Upcoming Challenges in Cellular Mobile Communications

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Performance Metric: Channel Capacities [P1-P4]

Capacity (Shannon, Foschini&Gans, Telatar)

$$C(P_{\mathrm{Tx}}) = \max_{\sum \mathrm{tr}\{\mathbf{R}_k\} \leq K} \frac{B}{K} \sum_{k=1}^{K} \log_2 \det \left(\mathbf{I} + \frac{P_{\mathrm{Tx}}}{\sigma_{\mathrm{n}}^2 N_{\mathrm{T}}} \mathbf{H}_k \mathbf{R}_k \mathbf{H}_k^{\mathrm{H}} \right)$$

Mutual Information (constrained capacity)

$$I(P_{\mathrm{Tx}}) = \frac{B}{K} \sum_{k=1}^{K} \log_2 \det \left(\mathbf{I} + \frac{P_{\mathrm{Tx}}}{\sigma_{\mathrm{n}}^2 N_{\mathrm{T}}} \mathbf{H}_k \mathbf{H}_k^{\mathrm{H}} \right)$$

Achievable Mutual Information (constrained by Standard)

$$I_{\mathrm{a}}(P_{\mathrm{Tx}}) = \max_{\mathbf{W} \in \mathcal{W}} \frac{\beta B}{K} \sum_{k=1}^{K} \log_2 \det \left(\mathbf{I} + \frac{\alpha P_{\mathrm{Tx}}}{\sigma_{\mathrm{n}}^2 N_{\mathrm{T}}} \mathbf{H}_k \mathbf{W} \mathbf{W}^{\mathrm{H}} \mathbf{H}_k^{\mathrm{H}} \right)$$

Performance Measures: Throughput Losses

- Channel State Information (CSI) Loss:

$$L_{\mathrm{CSI}}(P_{\mathrm{Tx}}) = C(P_{\mathrm{Tx}}) - I(P_{\mathrm{Tx}}); \quad L_{\mathrm{CSI}\%}(P_{\mathrm{Tx}}) = 100 \cdot \frac{C(P_{\mathrm{Tx}}) - I(P_{\mathrm{Tx}})}{C(P_{\mathrm{Tx}})}$$

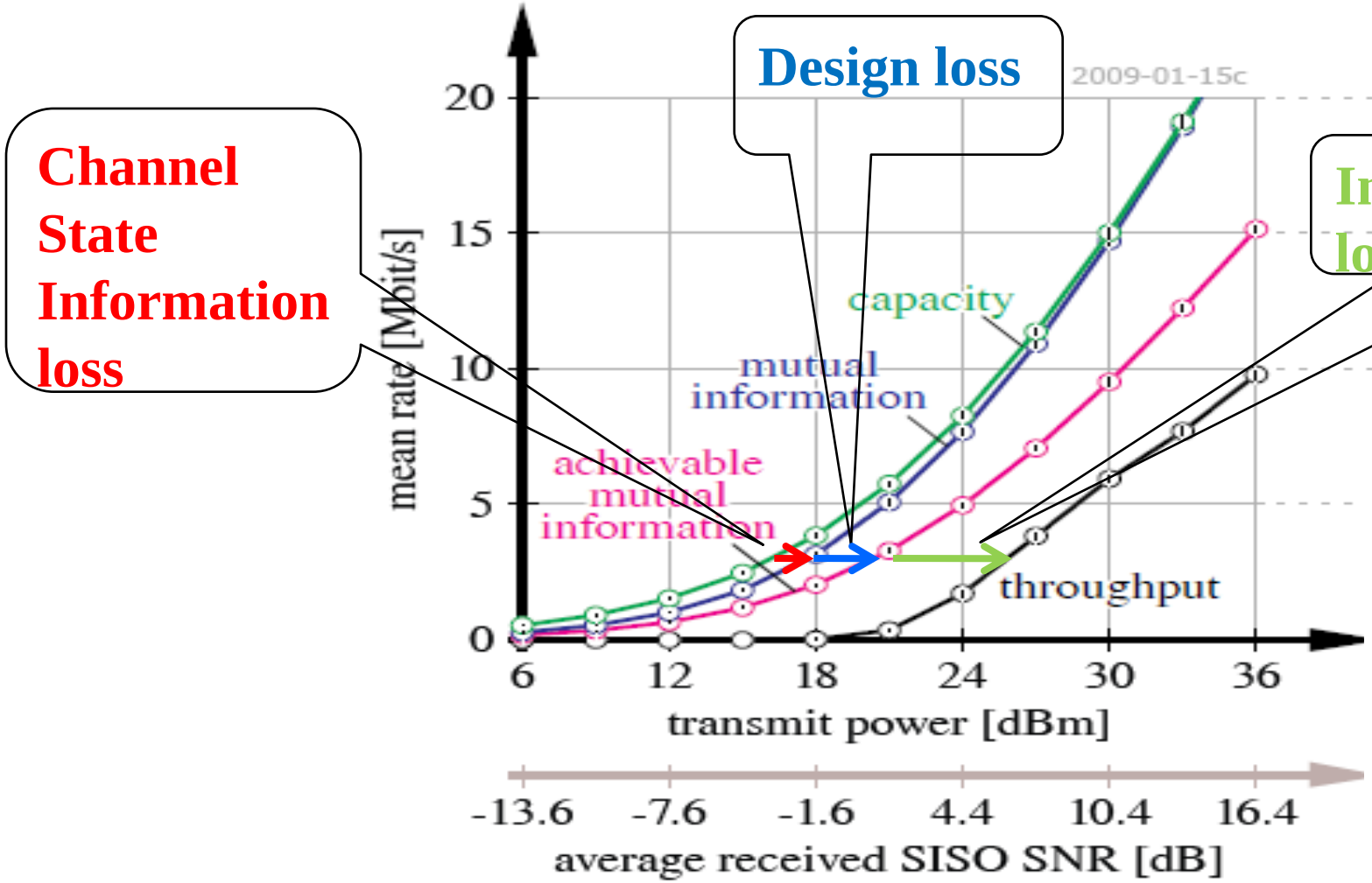
- Design Loss

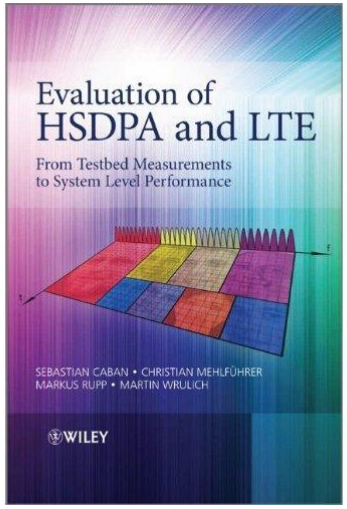
$$L_{\mathrm{d}}(P_{\mathrm{Tx}}) = I(P_{\mathrm{Tx}}) - I_{\mathrm{a}}(P_{\mathrm{Tx}}); \quad L_{\mathrm{d}\%}(P_{\mathrm{Tx}}) = 100 \cdot \frac{I(P_{\mathrm{Tx}}) - I_{\mathrm{a}}(P_{\mathrm{Tx}})}{C(P_{\mathrm{Tx}})}$$

- Implementation Loss

$$L_{\mathrm{i}}(P_{\mathrm{Tx}}) = I_{\mathrm{a}}(P_{\mathrm{Tx}}) - D_{\mathrm{m}}(P_{\mathrm{Tx}}); \quad L_{\mathrm{i}\%}(P_{\mathrm{Tx}}) = 100 \cdot \frac{I_{\mathrm{a}}(P_{\mathrm{Tx}}) - D_{\mathrm{m}}(P_{\mathrm{Tx}})}{C(P_{\mathrm{Tx}})}$$

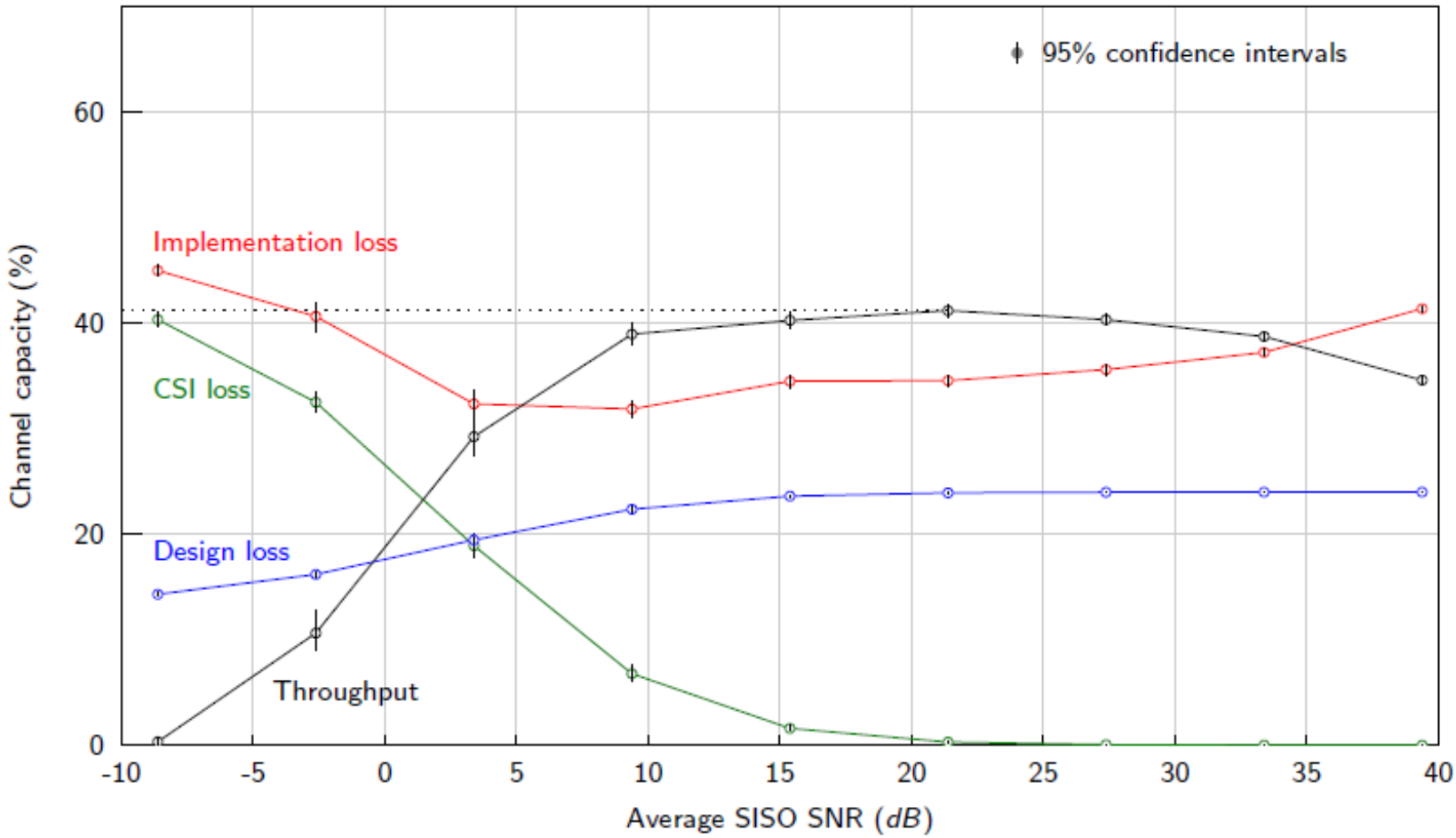
Throughput Losses [P4]





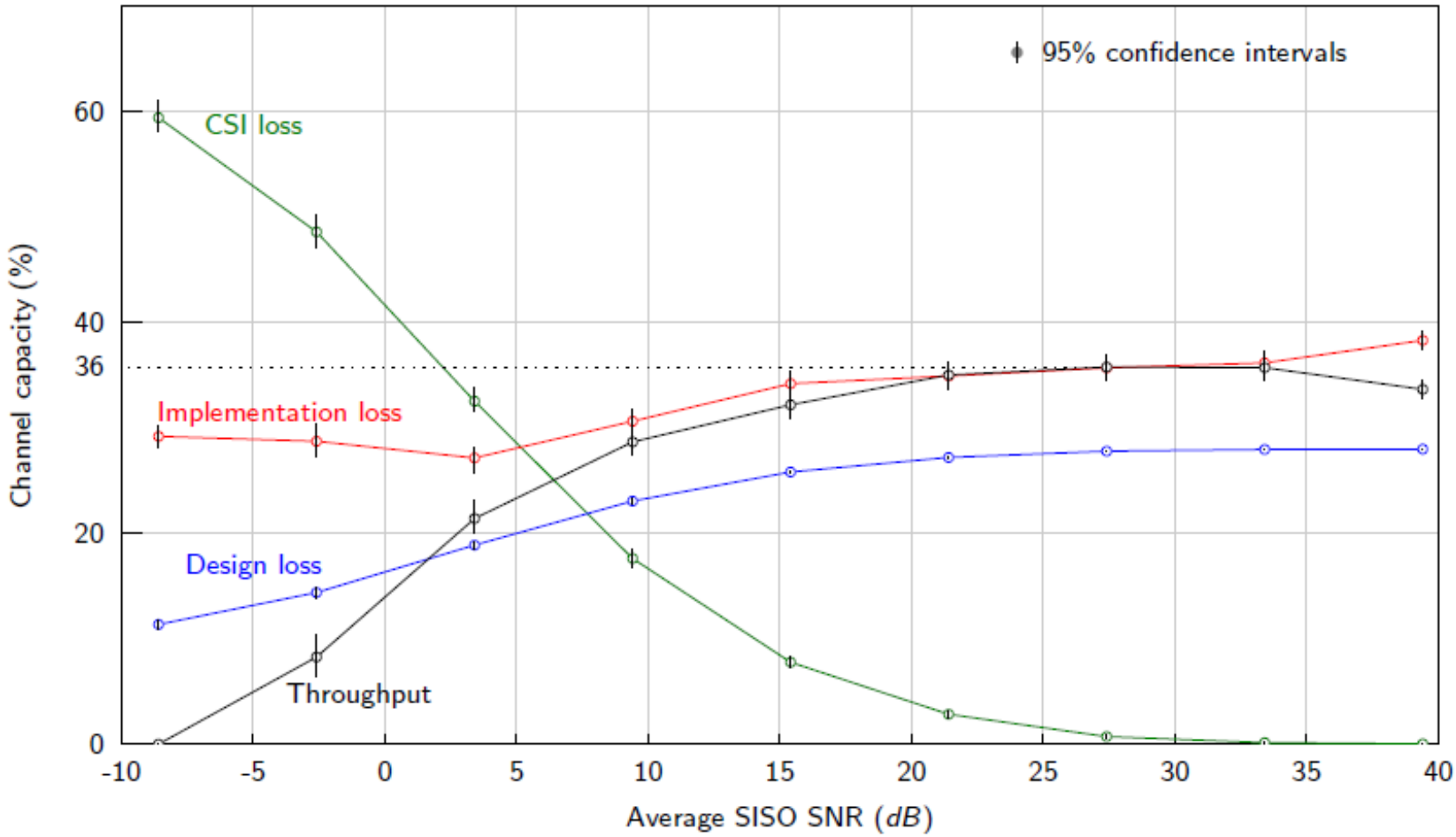
2x2 LTE OL Measurement with 10MHz Bandwidth

- [P1-P4]



4x4 LTE OL Measurement with 10MHz Bandwidth

- [P1-P4]



Challenges

- But what about MU capacity ? **[M1-M9]**
  - Difficult in theory
  - Even more difficult in practice to evaluate

- Today‘s communication is MIMO centric
  - While absolute capacity grows,
  - relative capacity decreases

- Too many pilots, why do we need pilots at all?

High Mobility

- Feasible Capacity

$$C = \alpha B \log_2\left(1 + \frac{P_S}{N}\right)$$

- Non-coherent loss: $\alpha = 1 - \varepsilon$
- Coherent loss: α given by proportion of pilots

$M_T x N_T$	1	2	4	8
CRS	4.76	9.52	14.28	–
UE-RS	7.14	7.14	14.28	14.28
CSI-RS	1.19	1.19	2.38	4.76

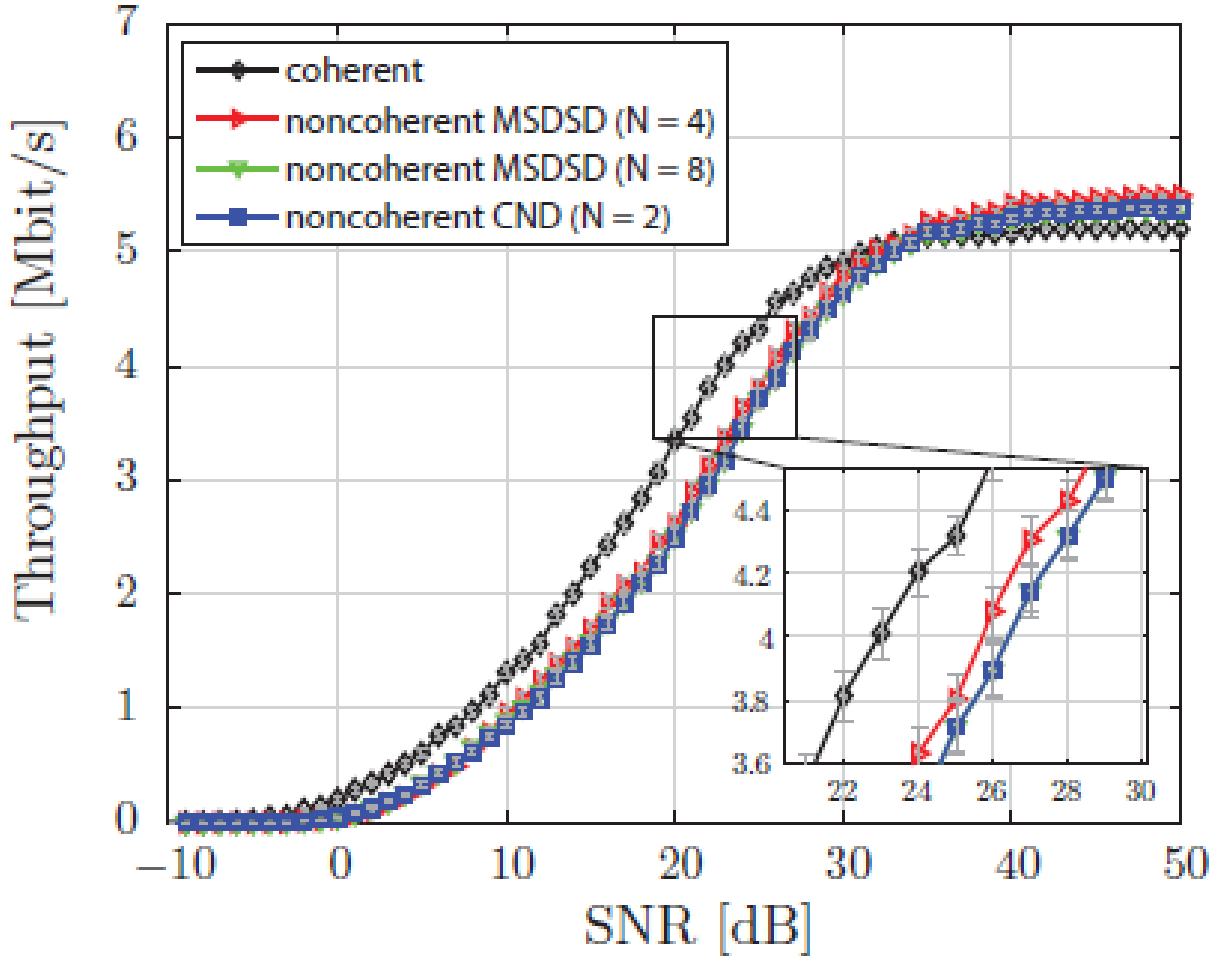
→ **LTE**

LTE A

- What is the best strategy????

High Mobility: Noncoherent Transmission [H9]

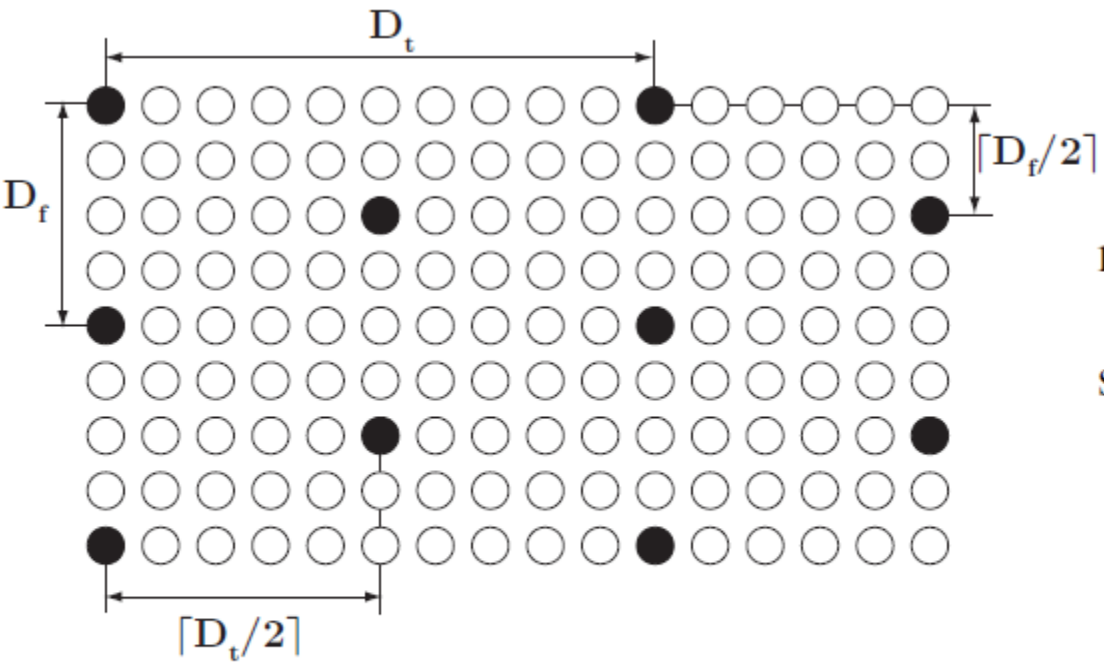
- MSDSD: Multiple Symbol Differential Sphere Decoding
- CND: Conventional Non Coherent



4.4% gain

High Mobility: Coherent Transmission [H2-H8]

- Consider pilot pattern in time/frequency grid



pilot symbol data symbol

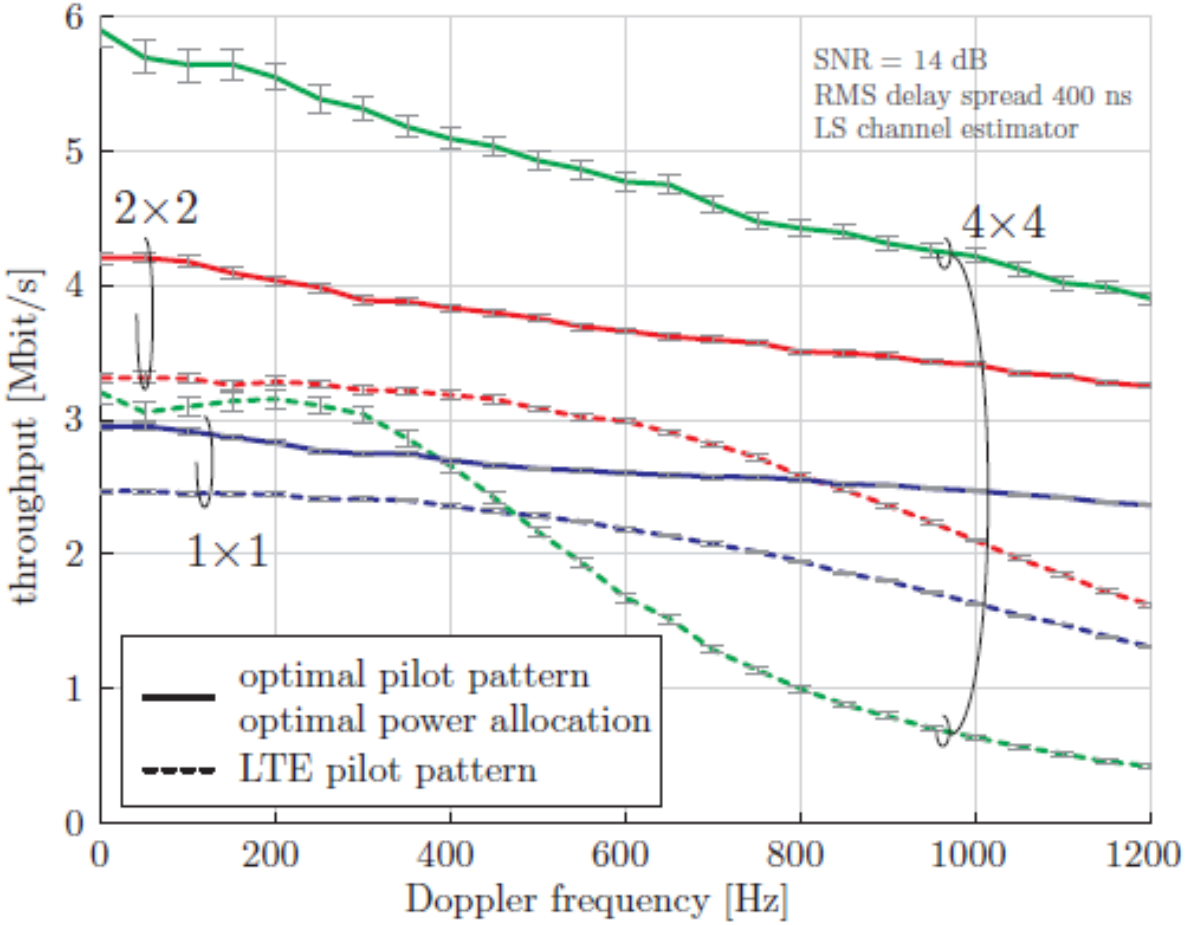
$$\underset{p_{\text{off}}, D_t, D_f}{\text{maximize}} \quad \bar{\mathcal{C}}\left(p_{\text{off}}, D_t, D_f\right)$$

$$\text{subject to} \quad N_d \sigma_d^2 + N_p \sigma_p^2 \leq \text{constant}$$

$$B\left(D_f, D_t\right) \leq \text{constant}$$

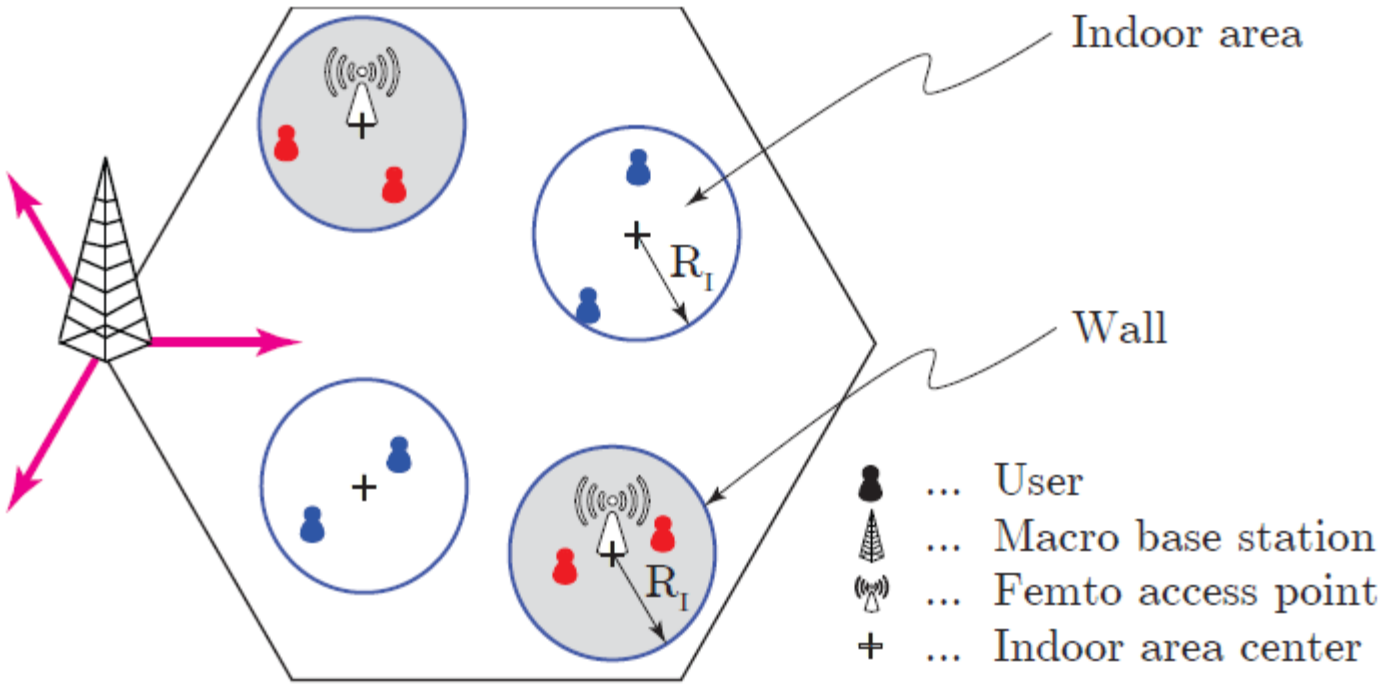
$$p_{\text{off}} = \frac{\sigma_p^2}{\sigma_d^2}.$$

High Mobility: Coherent Transmission [H4-H7]



Interference and its Mitigation [I1]

- As if interference from neighbor cells would not be enough….



Interference and its Mitigation [I2]

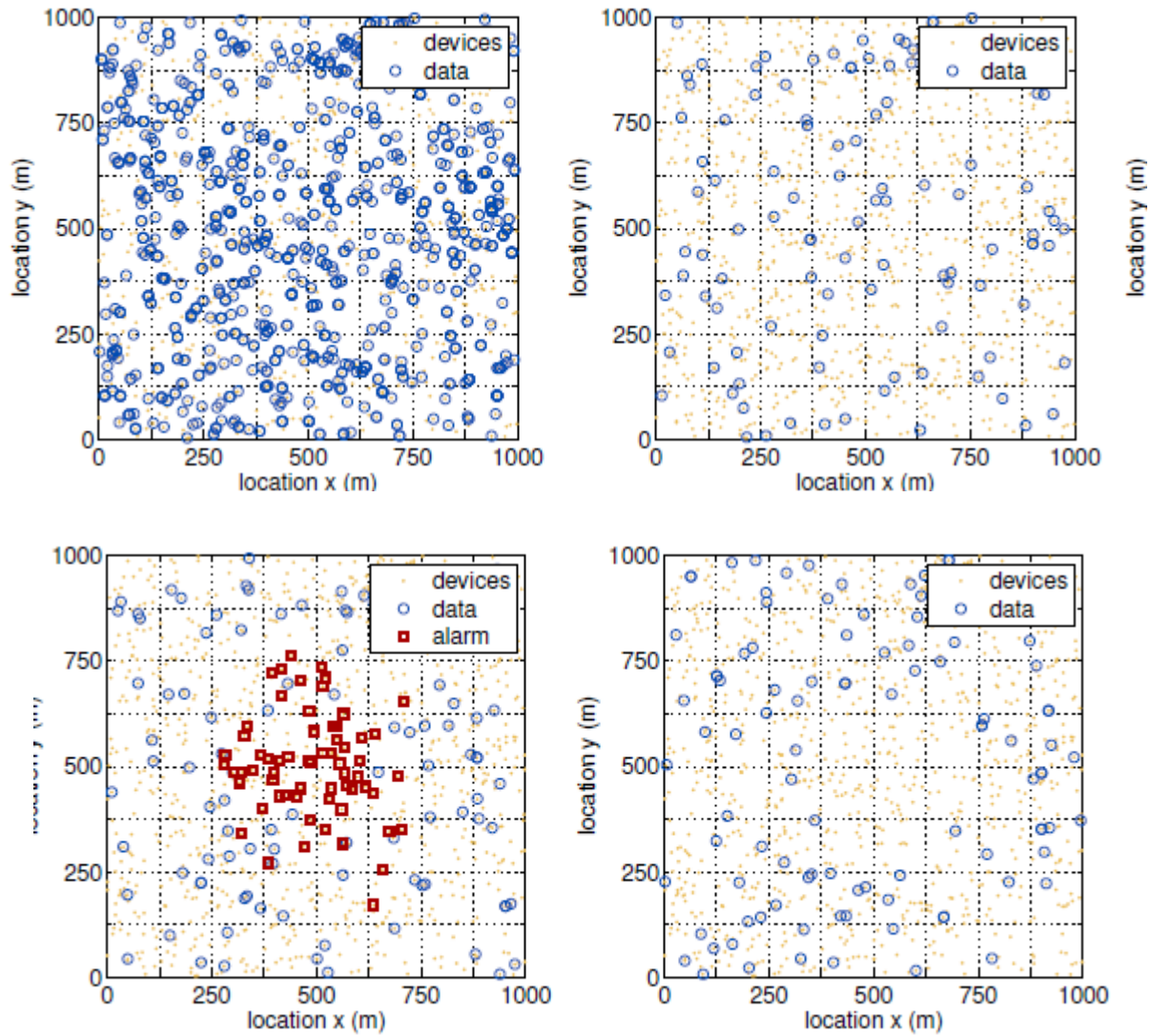
- Does M2M change traffic?

Startup

Regular

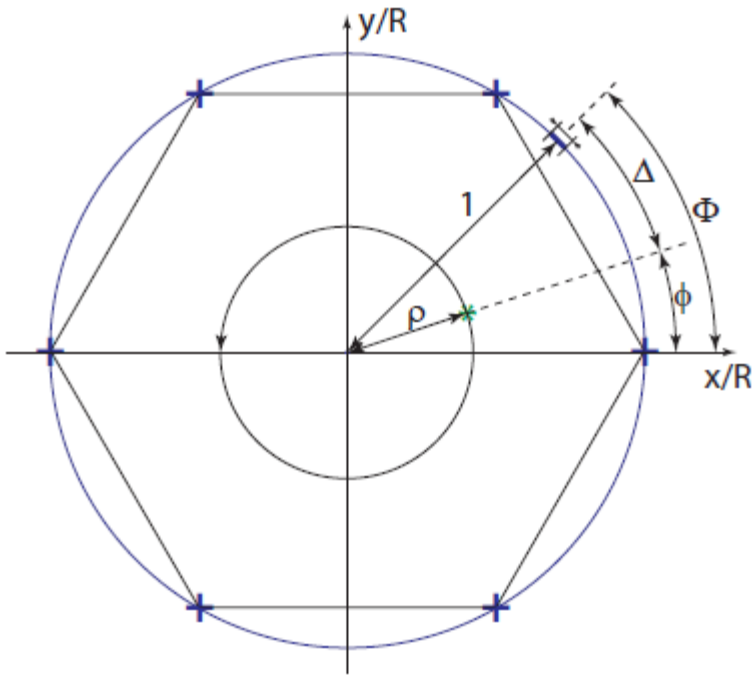
Alarm

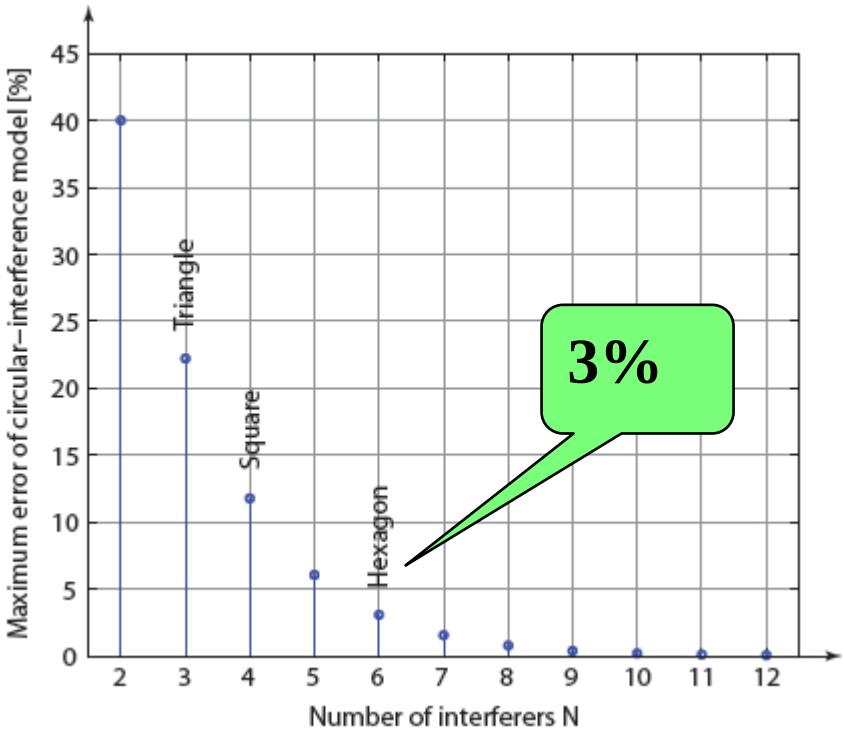
Silent



Interference and its Mitigation [I1]

- We thus need to describe interference in general as a function of
  - various scenarios
  - and user types





Conclusion

- Even 4G LTE exhibits relatively low spectral efficiency

- MU-MIMO Performance is the big ???
  - Definition?, Measurement?

- High Mobility
  - LTE requires substantial modification for this!

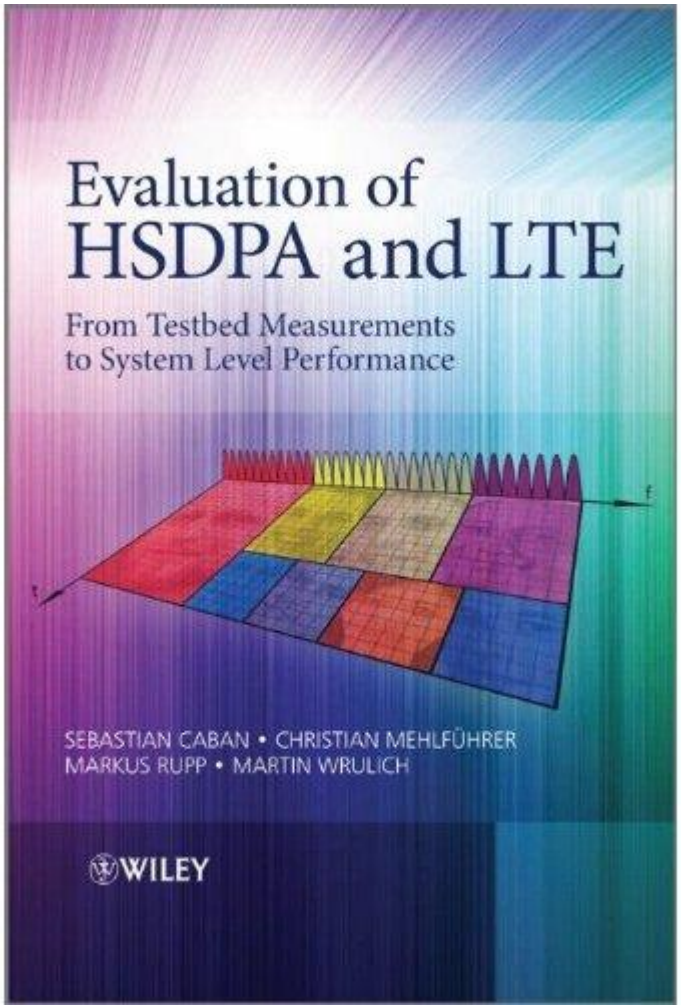
- HetNet
  - Lots of challenges ahead for proper strategies

- **<u>4G LTE will keep us busy for some time....</u>**



eit.

With help from…



Available now!

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