Nonlinear Prediction of Frequency-Domain Channel Parameters for Channel Prediction in Fading and Fast Doppler-Shift Change Environment

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1. Intruduction

Performance of mobile communications often suffers from various fading phenomena. To reduce the adverse effect, we may employ such techniques as diversity reception and error-correcting code. Another countermeasure is channel prediction [1] with which we predict the channel change in time to realize pre-equalization such as transmission power control or adaptive modulation. It leads also to high-capacity spatial-domain multiple access (HC-SDMA) [2].

There exist several methods in channel prediction, namely, autoregressive (AR) method [3] [4] [5] [6] super-resolution methods such as ROOT-MUSIC [7] and ESPRIT [8] , and time-domain direct prediction [9] . Each of them has problems more or less in its calculation cost and/or prediction precision.

Previously the authors proposed a low-calculation-cost and high-precision prediction method in frequency domain [10] where we presuppose the so-called Jakes' model [1], in which we consider the channel consists of finite discrete Doppler paths, in combination with chirp z-transform [11] for high-resolution extraction of frequency-domain channel parameters. In addition, we also demonstrated that a linear prediction of the channel parameters at the beginning of the prediction period greatly improves the performance of the channel prediction [12] [13] . However, in a series of practical experiments in the field, we found that sometimes the linear prediction fails to improve the performance or, in rare cases, degrade the communication quality.

In this paper, we propose a frequency-domain channel prediction employing chirp z-transform and nonlinear parameter prediction. Simulation results demonstrate that the prediction accuracy remains very high even in fast Doppler-shift change environment. We find that the bit-error rate (BER) is lower than the previous linear prediction results in a series of simulations. The calculation cost is very small, i.e., almost the same as that in the previous linear prediction method.

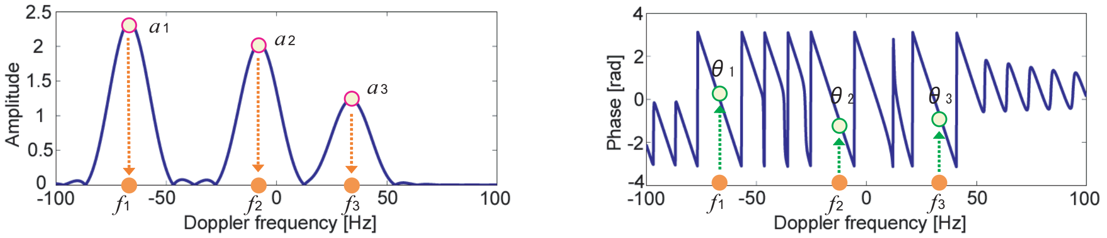
2. Nonlinear prediction of channel parameters in frequency domain

2.1 Channel model

According to the Jakes' model, a fading channel is modeled as the summation of sinusoids, which are the multi-path rays caused by scattering and reflection. Each signal path m can be characterized by a set of path parameters such as amplitude a_m, phase shift θ_m,and Doppler frequency f_m. The channel characteristic $c(t)$ as a function of time t is the summation of M complex signal paths expressed as

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

We can observe each signal path as an amplitude peak in the Doppler frequency spectrum that expresses the Fourier transform of the channel response as shown in Fig.1. Thus the path parameters of each dominant signal path can be obtained in the frequency domain if the frequency resolution is sufficiently high.



(a) (b)

Figure 1: Conceptual illustration representing the extraction of the frequency-domain channel parameters, namely, amplitude a_m, frequency f_m, and phase θ_m of dominant paths.

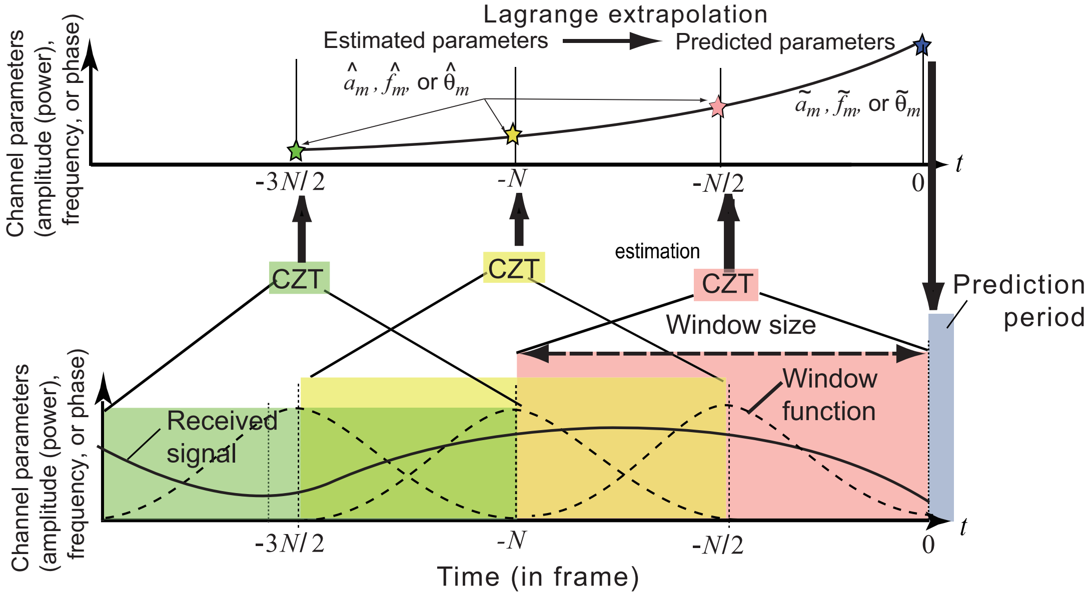


Figure 2: Schematic diagram of our proposed channel prediction based on chirp z-transform (CZT) and Lagrange extrapolation of frequency-domain channel parameters, namely, amplitude, frequency, and phase of dominant paths.

We use the chirp z-transform (CZT), instead of normal fast Fourier transform (FFT), to obtain the Doppler spectrum to realize both of a low calculation cost and a high frequency-domain resolution [10]. However, the CZT (or FFT) spectrum represents averaged channel characteristics in the CZT (FFT) window so that we cannot derive the channel parameters at the beginning of the channel prediction period $t = 0$.

Figure 2 is a schematic diagram showing our proposal. Since Fourier window such as Hanning window having length of N extracts the channel parameters with emphasis on the central part, the latest window centering at $-N/2$ cannot extract the parameters at $t = 0$, but does at $t = -N/2$. Then, we have to predict the channel parameters at $t = 0$ by using the parameters in the past ($t < 0$).

2.2 Nonlinear prediction of frequency-domain parameters

In this paper, we use three sets of estimated channel parameters $\hat{a}_m(t)$, $\hat{f}_m(t)$, $\hat{\theta}_m(t)$ at $t = -N/2$, $-N$ and $-3N/2$ to predict the parameters $\tilde{a}_m(0)$, $\tilde{f}_m(0)$, $\tilde{\theta}_m(0)$ nonlinearly by the Lagrange extrapolation for $t_1 = -3N/2$, $t_2 = -N$ and $t_3 = -N/2$ as, for example,

$$\tilde{a}_m(0) = \hat{a}_m(t_1)\frac{(0-t_2)(0-t_3)}{(t_1-t_2)(t_1-t_3)} + \hat{a}_m(t_2)\frac{(0-t_3)(0-t_1)}{(t_2-t_3)(t_2-t_1)} + \hat{a}_m(t_3)\frac{(0-t_1)(0-t_2)}{(t_3-t_1)(t_3-t_2)} \tag{2}$$

For the phase parameters $\tilde{\theta}_m(t)$, we apply the above parameter prediction after an appropriate phase unwrapping process.

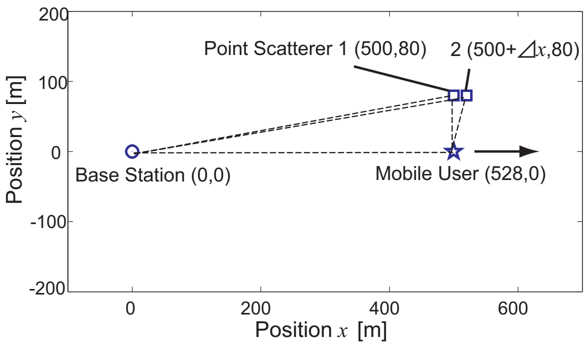


Figure 3: Geometrical setup.

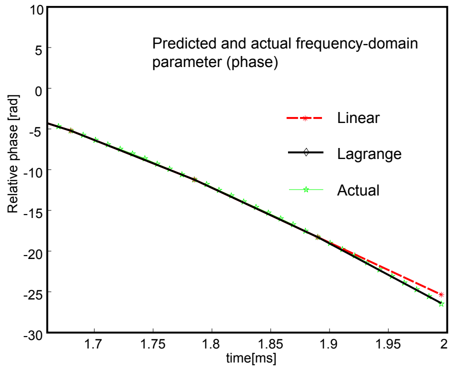


Figure 4: Linearly predicted and Lagrange-predicted phase parameters as well as the actual phase parameter.

3. Experiments

Among various cases, we present in this paper a set of results when the previously-proposed linear prediction method fails seriously. Figure 3 shows the geometrical setup. There are two scatterers separate by 15m almost right beside the mobile user. A base station is in the line of sight. Figure 4 shows linearly and nonlinearly (Lagrange) predicted phase parameters as well as actual one. The linear value differs from the Lagrange and actual values by several radians.

As a result, the channel characteristics estimated through the frequency-domain prediction differ from one another. In Fig.5, we find that the Lagrange results are almost the same as actual channel, while linearly predicted and non-predicted results deviate from them. Figure 6 shows the bit-error rate (BER) versus the signal-to-noise ratio (SNR) in an orthogonal frequency-division muptiplexing (OFDM) system with channel compensation using the prediction redults. The BER compensated based on the Lagrange prediction is almost the same as that based on actual channel characteristics whereas the linear prediction and non-prediction results are worse by 2 to 4 dB.

4. Conclusion

We proposed a nonlinear frequency-domain channel prediction in combination with chirp z-transform for channel prediction with low calculation cost and high accuracy in fading and fast Doppler-shift change environment. OFDM system simulation demonstrated that the Lagrange nonlinear prediction yields a BER performance better than that of linear prediction by 2 to 4 dB.

References

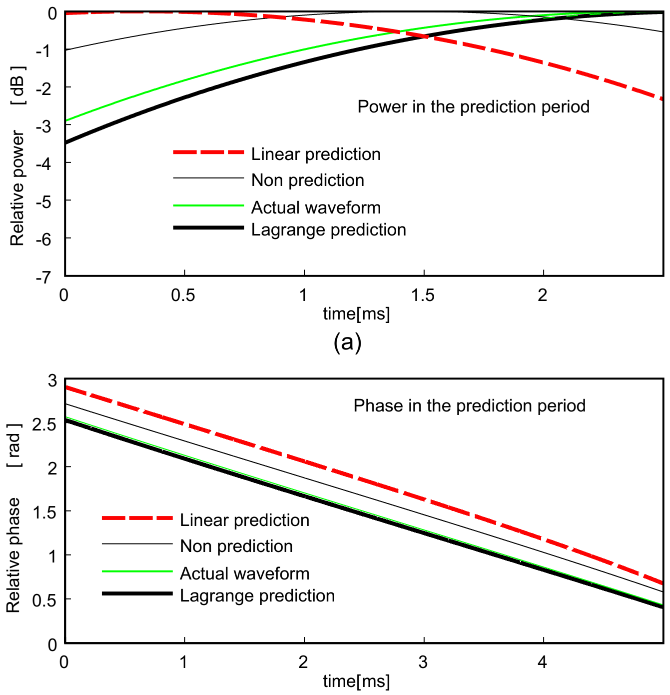
[1] W. C. Jakes, Ed., *Microwave Mobile Communications, 2nd edition.* Wiley-IEEE Press, 1994.

[2] *ANSI-ATIS 0700004-2005, High capacity spatial division multiple access (HC-SDMA)*, ANSI Std., September 2005.

[3] T. Eyceoz, A. Duel-Hallen, and H. Hallen, “Prediction of fast fading parameters by resolving the interference pattern,” in *Proceedings of the Asilomar Conference on Signals, Systems, and Computers*, vol. 1, 1997, pp. 167–171.

[4] ——, “Deterministic channel modeling and long range prediction of fast fading mobile radio channels,” *IEEE Transactions on Communications Letters*, vol. 2, no. 9, pp. 254–256, September 1998.

[5] A. Arredondo, K. Dandekar, and G. Xu, “Vector channel modeling and prediction for the improvement of downlink received power,” *IEEE Transactions on Communications*, vol. 50, no. 7, pp. 1121–1129, July 2002.



(a)

(b)

Figure 5: Predicted (a)power and (b)phase curves of the cannel as functions of time in the prediction period.

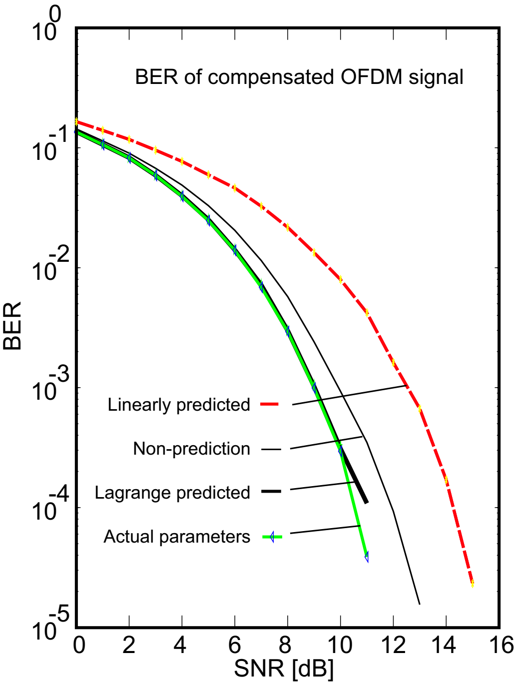


Figure 6: Bit error rate (BER) curves obtained for linearly-predicted, non-predicted, Lagrange-predicted, and with actual parameters when the geometry causes sever change in the Doppler effect.

[6] M. Sternad and D. Aronsson, “Channel estimation and prediction for adaptive OFDM downlinks,” in *Proceedings of the IEEE Vehicular Technology Conference 2003–Fall*, vol. 2, October 2003, pp. 1283–1287.

[7] J. Hwang and J. Winters, “Sinusoidal modeling and prediction of fast fading processes,” in *Proceedings of the IEEE Globecom*, November 1998, pp. 892–896.

[8] J. Andersen, J. Jensen, S. Jensen, and F. Frederiksen, “Prediction of future fading based on past measurements,” in *Proceedings of the IEEE Vehicular Technology Conference 1999–Fall*, 1999.

[9] F. Maehara, F. Sasamori, and F. Takahata, “Linear predictive maximal ratio combining transmitter diversity for OFDM-TDMA/TDD systems,” *IEICE Transactions on Communications*, vol. E86-B, pp. 221–229, 2003.

[10] S. Tan and A. Hirose, “Low-calculation-cost fading channel prediction using chirp z-transform,” *Electronics Letters*, vol. 45, no. 8, pp. 418–420, 2009.

[11] L. R. Rabiner, R. W. Schafer, and C. Rader, “The chirp z-transform algorithm,” *IEEE Transactions on Audio and Electroacoustics*, vol. 17, pp. 86–92, 1969.

[12] S. Ozawa, S. Tan, and A. Hirose, “Channel prediction experiment based on linear prediction in frequency domain,” in *Asia-Pacific Microwave Conference (APMC) 2010 Yokohama*, December 2010, pp. 1280–1283.

[13] ——, “Errors in channel prediction based on linear prediction in frequency domain – combination of time-domain and frequency-domain techniques –,” *URSI Radio Science Bulletin*, vol. 337, pp. 25–29, 2011.