BEM-based UKF Channel Estimation for 5G-enabled V2V Channel

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Contents

PART ONE
Background

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Background

High-Speed Environment

Doubly-selective channel:

- Multipath effects
- Doppler effects

Challenge:

Time and frequency selective fading

Solution:

Time domain channel estimation method

Non-stationary channel:

- The Channel Impulse Response (CIR) is changing during an OFDM symbol
- Time correlation coefficients are time-varying

Solution:

Joint estimating the CIR and time correlation coefficients

Background

BEM

The Basis Expansion Model (**BEM**) is used to compresses the CIR into a low-dimensional space based on a series of base vectors, which effectively **reduce the space complexity** of time domain channel estimation.

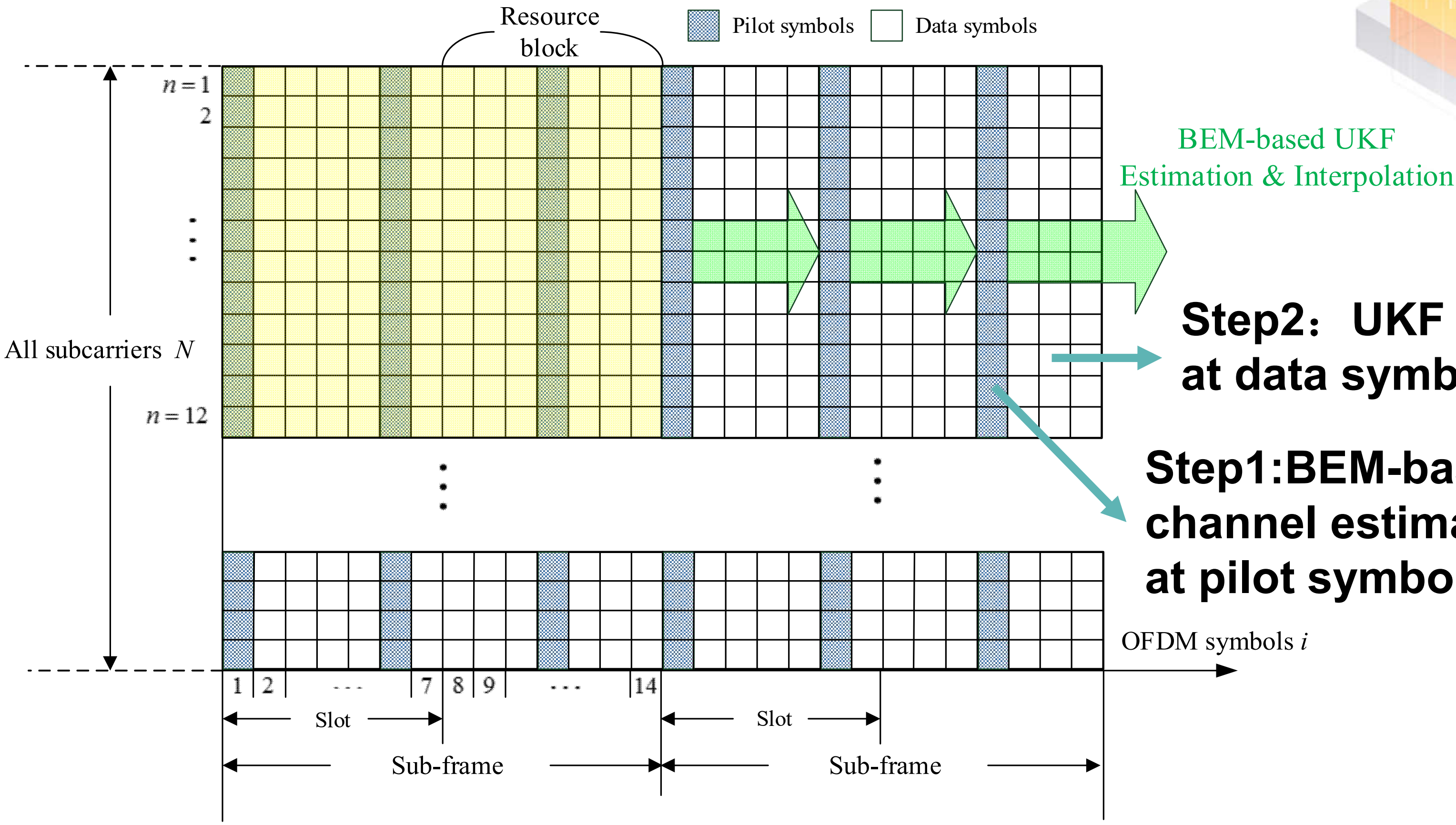
UKF

The Unscented Kalman Filter (**UKF**) is a more effective state estimation method for non-linear state space model. For certain systems, the resulting UKF filter **more accurately** estimates the true mean and covariance.

PART TWO
System Model

System Model

Frame Structure and pilot pattern



Step2：UKF interpolation at data symbols

Step1:BEM-based channel estimation at pilot symbols

Fig. 1 Frame structure and pilot pattern.

System Model

BEM Channel Model:

The CIR matrix: $$\mathbf{g}_i = \begin{bmatrix} h_i(0,0) & 0 & \cdots & h_i(0,L-1) & \cdots & h_i(0,1) \\ h_i(1,1) & h_i(1,0) & 0 & \cdots & \cdots & h_i(1,2) \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ 0 & \cdots & 0 & h_i(N-1,L-1) & \cdots & h_i(N-1,0) \end{bmatrix}$$

The N-1 th CIR sample point whose delay is L-1 on i th OFDM symbol

$$h_i(k,l) = \sum_{q=0}^{Q-1} b_{k,q} c_{i,l}^{q} = \boldsymbol{b}_k^{\mathrm{T}} \boldsymbol{c}_{i,l}$$

The base vectors of BEM (the Complex Exponential BEM is used)

The coefficients of BEM (The state of channel)

$$\boldsymbol{h}_i = \left[\boldsymbol{h}_{i,0}^{\mathrm{T}}, \ldots, \boldsymbol{h}_{i,L-1}^{\mathrm{T}}\right]^{\mathrm{T}} = \boldsymbol{B}\boldsymbol{c}_i$$

The base matrix *B* is constant, so the CIR could be described by c_i.

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System Model

Origin Model

$$y_i = H_i s_i + z_i$$

Received symbols

Transmitted symbols

CIR matrix

BEM

BEM

$$y_i = A_i c_i + z_i$$

The state of channel

$$A_i = F\tilde{S}_i B$$

The witness matrix

The Fourier transforming matrix

Cyclic form of transmitted sequence

TV-AR（time-varying auto regression） Channel Model:

$$c_{i+1} = R_i c_i + v_i$$

where R_i is the correlation matrix of coefficients of BEM for adjacent OFDM symbols, v_i is the process noise with variance σ_v^2. And the correlation matrix is a diagonal matrix under CE-BEM.

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PART THREE
BEM-based UKF

BEM-based UKF

Non-linear state space model

System model with BEM:

$$y_i = A_i c_i + z_i$$

TV-AR model:

$$c_{i+1} = R_i c_i + v_i$$

Time-varying correlation matrix

$$r_i = vec\left(R_i\right)$$

AR Model

State space model:

$$\begin{cases} r_{i+1} = r_i + w_i \\ c_{i+1} = R_i c_i + v_i \\ y_i = A_i c_i + z_i \end{cases}$$

Redefine the state variable

$$x_i = \begin{bmatrix} r_i & c_i \end{bmatrix}^{\mathrm{T}}$$

Non-linear state space model:

$$\begin{cases} x_{i+1} = f\left(x_i\right) + u_i \\ y_i = \begin{bmatrix} 0 & A_i \end{bmatrix} x_i + z_i \end{cases}$$

$$f\left(x_i\right) = \begin{bmatrix} r_i \\ R_i c_i \end{bmatrix} = \begin{bmatrix} r_i \\ diag\left(r_i\right) c_i \end{bmatrix}$$

BEM-based UKF

State Prediction

1. Generating sigma points.
2. Substituting the sigma points into the transformation equation.
3. Calculating the means of the *a priori* state variable and covariance matrix.

State Updating

1. Generating sigma points.
2. Substituting.
3. Calculating the mean, covariance matrix and cross covariance matrix of measurement variable.
4. Computing the gain of fileting and the a posterior estimates and covariance matrix of state variable.

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PART FOUR
Simulation and Analysis

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Simulation

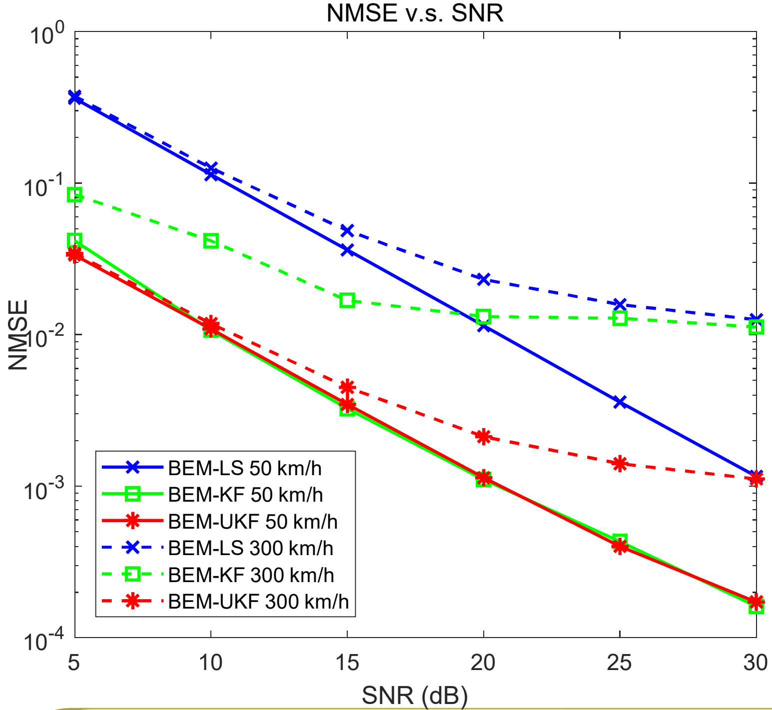
Parameters

Table 1 Parameters of Simulation System

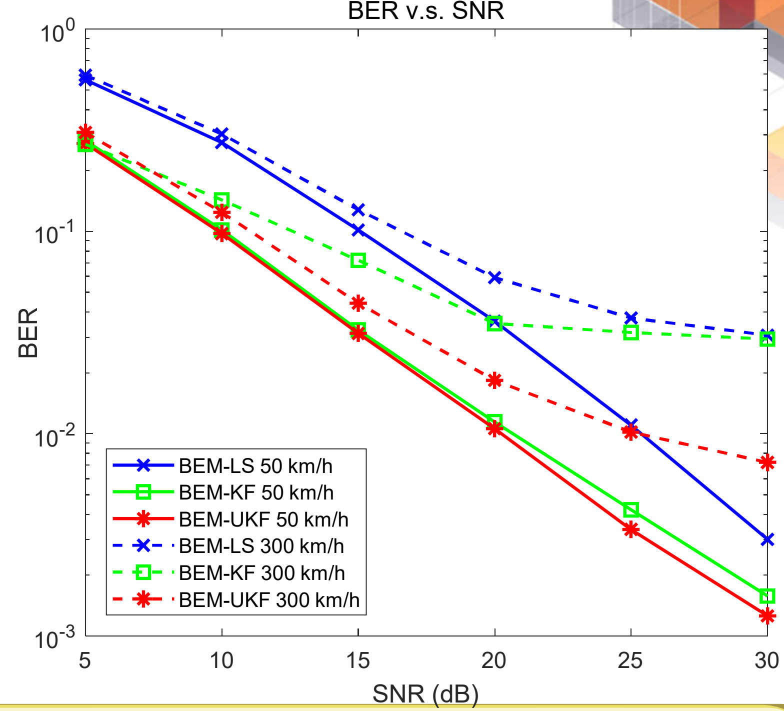
Parameters	Value
Frequency of carrier	2.8 GHz
Bandwidth	5 MHz
Number of subcarriers	300
Length of FFT	512
Length of CP	36
Dimension of base vectors Q	16
Modulation	QPSK
Non-stationary channel	WINNER-II D2a

Simulation

NMSE(normalized mean squared error)



BER(bit error rate)



(1) Obviously, the BER and NMSE performances of BEM-UKF is better than other two traditional methods，namely, BEM-LS (Least Square），and BEM-KF (Kalman Filter)

(2) Performance improvement is more significant in the high speed environments.

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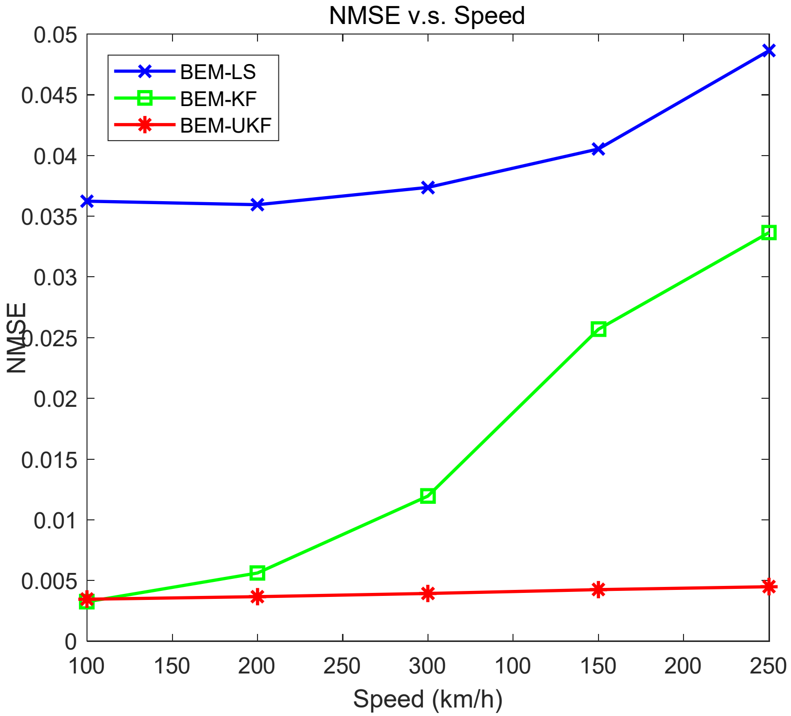
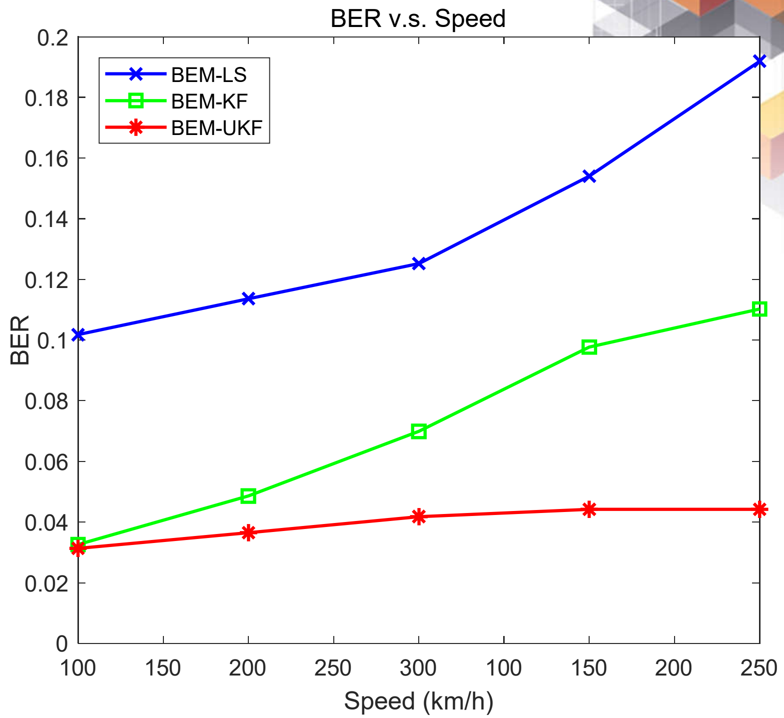
Simulation
Velocity





The lines of BEM-UKF are flat in two graphs, the NMSE and BER performances of BEM-UKF are rarely influenced by the increasing velocity. It is obvious that the robustness of BEM-UKF is stronger than BEM-LS and BEM-KF.

Conclusion & Future work

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Conclusion

- The BEM is adopted to reduce the complexity of channel estimation and eliminate the ICI (inter-carrier interference).
- An UKF-based method is proposed to jointly estimate CIR and time-varying time correlation coefficients in a non-linear state space model.
- The performances of proposed BEM-based UKF channel estimation and interpolation method in different speed environments is analyzed.

Future work

- Attempt to apply Artificial Intelligence (AI) to channel estimation in high-speed mobile environment.

- Research Channel estimation based on superimposed pilot and data symbols.

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Thank You !