction Result

Fig.2. presents the performance comparison between CALP and DALP when a new component with a different Doppler shift and a relative small amplitude is added into Jakes channel model at $t_0 = 0.5s$. The amplitude of the new SC is set as $A_1^{'} = 0.3e^{j0.5\pi}$, while the Doppler frequency as is $f_1^{'} = 50Hz$. The first stage before t_0 is the prediction result for deterministic Jakes model when CALP and DALP with steady states both have very small prediction errors, but the error of DALP is a little bigger due to the superimposed excess mean-square error. When the new SC appears, both of the two methods have abrupt prediction error. After the short period, the DALP can quickly converge with a much smaller prediction error for it utilizes the prediction error of CALP. Note that over the short interval after the abrupt change, the prediction error of CALP fluctuates greatly. This is caused by the non-stationary nature of the channel samples vector, but the weight changes in this stage is small and as is observed in the figure that the changes almost have no effect on the following convergence process.

Another circumstance in this paper is that the receiver approaches the scatter slowly. In this case, the amplitude of the new appeared SC ($A_1^{'}$) increases from zero with time, and it should be revised as a time-varying parameter $A_1^{'}(n)$. Fig.3. shows the comparison when the amplitude of the new SC with a different Doppler shift gradually increases from zero at a rate of 0.1/s. The Doppler frequency is set as $f_1^{'} = 50Hz$. In this simulation, the prediction error of CALP first increases to a relative high point, and then need a long time to converge, while the DALP maintains a very small prediction error during the convergence process.

C. Discussion

The two circumstances often happen in realistic radio channel, and the proposed DALP method shows a good prediction performance. The DALP is just a simple combination of two adaptive linear predictors, but it is based on the fact that the prediction error of CALP is an adaptive AR process which can also be predicted, and the effectiveness of DALP is validated in the above simulations. Also, the computational complexity of this algorithm is just a little higher than that of CALP because the order of LP for error is low. However, when the radio channel is stationary, the prediction accuracy of DALP is a bit lower due to superimposed excess mean-square error. Thus, the DALP method, alternated with CALP method will produce a better overall result, and the alternating algorithm will be one of our primary focuses in the future research.

V. Conclusion

A robust DALP method is proposed in this paper to predict abruptly changed radio channel due to the appearance or disappearance of SCs. As the prediction error of CALP can be modeled by an adaptive AR process, a linear predictor with relative low order is used to track the error of CALP and then to predict the radio channel by combination with CALP at the cost of slightly higher computational complexity. The proposed DALP method is just a simple combination of two adaptive linear predictors, but it is based on the fact that the prediction error of CALP is an adaptive AR process. The performance of DALP is evaluated under two common circumstances and it presents an impressive convergence rate as well as prediction accuracy. But for stationary radio channel, the prediction accuracy is a bit lower than CALP. As a result, for the abruptly changed radio channel, the DALP method will improve the prediction performance.

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