Channel Estimation of LTE Downlink in High Speed Environment

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Outline

- 1. Introduction
- 2. Channel model & LTE OFDM reception
- 3. Extended Kalman Filter (EKF)
  - augmented state space model
  - EKF for channel estimation
  - EKF for channel interpolation
- 4. Implementation consideration
- 5. Simulation results
- 6. Summary

Motivation

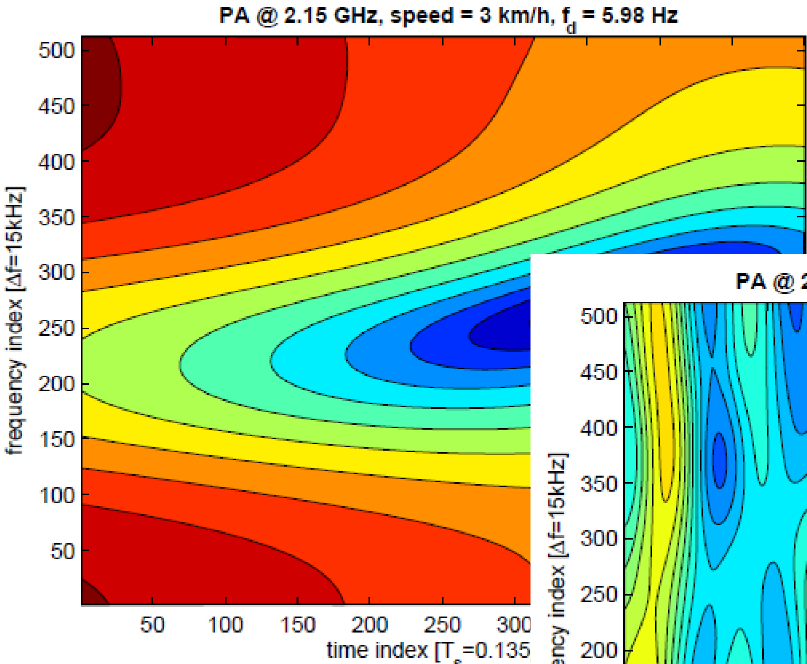
- Future network aiming at improved mobility and certain QoS guarantees.
- within current LTE specifications, the description of UE speed is <120kmph
- LTE at velocity up to 350kmph is desired.
- Challenges in high-mobility applications (e.g. high speed train)

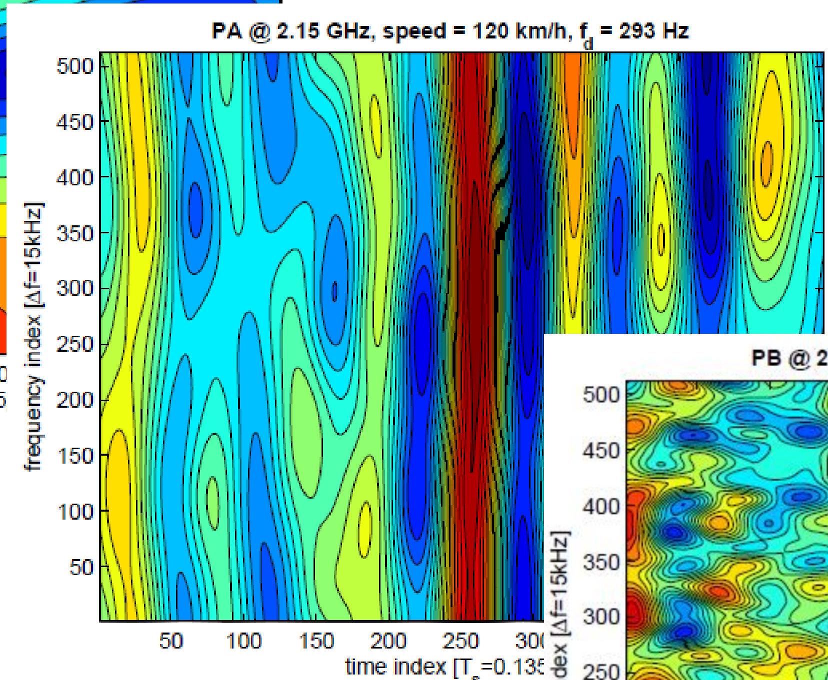
  low sensitivity to high speed (the Doppler effect)

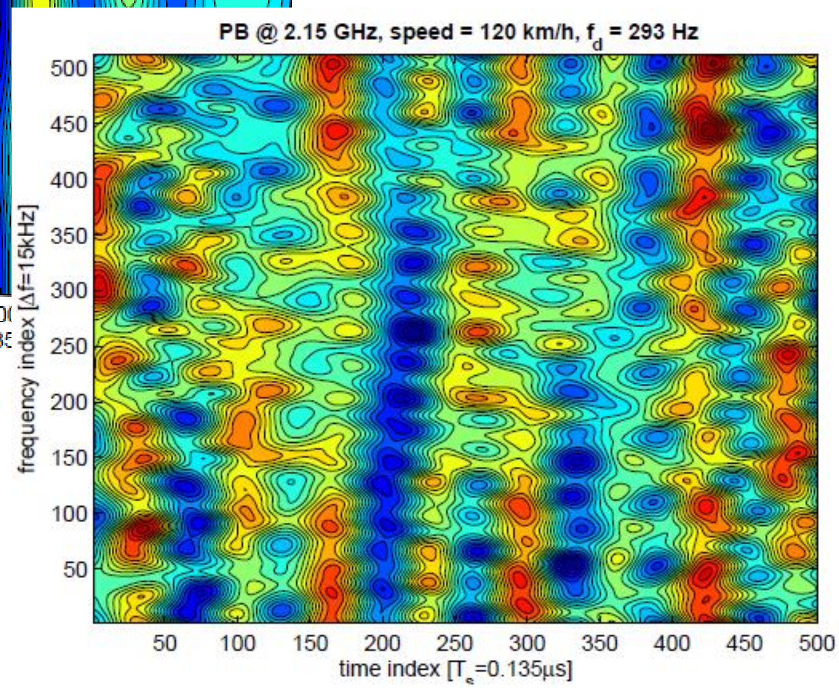
  fast switch

Wireless channels in high speed environment

Time-varying channel transfer function





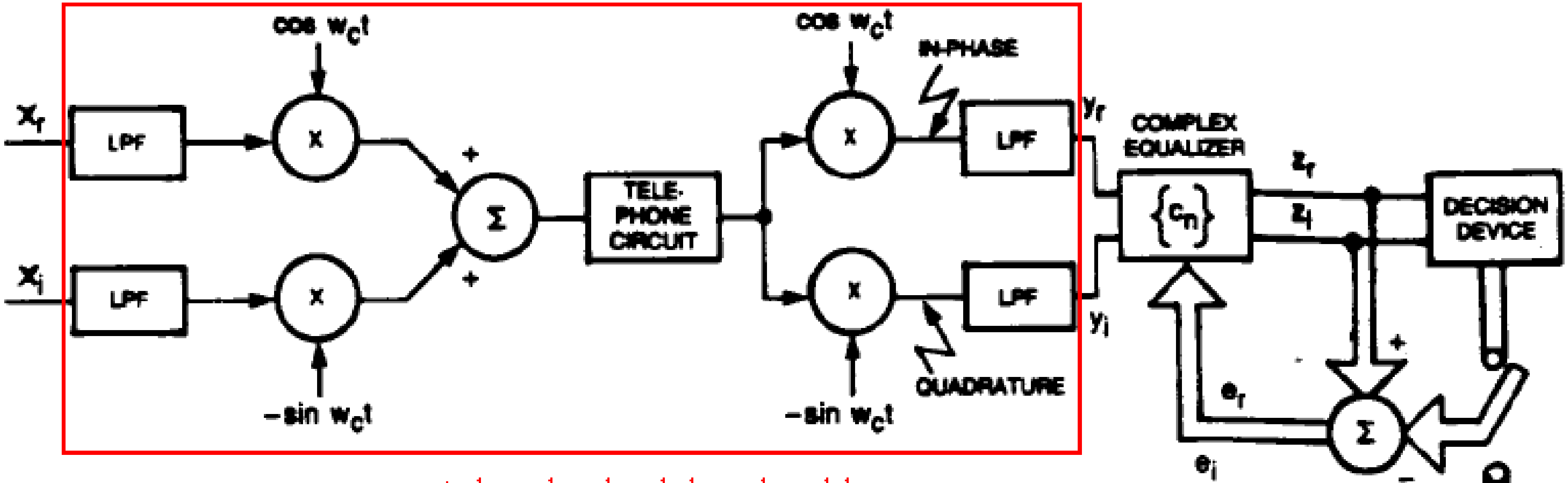


$$g(\tau) = \sum_{n=1}^{R} \alpha_n \cdot \delta(\tau - \tau_n)$$

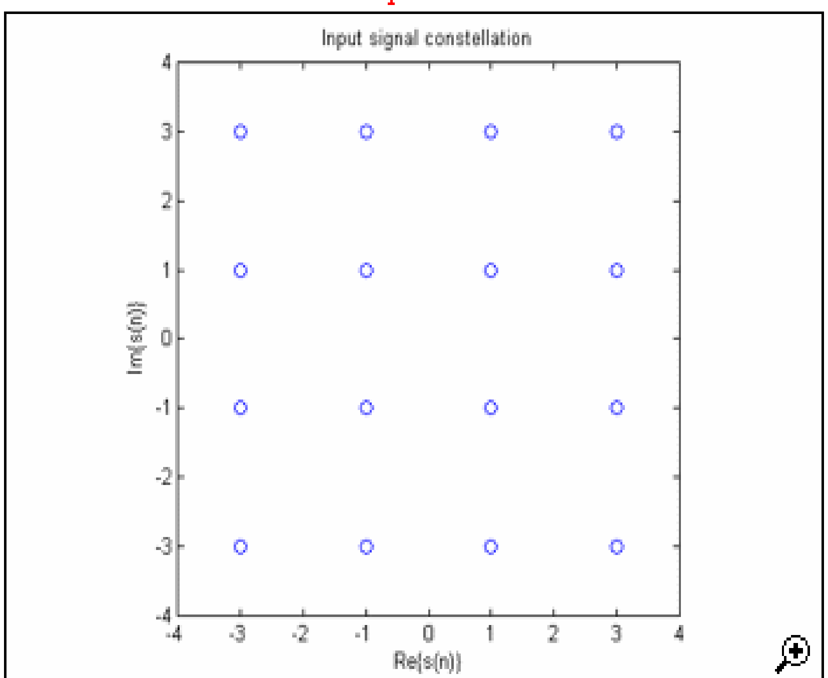
(b) low Delay Spread and high

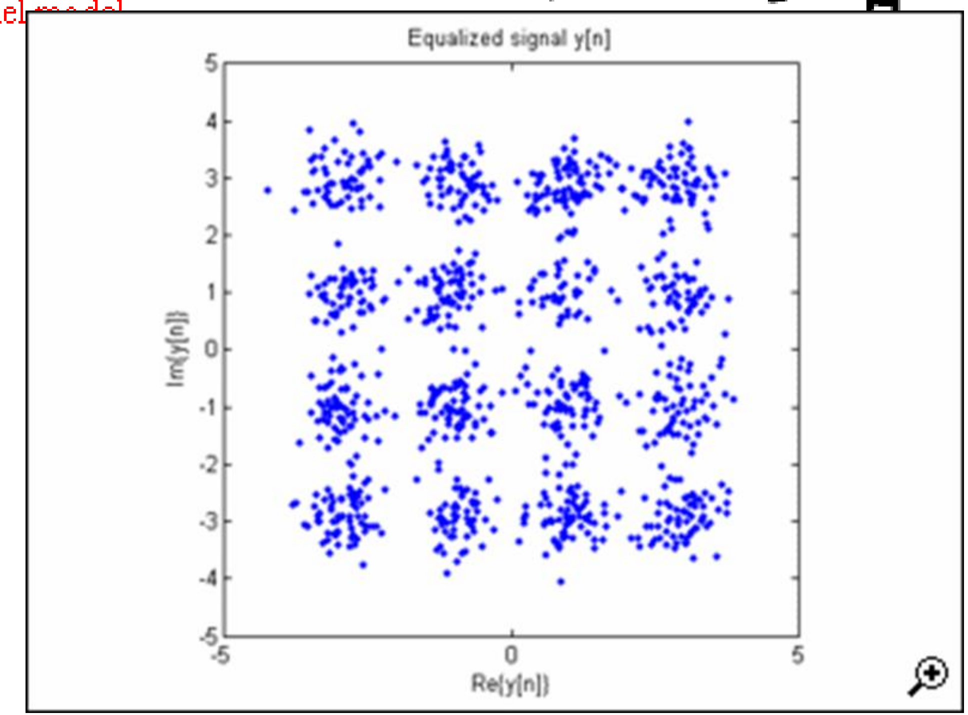
Ref: Muhammad Saad Akram, *Pilot-based Channel Estimation in OFDM Systems,* Nokia Mobile Phones

QAM system and channel estimation



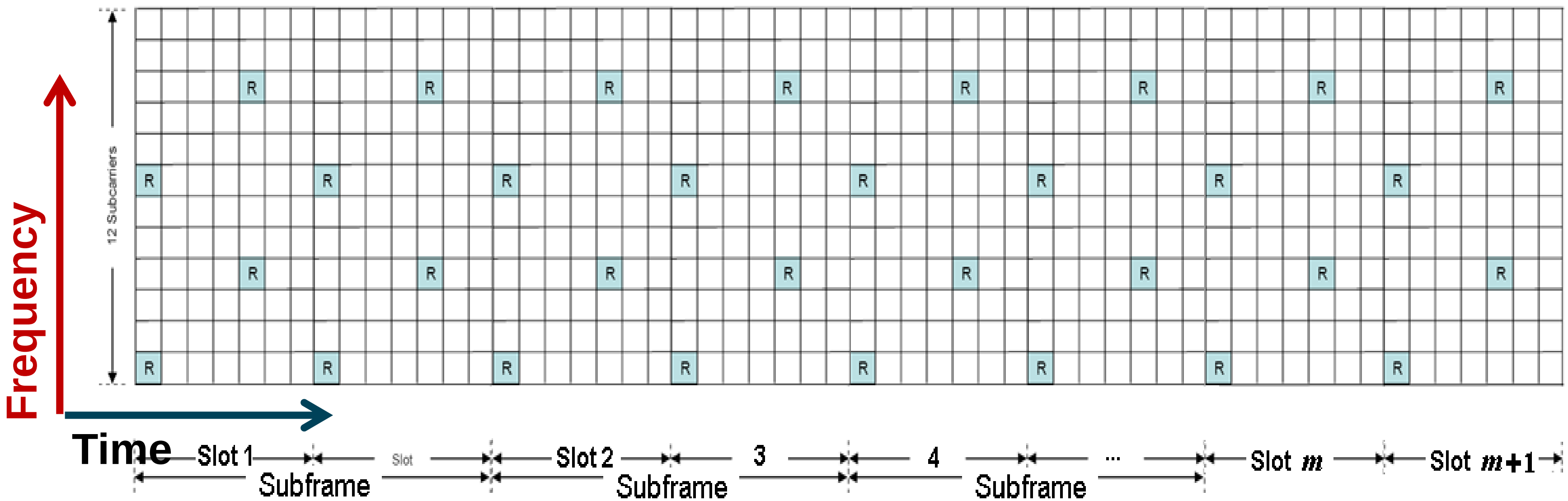
represented as a baseband channel model





2. LTE reception and Channel model

Pilot-symbol assisted modulation (PSAM) in LTE/OFDM



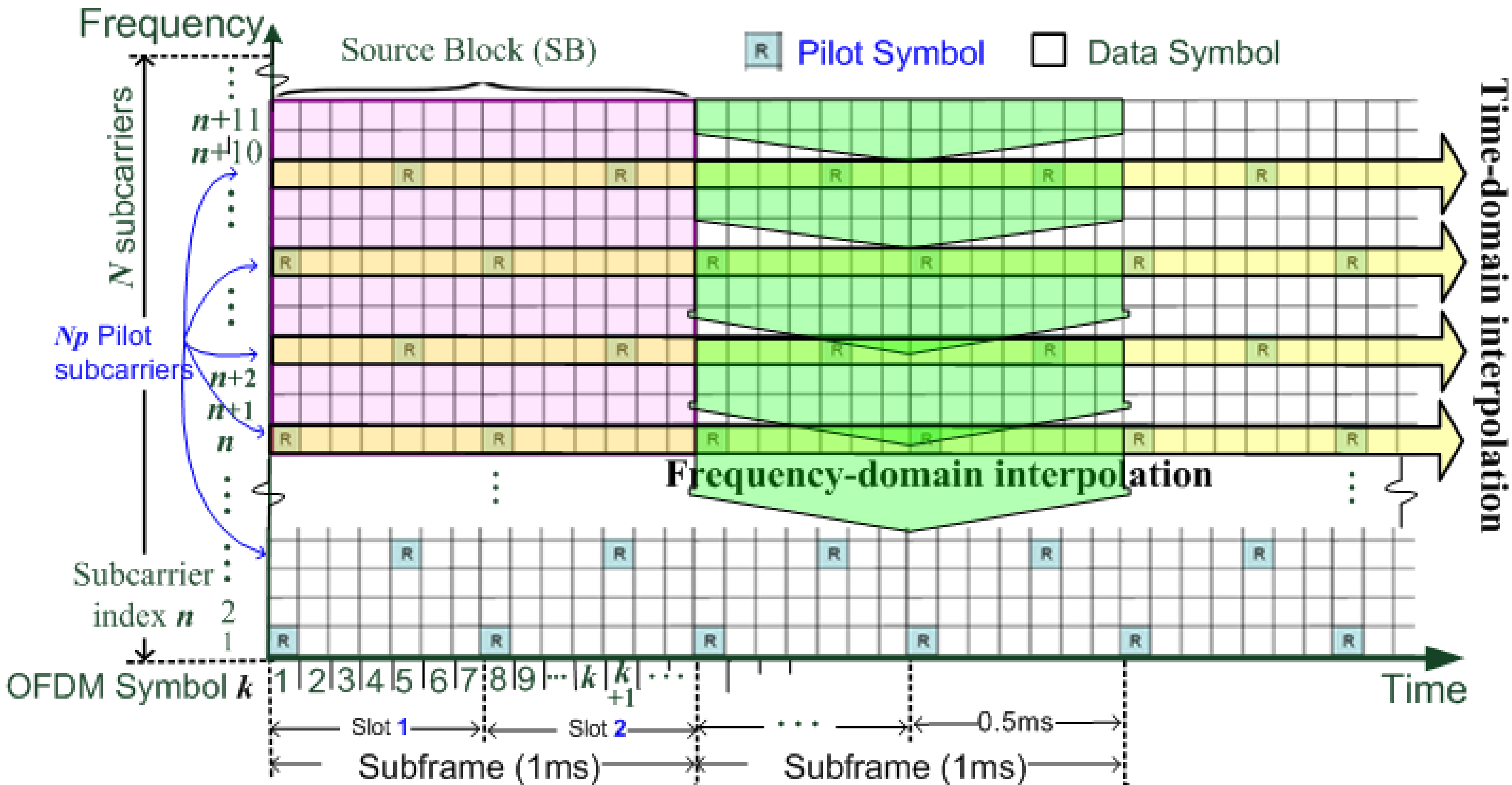
LTE downlink frame structure with scattered pilots

- Known OFDM symbol, so-called pilots or reference symbols are inserted into the data stream
- Three kind of Time-Frequency allocation of pilot symbols:
  block pilot, pilot subcarriers and **scattered pilots**

2. LTE reception and Channel model

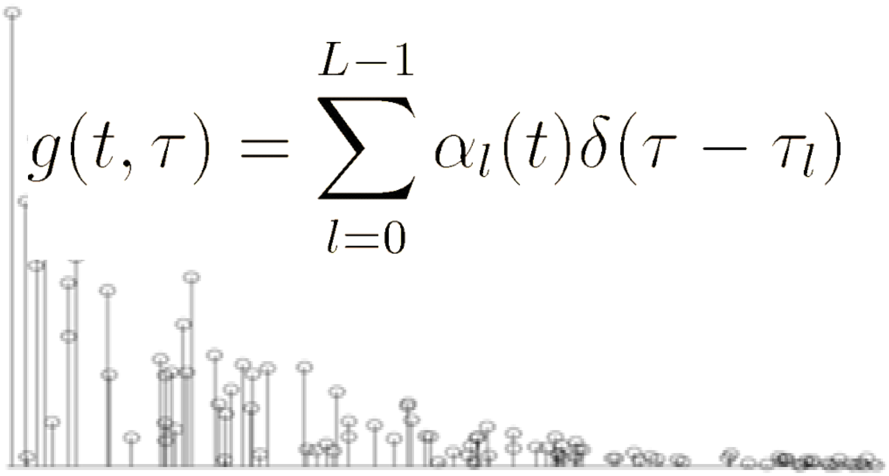
Pilot-aided channel estimation

1. Channel estimation at the pilot symbol location
2. Time-domain interpolation
3. Frequency-domain interpolation



2. Channel model and LTE reception

- 2.1 Multi-path Time-varying channel model



$$g(t,\tau) = \sum_{l=0}^{L-1} \alpha_l(t)\delta(\tau - \tau_l)$$

Channel Impulse Response (CIR)

$$\mathbf{g}_k = \left[g_{k,0}\ g_{k,1}\ \cdots\ g_{k,L-1}\right]^T$$

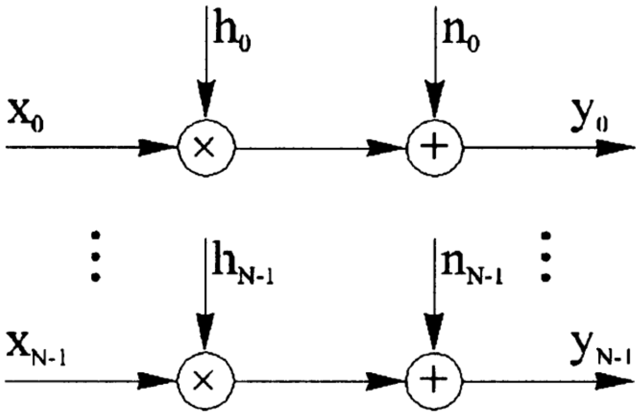
Channel Frequency Response (CFR)

$$\bar{\mathbf{h}}_k = \left[h_k[1]\ h_k[2]\ \cdots\ h_k[N]\right]^T$$

$$h_{k+1,n} = a_n h_{k,n} + v_{k,n}$$

- An AR model describes the time variation of $h_k[n]$
- $h_k[n]$: channel attenuation to be estimated at the k-th OFDM symbol and at n-th subcarrier.

2.2 LTE OFDM reception



The received signal:

$$\mathbf{y}_k = \mathbf{X}_k \mathbf{h}_k + \mathbf{w}_k$$

$$\mathbf{X}_k = \mathrm{diag}(\mathbf{x}_k) = \begin{bmatrix} x_{k,1} & 0 & 0 & \dots & 0 \\ 0 & x_{k,2} & 0 & \dots & 0 \\ 0 & \vdots & & \dots & 0 \\ 0 & 0 & 0 & \dots & x_{k,N_p} \end{bmatrix}$$

- LTE OFDM Channel equaliser:

$$\hat{x}_{k,n} = y_{k,n}/h_{k,n}$$

- Goal of channel estimation:

$$\arg \min_{\mathbf{h}} \sum_k ||\mathbf{x}_k - \mathbf{y}_k./\mathbf{h}_k||_2$$

- Key issue: how to get the right value of $h_{k,n}$

3. Extended Kalman Filter (EKF) for LTE channel estimation

$$\begin{cases} \mathbf{h}_{k+1} = \mathbf{A}_k \mathbf{h}_k + \mathbf{v}_k \\ \mathbf{y}_k = \mathbf{X}_k \mathbf{h}_k + \mathbf{w}_k \end{cases}$$

- h_k is the unknown CFR
- A_k is the parameters representing the time correlation coefficients of CFR
- V_k respresents the channel modelling error
- W_k is the noise in the channel

- Estimate h_k and A_k from the received y_k (fully known) and the transmitted X_k (partially known at pilot location only)

Augmented model

- A non-linear problem:

to simultaneously estimate both h_k and A_k

$$\begin{cases} \mathbf{a}_{k+1} = \mathbf{a}_k + \epsilon_k \\ \mathbf{h}_{k+1} = \mathbf{A}(\mathbf{a}_k)\mathbf{h}_k + \mathbf{v}_k \\ \mathbf{y}_{k+1} = \mathbf{X}_k \mathbf{h}_k + \mathbf{w}_k \end{cases}$$

$$\mathbf{z}_k = [\mathbf{a}_k^T \quad \mathbf{h}_k^T]^T$$

$$\begin{cases} \mathbf{z}_{k+1} = f(\mathbf{z}_k) + \mathbf{u}_k \\ \mathbf{y}_k = \begin{bmatrix} \mathbf{0}_{1\times N_A} & \mathbf{X}_k \end{bmatrix} \mathbf{z}_k + \mathbf{w}_k \end{cases}$$

and $f(\mathbf{z}_k) = \begin{bmatrix} \mathbf{a}_k \\ A(\mathbf{a}_k)\mathbf{h}_k \end{bmatrix}$

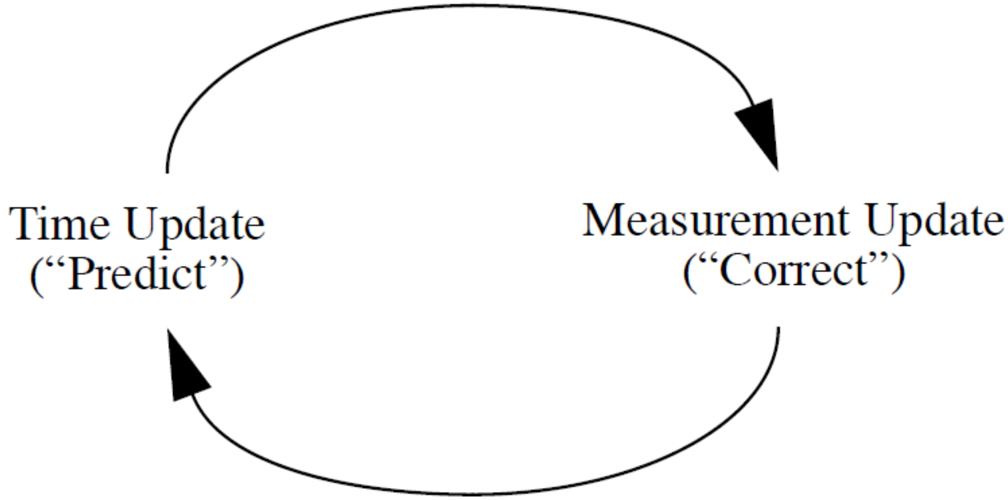
linearisation

$$\begin{cases} \mathbf{z}_{k+1} = \mathbf{F}_k \mathbf{z}_k + \mathbf{u}_k \\ \mathbf{y}_k = \begin{bmatrix} \mathbf{0} & \mathbf{X}_k \end{bmatrix} \mathbf{z}_k + \mathbf{w}_k \end{cases}$$

and $\mathbf{F}_n = \begin{bmatrix} \mathbf{I}_{N_A} & \mathbf{0} \\ \hat{\mathbf{H}}_{n|n} & \hat{\mathbf{A}}_{n|n} \end{bmatrix}$

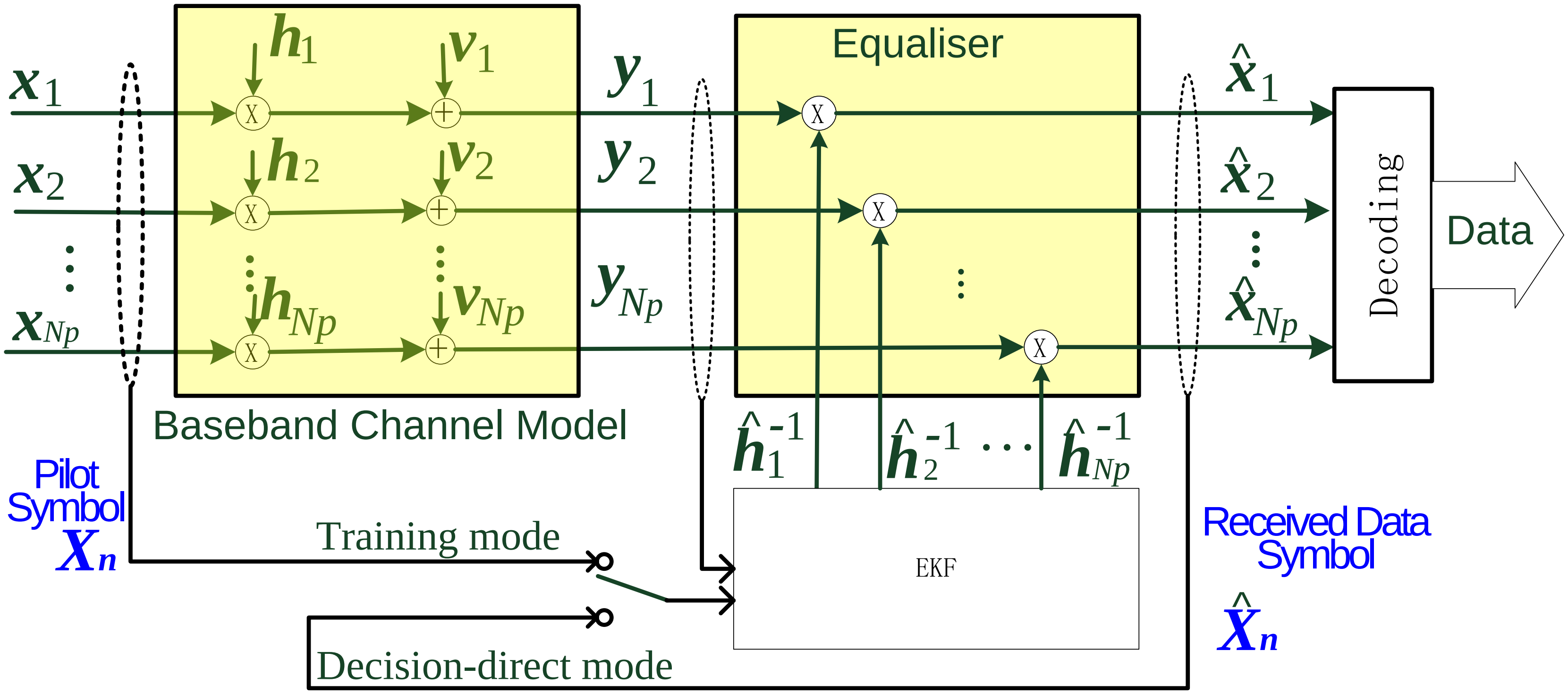
A joint state and parameter estimation.

EKF for channel estimation



- **1. Prediction: Estimate** *a priori* k**-th CFR** $\hat{h}_k$ **from** *(k-1)***-th channel estimation** $\hat{h}_{k-1}$ **before receiving a OFDM symbol.**
- **2. Correction: Correct the** *a priori* k**-th CFR** $\hat{h}_k$ **by using the received OFDM symbole to get a better** *a posteriori* k**-th CFR** $\hat{h}_k$

EKF for channel interpolation a decision-directed approach



- For the pilot symbol, the transmitted symbol x_k is known, use x_k for channel estimation.
- For the data symbol, the transmitted symbol x_k is unknown, use the decoded $\hat{x}_k$ for channel estimation.

4. Implementation consideration

- ***Initialisation: by Least Squares Estimation***

$$\hat{\mathbf{h}}_{0,LS} = (\mathbf{X}_0^H \mathbf{X}_0)^{-1} \mathbf{X}_0^H \mathbf{y}_0 \quad (1)$$

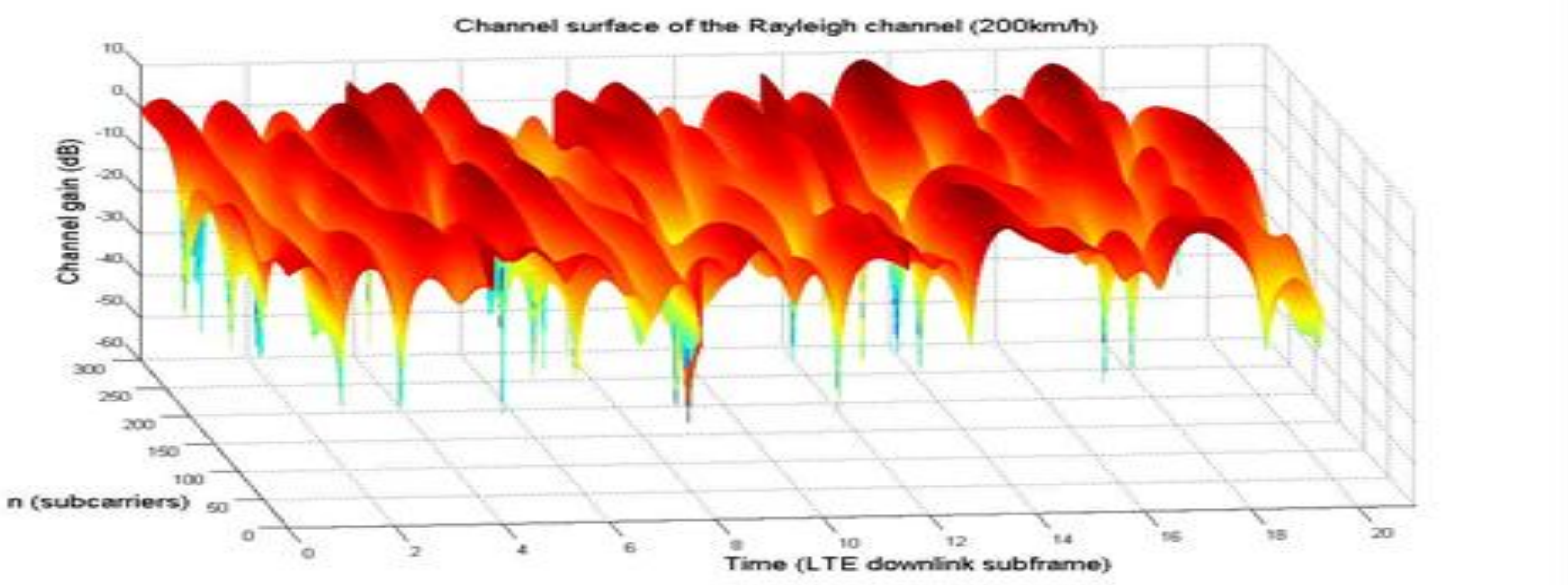
$$= [\frac{y_{0,1}}{x_{0,1}}, \frac{y_{0,2}}{x_{0,2}}, \ldots, \frac{y_{0,N_p}}{x_{0,N_p}}] \quad (2)$$

Selection of the covariance matrices for channel (measurement) noise W_k

$$\sigma_w^2 = \frac{P_{tx}}{10^{SNR/10}}$$

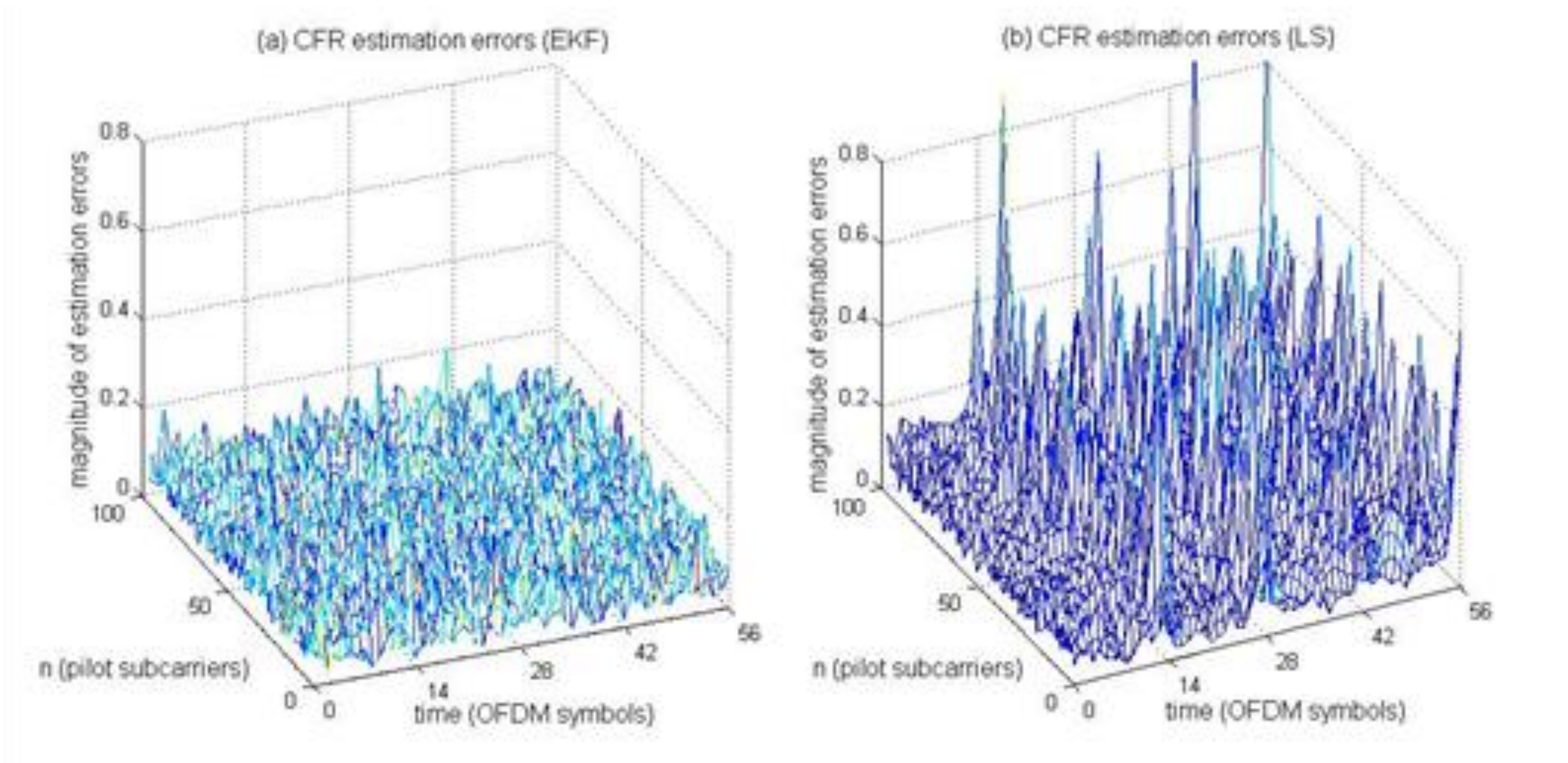
5. Simulation results

1. Channel configuration:
   a rural area channel model defined by 3GPP



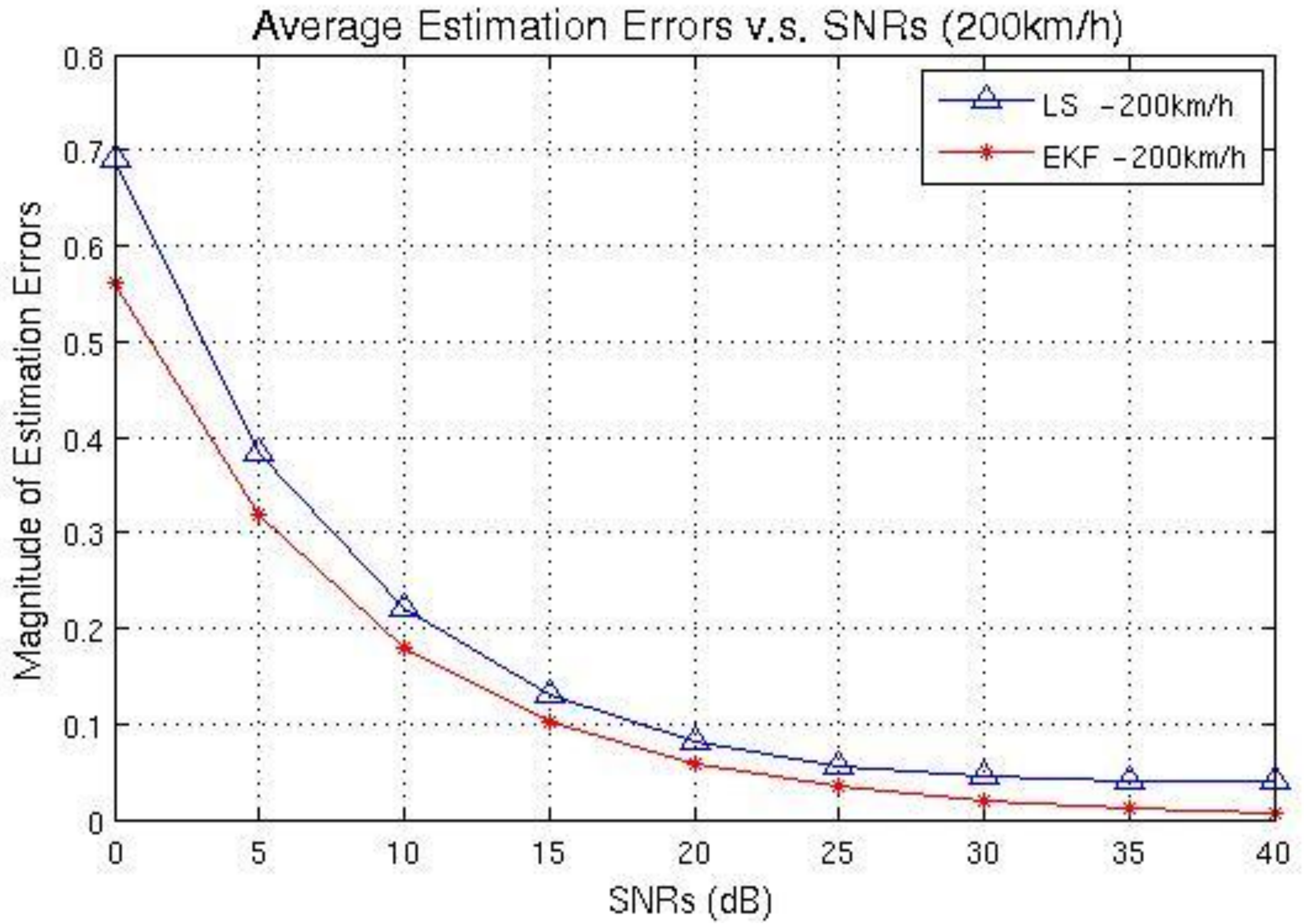
2. 512 subcarriers of which 300 are for data transmission.
3. Two speeds of user equipment (UE) 50 and 200 km/h
4. SNR varying from 0 to 40 dB at a step size of 5 dB.
5. Repeated 20 times (20 runs) at each SNR

Channel estimation Error

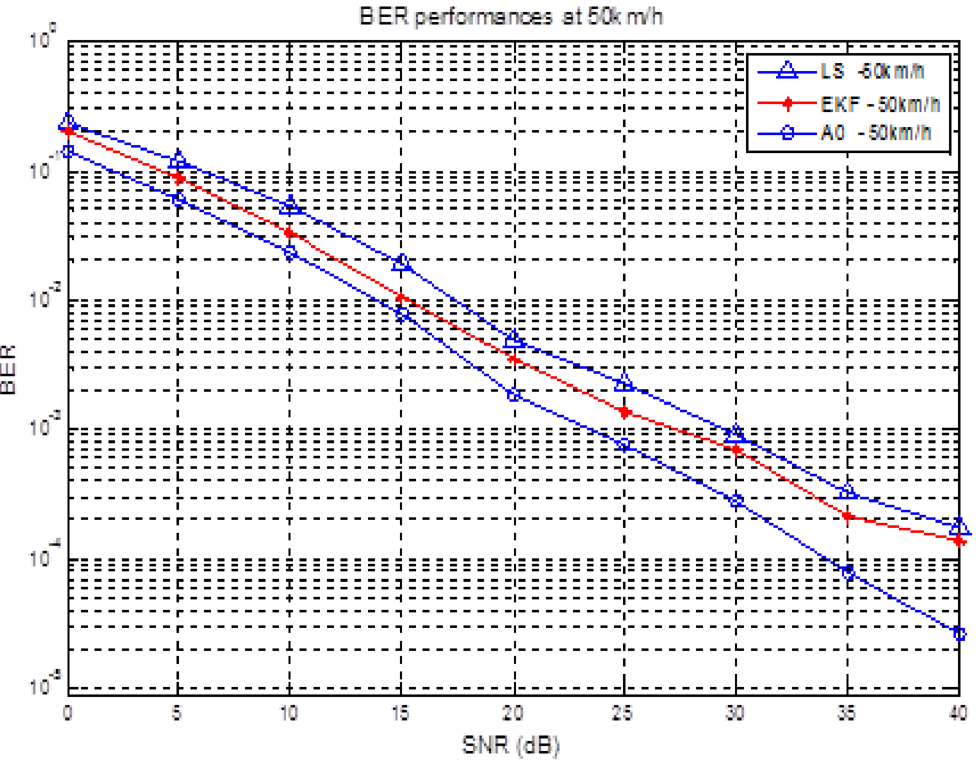


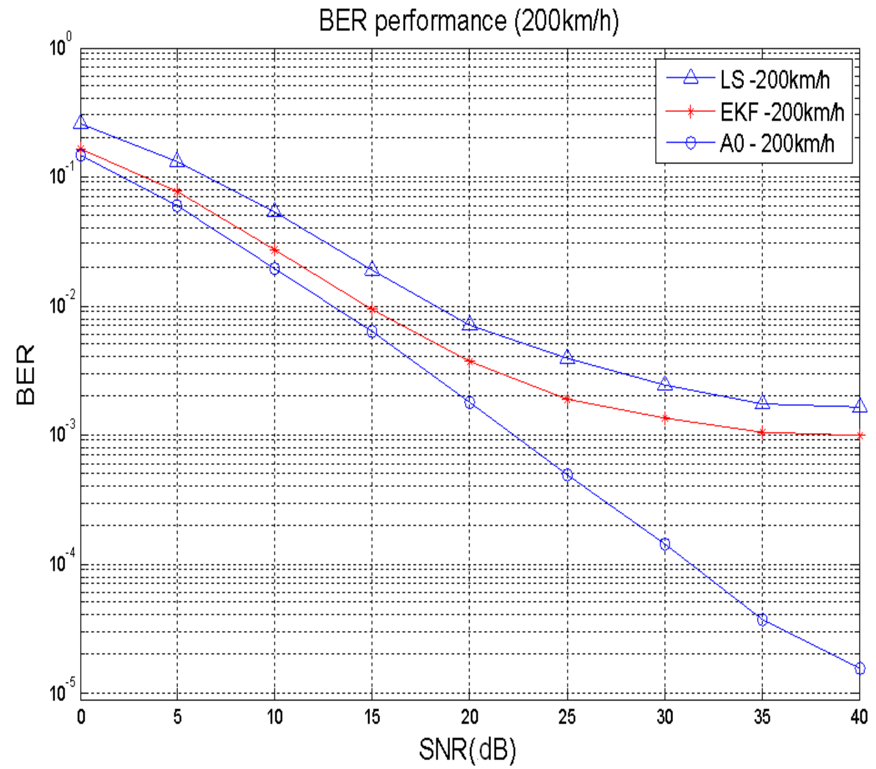
Left: by the EKF; right: by the least square estimation

Mean square estimation error



BER performances





- Left: 50km/h; Right: 200km/h
- the EKF interpolation filter improved the LS
- In Particular, a SNR gain up to 8 dB obtained for certain BERs (e.g. 0.002) at high-velocity.

6. Summary

- The time-varying radio channel is

  modeled as an AR process

  presented as an state space form
- An extended Kalman filter is developed for both

  1. channel estimation at pilot symbols

  2. interpolation at data symbols
- A significant improvement of BER performance
- Future work for further improvement:

  initialised by MMSE， etc.

  error propagation in decision-directed mode

Thanks

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Questions ?