Evaluation of Interference Cancellation Architectures for Heterogeneous Cellular Networks

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Outline

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1. Motivation
   - From Homogeneous to Heterogeneous Cellular Networks
   - Challenge - Inter-Channel Interference Cancellation
2. Basic Concepts
3. Signal & System Model
4. Metric Computing Device
5. Simulation Results
6. Summary

From Homogeneous to Heterogeneous Cellular Networks

- Current homogeneous cellular networks are reaching their breaking point
- Introducing pico/femto base-stations and relay nodes in a macro cellular networks:
  - improves spatial reuse and coverage
  - allows to achieve higher data rates
- Totally random base stations (BS) placement
- Significant imbalance in the downlink transmit powers: Home eNode B (HeNB) vs. macro eNode B

Inter-Channel Interference (ICI) Management

Conventional ICI management approaches need to be revised:

- ICI Avoidance:

  Complexity of cell coordination based systems increases drastically

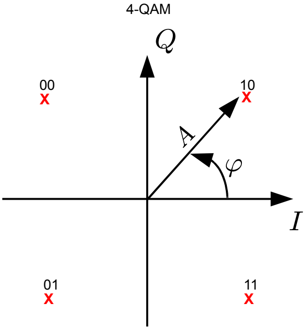
- ICI Mitigation:

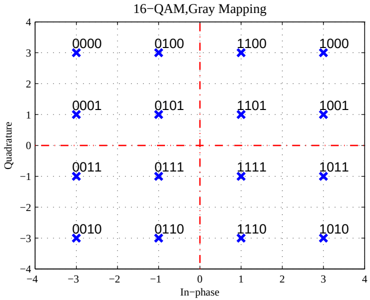
  Signal randomization at the transmitter $\rightarrow$ Interference is just noise

Interference cancellation at the user equipment (UE)

Outline

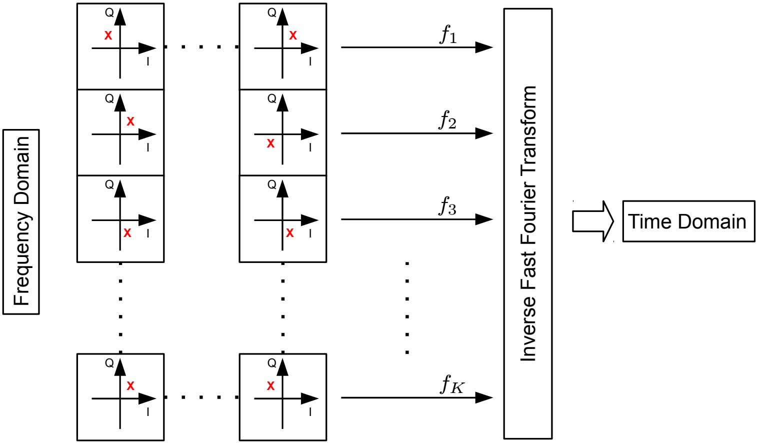
Quadrature Amplitude Modulation (QAM)



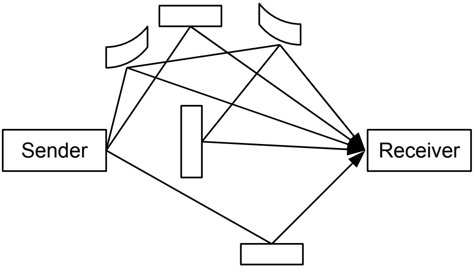


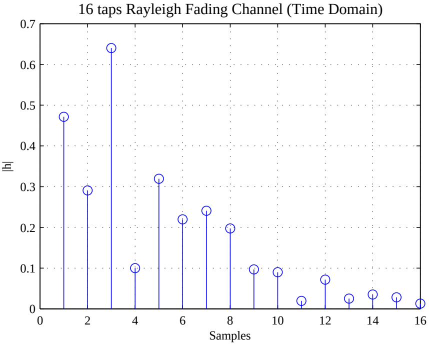
- Possibility to transport n-bits using one symbol
- Information is embedded in both: amplitude A and phase φ

Orthogonal Frequency Division Multiplexing (OFDM)



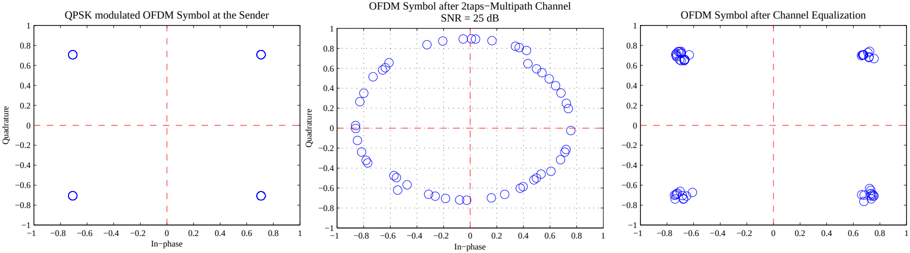
Propagation Channel: Rayleigh Multipath Fading





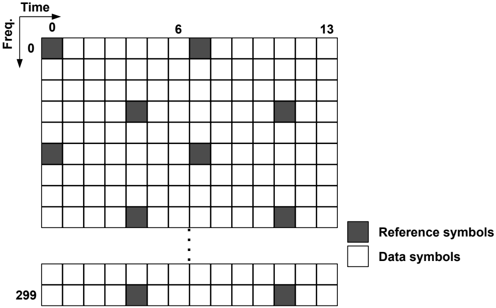
- Non line of sight (NLOS) multipath propagation channel.
- Each tap = delayed and attenuated signal copy

Multipath Fading's Effect on the Signal



- Mulipath channel effect needs to be corrected in the receiver
- Equalization needs knowledge about the propagation channel

Pilot-Based Least Squares (LS) Channel Estimation



- Pilots are reference symbols.
- Each cell has a specific pilot pattern.

- Position and modulation scheme are well known by the receiver.

and more Definitions

- Additive White Gaussian Noise (AWGN):

  Normally distributed random signal with equal power over all frequencies
- Signal to Noise Ratio:

  SNR = signal power/noise power [dB]
- Signal to Interference Ratio:

  SIR = signal of interest power/co-channel interferer power [dB]
- Mean squared Error:

  MSE = average squared difference between a value v and its estimation $\hat{v}$.

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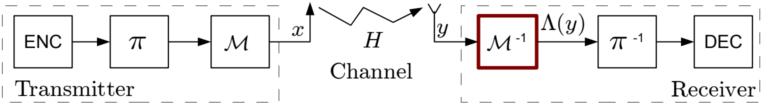
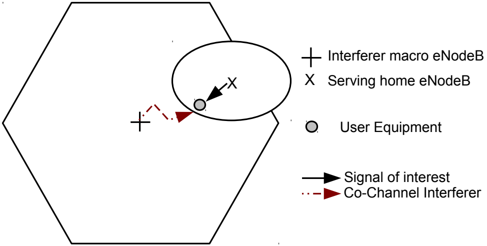
Transceiver System Model

Bit interleaved coded modulation (BICM) transceiver



- Sender: encoder (ENC), bit interleaver π, modulator $\mathcal{M}$
- Receiver: metric computing device $\mathcal{M}^{-1}$, deinterleaver π^{-1} and decoder (DEC)

Interference Model



System Assumptions

1. x_1: symbol of interest (SOI), 4-QAM
2. x_2: Co-Channel interferer symbol, 4-QAM
3. H_1: SOI's channel
4. H_2: interferer's channel

Signal Model

Signal Model: Interference-Ignorant Receiver (II-R)

$$y_{\text{II-R}} = \mathrm{H}_1 x_1 + z \tag{1}$$

- Interference in the II-R is considered to be part of the AWGN z

Signal Model: Interference-Aware Receiver (IA-R)

$$y_{\text{IA-R}} = \mathrm{H}_1 x_1 + \mathrm{H}_2 x_2 + z \tag{2}$$

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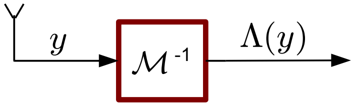
Metric as Log-Likelihood Ratio (LLR) (1)

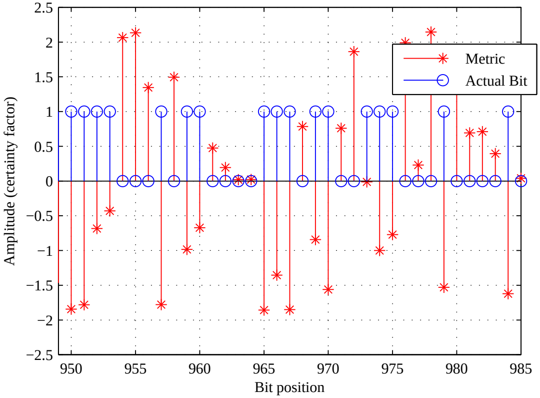


$\Lambda(y)$ is the log-likelihood ratio of a bit

1. $\Lambda(y) > 0 \longrightarrow$ Bit is more likely to be a 0.
2. $\Lambda(y) < 0 \longrightarrow$ Bit is more likely to be a 1.

Data is passed from one component to another in form of LLR.
The main physical difference between II-R and IA-R is $\mathcal{M}^{-1}$

Metric as Log-Likelihood Ratio (LLR) (2)



Amplitude = Certainty factor

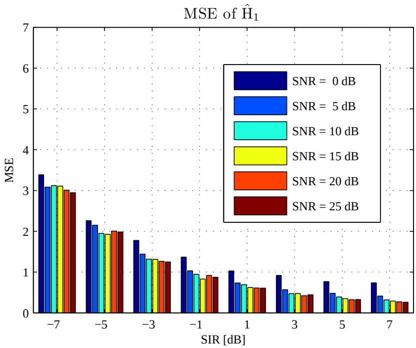
IA-LLR, an optimized II-LLR

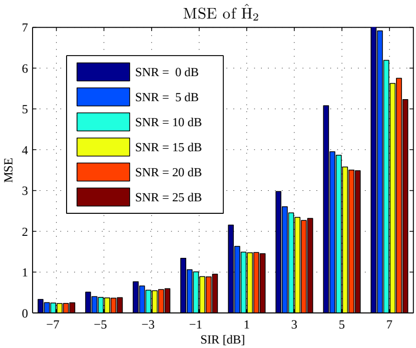
$$\Lambda^{\text{IA-R}}(y) = \Lambda^{\text{II-R}}(y) + \Psi(\hat{\mathrm{H}}_1, \hat{\mathrm{H}}_2), \tag{3}$$

$\Psi()$ is a cost function depending on:

- $\hat{\mathrm{H}}_1$: channel estimation of the signal of interest
- $\hat{\mathrm{H}}_2$: Interferer-channel estimation.

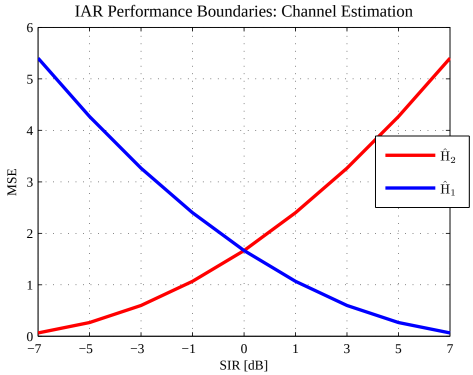
Mean Squared Error, Quality Factor for Estimations (1)





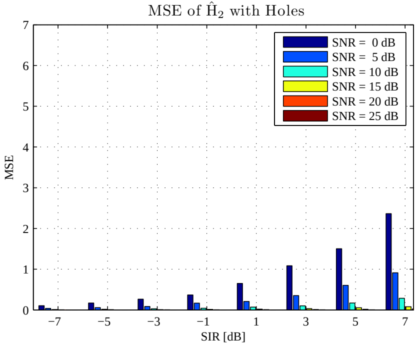
SIR $< 0 \longrightarrow$ MSE of $\hat{H}_1 \nearrow$ SIR $> 0 \longrightarrow$ MSE of $\hat{H}_2 \nearrow$

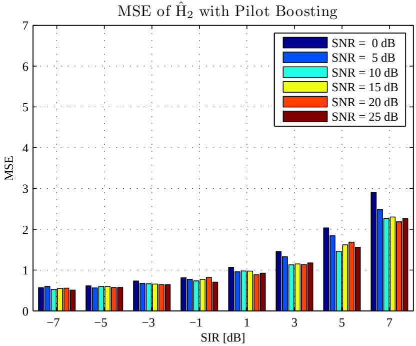
Mean Squared Error, Quality Factor for Estimations (2)



IAR Performance Boundaries: $\hat{H}_1$ & $\hat{H}_2$

Base Station Channel Estimation Enhancement





Serving BS: Holes

Interferer BS: Pilot Boosting

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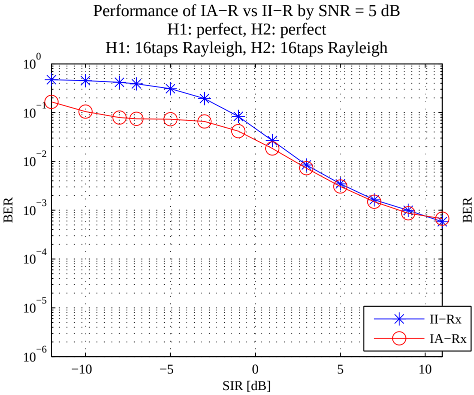
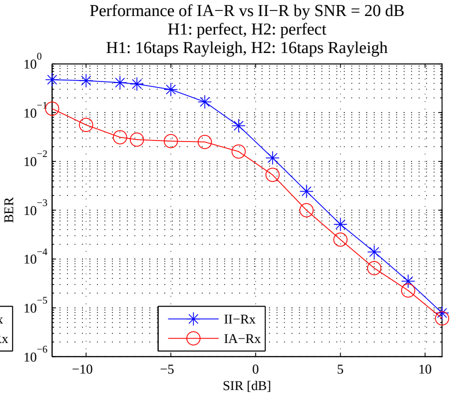
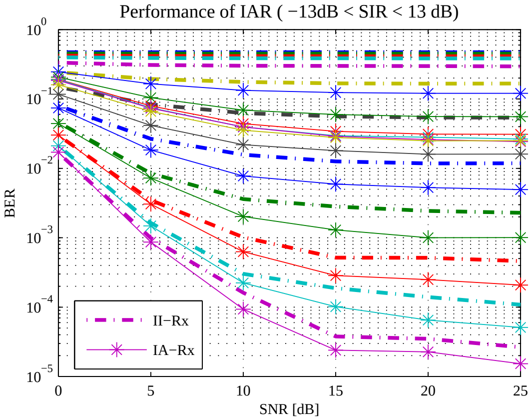
Theory: Perfect Channel Knowledge (1)



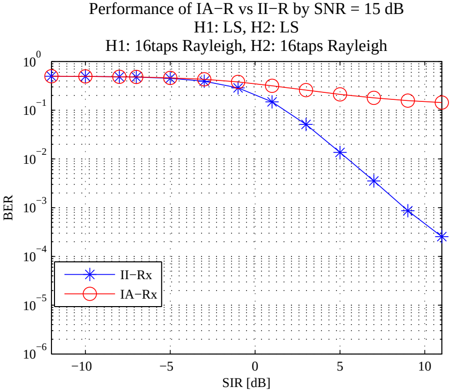


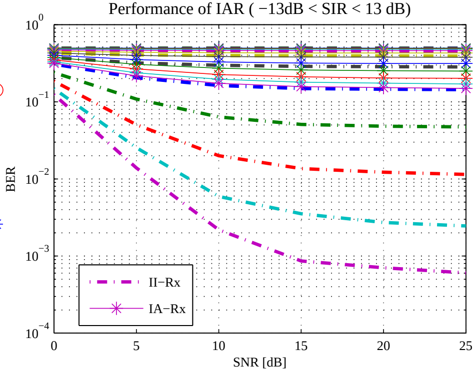
Theory: Perfect Channel Knowledge (2)



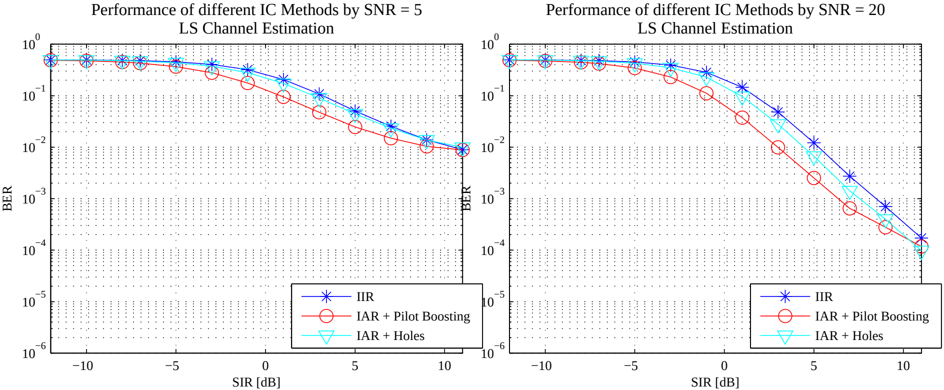
Under the assumption perfect channel knowledge, IA-R always out performs II-R

The Hard Reality: Channel Estimation

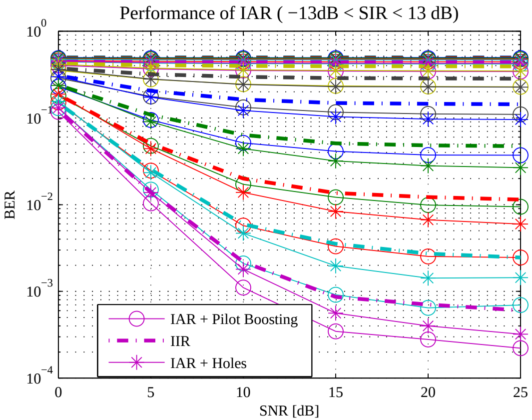




Proposed Solution: Base Station Enhancement (1)



Proposed Solution: Base Station Enhancement (2)



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Summary

- Interference cancellation at the receiver is a very promising technology, but still at the begin
- Sole limitation of the IA-R is the quality of the channel estimation
- Base Stations need to be involved in the channel estimation process
- Worst case, switch off the cost function $\Psi()$ and IA-R becomes II-R

Reference

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[2] Ghaffar R. and Knopp R., Interference-aware receiver structure for multi-user MIMO and LTE. *Eurasip Journal 2011*.
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[4] Stefania Sesia, Issam Toufik, and Matthew Baker. LTE, The UMTS Long Term Evolution. *Wiley Publishing, 2009*.

Questions?

Thank You!