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Analyzing Performance of Joint SVR Interpolation for LTE System with 64-QAM Modulation under 500 Km/h Mobile Velocity

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Abstract

Context:

- Support Vector Machine Regressin
- LTE Communication System

Problematic:

- Estimate the coefficients of a frequency selective time varying multi-path fading under very high mobility conditions

Proposed solution :

- Complex SVR algorithm based on kernel functions and using a robust cost function

Results:

- Best performances are obtained by Complex SVR

Outline

1. OFDM System Model
2. Complex SVR approach
3. Simulation Results
4. Conclusion

OFDM System Model

Time domain transmitted signal

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

$x(n)$: time domain transmitted signal,

N: nombre of subcarriers,

$X(k)$:complex QAM symbols.

Time domain received signal

$$y(n) = \sum_{k=0}^{N-1} X(k)\, H(k) e^{j\frac{2\pi}{N}kn} + w_g(n) \qquad n = 0, \cdots, N-1.$$

$y(n)$: time domainreceived signal,

$H(k) = DFT_N\{h(n)\}$:channel'sfrequencyresponseat the k^{th}subcarrier,

$w_g(n)$:complex white Gaussian noise $N(0, \sigma_{w_g}^2)$,

OFDM System Model

Time domain received signal

$$y(n) = y^P(n) + y^D(n) + w_g(n)$$

$$y(n) = \sum_{k\in\Omega_P} X^P(k)\,H(k)e^{j\frac{2\pi}{N}kn} + \sum_{k\notin\Omega_P} X^D(k)\,H(k)e^{j\frac{2\pi}{N}kn} + w_g(n)$$

$X^P(k)$: complex pilot symboltransmitted at the k^{th}subcarrier,

$X^D(k)$: complex data symboltransmittedatthe k^{th}subcarrier.

w_g: Additive White Gaussien Noise.

Frequency domain received signal

$$Y(k) = DFT_N\{y(n)\} = \frac{1}{N}\sum_{n=0}^{N-1} y(n)\,e^{-j\frac{2\pi}{N}kn}, \qquad k = 0,\cdots,N-1.$$

$$Y(k) = X(k)H(k) + W_G$$

$$Y = \boldsymbol{X}H + W_G$$

Matrix notation

$$Y = [Y(0),\cdots,Y(N-1)]^T$$

$$\boldsymbol{X} = diag\big(X(0),X(1),\cdots,X(N-1)\big)$$

$$H = [H(0),\cdots,H(N-1)]^T$$

$$W_G = [W_G(0),\cdots,W_G(N-1)]^T.$$

Complex SVR Approach

Principle

The transmitting pilot symbols:

$$\boldsymbol{X}^P = diag(X(i, m\Delta p)), \qquad m = 0, \cdots, N_P - 1.$$

Δp: pilot intervall in frequency domain.

N_P: Number of pilot symbols.

Training phase

$$\widehat{H}^P = \boldsymbol{X}^{P^{-1}} Y^P,$$

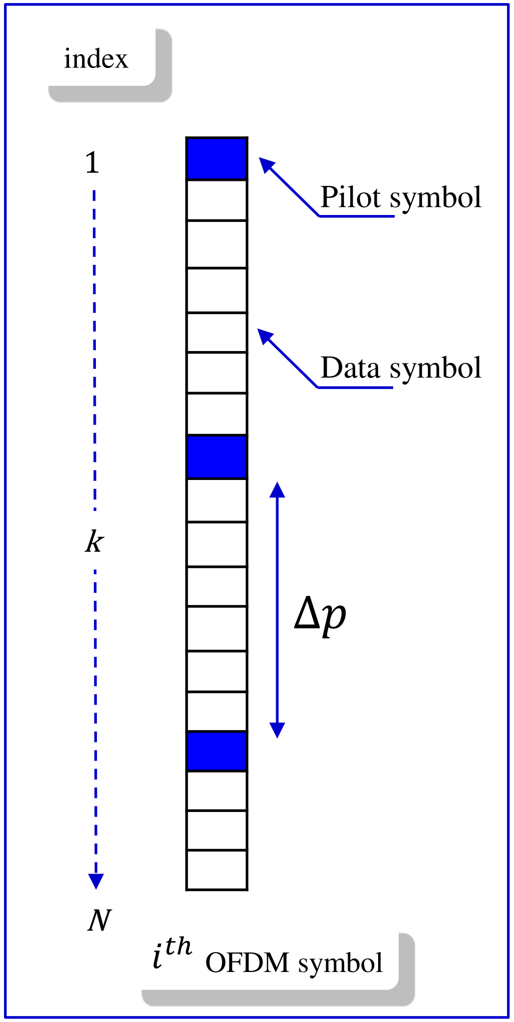
$Y^P = Y(i, m\Delta p)$: received pilot symbol at pilot position $m\Delta p$

$\widehat{H}^P = \widehat{H}(i, m\Delta p)$: frequency response at pilot position $m\Delta p$.

Estimation phase

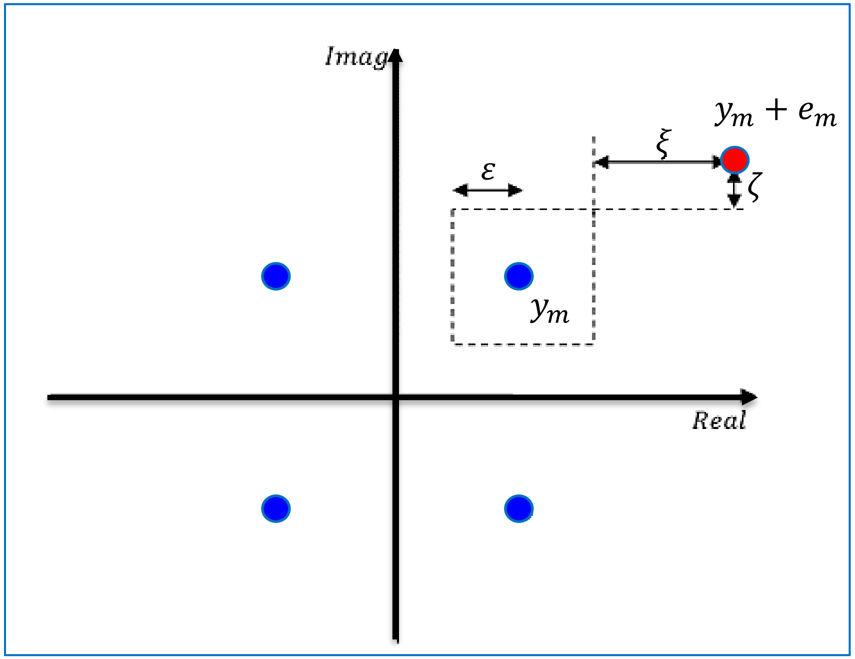
$$\widehat{H}(i, k) = \boldsymbol{f}\left(\widehat{H}^P(i, m\Delta p)\right)$$

$\boldsymbol{f}(\cdot)$: SVR interpolating function for all data subcarriers, $k = 0, \cdots, N - 1$.



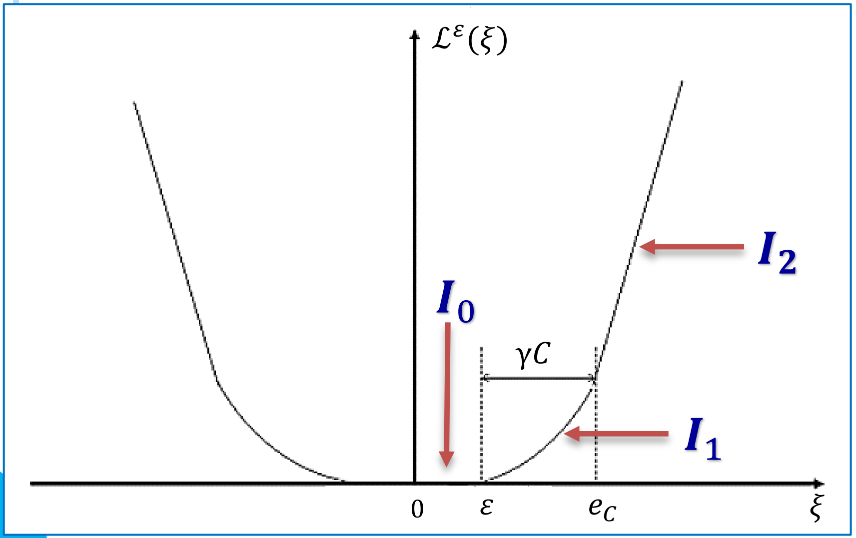
Complex SVR Approach

ε- insensitivity zone and losses



minimize
w

$$\frac{1}{2}\|w\|^2 + \sum_{m=1}^{M}\left(\mathcal{L}^{\varepsilon}(\Re(e_m), \varepsilon, \gamma, C) + \mathcal{L}^{\varepsilon}(\Im(e_m), \varepsilon, \gamma, C)\right)$$



ε-Huber Loss Function

$$\mathcal{L}^{\varepsilon}(e_m,\varepsilon,\gamma,C)=\begin{cases}0, & |e_m|\le\varepsilon\\ \dfrac{1}{2\gamma}(|e_m|-\varepsilon)^2, & \varepsilon\le|e_m|\le\gamma C+\varepsilon\\ C(|e_m|-\varepsilon)-\dfrac{1}{2}\gamma C^2, & |e_m|\ge\gamma C+\varepsilon\end{cases}$$

I_0: ε-insensitivity zone

I_1: zone with quadraticcost

I_2: zone with linearcost

Complex SVR Approach

SVR Estimator Formulation

$$\widehat{H}(m\Delta p) = \mathbf{w}^H \boldsymbol{\phi}(m\Delta p) + b + e_m, \qquad m = 0, \cdots, N_P - 1.$$

Primal problem

$$\underset{\mathbf{w}}{minimize} \quad \frac{1}{2}\|\mathbf{w}\|^2 + \frac{1}{2\gamma}\sum_{m\in I_1}(\xi_m + \xi_m^*)^2 + C\sum_{m\in I_2}(\xi_m + \xi_m^*)$$

$$+\frac{1}{2\gamma}\sum_{m\in I_3}(\zeta_m + \zeta_m^*)^2 + C\sum_{m\in I_4}(\zeta_m + \zeta_m^*) - \frac{1}{2}\sum_{m\in I_2, I_4}\gamma C^2$$

$$\begin{aligned} s.t. \quad & \Re(\widehat{H}(m\Delta p) - \mathbf{w}^H\boldsymbol{\phi}(m\Delta p) - \mathrm{b}) \le \varepsilon + \xi_m \\ & \Im(\widehat{H}(m\Delta p) - \mathbf{w}^H\boldsymbol{\phi}(m\Delta p) - \mathrm{b}) \le \varepsilon + \zeta_m \\ & \Re(-\widehat{H}(m\Delta p) + \mathbf{w}^H\boldsymbol{\phi}(m\Delta p) + \mathrm{b}) \le \varepsilon + \xi_m^* \\ & \Im(-\widehat{H}(m\Delta p) + \mathbf{w}^H\boldsymbol{\phi}(m\Delta p) + \mathrm{b}) \le \varepsilon + \zeta_m^* \\ & \xi_m, \xi_m^*, \zeta_m, \zeta_m^* \ge 0. \end{aligned}$$

Complex SVR Approach

=> After derivation of the Lagrangian with respect to primal variables, we obtain:

$$\boldsymbol{w} = \sum_{m=0}^{N_P-1} \psi_m \, \boldsymbol{\phi}(m\Delta p)$$

$$\psi_m = \left(\alpha_{\Re,m} - \alpha^*_{\Re,m}\right) + j\left(\alpha_{\Im,m} - \alpha^*_{\Im,m}\right)$$

$\alpha_{\Re,m}, \alpha^*_{\Re,m}, \alpha_{\Im,m}, \alpha^*_{\Im,m} \geq 0.$

$$\widehat{H}(k) = \sum_{m=0}^{N_P-1} \psi_m \, K(m\Delta p, k) + b$$

$k = 1, \cdots, N.$

b : is the biasterm.

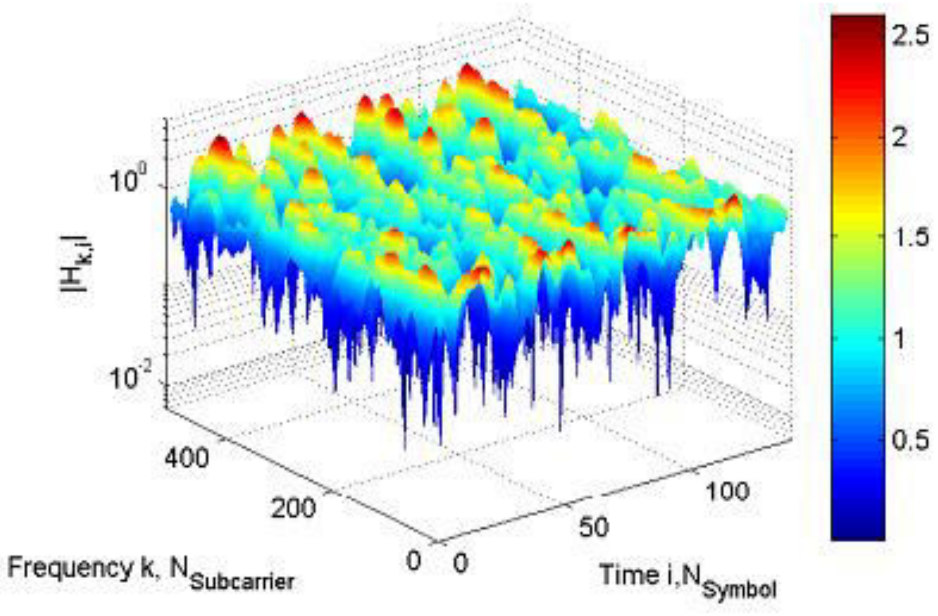
$$\mathbf{G}(u,v) = < \boldsymbol{\phi}(u\Delta p) \cdot \boldsymbol{\phi}(v\Delta p) >= K(u\Delta p, v\Delta p)$$

Simulation results

LTE Downlink system

Power delay profile for LTE – 3GPP Extended Vehicular A (EVA) channel

Excess tap delay (ns)	Relative power of taps (dB)
0	0,0
30	-1.5
150	-1.4
310	-3.6
370	-0.6
710	-9.1
1090	-7.0
1730	-12.0
2510	-16.9



Variations in time and in frequency (mobile speed = 500Km/h)

Simulation results

LTE Downlink system

$$SNR_{dB} = 10\ log_{10}\left(\frac{E\left\{\left|y(n) - w_g(n) - i(n)\right|^2\right\}}{\sigma_{w_g}^2}\right)$$

Simulation system

1400 OFDM symbols = 10 radio frame LTE.

Radio frame LTE duration = 10 ms.

01 Radio frame LTE = 10 subframes.

01 subframe = 02 slots.

01 slot duration = 0.5 ms.

LTE − 3GPP simulation parameters

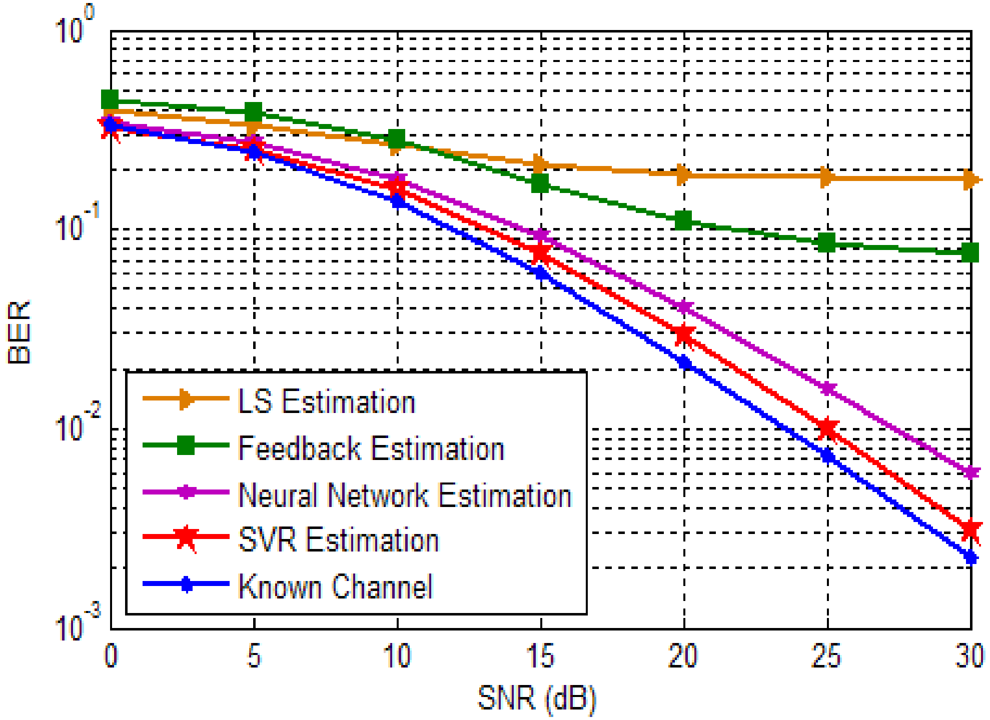
Parameters	Specifications
OFDM System	LTE / Downlink
Constellation	64-QAM
Mobile Speed (Km/h)	500
$T_s(\mu s)$	72
$f_c(GHz)$	2.15
$\delta f(KHz)$	15
B(MHz)	5
Size of DFT/IDFT	512
Numberof paths	9

SVR parameters

$$C = 100, \gamma = 10^{-5}, \varepsilon = .001$$

Simulation results

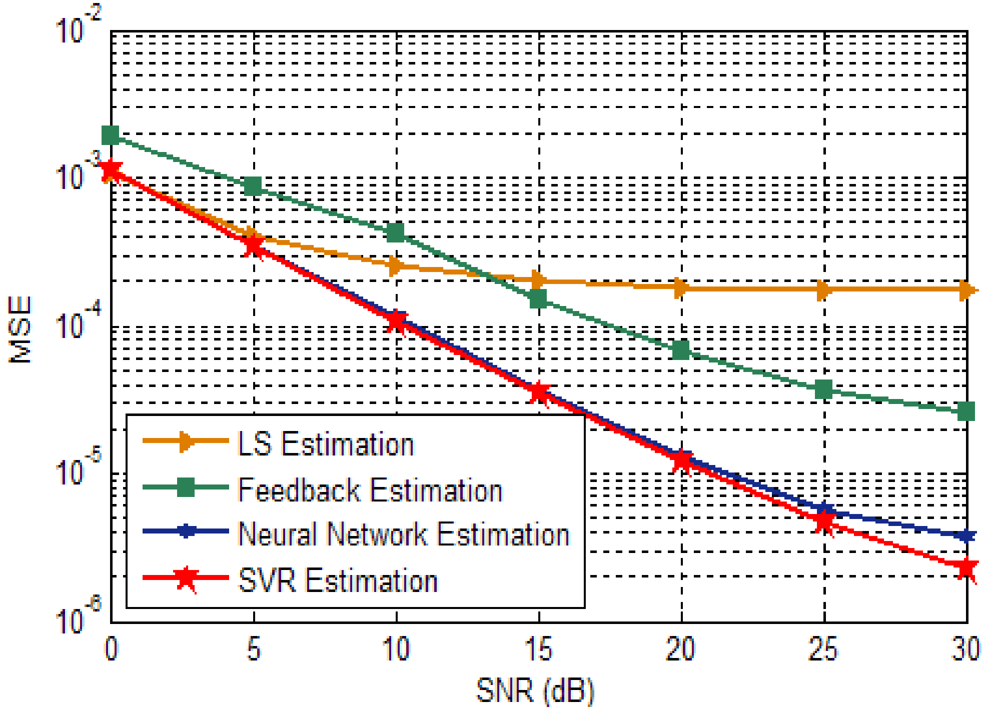
BER vs. SNR



BER as a function of SNR

Simulation results

MSEvs. SNR



MSE as a function of SNR

Conclusion & Discussion

Conclusion

- Complex SVR approach has been developed and applied to LTE Downlink System under high mobility conditions (500 Km/h) using 6-QAM modultion scheme with real scenarios according to 3GPP specifications

Future Work

Apply the complex SVR in :

- LTE-Advanced and 5G systems.

References

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Thank You for Your Attention