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CHANNEL ESTIMATION COMBINED WITH ICI SELF CANCELLATION SCHEME AND UNSCENTED KAMAN FILTER

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Abstract: **-** A well-known problem of the Orthogonal Frequency Division Multiplexing (OFDM) syste for mobile environment is the fading channel which degrades the system performance. Many methods have been proposed for channel estimation such as LS (Least Square), MMSE (Minimum Mean Square Error), Kalman Filter.…A fading channel with Doppler effect from the moving of receivers degrades system because of complicated changes and hard estimation. That is why traditional estimators do not have good performance. This paper introduces two new solutions of channel estimation for reducing Doppler Effect.

The first is that we combine between traditional estimation such as Least Square and self cancellation scheme [1]. The second is that we apply Unscented Kalman theory for channel estimation so that we can approximate channel estimation as a problem of nonlinear estimation. We compared these results together as well as with traditional estimator (Least Square). These algorithms had good results in simulations.

Keywords: OFDM system, channel estimation, ICI self-cancellation scheme, Kalman filter, Extended Kalman filter, Unscented Kalman filter.

1. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is a modulation scheme, which is used in several wireless systems for transferring data at high rate. The main disadvantage of this scheme is the inter-carrier interference (ICI), caused by Doppler shift due to relative motion between the transmitter and receiver, or by differences between the frequencies of the local oscillators at the transmitter and receiver. The effect of ICI on OFDM symbols will degrade the system performance. OFDM systems with long symbol durations are more vulnerable to time-selective fading than Single-carrier systems. This is specially the case in mobile environments and closely related to Doppler spread. Under this condition, the orthogonality between sub-channels cannot be maintained and the Inter-Carrier Interference (ICI) will be introduced. ICI will decrease the signal to interference ratio (SIR). Low SIR will introduce an error floor in signal detection [2]. Therefore, ICI suppression has a great significance for OFDM system.

The channel estimation can be performed by inserting pilot tones into OFDM symbol [3], [4]. In this paper, channel estimation is studied for comb-type pilot. The comb-type pilot channel estimation consists of algorithms to estimate the channel at pilot frequencies and to interpolate the channel. The interpolation of the channel for comb-type can use one of the different interpolation methods such as linear interpolation, second order interpolation, low-pass interpolation, spline cubic interpolation, and time domain interpolation [5].

Currently, there are many different methods for reducing ICI including frequency-domain equalization [6], time-domain windowing schemes [7],[8], ICI-self-cancellation scheme [1], frequency offset estimation and compensation techniques and Doppler diversity [9]... Among the schemes, the ICI-self-cancellation scheme and Kalman filter are good ways to combat against ICI. The Kalman filter, even though quite general, is in this case not applicable due to its limitation to linear models. For channel estimation with ICI reduction, in this paper we use the Unscented Kalman Filter (UKF) [10]. UKF improves the performance of Kalman filter by using a deterministic sampling approach and when propagated through the true nonlinear system captures the prior mean and covariance till to the third order of Taylor series expansion for any non-linearity.

In this paper, we propose two new solutions for channel estimation by combining ICI self- cancellation Scheme with Least Square (LS) for channel estimation and channel estimation for based on Unscented Kalman Filter.

2. SYSTEM MODEL

OFDM converts serial data stream into parallel blocks of size N and modulates these blocks using inverse fast Fourier Transform (IFFT). Time domain samples of an OFDM symbol can be obtained from frequency domain data symbols as Fig. 1 shows a typical block diagram of OFDM system with pilot signal assisted. The binary information data are grouped and mapped into multi-amplitude multi-phase signals.

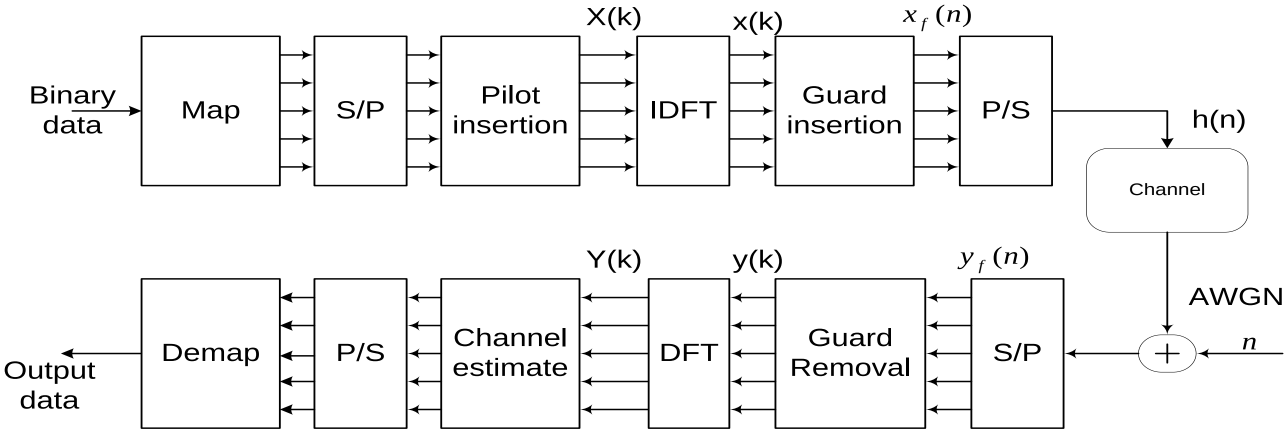

Figure 1. OFDM system model

The binary information is first grouped and mapped according to the modulation in "signal mapper". After inserting pilots either to all sub-carriers with a specific period or uniformly between the information data sequence, IFFT block is used to transform the data sequence of length N {X(k)} into time domain signal {x(n)} with the following equation:

$$x(n) = IFFT\{X(k)\} = \sum_{k=0}^{N-1} X(k) e^{j\frac{2\pi kn}{N}} \qquad (1)$$

$$n = 0,1,2,\ldots N-1$$

Where N is FFT length

Following IFFT block, guard time, which is chosen to be larger than the expected delay spread, is inserted to prevent Inter-Symbol Interference. This guard time includes the cyclically extended part of OFDM symbol in order to eliminate inter-symbol interference (ISI). The total OFDM symbol is given as follows:

$$x_f(n) = \begin{cases} x(N+n), & n = -N_g, -N_g+1, \cdots, -1 \\ x(n), & n = 0,1,\cdots N-1 \end{cases} \qquad (2)$$

Where N_g is the length of the guard interval.

Signal after the conversion from parallel to serial will be passed through fading channel and added noise. At the receiver, the receiver signal is

$$y_f(n) = x_f(n) \otimes h(n) + w(n) \qquad (3)$$

Where w(n) is additive white Gaussian noise and h(n) is the channel impulse response.

Following FFT block, the pilot signals are extracted and the estimated channel $H_e(k)$ for the data sub-channels is obtained in channel estimation block. Then the transmitted data is estimated by:

$$X_e(k)=\frac{Y(k)}{H_e(k)} \quad k=0,1,\cdots N-1 \tag{4}$$

Then the binary information data is obtained back in “signal de-mapper” block. Comb-type pilot is used in this paper [5]. In this comb-type pilot system, since only some sub-carriers contain the pilot signal, the channel response of non-pilot sub-carriers can be estimated by interpolating neighboring pilot-sub channels. Therefore, an effective channel interpolation algorithm is necessary to estimate channel response at the data-subcarrier by using the information from comb-pilot data. We use linear interpolation algorithm in this paper.

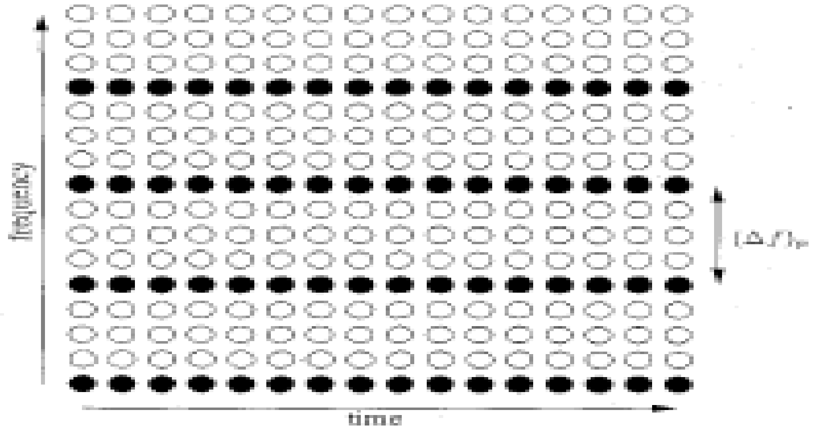

Figure 2. Comb-type pilot sub-carrier arrangement

3. CHANNEL ESTIMATION COMBINED WITH ICI SELF-CANCELLATION SCHEME

The main idea of ICI-self-cancellation scheme is to modulate one data symbol onto the next subcarrier with predefined inversed weighting coefficient “-1”. By doing so, the ICI signals generated within a group can be “self-cancelled” each other [1]. . Figure 2 shows the block diagram of typical ICI self-cancellation scheme for the OFDM system. The ICI self-cancellation scheme based on a data allocation of ($X(k)$, $X(k+1)=-X(k)$), k=0,2,…,N-2, has been proposed to deal with the inter-carrier interference. The received signal $Y(k)$ is determined by the difference between the adjacent subcarriers

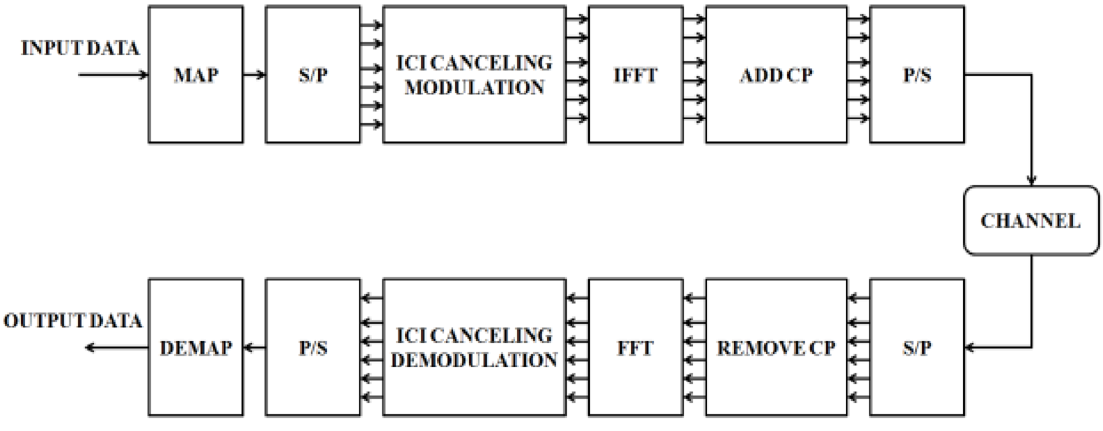

Figure 3. **The OFDM system using ICI-self cancellation scheme.**

Assume the transmitted symbols are constrained, then, the received signal within k^{th} subcarrier becomes as

$$Y'(k) = \sum_{l=0}^{N-1} X(l)S(l-k) + n(k) \quad = \sum_{\substack{l=0\\ even}}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n(k)$$

$$= \sum_{\substack{l=0\\ even}}^{N-2} X(l)S'(l-k) + n(k) \tag{5}$$

The demodulation is designed to work in such a way that each signal at the $(k+1)^{th}$ subcarrier (where k denotes even number) is multiplied by "-1" and then summed with the one at the k^{th} subcarrier. Then the resultant data sequence is used for making symbol decision. It can be represented as

$$Y''(k) = Y'(k) - Y'(k+1) \tag{6}$$

The ICI coefficient for ICI self-cancellation scheme is denoted as

$$S''(l-k) = -S(l-k-1) + 2S(l-k) - S(l-k+1) \tag{7}$$

We use ICI self-cancellation scheme, then we can apply it for channel estimation with traditional estimator such as Least Square such as figure 3 below.

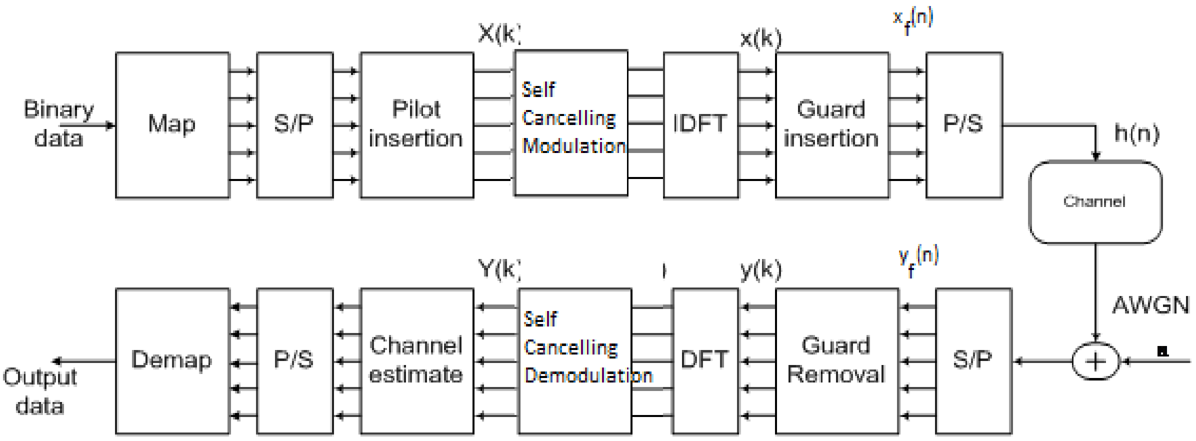

Figure 4. Channel estimation combined with self cancellation scheme

With this algorithm, we can combine channel estimation with self cancellation scheme to reduce ICI and Doppler effect from fading channel.

4. CHANNEL ESTIMATION BASED ON UNSCENTED KALMAN FILTER

Channel estimation based on Kalman Filter is one of solutions for ICI reduction. The main idea of the Kalman filter is to use a linear filter to update the mean and the covariance of the estimate so that the covariance of the estimation error is kept minimum. The Kalman filter, even though quite general, is in many cases not applicable due to its limitation to linear models. Many real situations have either nonlinear dynamics or nonlinear measurements such as fading environment with ICI effect. Over time, an approximate extension to the Kalman filter was developed: the Extended Kalman filter (EKF) that uses linearization about the current mean and covariance models to handle nonlinear models.

The Extended Kalman filter (EKF) is the non-linear version of the Kalman filter which makes linear to the current mean and covariance. The main idea of the Kalman filter is to use a linear filter to update the mean and the covariance of the estimate so that the covariance of the estimation error is kept minimal. Similar to a Taylor series, we can make linear to the estimation around the current estimate using the partial derivatives of the process and measurement functions to compute estimates even in the face of non-linear relationships. However, EKF has errors in linear approximation for non linear state.

The Unscented Kalman Filter (UKF) addresses the approximation issues of the EKF. The state distribution is again represented by a Gaussian Random Variable (GRV), but is now specified using a minimal set of carefully chosen sample points. These sample points completely capture the true mean and covariance of the GRV, and when propagated through the true non-linear system, captures the posterior mean and covariance accurately to the 3rd order (Taylor series expansion) for any non-linearity.

We can estimate channel response *H* from the following equation:

$$H(n+1)= f(H(n)) +v_1(n) \quad (8)$$

$$Y (n)= c(H(n)) +v_2(n) \quad (9)$$

With *f(H), c(H)* can both be nonlinear. The proposed algorithm of channel estimation based on Unscented Kalman Filter is as below

Assume $H(n) = e^{i\varepsilon(n)}$

With $H(n) = \left[H_1(n), H_2(n), \dots, H_{Np}(n)\right]^T = [e^{i\varepsilon_1(n)}, e^{i\varepsilon_2(n)}, \dots, e^{i\varepsilon_{Np}(n)}]^T$ (10)

With Ɛ(n) is unknown function depends on the variable *n*

- **At the first OFDM symbol:**

We use Least Square algorithm for channel estimation

$$H_0 = \frac{Y_p}{X_p} \quad (11)$$

With Y_P is the pilot signal at the receiver, X_P is the pilot signal at the transmitter.

Following matrix H_1, we can determine

$$\text{Calculate:}\varepsilon(0) = \frac{\ln H_0}{i} \quad (12)$$

$$\bar{\varepsilon}(0) = E[\varepsilon(0)] = \varepsilon(0) \quad (13)$$

Covariance:

$$P_0 = E[(\varepsilon(0) - \bar{\varepsilon}(0))(\varepsilon(0) - \bar{\varepsilon}(0))^T] = 0 \quad (14)$$

- **At other OFDM symbol (n>1):**

Step 1: Computing sample point:

The random variable to be estimated is initialized with constant, thus the dimension of x is 1, i.e., L = 1. That gives 2L +1 = 3 sample (sigma) points.

$$\chi_0 = \bar{\varepsilon}(n-1)(15)$$

$$\chi_1 = \bar{\varepsilon}(n-1) + \sqrt{(L+K)P_{n-1}} \quad (16)$$

$$\chi_2 = \bar{\varepsilon}(n-1) - \sqrt{(L+K)P_{n-1}} \quad (17)$$

$$\chi_i(n-1) = [\chi_0\chi_1\chi_2] \quad (18)$$

The weighting factors are:

$$W_0^{(m)} = \frac{K}{L+K}, W_0^{(c)} = \frac{K}{L+K}$$

$$W_0^{(m)} = W_0^{(c)} = \frac{1}{2(L+K)} \text{với } i = 1{,}2 \quad (19)$$

$$K = \alpha^2 L - L \text{với } \alpha = 0{,}001$$

Step 2: Weighting outputs and covariance:

Transforming the state equation yields:

$$D_i(n|n-1) = \chi_i(n-1) \quad (20)$$

the weighted state variable becomes

$$\bar{\varepsilon}(n|n-1) = \sum_{i=0}^{2L} W_i^{(m)} D_i(n|n-1) \quad (21)$$

Covariance:

$$P_{n|n-1} = \sum_{\boldsymbol{i=0}}^{\boldsymbol{2L}} W_i^{(c)} [D_i(n|n-1) - \bar{\varepsilon}(n|n-1)][D_i(n|n-1) - \bar{\varepsilon}(n|n-1)]^T + Q_1$$

$$D_0^*(n|n-1) = \bar{\varepsilon}(n|n-1) \quad (22)$$

$$D_1^*(n|n-1) = \bar{\varepsilon}(n|n-1) + \sqrt{(L+K)P_{n|n-1}} \quad (23)$$

$$D_2^*(n|n-1) = \bar{\varepsilon}(n|n-1) - \sqrt{(L+K)P_{n|n-1}} \quad (24)$$

Propagating the output through the non-linear equation gives:

$$\mathscr{y}(n|n-1) = g[D_i^*(n|n-1)] = X_p(n|n-1)e^{iD_i^*(n|n-1)} \quad (25)$$

Weighting the output:

$$\bar{y}(n|n-1) = \sum_{i=0}^{2L} \boldsymbol{W_i^{(m)}} \mathscr{y}_i(n|n-1) \quad (26)$$

Weighting the covariance with respect to outputs we will have:

$$P_{\hat{y}(n)\hat{y}(n)} = \sum_{i=0}^{2L} W_i^{(c)} [\mathscr{y}_i(n|n-1) - \bar{y}(n|n-1)][\mathscr{y}_i(n|n-1) - \bar{y}(n|n-1)]^T \quad (27)$$

Also weighting covariance with respect to outputs and inputs we have:

$$P_{\varepsilon(n)y(n)} = \sum_{i=0}^{2L} W_i^{(c)} [D_i^*(n|n-1) - \bar{x}(n|n-1)][\mathscr{y}_i(n|n-1) - \bar{y}(n|n-1)]^T \quad (28)$$

Step 3: Measurement update:

Computing the Kalman gain:

$$K_{\boldsymbol{n}} = P_{\varepsilon(n)y(n)} P_{\hat{y}(n)\hat{y}(n)}^{-1} \quad (29)$$

Using the Kalman gain given above, the value of the measurement and state covariance are updated as:

$$\overline{\varepsilon}(n|n) = \overline{\varepsilon}(n|n-1) + K_n\big(y(n) - \overline{y}(n)\big) \tag{30}$$

$$P_{n|n} = P_{n|n-1} - K_n P_{\hat{y}(n)\hat{y}(n)} K_n^T \tag{31}$$

Finally, channel frequency response at the nth OFDM symbol for pilot carriers is calculated:

$$H(n) = e^{i\overline{\varepsilon}(n)} \tag{32}$$

Step 4: with linear interpolation algorithm, we have channel frequency response at data carriers.

Then, we can go back to step 2 after increasing the time step to the next OFDM symbol n+1, and the process is repeated for a given number of OFDM preamble symbols.

5. SIMULATIONS AND RESULTS

The paper uses parameters of IEEE 802.16e to simulate OFDM system. In this paper, we use modulation schemes 4-QAM for simulation.

Table 1. **Simulation parameters**

IEEE 802.16e Parameter	
Number of Sub-carrier	840
FFT size	1024
Modulation	4-QAM
Number of pilot-carrier	210
ITU-R channel B	Vehicular
Fixed Guard Interval	256
License frequency	2.5 GHz
Bandwidth	20 MHz

The channel we used is ITU-R channel model, which was developed according to the ITU-R M.1225 Recommendation [11]. This type of model is used for the simulation of an IEEE 80216e-2005 system (a mobile WiMAX system). The ITU wideband channel is described based on a tapped delay line model, with a maximum number of 6 taps. Channel model ITU for 3 environments: indoor (1 – 5 km./h), pedestrian (5-30 km/h), vehicular (30 – 250 km/h) is as below and empirical model (channel B) is used to describe multi path channel.

Table 2: **Indoor channel model**

Tap	Channel A		Channel B	
	Delay (ns)	Power (dB)	Delay (ns)	Power (dB)
1	0	0	0	0
2	50	-3	100	-3.6
3	110	-10	200	-7.2
4	170	-18	300	-10.8
5	290	-16	500	-18
6	310	-32	700	-25.2

Table 3: **Pedestrian channel model**

Tap	Channel A		Channel B	
	Delay (ns)	Power (dB)	Delay (ns)	Power (dB)
1	0	0	0	0
2	110	-9.7	200	-0.9
3	190	-19.2	800	-4.9
4	410	-22.8	1200	-8
5	-	-	2300	-7.8
6	-	-	3700	-23.9

Table 4: **Vehicular channel model**

Tap	Channel A		Channel B	
	Delay (ns)	Power (dB)	Delay (ns)	Power (dB)
1	0	0	0	0
2	0.4	-1	0.8	-1
3	0.8	-9	1.6	-9
4	1.2	-10	2.2	-10
5	1.8	-15	3.6	-15
6	2.6	-20	5.2	-20

We simulate three algorithms as below:

Standard algorithm is used with a traditional estimator which is Least Square. ICI self Cancellation is used as combined algorithm between Least Square and Self Cancellation Scheme. Unscented Kalman Filter (UKF) is used as an algorithm applying UKF theory for channel estimation.

In the figure 5, the receiver with speed of 5 km/h is simulated and we can see UKF algorithm and ICI Self Cancellation have better performance than standard system and UKF is the best. In indoor channel and pedestrian channel, the OFDM system with ICI self-cancellation scheme and the system using UKF have the performance better than the standard OFDM. We realize that Unscented Kalman (UKF) had 5 dB better than Least Square at noise level of 10^{-3} and UKF had the best performance when compared with others. UKF is also an adaptive filter and in this condition, it shows very good performance.

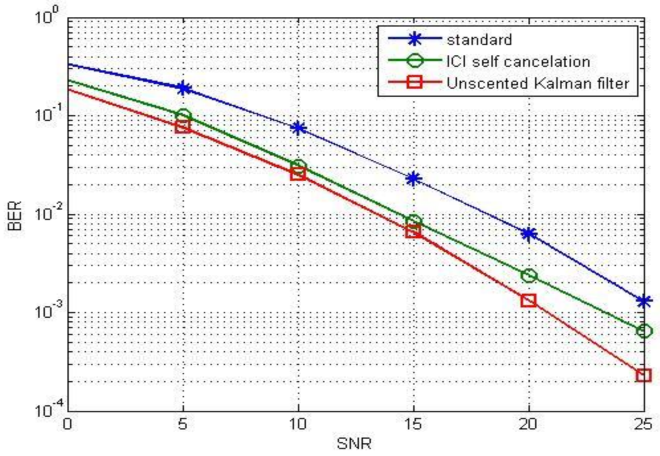

Figure 5. **Pedestrian channel with mobile speed v=5km/h.**

In the pedestrian condition, we simulate receiver with 10 km/h. In this simulation, UKF has the best performance than others. Meanwhile, ICI self cancellation has better performance than standard. However, from 20 dB or higher, Least Square has better performance. In this condition, we also can see that Unscented Kalman (UKF) had nearly 4 dB better than Least Square at noise level of 10^{-3}.

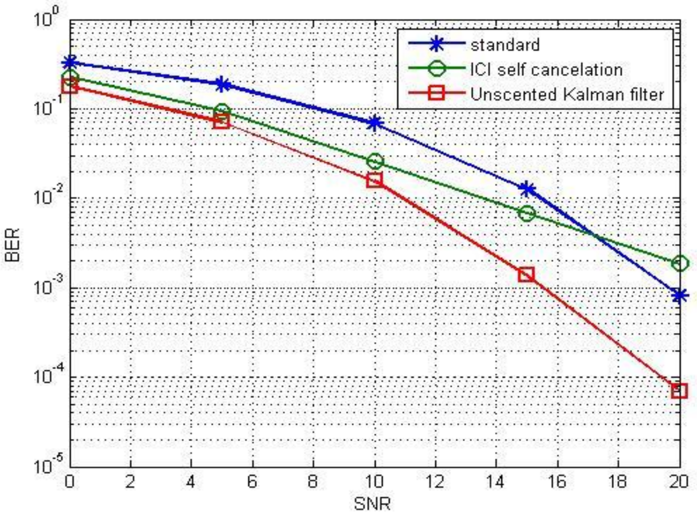

Figure 6: **Vehicular channel with mobile speed v=10km/h.**

For vehicular channel, the two systems still have the performances better than the standard OFDM with SNR from 0 to 20 dB. However, when the mobile speed is increased, the OFDM using UKF does not perform well at the high SNR (SNR from 25 to 40 dB). Figure 7 below shows the performance of these three systems according to the mobile speed at SNR=20dB. This means that these algorithms do not improve performance more than standard system with high velocity of receivers at high SNR. We also can see from velocity of 30 km/h, ICI self cancellation has nearly the same performance as standard.

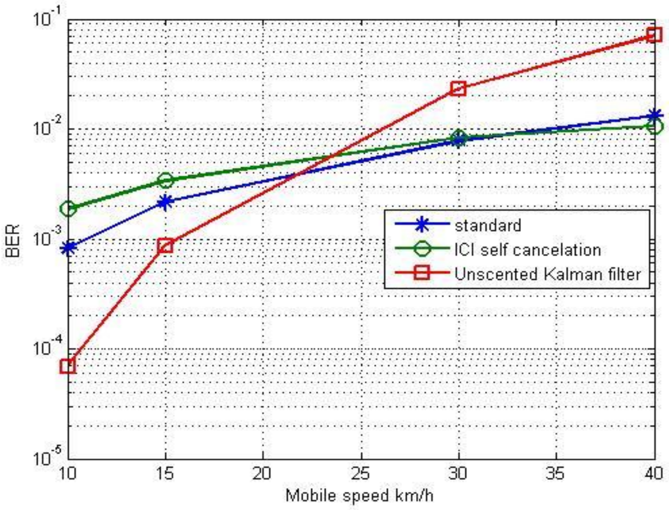

Figure 7. **BER in vehicular channel with different mobile speed.**

We can say that combined algorithm between Least Square and ICI self Cancellation Scheme had better performance than Least Square with low velocity and specially for low SNR. For other condition, it had nearly the same performance as Least Square. For UKF algorithm, we can have the best performance in low velocity. For high velocity in vehicular condition, it does not have good performance.

6. CONCLUSION

The paper performed channel estimation analysis and proposed the new algorithms for channel estimation. The paper proposed the combined algorithm between Least Square Estimator with ICI Self Cancellation and the algorithm of channel estimation based on Unscented Kalman Filter. The upper results can show that these methods had good performance in all fading environment such as: indoor, pedestrian, vehicular model. However, they also have not good performance in some specific conditions. For future research, we can expand other ICI reduction methods to achieve better results.

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