Channel Prediction Based on Chirp Z-Transform and Linear Parameter Prediction

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Abstract

Fast fading channel prediction using chirp z-transform (CZT) and linear parameter prediction is proposed. The fading channel is modeled as a deterministic process, which can be approximated as the summation of some sinusoids. To mitigate quickly changing fading channel characteristic caused by relative movement between transmitter, receiver, and reflectors, a novel channel prediction method is proposed. The proposed method estimate dominant path parameters from the Doppler spectrum, calculated using chirp z-transform, and predict the future path parameters using linear prediction. Future channel characteristic can then be extrapolated from the predicted parameters. Evaluation shows that this method can increase accuracy of channel prediction.

Keywords: ── channel prediction, chirp z-transform, parameter prediction, Doppler spectrum

1. Introduction

The future wireless communication systems will need seamless broadband connection for highly mobile users, where communications between highly moving nodes can be heavily distorted by the fast power fading and fast phase rotation characteristic of fast fading channel. Some possible solutions, such as using the frequency diversity, space diversity, and error coding, only work in receiver at the receiving mode because they do not have any information of the channel characteristic during the transmitting mode. To improve the performance during the transmitting mode, channel prediction can gives way to adaptive transmission methods, which are able to adapt the future transmission parameters based on the future channel prediction [1].

Many of the channel prediction approach by other researches were using the autoregressive (AR) method such as [2] and [3], which need high computational cost to estimate its parameters. The same drawbacks also apply to channel prediction using high-resolution methods, such as the ROOT-MUSIC [4] and ESPRIT [5]. On the other side, some low cost approaches using linear prediction methods such as [6] and [7] are simply not accurate enough to predict the behaviour of fast fading channel for most applications.

This paper proposed a channel prediction method using the chirp z-transform (CZT), which has lower calculation cost and better stability compared to the AR and high-resolution methods. It offers much higher accuracy compared to the linear prediction methods. The prediction is accomplished by estimating the parameters of all dominant signal paths in the Doppler spectrum, calculated using CZT, and then linearly predicts the future path parameters to reduce the inaccuracy caused by windowing in the CZT calculation, using Newton backward difference interpolation.

2. Theory

The fading channel model for wireless communication systems is can be considered to have a deterministic process, such as the classic Jakes model, which can accurately approximate a fading channel based on the summation of some sinusoids. These sinusoids are the multiple signal paths caused by reflections in the environment. Physical evaluations showed that the number of dominant sinusoids is relatively small. Although the detail physics of the channel are very complex, many of them can be assumed constant, such that, each signal path can be characterized by parameters: amplitude, a_m, phase shift, θ_m, and Doppler frequency, f_m. The channel characteristic, $c(t)$, is the summation of these M complex signal paths, that is

$$c(t) = \sum_{m=1}^{M} a_m e^{j(2\pi f_m t + \theta_m)} \tag{1}$$

For channel prediction, observation of past estimated channel characteristic is essential to estimate its future values. In many applications, the channel characteristic can be estimated in the receiving mode, using a priory known pilot symbols. Further estimation of the channel in the received payload symbols can be achieved using the frequency diversity, space diversity, error coding, or other methods. By transforming the time domain channel characteristic into frequency domain, the dominants signal paths and their parameters can be estimated from the peaks in the frequency spectrum, and then the future channel characteristic can be extrapolated using (1).

The maximum Doppler frequency in fast fading channel is usually much lower compared to the symbol rate, therefore the resulting Doppler spectrum will only have a group of signal peaks close to one another around the zero frequency. Accurate distinction of these peaks using fast Fourier transform (FFT) will require a long interval of information. However, long interval of window is rather harmful, since the channel characteristic is changing during that interval. Therefore, it is preferable to observe short time domain information while maintain accurate distinction of the peaks. The authors have proposed the frequency domain interpolation method using the chirp z-transform (CZT) to increase the accuracy of peak's parameters estimation, while maintaining short time interval window and low calculation cost.

The discrete fourier transform can be seen as a special case of the more general z-transform, in which the z-transform is evaluated only at a number of equally spaced points on a unit circle in the z-plane. The z-transform of N time samples of the estimated channel, $\hat{c}(n)$, at L equally spaced complex points, z_k, is expressed as

$$\hat{C}(z_k) = \sum_{n=0}^{N-1} \hat{c}(n) z_k^{-n} \quad \text{where} \quad z_k = z_0 z_s^{\,k} \quad \text{and} \quad k = 0, 1, 2, \ldots, L\text{-}1. \tag{2}$$

In case of CZT, the set of the complex points can form an arc on the unit circle starting from a starting angle, ϕ_0, and each point is separated by a separation angle, ϕ_s, therefore $z_0 = e^{j\phi_0}$ and $z_s = e^{j\phi_s}$. The starting and separation angles are calculated according to the desired frequency range of the resulting spectrum from f_{start} to f_{end}, and L number of frequency bins, as

$$\phi_0 = \frac{f_{start}}{f_s} 2\pi \tag{3}$$

and

$$\phi_s = \frac{f_{end} - f_{start}}{f_s\, L} 2\pi \tag{4}$$

where f_s is the sampling frequency. The z-transform is therefore can be written as

$$\hat{C}(z_k) = \sum_{n=0}^{N-1} \hat{c}(n) z_0^{-n} z_s^{-nk} \tag{5}$$

Furthermore, by replacing the product, nk, with $[n^2 + k^2 - (k-n)^2]/2$, the z-transform can be expressed in the form of convolution, as the following

$$\hat{C}(k) = h^*(k) \sum_{n=0}^{N-1} g(n) h(k-n) \quad \text{where} \quad g(n) = \hat{c}(n) z_0^{-n} h^*(n)\text{, and } h(k) = z_s^{\,k^2/2} \tag{6}$$

In (6), $h^*(k)$ and $h^*(n)$ are constant sequences with frequency increase linearly with time, or called chirp sequence; hence, the transformation is called the chirp z-transform. The calculation cost of CZT is proportional to $(N+L)\log(N+L)$, assuming that $(N+L)$ is a power of two, compared to $O(N^3)$ for eigendecomposition calculation of the AR and high-resolution methods.

Prior to the CZT calculation, windowing is usually important to reduce spectral leakage in the Doppler spectrum. Most windowing will have largest weight at or around the middle of the window, hence paying more attention to the middle part of the time domain window. Because the path parameters are changing during that window interval, it is better to pay more attention to the last part of the window. However, it is not possible to estimate the parameters at the current time, because future information of the channel is required. Therefore, linear parameter prediction is proposed to predict the current parameters based on their past values.

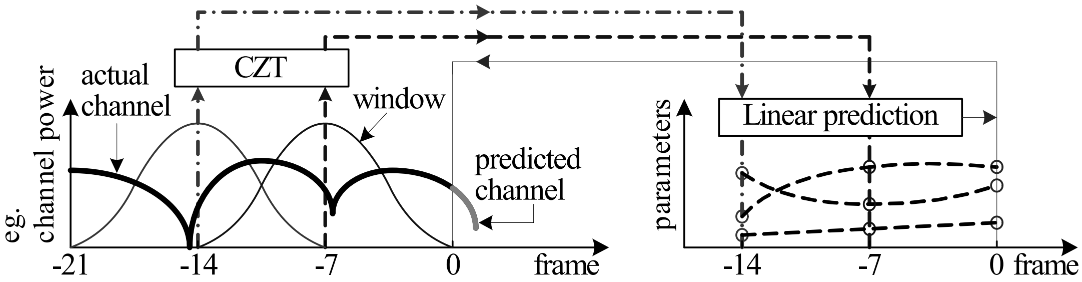

Figure 1: Linear path parameter prediction scheme

Figure 1 shows the simplified prediction scheme with only three parameters. To estimate the parameters of frame 0, the past 14 frames are windowed and feed through the CZT. However, because of the windowing, the parameters estimated from the last window are the approximate of the previous seventh frame parameters. The proposed method uses the Newton backward difference interpolation as the one in [6], to predict the approximate parameters at current time. The predicted parameters can then be used to predict the channel characteristic for the next frame.

The Newton backward difference interpolation of order *K* can be calculated from the series

$$f(n) = f(n_0) + r\nabla f(n_0) + \frac{r(r+1)}{2!}\nabla^2 f(n_0) + \cdots + \frac{r(r+1)\ldots(r+K-1)}{K!}\nabla^K f(n_0) \tag{7}$$

where $r = (n-n_0)/f_s$, $\nabla f(n_0) = f(n_0) - f(n_{-1})$ and $\nabla^K f(n_0) = \nabla^{K-1} f(n_0) - \nabla^{K-1} f(n_{-1})$ (8)

The coefficient, r, is calculated from the difference between the future time, n, and current sample time, n_0, normalized to the sampling rate. Meanwhile the backward difference, $\nabla f(n_0)$, is calculated from the difference between the value at current sample and at one sample ahead.

3. Evaluation

Implementation of channel prediction to the time division duplex (TDD) scheme is straightforward, since a single frequency band is used for receiving and transmitting mode. From the base station point of view, the information in the past uplink intervals can be used to estimate the past channel characteristic, and the result of the prediction can be used directly to predict the next downlink channel. Therefore, the proposed method is evaluated for a TDD system in a simulated fast fading channel using ray-tracing method. The simulated environment consisted of two fixed reflectors and one user, moving away from the base station at 14 m/s, or about 50 km/h. Each TDD frame is 5 ms long with symbol rate of 500 kHz. Binary phase shift keying (BPSK) is used to modulate the carrier signal at the frequency of 2 GHz. The Doppler spectrum is calculated from the time domain information of the past 14 uplink frames, using CZT with 210 frequency bins and frequency range from –200 to 200 Hz.

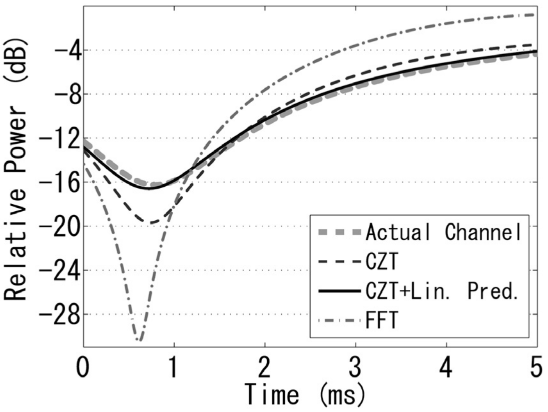

Figure 2: Typical power prediction result

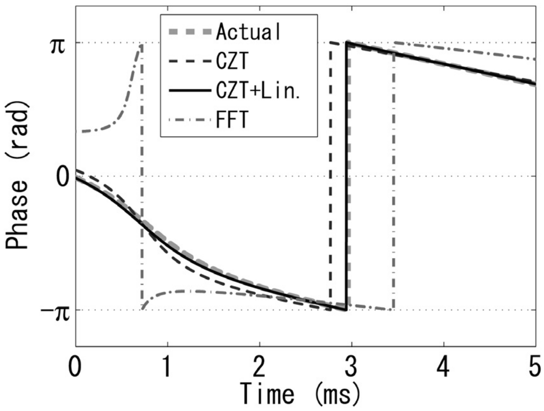

Figure 3: Typical phase prediction result

The channel prediction results are compared to the actual channel power and phase, which are shown as the dashed thick curves. The CZT with linear prediction results, shown in solid curves, have increased accuracy compared to the prediction result using CZT only, which are shown in dashed thin curves. The calculation of Doppler spectrum without interpolation (using FFT) gave the worst results, especially in the phase prediction, as shown in the dash-dotted curves.

Noise has very small effect to the prediction, because the noise power had been spread across the entire sampling bandwidth in the Doppler spectrum calculation. Therefore, the linear prediction is less likely effected by the noise. However, the linear prediction can be difficult to use in a severe condition, such as, when the path parameters are changing very quickly during the observation window. In such condition, low pass filter of the path parameters before calculating linear prediction might improve the performance.

4. Conclusion

We have proposed a channel prediction method using the chirp z-transform and Newton backward difference interpolation to improve power and phase prediction accuracy. The proposed method has low calculation cost compared to the AR and high-resolution methods, however it can maintain high prediction accuracy. In the evaluation, the method is implemented for a TDD system in a simulated fast fading channel. The results of CZT with linear parameter prediction method showed improvement over the CZT only method and much better compared to the FFT method.

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