Prediction-based resource allocation in OFDMA

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Introduction

Motivation

- OFDMA is a popular physical layer technique (WiMAX, LTE)
- Resource allocation (RA) by physical layer scheduling
  - Increases system throughput
  - Fairness issue
  - Outdated channel state information in the transmitter (CSIT)
- Prediction-based RA has been shown to improve fairness
  - No consideration of prediction error characteristics so far
  - Prediction error increases with prediction horizon

Contributions

- Analysis of the prediction horizon
  - Length vs. accuracy
- Characterization of the prediction error
  - Many samples of the prediction error in OFDMA
    - Histograms to approximate error statistics
  - No specific error model assumed
    - Applies to general long-range channel predictors
- Realistic simulation parameters
  - LTE parameters
  - ITU Vehicular A channel
  - Practical low-complexity long-range channel predictor

System model

- OFDMA downlink transmission
- *N* subchannels → allocation in the resolution of 1 subcarrier
- *K* active mobile stations (MSs)
  - Independent fading channels, same statistics
- Time slot based resource allocation
  - *M* OFDM symbols = 1 time slot
  - Channel approximately constant for 1 time slot
- Transmitted power equally distributed among subchannels

Prediction-based resource allocation

$$R_k(s) = M \sum_{n\in\mathcal{I}_k} r_k(s,n)$$

→ Rate achieved by user *k* on time slot *s*

Subchannels allocated to MS *k*

Prediction-based PFS (P-PFS) checks W future time slots (TS) when assigning the next time slot such that

$$P^{(s+1)}(\bar{R}_k^W) = \arg\max_{\mathcal{P}} \sum_{k=1}^{K} \log(\bar{R}_k^W)$$

where

$$\bar{R}_k^W = \left(1-\frac{1}{\tau}\right)\bar{R}_k(s) + \frac{1}{\tau}\sum_{w=1}^{W}\left(1-\frac{1}{\tau}\right)^{W-w}\check{R}_k(s+w)$$

Average rate

Achievable rate

P-PFS relies on the predicted achievable rates

Characterization of the prediction error is required

Error-aware prediction-based resource allocation

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Error-aware prediction-based RA

Achievable rates are computed to meet the target BER as

Perfect CSIT	Imperfect CSIT
$P_e(s,n) \approx c_1 \exp\left\{\frac{-c_2\gamma\|H(s,n)\|^2}{2^{\beta(s,n)}-1}\right\}$	$\bar{P}_e(s,n) = E_{\|H(s,n)\|\,\|\hat{H}(s,n)}\{P_e(s,n)\}$

Mean **SNR**

Bits/symbol

Estimated/predicted CSIT

W pdfs needed to predict W time slots

Closed form solutions exist for the estimated but not for the predicted CSIT

Error-aware prediction-based RA

Expressing $\bar{P}_e(s,n)$ for each *w* in terms of the prediction error e_w

$$\bar{P}_{e_w}(s+w,n) = \hat{P}_{e_w}(s+w,n)\cdot\boxed{\rho_w(n)} \longrightarrow \text{Correction factor}$$

$$\rho_w(n) = \frac{1}{\sigma_H^2}\int_{-\infty}^{\infty}\exp\left\{\frac{-c_2\gamma\theta(s+w,n)}{2^{\beta(s+w,n)}-1}\right\} f_{e_w}(e_w)\,de_w$$

where

$$\theta(s+w,n) = 2\sigma_H^2\left|\hat{H}(s+w,n)\right|_{|H(s,n)} e_w + \sigma_H^4 e_w^2$$

with

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Characterization of $f_{e_w}(e_w)$
is needed to evaluate $\rho_w(n)$

Error-aware prediction-based RA

Error samples for different subcarriers can be used to construct a histogram to estimate $f_{e_w}(e_w)$

Interval width

Defining the intervals $\Delta_i = \{ e_w : \epsilon_i - \frac{\omega}{2} < e_w \leq \epsilon_i + \frac{\omega}{2} \}$

Histogram thresholds

Number of samples within the ith interval

Results in $\hat{f}_{\epsilon_i}(e_w) = \frac{Q_i}{Q_w}$ for $e_w \in \Delta_i$

Total number of samples

such that the correction factor can be rewritten as

$$\hat{\rho}_w(n) = \frac{1}{\sigma_H^2} \sum_{-\epsilon_Q}^{\epsilon_Q} \exp\left\{ \frac{-c_2 \gamma \tilde{\theta}(s+w,n)}{2^{\beta(s+w,n)} - 1} \right\} \hat{f}_{\epsilon_i}(\epsilon_i)$$

$$\boxed{\bar{P}_{e_w}(s+w,n) = \hat{P}_{e_w}(s+w,n) \cdot \hat{\rho}_w(n)}$$

The value of $\beta^*(s+w,n)$ satisfying BER is fed to P-PFS

Channel estimator/predictor

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Channel estimator/predictor

BEM Estimators	Kalman Estim/pred
Good fit to practical channels (Robust to Doppler shape)	Good fit to practical channels (Robust to Doppler shape)
Not suitable for prediction	Good prediction performance
Low computational cost	High computational cost

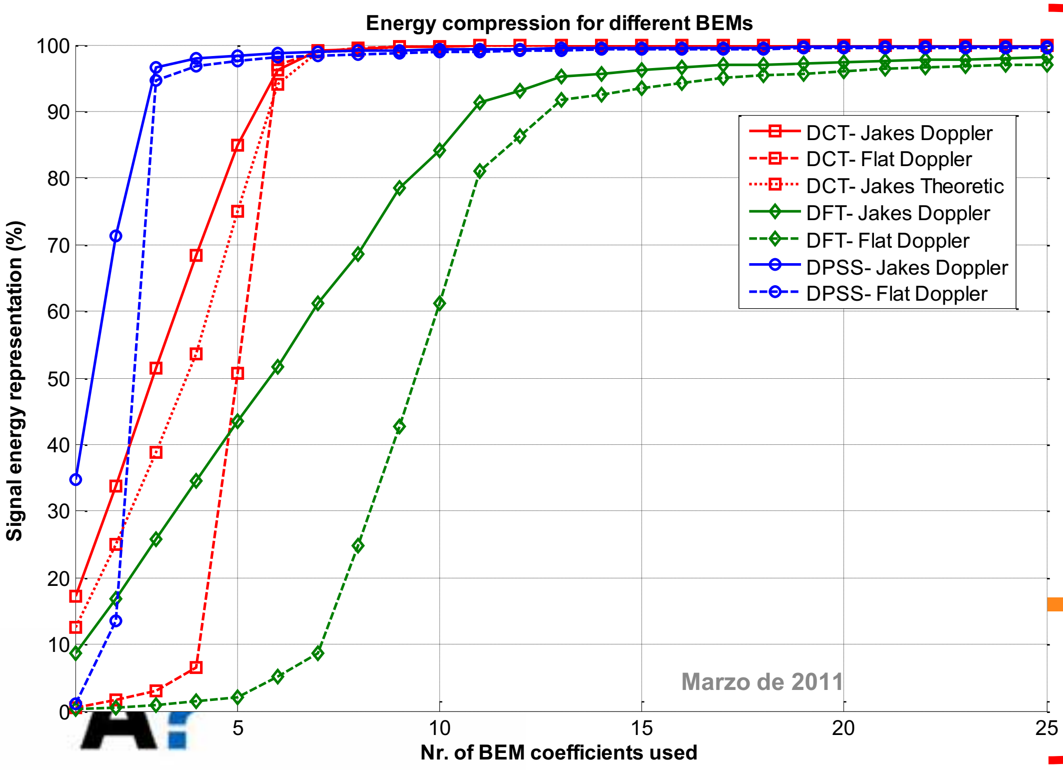
Recursive basis expansion model (BEM) estimator/predictor

- Good fit to practical channels (Robust to Doppler shape)
- Good prediction performance
- Low computational cost

Recursive Basis Expansion Model

- Evolution of the temporal channel can be expressed using BEM $\hat{\mathbf{H}} = \bar{\mathbf{T}}^H \bar{\gamma}$ as
- Different BEMs lead to different compressions

$$E\left\{\sum_{m=0}^{M-1} |H(m)|^2\right\} = E\left\{\sum_{m=0}^{M-1} \left|\hat{H}(m)\right|^2\right\} + \sigma_e^2$$



DCT → Good compression and simple basis functions

Recursive BEM estimator

- For DCT → $[\bar{\mathbf{T}}]_{i,m} = A(m)\cos\left(\frac{\pi\left(i+\frac{1}{2}\right)m}{M}\right)$

- $\bar{\mathbf{T}}$ can be represented with a filter bank as

$$\hat{H}_{(DCT)}(m) = H_{DCT}(q^{-1})H(m) = \sum_{i=0}^{G-1} H_{DCT_i}(q^{-1})H(m)$$

where

$$H_{DCT_i}(e^{j\omega}) = c_i \frac{(-1)^i - (-1)^i e^{-j\omega} - e^{-j\omega M} + e^{-j\omega(M+1)}}{1 + 2\cos(i\pi/M)e^{-j\omega} + e^{-j2\omega}}$$

which can in turn be approximated by

$$H_F(e^{j\omega}) = \beta_0 \frac{0{,}5(1-s_{20})(1+e^{-j2\omega})}{1-s_{20}e^{-j2\omega}} + \sum_{i=1}^{G-1} \beta_i \frac{0{,}5(1-s_{2i})(1-e^{-j2\omega})}{1+(s_{2i}+1)s_{1i}e^{-j\omega}+s_{2i}e^{-j2\omega}}$$

Recursive DCT BEM estimator

The filter bank can be inserted into a Kalman formulation having a steady-state solution as the basis set is time invariant

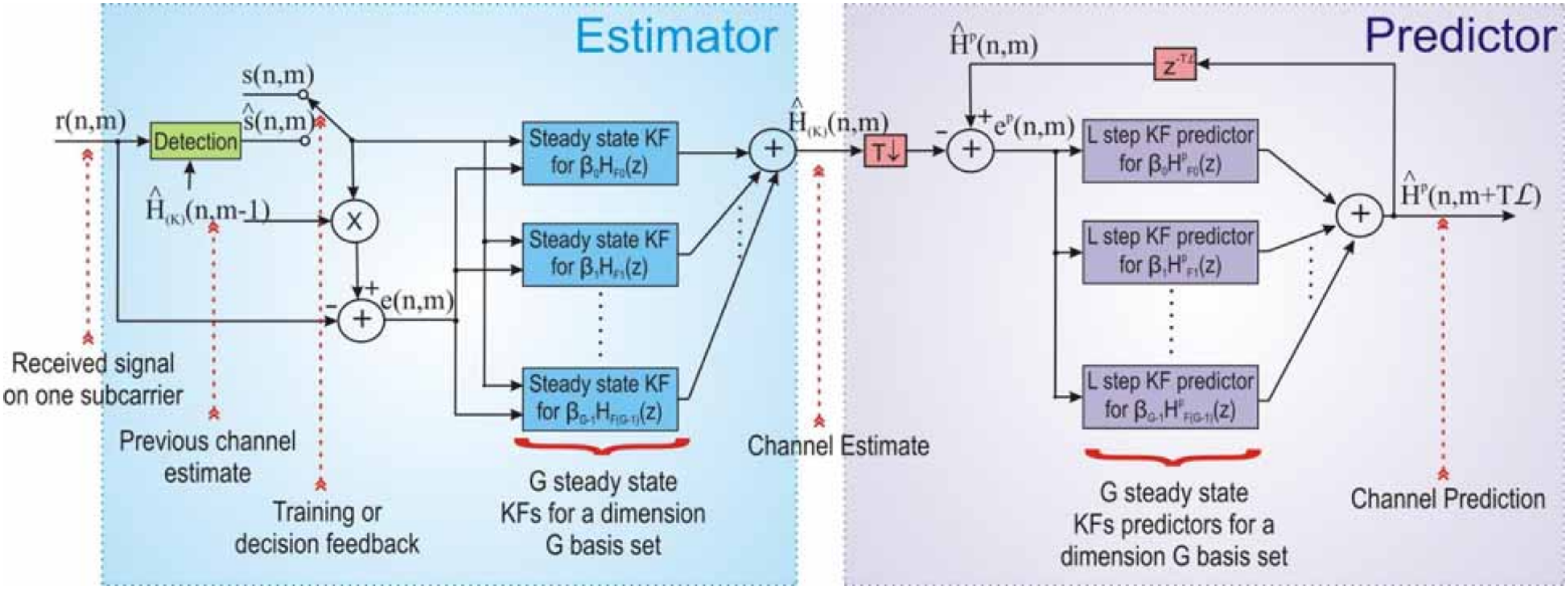
$$\left\{\begin{aligned} \mathbf{x}_i(m+1) &= \mathbf{A}_i\mathbf{x}_i(m) + \mathbf{b}_i\bar{H}(m)\\ \hat{H}_{i(F)}(m) &= \mathbf{c}_i\mathbf{x}_i(m) + d_i\bar{H}(m)\\ \hat{H}_{(F)}(m) &= \textstyle\sum_{i=0}^{G-1}\hat{H}_{i(F)}(m), \end{aligned}\right. \Longrightarrow \left\{\begin{aligned} e(m) &= r(m) - \hat{s}(m)\hat{H}_{(K)}(m-1)\\ \mathbf{x}_i(m) &= \mathbf{A}_i\mathbf{x}_i(m-1) + \mathbf{k}_i\hat{s}^*(m)e(m)\\ \hat{H}_{i(K)}(m) &= \mathbf{c}_i\mathbf{x}_i(m)\\ \hat{H}_{(K)}(m) &= \textstyle\sum_{i=0}^{G-1}\hat{H}_{i(K)}(m). \end{aligned}\right.$$

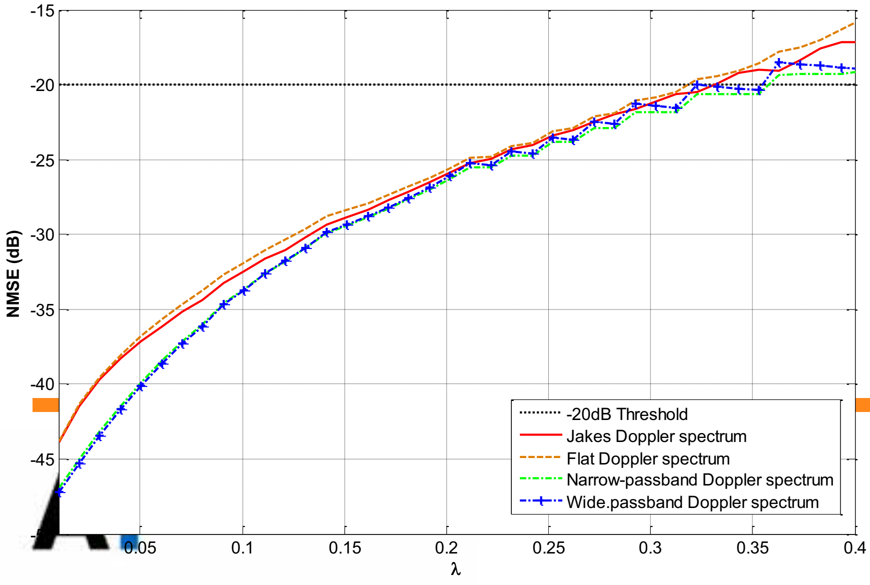
Recursive BEM long-range predictor

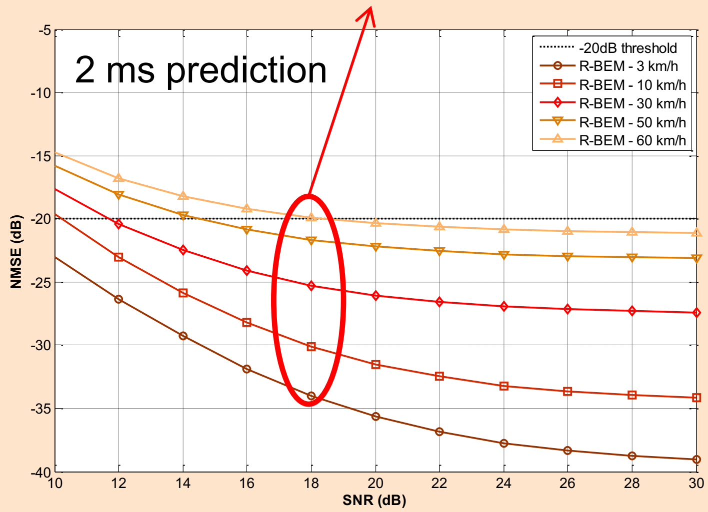
- Doppler bandwidth << OFDM bandwidth
- Temporal evolution → highly oversampled

} Decimation in time and extrapolation of the Kalman filter

$$\begin{aligned} e^p(m+\ell) &= \hat{H}_{(K)}(m+\ell-T) - \hat{H}^p(m+\ell-T)\\ \mathbf{x}^p_{i\ell}(m+\ell) &= (\mathbf{A}^p_i)^{\mathcal{L}}\mathbf{x}^p_{i\ell}(m+\ell-T\mathcal{L}) + \mathbf{k}^p_i e^p(m+\ell)\\ \hat{H}^p_i(m+\ell) &= \mathbf{c}^p_i\mathbf{x}^p_{i\ell}(m+\ell)\\ \hat{H}^p(m+\ell+T(\mathcal{L}-1)) &= \textstyle\sum_{i=0}^{G-1}\beta_i\hat{H}^p_i(m+\ell), \end{aligned}$$






Up to 60 km/h speeds at moderate SNR

Numerical Results

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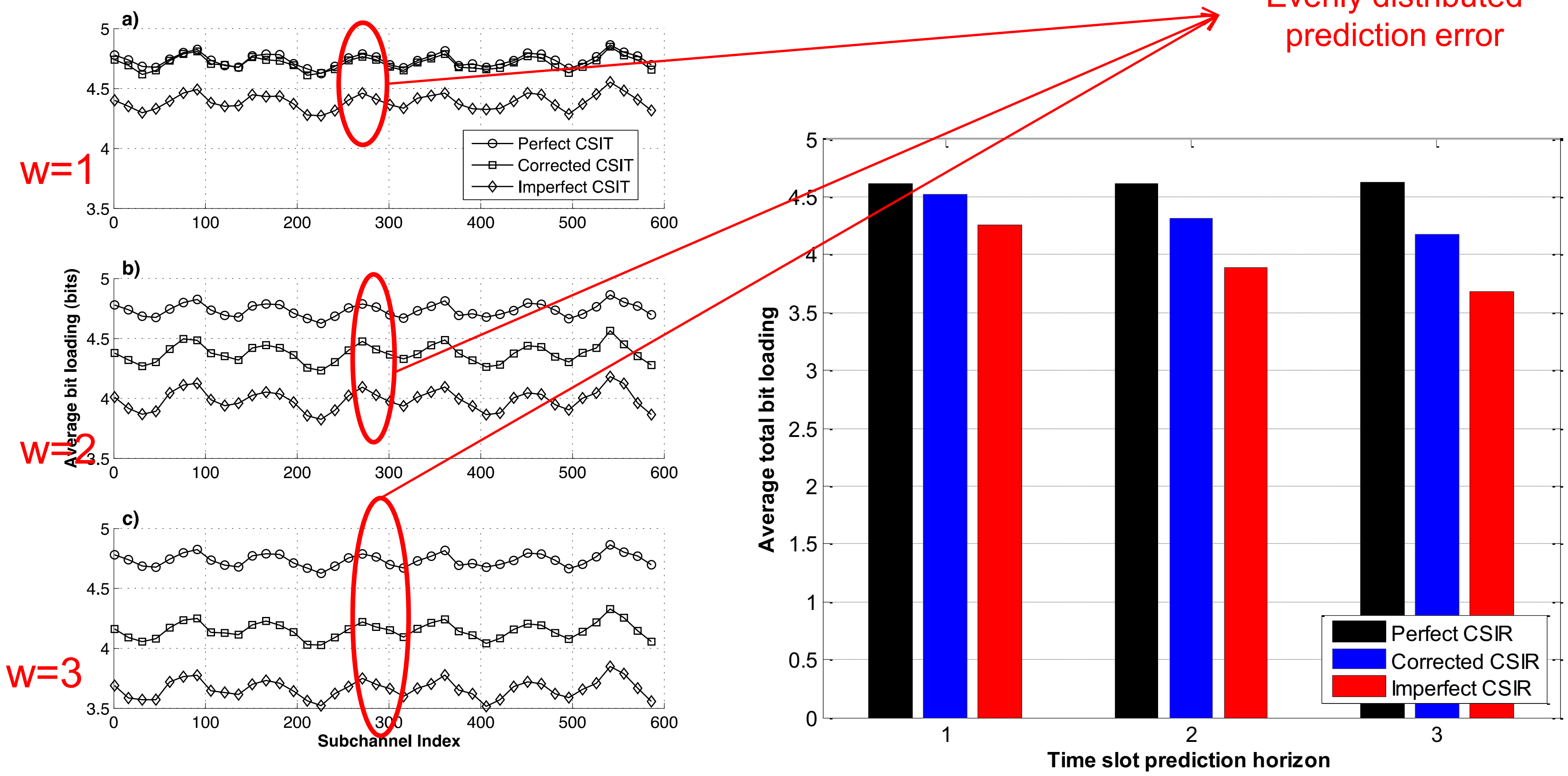
Numerical results

System (LTE) parameters	Histograms parameters
•Carrier frequency → 2 GHz •Bandwidth → 10 MHz •Subcarrier spacing → 15 KHz •Cyclic prefix → 5 µs •FFT size → 1024 •N = 600 subcarriers (90% bandwidth) •M = 15 OFDMA symbols = 1 ms •W = 3-time slot prediction •4, 16 and 64 QAM available •Target BER = $1 . 10^{-3}$ •ITU-Vehicular A channel 60 km/h •SNR → 25 dB	•Q = 600 (all subchannels used) •ω = 0.078 •Histogram limits ± 0.8

Numerical results

Single user, degradation of bit loading



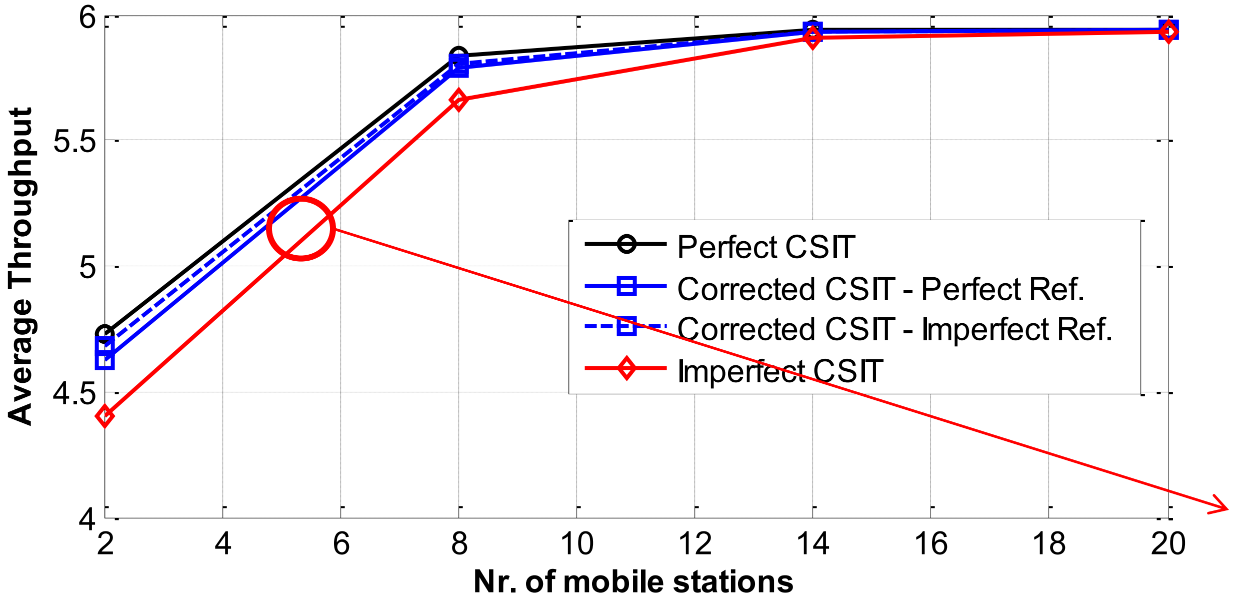
Evenly distributed prediction error

Numerical results

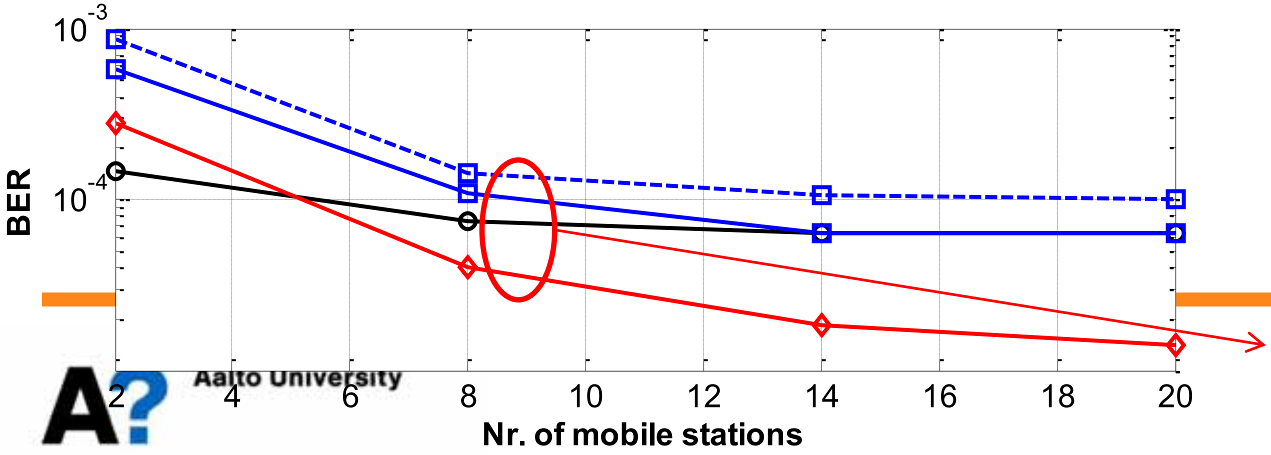
Impact to bit loading

Total system throughput

$$R(s) = \sum_{k=1}^{K} R_k(s)$$

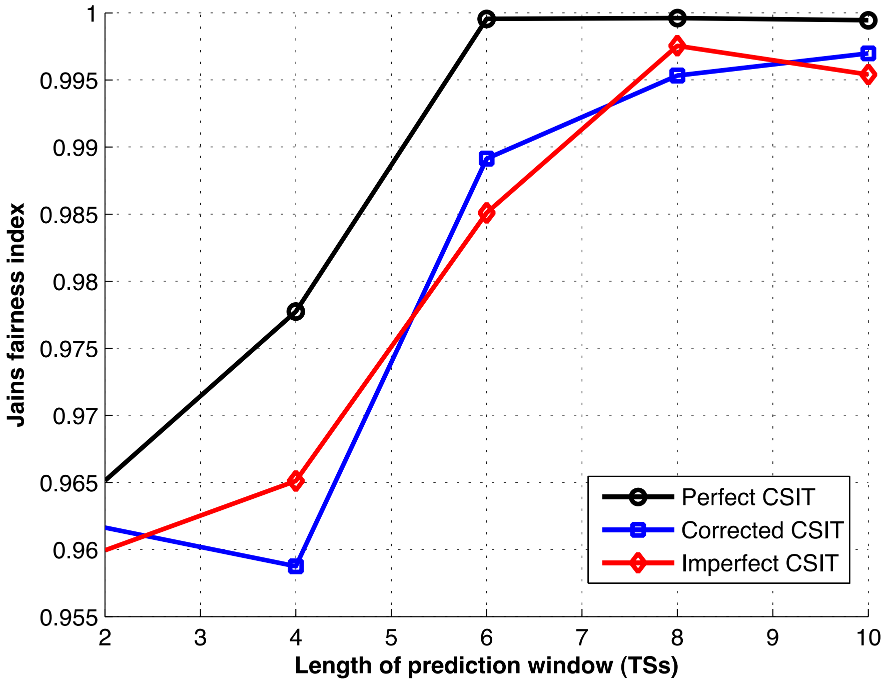


Reduced degradation of system throughput

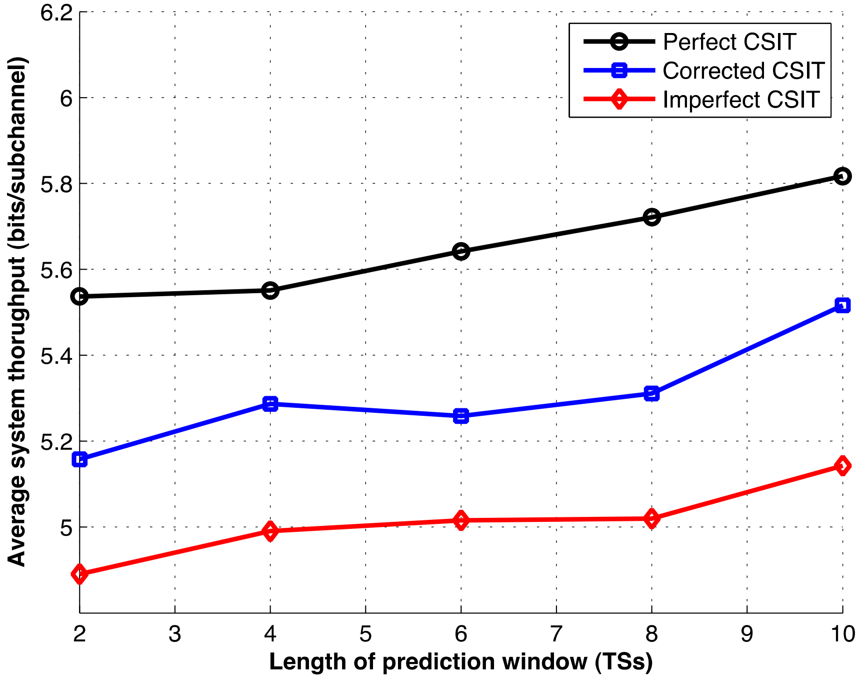


BER improvement

Numerical Results



Fairness



Throughput

$$\mathcal{J}(x_1, x_2, \ldots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \cdot \sum_{i=1}^{n} x_i^2}$$

Conclusion

Conclusion

- A scheme to compensate the prediction error was proposed for he prediction-based resource allocation within mobile OFDMA.
- The scheme was evaluated under realistic system conditions.
- The scheme outperforms those that disregard prediction error.

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References

[1] S. Stefanatos and N. Dimitriou, "Downlink OFDMA resource allocation under partial channel state information," in *IEEE ICC '09*, 2009, pp. 1–5.

[2] I. Wong and B. Evans, "Optimal resource allocation in the OFDMA downlink with imperfect channel knowledge," *IEEE Trans. Commun.*, vol. 57, no. 1, pp. 232–241, January 2009.

[3] J. Hajipour and V. C. M. Leung, "Proportional fair scheduling in multi-carrier networks using channel predictions," in *IEEE ICC '10*, 2010, pp. 1–5.

[4] S. Najeh, H. Besbes, and A. Bouallegue, "Predictive approach for OFDMA resource allocation over fixed wireless channels," in *IEEE 3rd ICSCS*, 2009, pp. 1–5.

[5] 3GPP, "Physical layer aspects for evolved UTRA," 3GPP technical report, TR 25.814, Ver. 1.0.3, Feb. 2006.

[6] J. Schmidt, J. Cousseau, and R. Wichman, "Channel prediction for link adaptation in fast fading environments," in *XII Reunin de trabajo en procesamiento de la informacion y control. Rio Gallegos. Argentina*, Oct 2007.

[7] J. Schmidt, J. Cousseau, R. Wichman, and F. Gregorio, "Fast-fading channel estimator using DCT and simplified Kalman filter," in *IEEE 8th SPAWC*, June 2007, pp. 1–5.

[8] J. Schmidt, J. Cousseau, R. Wichman, and S. Werner, "Low-complexity channel prediction using approximated recursive DCT," *Submitted to IEEE Transaction on Circuits and Systems*.

[9] D. Schafhuber and G. Matz, "MMSE and adaptive prediction of time-varying channels for OFDM systems," *IEEE Trans. Wireless Commun.*, vol. 4, no. 2, pp. 593–602, March 2005.

[10] A. Duel-Hallen, "Fading channel prediction for mobile radio adaptive transmission systems," *Proceedings of the IEEE*, vol. 95, no. 12, pp. 2299–2313, Dec. 2007.

[11] D. Tse and P. Viswanath, *Fundamentals of Wireless Communication.* Cambridge University Press, 2004.

[12] S. Ye, R. Blum, and L. Cimini, "Adaptive OFDM systems with imperfect channel state information," *IEEE Trans. Wireless Commun.*, vol. 5, no. 11, pp. 3255–3265, November 2006.

[13] Y. Yao and G. Giannakis, "Rate-maximizing power allocation in OFDM based on partial channel knowledge," *IEEE Trans. Wireless Commun.*, vol. 4, no. 3, pp. 1073–1083, May 2005.

[14] M. Jeruchim, P. Balaban, and K. Shanmugan, *Simulation of Communication systems.* New York: Plenum Press, 1992.

[15] ITU, "Guidelines for evaluation of radio transmission technologies for imt-2000," ITU-R Recommendation M.1225, 1997.