Effect of Noise Variance Estimation on Channel Quality Indicator in LTE Systems

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Outline

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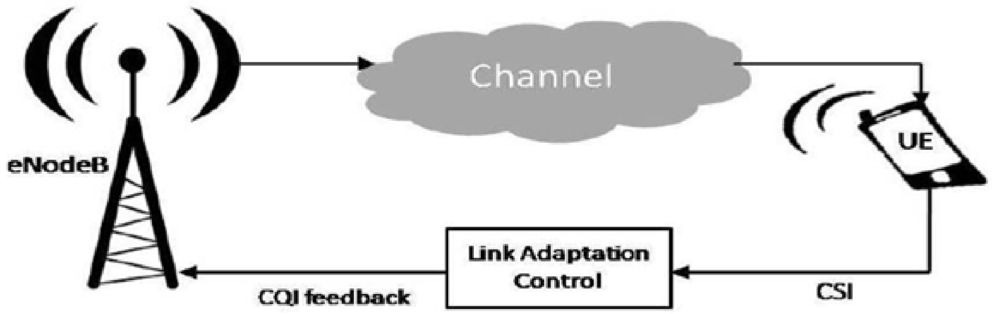
- Noise Variance Calculation Methods
- System Model (LTE)
- Cyclic-prefix Based Noise Variance Estimation
- Pilot-based Noise Variance Estimation
- CQI Calculation (MIESM)
- Simulation Results

Introduction

- 3GPP LTE: high data rate communication is possible due to advanced techniques e.g., OFDM, adaptive modulation and coding (AMC), and link adaptation (LA)
- LA is often used to cope with the channel variations
- The channel quality indicator (CQI) is an important LTE metric that allows successful LA



Introduction

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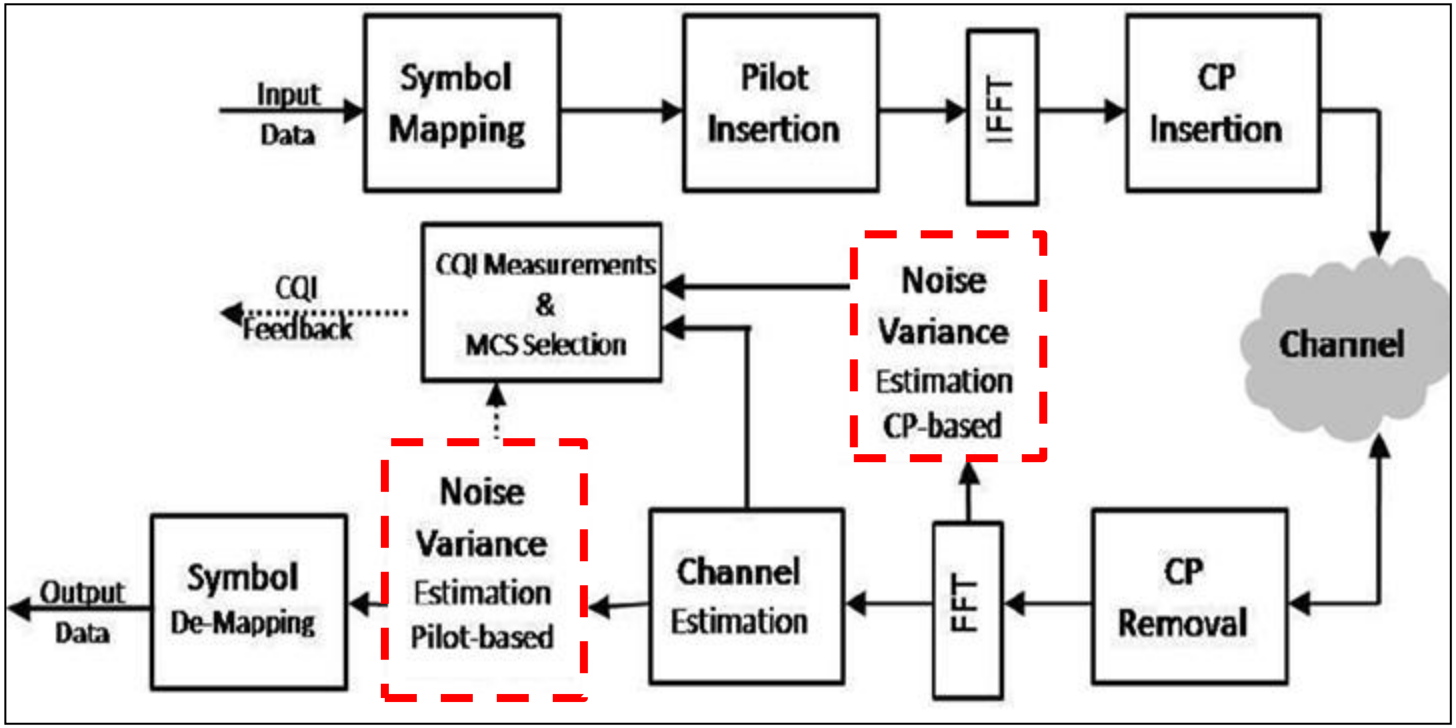
- The UE performs some measurements e.g., channel and noise variance estimations, based on which the CQI is calculated and fed back to the base station
- In this work, we study the effect of the noise variance estimation on the CQI calculation in LTE systems
- We assess the performance of a widely-used CQI algorithm, the mutual information effective SINR mapping (MIESM)
- We compare the performance in the presence of the channel estimation errors and the interference signals

System Model

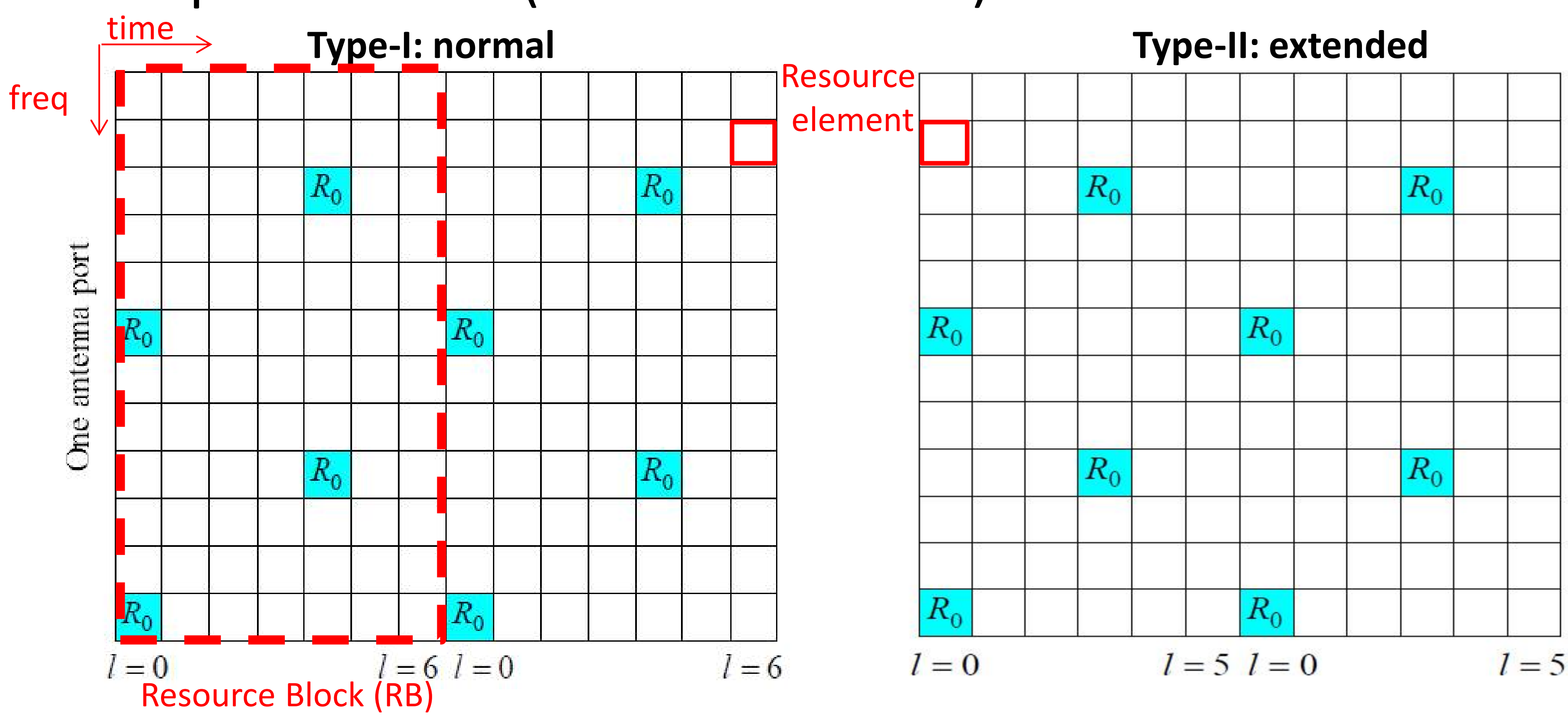
- The LTE system uses OFDM with bandwidth that varies from 1.4 MHz (corresponding to 72 subcarriers) up to 20 MHz (1200 subcarriers)



Downlink system Model

System Model

- The LTE system uses OFDM with bandwidth that varies from 1.4 MHz (corresponding to 72 subcarriers) up to 20 MHz (1200 subcarriers)



CQI Computation

- In order to assess the quality of the channel, the UE computes the signal-to-noise ratio (SNR) at each resource element $SNR_{nm} = \left|\widehat{H}_{nm}\right|^2 / \hat{\sigma}^2$ (*n*: freq. index, *m*:time index)
- It then combines these SNR_{nm} in one effective SNR_{eff} that is used to select the best modulation and coding scheme (high throughput and low frame error rate)

CQI Computation

- Several algorithm exist to obtain SNR_{eff}
  - Exponential effective SINR mapping (EESM)
  - mutual information effective SINR mapping (MIESM)

- In this work, we adopt MIESM

Noise-Variance Estimation

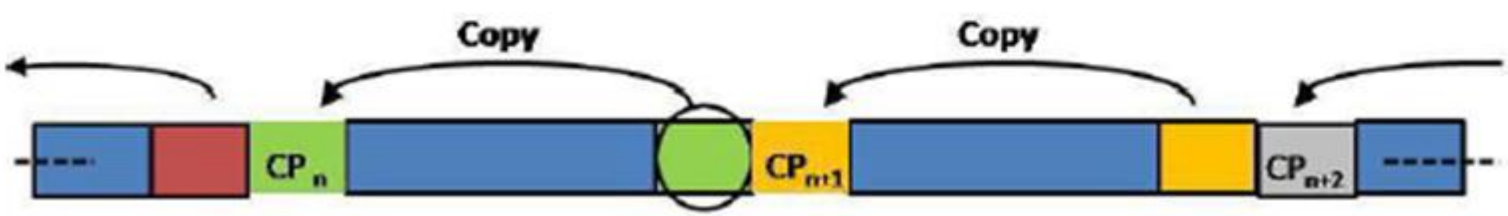
- Noise variance estimation methods
  - Data aided (DA) estimators (known pilot sequence)
  - Non-data aided estimators

Noise-Variance Estimation

- Noise variance estimation methods
  - Data aided (DA) estimators (known pilot sequence)
  - Non-data aided estimators
- In our system model
  - Data aided (DA) estimators: Pilot-based (freq. domain)
  - Non-data aided estimators: CP-based (time domain)

Noise-Variance Estimation

- Cyclic-Prefix based method
  - Uses the CP of the OFDM symbols



Noise-Variance Estimation

- Cyclic-Prefix based method
  - Uses the CP of the OFDM symbols

$$\hat{\sigma}^2 = \frac{\sum_{m=1}^{M} \sum_{n=d_{max}+1}^{N_g} \left| y_m(n) - y_m\left(n + N - N_g\right) \right|^2}{2M\left(N_g - d_{max}\right)}$$

$y_m(n)$: *n*-th sample of the received signal at the *m*-th OFDM symbol

M: number of OFDM symbols used in the estimation process

N_g: number of samples in the CP

d_{max}: maximum delay spread (fixed)

Noise-Variance Estimation

- Pilot based method
  - Uses the CP of the OFDM symbols

$$\hat{\sigma}^2 = \frac{1}{N_{total}} \sum_{n} \sum_{m} \left| Y_{nm} - \hat{H}_{nm} X_{nm}^* \right|^2$$

Y_{nm}: the *n*-th FFT sample of the received signal at the *m*-th OFDM symbol

$\hat{H}_{nm}$: the estimated channel

X_{nm}^*: the pilot symbol

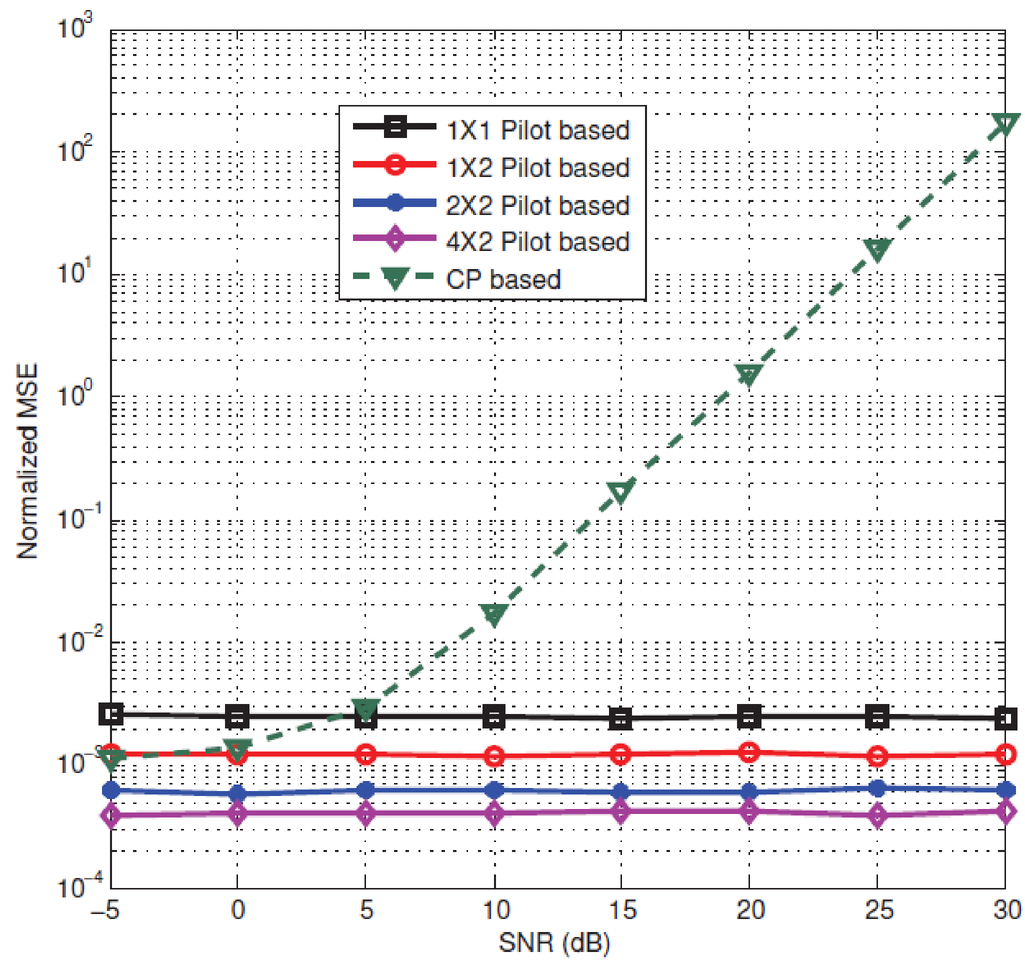
N_{total}: total number of pilots used in the estimation process

Link-Level Simulator

Parameters	Assumptions
System bandwidth	10 MHz
Antenna configuration	$1 \times 1, 1 \times 2,\ \ 2 \times 2,\ \ 4 \times 4$ uncorrelated
Propagation channel	ETU, EPA and EVA
Doppler	0, 5, 70, and 300Hz
MS receiver type	MRC
Channel estimation method	MMSE-based approach
CSI feedback delay	8 ms
Modulation/coding	CQI table (Rel-8)

Link-Level Simulator

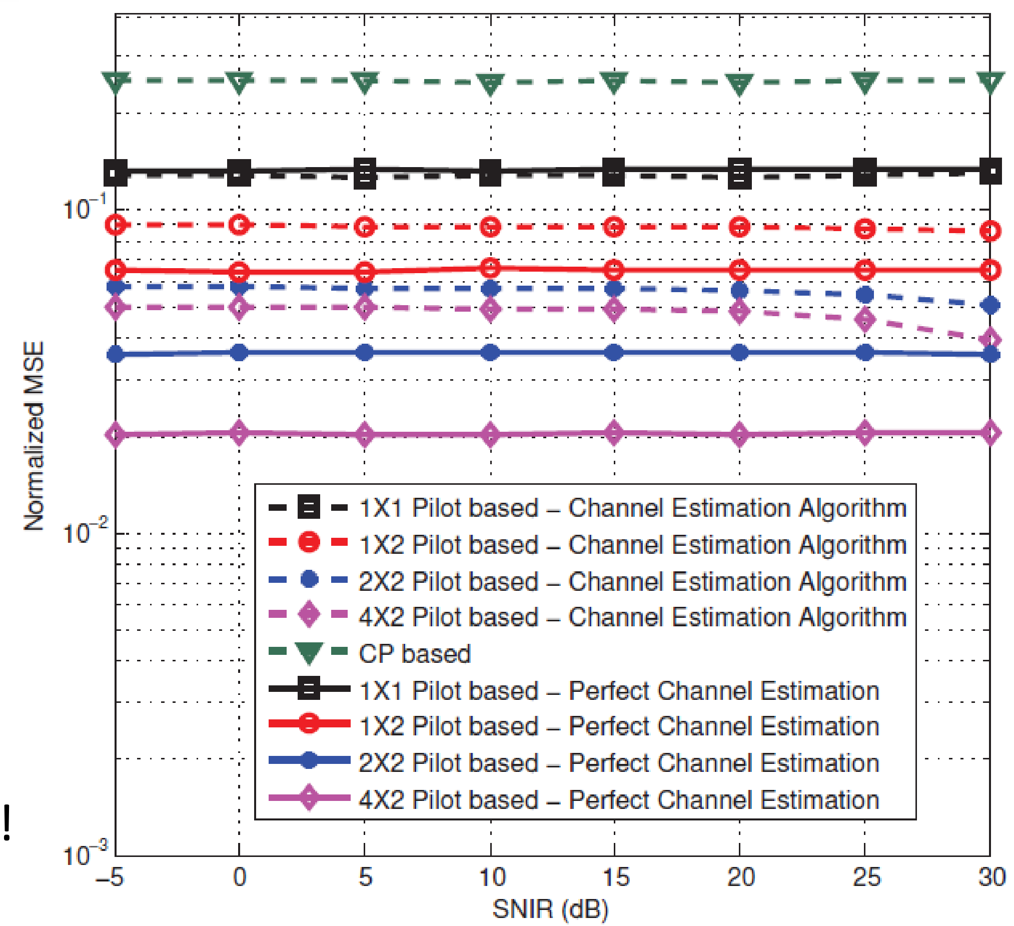
- CP-based method provides more accurate results compared to the pilot-based one at low SNR and small number of pilots
- By using more antennas, the number of observations (pilots) increases and the performance of the pilot-based improves (e.g. MIMO or in the high SNR).



NMSE of both estimation methods with perfect channel estimation and ETU-0Hz channel

Link-Level Simulator

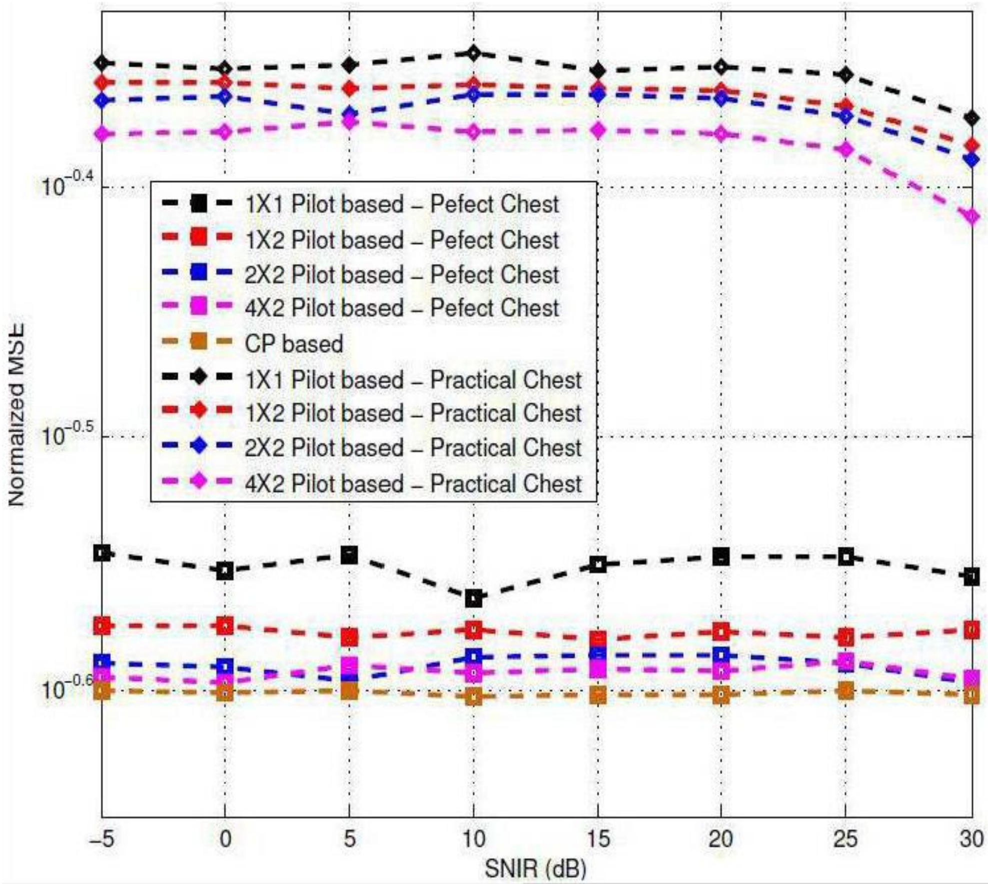
- We simulate the case of 10 MHz LTE bandwidth over EPA-5Hz with/without perfect channel and in the presence of synchronous LTE interfering signal
- The performance of the pilot-based is superior even in the presence of channel estimation error.
- The CP-based algorithm cannot detect the interference power in synchronous interfering LTE signal!
- Misleading noise variance estimate results in an optimistic (high) CQI!



NMSE of both estimation methods, with an LTE synchronous interference, and EPA-5Hz channel

Link-Level Simulator

- If the number of RBs is reduced (for complexity reason or sub-band interference estimation), the pilot-based method performance may degrade significantly
- By using more antennas, the number of observations (pilots) increases and the performance of the pilot-based improves (e.g. MIMO or in the high SNR).
- However, the sensitivity to the channel estimation method is evident



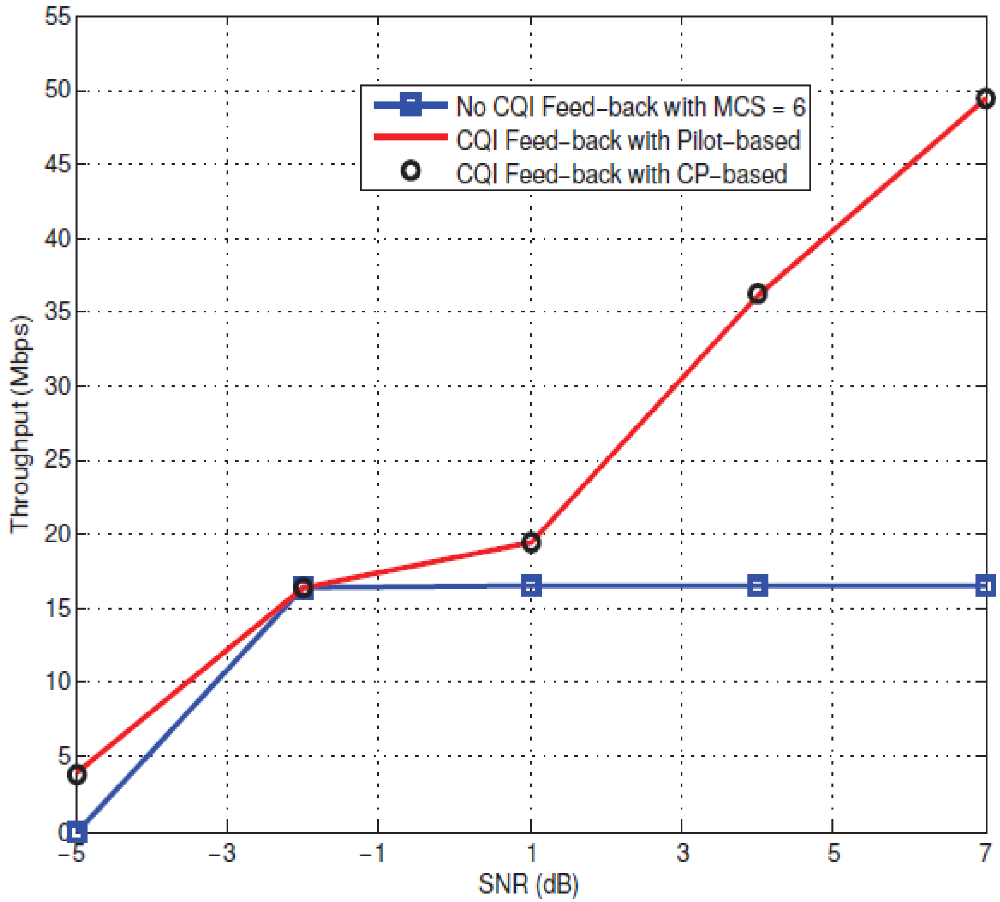
NMSE of both estimation methods using 1 RB

Link-Level Simulator

- Throughput curves:

- No CQI reporting : throughput floor

- CQI-reporting: throughput increases in both methods

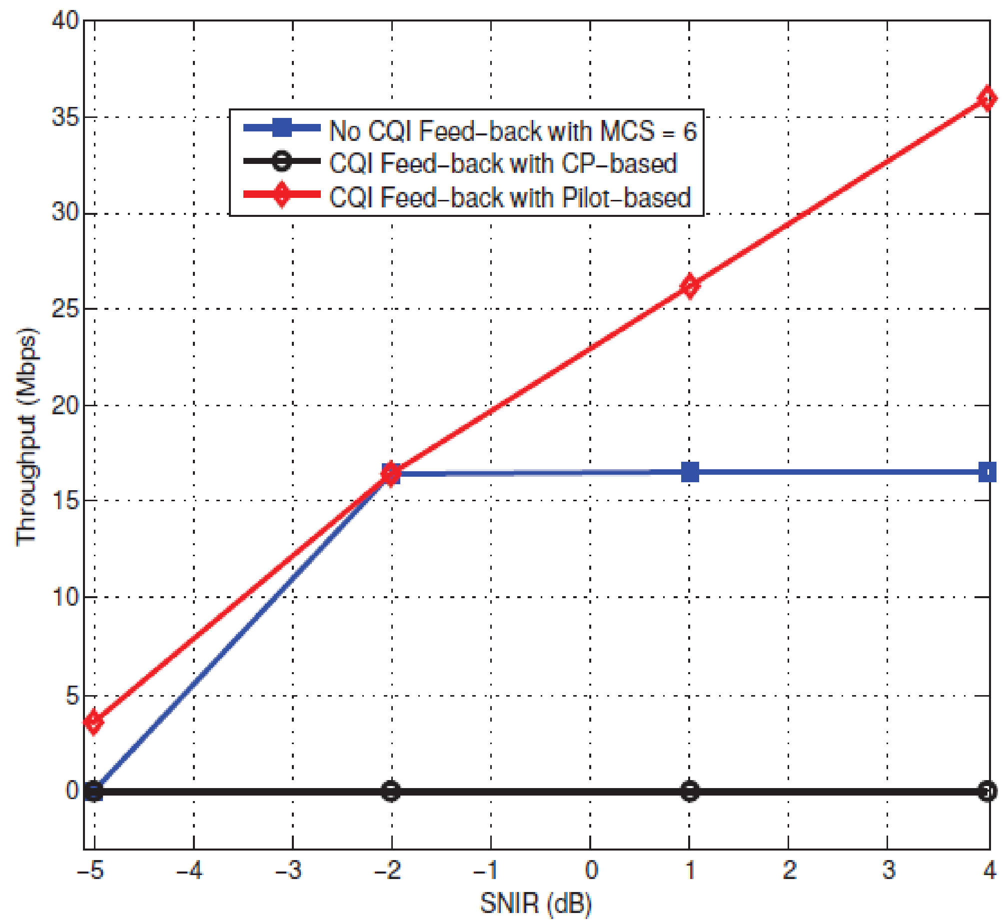


The throughputs of 1x2 system in an AWGN channel in the cases of: no feed-back, CQI with both noise-variance estimation methods.

Link-Level Simulator

- Throughput curves:
- CP-based is much worst since it reports a misleading noise estimate resulting in an optimistic (high) CQI that does not reflect the actual interference situation. The corresponding MCS results in erroneous transmission and thus low throughput.

- The cases of other channel types and colored interference are still under investigation



The throughputs of 1x2 system in an AWGN Channel with an LTE interfering signal in the cases of: no feed-back, CQI with both estimation methods.

Conclusion

- The pilot-based method is more robust to the presence of interference signals in the LTE band, a common scenario that is a part of the LTE-standard conformance tests.
- An extension to this work is the colored interference case (tradeoff between the number of pilots and the noise-variance estimate)
- The CP-based method is more robust to the channel estimation error compared to the pilot-based one
- Another extension to this work is to include different impairments e.g., IQ, frequency/time offsets (causing ICI thus degrading the pilot-based performance)

Thank you