A Phase Noise Immune Equalization Algorithm for Millimeter Wave SC-FDE System

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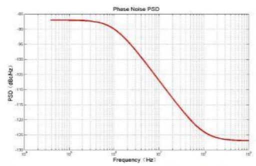
Abstract **: To solve the problem that phase noise affection of high-order modulation in millimeter wave broadband system, this paper analyzes and modifies the theoretical model of phase noise given in 802.11ad and 802.15.3c standards, and generates the actual noise values based on modified model for simulation analysis. The frame structure given in standards is optimized for SC-FDE system to estimate noise and channel state by adding data block 0. An improved MMSE equalization algorithm is proposed in this paper to track the channel and phase noise changes in real time and obvious phase noise immunity characteristic is obtained compared with traditional algorithm.**

Phase noise model

"One pole/one zero" model of phase noise PSD

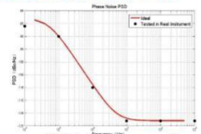
$$PSD(f) = PSD(0)\frac{1+(f/f_z)^2}{1+(f/f_p)^2}$$



Model in IEEE 802.15.3.c and IEEE 802.11ad standards

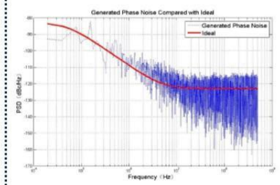
Modified model based on true measurement result

Measured Phase Noise in Prototype



Modified phase noise model

Actual phase noise values generation

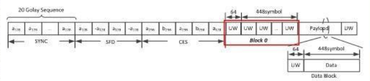


Take $\sqrt{PSD}$ as the phase noise frequency response , and generate a group of Gaussian noise ω(t) that obeys the standard normal distribution. Through the filter composed of $\sqrt{PSD}$, the actual phase noise θ(t) is obtained

This paper analyzes the theoretical model of phase noise given in 802.11ad and 802.15.3c millimeter wave standards, modifies the theoretical model with the measured phase noise of actual equipment, and simulates the actual phase noise values that conforms to the modified model as the simulation input.

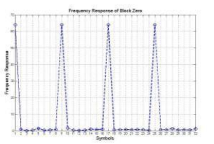
Optimized frame structure

Optimized frame structure



Based on the SC-FDE frame structure of 802.15.3c protocol, data block 0 is added between the channel estimation sequence (CES) and the data load. The length of data block 0 is the same as that of ordinary data block, which is composed of repeated UW.

Noise estimation based on optimized frame

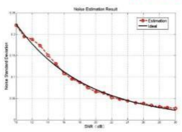


Eight consecutive UW sequences undergo 512 point FFT (SNR=30dB)

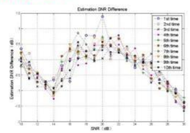
The frequency sequence obtained through P times repeated UW sequence in the time domain transformed by N_b point FFT, is equal to the original UW frequency sequence interpolated with $P-1$ zeros. Therefore, the zero value frequency point of data block 0 can be used to obtain the estimated noise power $\hat{\sigma}_w^2$ in the frequency domain.

$$\hat{\sigma}_w^2 = \frac{\sum_{X_{ces}(k)=0} |Y_{ces}(k)|^2}{N_b - N_c}$$

Noise estimation results



Comparison of noise estimates and actual noise



Comparison between estimated SNR and actual SNR (10 times simulations)

Optimizing the frame structure of 802.15.3c protocol by adding data block 0, which can be used for noise estimation. By this method, 512 points of FFT computing resources in the equalizer can be reused, resource overhead can be reducing effectively. After 10 simulation calculations, the error between the estimated signal-to-noise ratio and the actual signal-to-noise ratio is within ± 1.5dB.

Channel equalization

Ⅰ Initial channel estimation

Remove the first UW sequence (i.e. CP) of data block 0, Average the remaining number of P time domain received signals of UW

$$\overline{y_c} = \frac{1}{P}\sum_{S=1}^{P} y_c = U_c h_c + \frac{1}{P}\sum_{S=1}^{P} n_c = U_c h_c + \overline{n_c}$$

According to the LS algorithm, the frequency domain LS channel can be estimated as:

$$\hat{h}_{fc} = U_{fc}^{-1}\overline{y}_{fc}$$

Ⅱ DFT interpolation filtering

$$\hat{\mathrm{h}}_{fb} = \mathrm{F}_b\left[\mathrm{I}_{Nc}; 0_{(N_b-N_c)\times N_c}\right]\mathrm{F}_c^{\mathrm{H}}\hat{\mathrm{h}}_{fc}$$

Ⅲ Channel tracking

Remove the multipath by estimated channel $\hat{h}_{fc}$, the received UW in ordinary data block is:

$$r_i(m) = e^{j\phi_i'(m)}\tilde{r}_i(m) + n_i'(m), L-1 \le m \le N_c - 1 i \ge 0$$

Using MMSE criteria, the CPE generated by phase noise on the UW is:

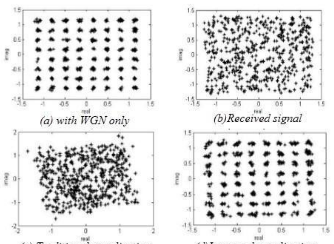
$$P_i'(0) = \frac{1}{N_c - L + 1}\sum_{m=L-1}^{N_c-1}\frac{\tilde{r}^*(m)r_i(m)}{|\hat{r}(m)|^2 + \sigma^2}$$

CPE on the data block can be obtained by linear interpolation of CPE generated on the CP of the data block:

$$\widetilde{P}_i'(0) = \frac{(\widetilde{P}_{i+1}'(0) + \widetilde{P}_i'(0))}{2} + \frac{(\widetilde{P}_{i+1}'(0) - \widetilde{P}_i'(0))}{2P}$$

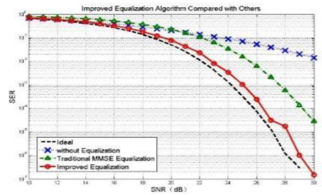
Using MMSE criterion, obtain the frequency-domain equalization coefficient:

$$C(k) = \frac{H_i^*(k)}{|H_i(k)|^2 + \sigma_w^2}, 0 \le k \le N_b - 1$$



(a) with WGN only *(b)Received signal*

(c) Traditional equalization *(d)Improved equalization*



Comparison between the algorithm in this paper and the traditional algorithm.