DFT-Based Channel Estimation and Noise Variance Estimation Techniques for SC-FDMA

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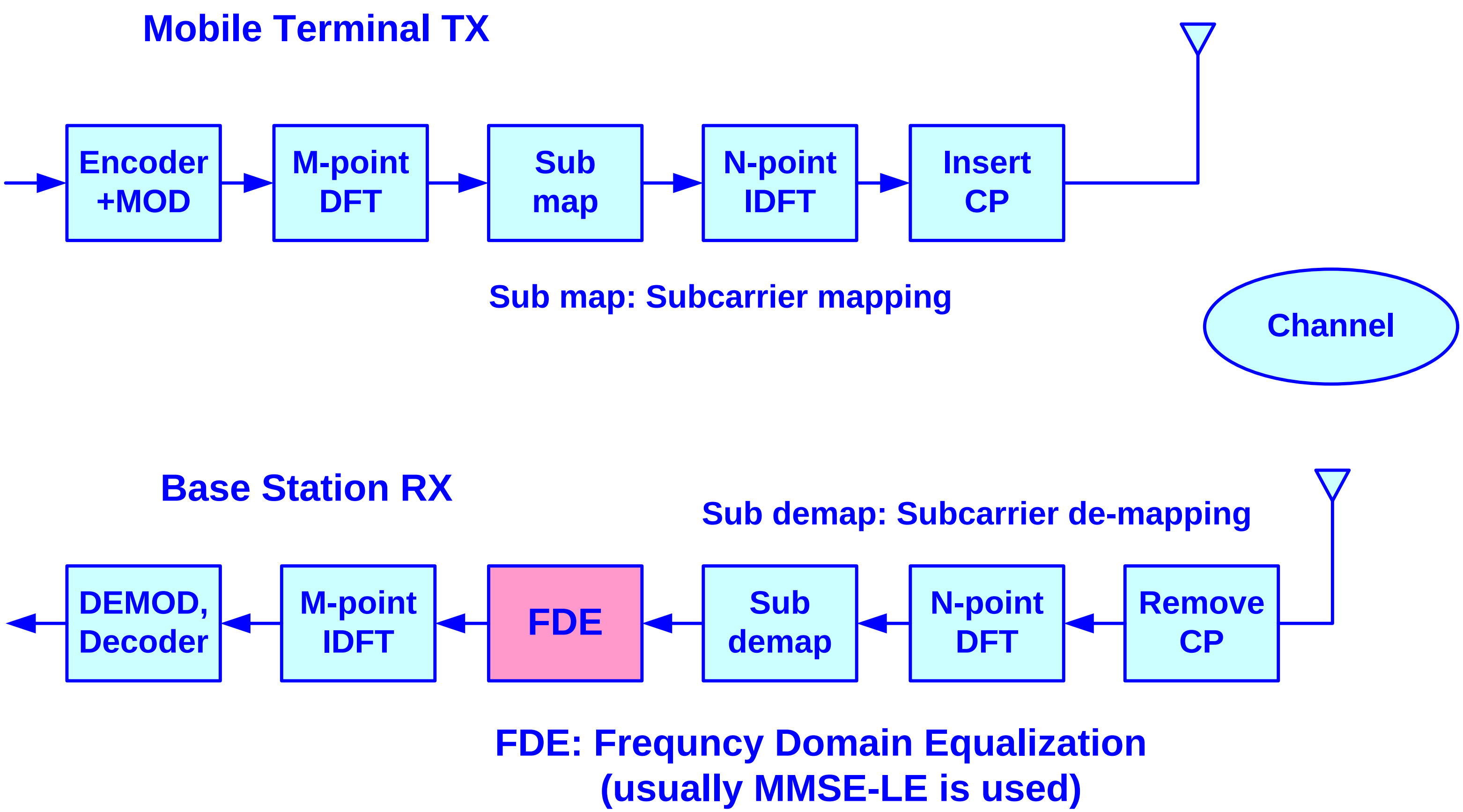
Outline

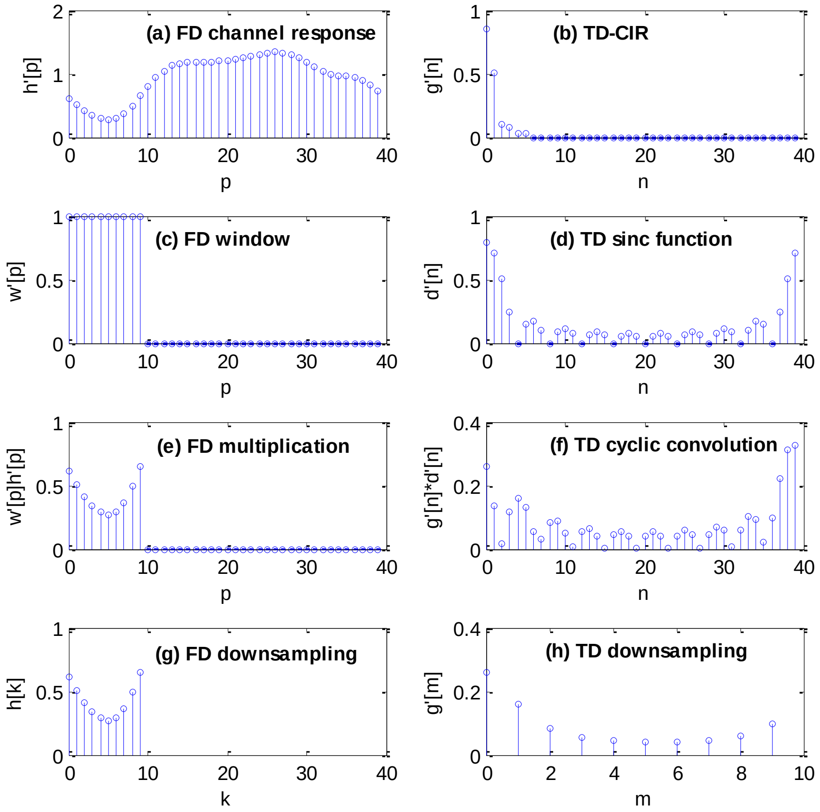
- Introduction to SC-FDMA systems and channel energy smearing effect
- DFT-based channel estimation: the denoise channel estimator and the Approximate-LMMSE (ALMMSE) channel estimator
- Proposed DFT-based noise variance estimation
- Performance of A-LMMSE channel estimator with mismatch
- Conclusions

SC-FDMA Transceiver Architecture



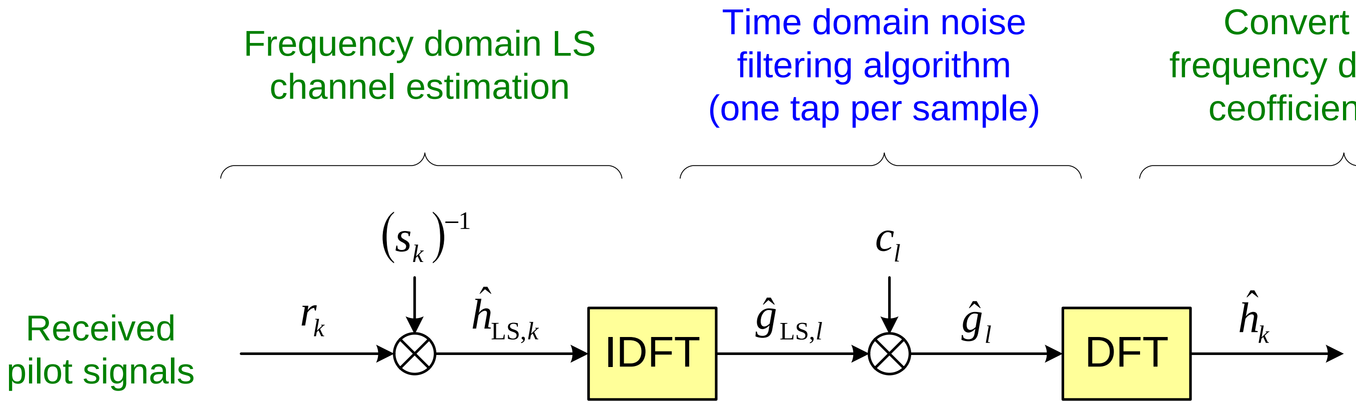
- SC-FDMA is currently employed in the 3GPP LTE uplink standard.
- The subcarrier mapping scheme can be localized or interleaved.
- We focus on channel estimation and noise estimation schemes here.

Equivalent Channel Energy Smearing Effect



- Since the DFT assumes a periodic extension, the discontinuities at the frequency edges give rise to an energy smearing effect to the equivalent channel impulse response. The channel energy is smeared over all the taps and most of the channel energy is concentrated in just a few taps. This should be taken into account in the DFT-based channel estimator design.

Block diagram of DFT-Based Channel Estimator



- Frequency domain least squares (LS) channel estimation is commonly used. The obtained LS channel estimate can be viewed as the noisy observation of the channel response. As most of channel energy will be concentrated in a few taps, a time domain filter (one tap per sample) can be designed to reduce the estimation error. Hence more accurate channel estimate can be obtained.

Denoise Channel Estimator

- The filter coefficients for the denoise channel estimator are:

$$c_l = \begin{cases} 1, & l \notin A \,(\text{energy concentration region}) \\ 0, & l \in A \,(\text{energy smearing region}) \end{cases}$$

- At low SNR, the noise is large compared to the smeared channel energy in the energy smearing region, and this approach can achieve good channel estimation performance.
- At high SNR, the noise is small compared to the smeared channel energy. Hence the truncation of the channel energy smearing taps leads to an estimation error floor at high SNR.
- The time domain multiplication results in a cyclic convolution in the frequency domain. Since the FD channel response at two edges can be highly uncorrelated, smoothing the FD channel estimate cyclically introduce larger errors at the FD edges.

Approximate LMMSE Channel Estimator

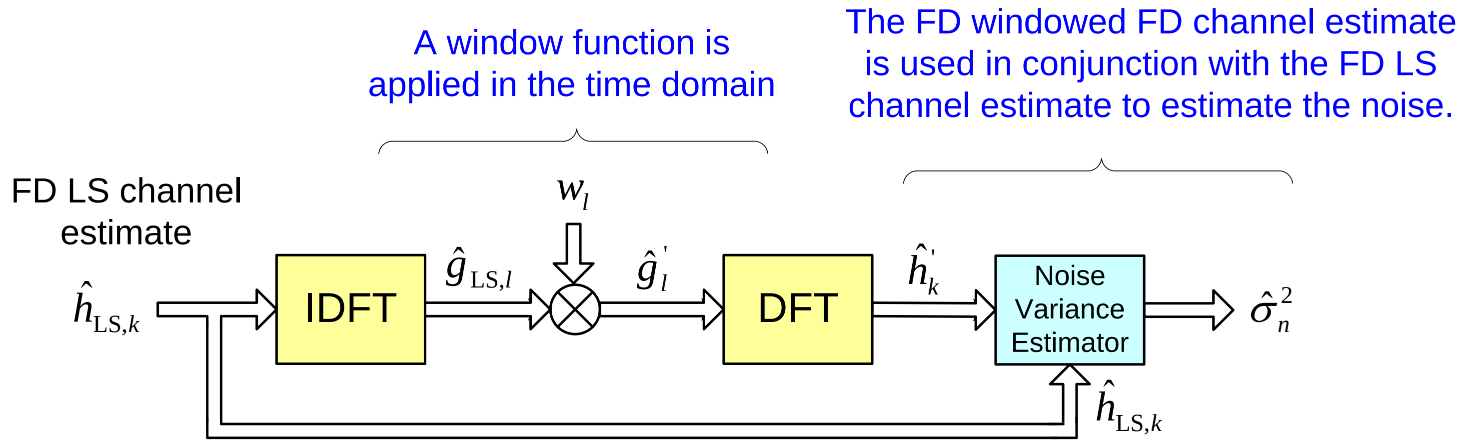
- The A-LMMSE channel estimator is designed to minimize the MSE on each tap. The estimator coefficients are

$$c_l = \frac{\gamma_l}{\gamma_l + \sigma_n^2}$$

- Knowledge of the expected channel power delay profile (PDP) γ_l and noise variance σ_n^2 is required to calculate the estimator coefficients. The rectangular PDP will be used in the simulation, as this assumption makes the A-LMMSE estimator robust to the correlation mismatch. DFT-based noise variance estimator is described in the following slides.

DFT-Based Noise Variance Estimator

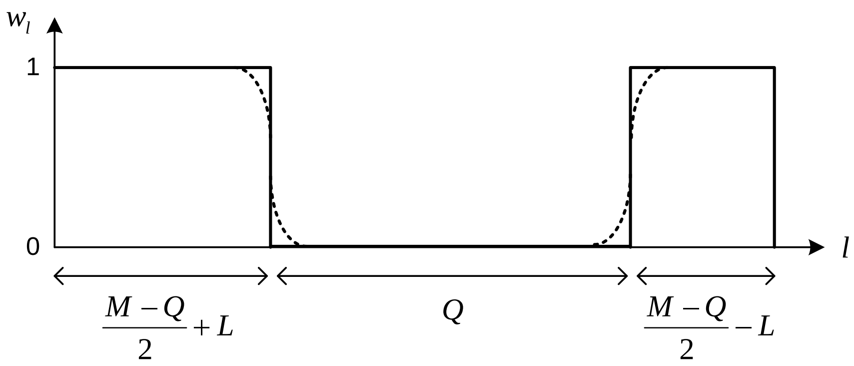
- The low-rank DFT-based noise variance estimator assumes that all the taps in the energy smearing region contain noise only and use them to estimate the noise variance. However, since the non-negligible smeared channel energy, this approach this significant bias at high SNR.
- The diagram below shows the proposed noise variance estimator.



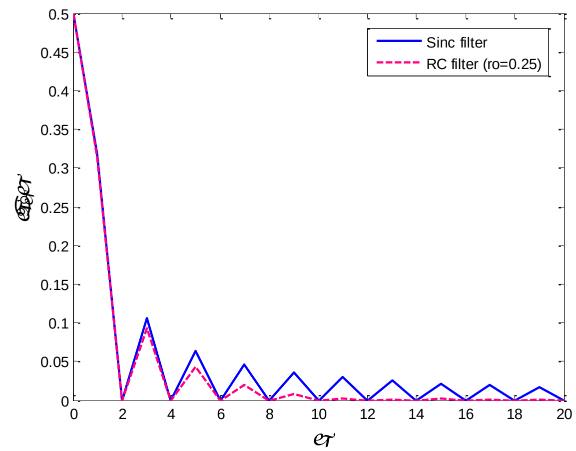
Windowed DFT-based noise variance estimator

Windowed DFT-Based Noise Variance Estimator

Time-domain window function:

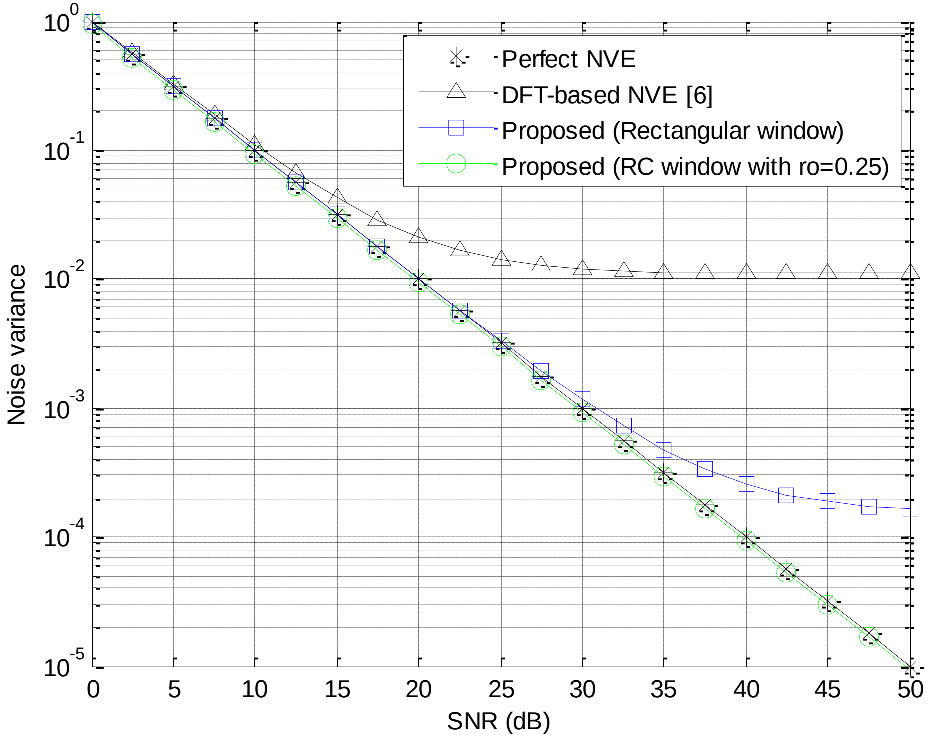


Frequency domain response:



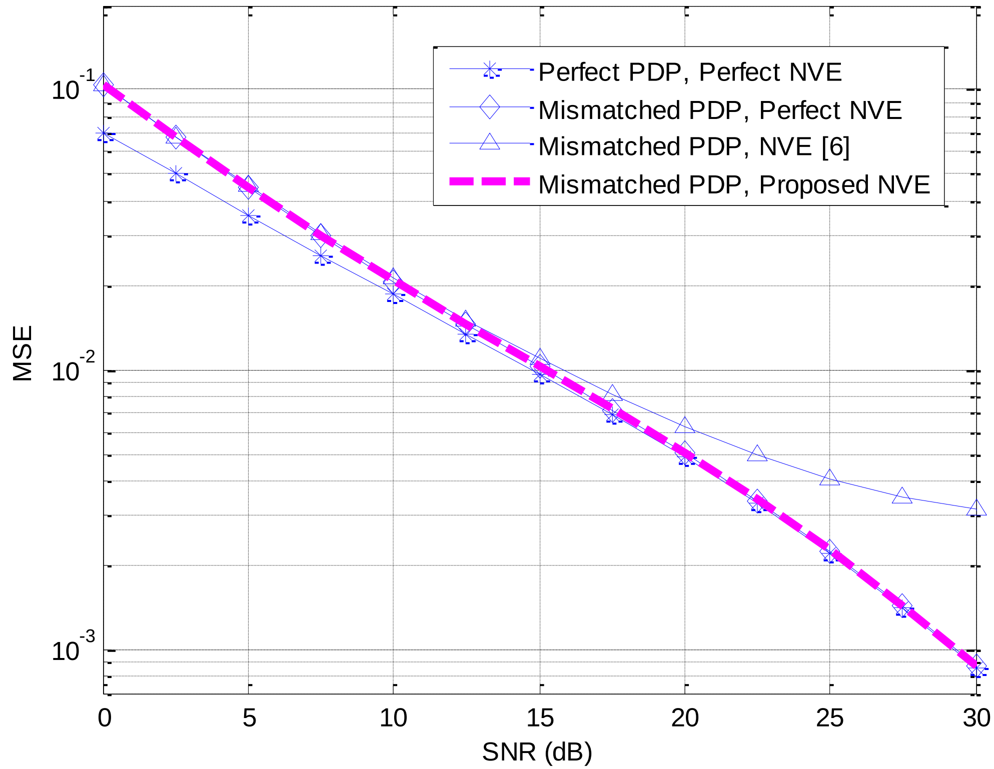
- As mentioned earlier, the channel distortion due to the time domain filtering mainly occurs at the FD edges. By taking the squared difference between the windowed FD channel estimate and the FD LS channel estimate (exclude the edged subcarriers), the noise variance can be estimated.
- To further reduce the bias, a smooth window function (e.g. RC window) can be applied since it has smaller FD sidelobe that helps to reduce the bias due to channel distortion.

Simulation Results – Noise variance estimation



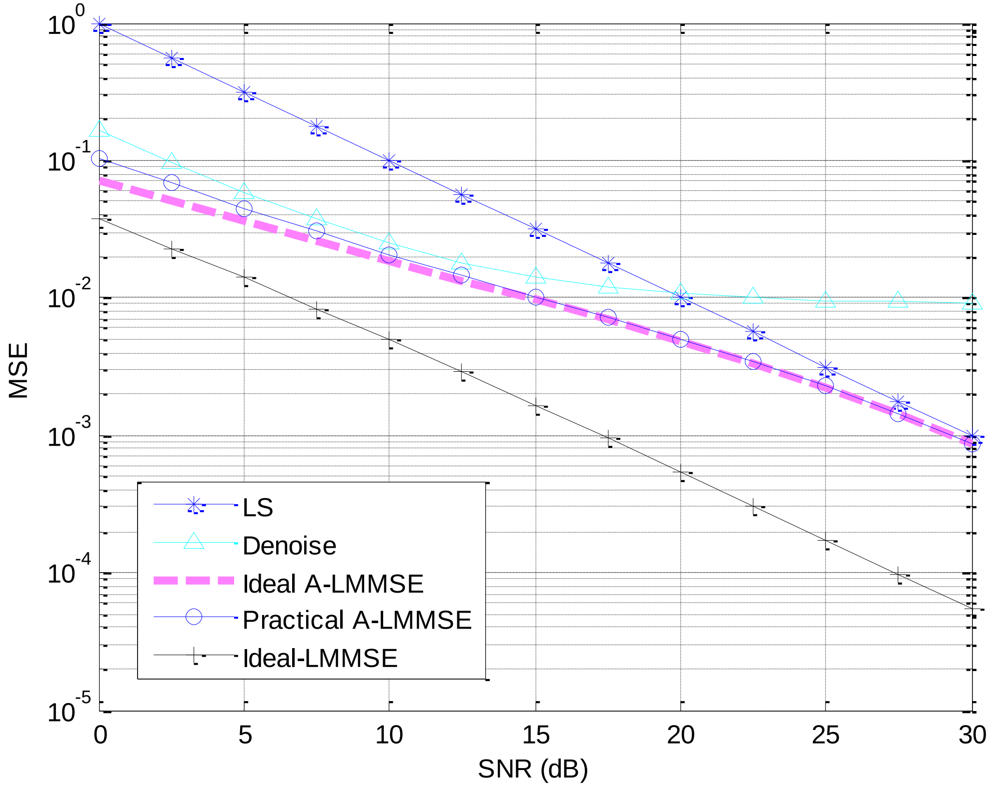
- The low-rank noise variance estimator gives large bias at high SNR due to non-negligible smeared channel energy.
- The proposed windowed noise variance estimator gives much lower bias. When a smooth window function is applied, it remains unbaised up to a SNR of 50dB.

MSE of the A-LMMSE channel estimator with mismatch



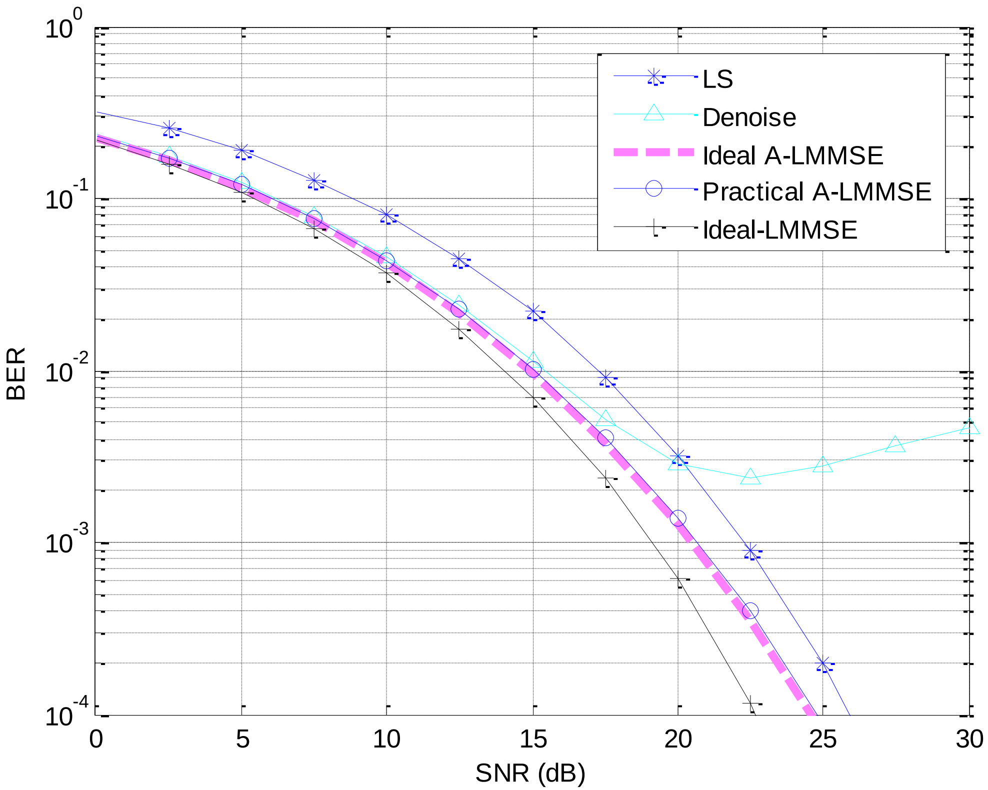
- Results show that the practical A-LMMSE channel estimator (with the rectangular PDP assumption and the proposed noise variance estimator) is able to achieve similar performance as the ideal A-LMMSE estimator.

MSE of the A-LMMSE channel estimator with mismatch



- The denoise channel estimator gives estimation error floor at high SNR.
- The A-LMMSE channel estimator is able to achieve good noise reduction performance at low SNR and converge to LS performance at high SNR.

BER of SC-FDMA with different channel estimator



- The conventional LS channel estimator gives about 3dB performance loss compared to the ideal-LMMSE case. As the standard LMMSE channel estimator requires very high complexity (e.g. matrix inversion), the A-LMMSE provides a good compromise between the complexity and performance.

Conclusions

- The commonly used LS channel estimator gives about 3dB performance loss compared to the ideal-LMMSE channel estimator. DFT-based channel estimator can be used to improve the SC-FDMA performance (A-LMMSE channel estimator is recommended).
- Windowed DFT-based noise variance is proposed. By applying a smooth window function, the noise variance estimation remains unbiased upto a SNR of 50dB.
- Using the proposed windowed noise variance estimator and the rectangular PDP assumption, the practical A-LMMSE channel estimator achieve similar performance as the ideal A-LMMSE.

Thank You

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