Upcoming Challenges in Cellular Mobile Communications

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Performance Metric: Channel Capacities [P1-P4]

Capacity (Shannon, Foschini&Gans, Telatar)

\[
C(P_{tx}) = \max_{\sum \text{tr}\{R_k\} \leq K} \frac{B}{K} \sum_{k=1}^{K} \log_2 \det \left( I + \frac{P_{tx}}{\sigma_n^2 N_T} H_k R_k H_k^H \right)
\]

Mutual Information (constrained capacity)

\[
I(P_{tx}) = \frac{B}{K} \sum_{k=1}^{K} \log_2 \det \left( I + \frac{P_{tx}}{\sigma_n^2 N_T} H_k H_k^H \right)
\]

Achievable Mutual Information (constrained by Standard)

\[
I_a(P_{tx}) = \max_{W \in \mathcal{W}} \beta \frac{B}{K} \sum_{k=1}^{K} \log_2 \det \left( I + \frac{\alpha P_{tx}}{\sigma_n^2 N_T} H_k W W^H H_k^H \right)
\]
Performance Measures: Throughput Losses

- Channel State Information (CSI) Loss:

\[
L_{\text{CSI}}(P_{\text{Tx}}) = C'(P_{\text{Tx}}) - I(P_{\text{Tx}}); \quad L_{\text{CSI}}\%(P_{\text{Tx}}) = 100 \cdot \frac{C(P_{\text{Tx}}) - I(P_{\text{Tx}})}{C(P_{\text{Tx}})}
\]

- Design Loss

\[
L_{d}(P_{\text{Tx}}) = I(P_{\text{Tx}}) - I_{a}(P_{\text{Tx}}); \quad L_{d}\%(P_{\text{Tx}}) = 100 \cdot \frac{I(P_{\text{Tx}}) - I_{a}(P_{\text{Tx}})}{C'(P_{\text{Tx}})}
\]

- Implementation Loss

\[
L_{i}(P_{\text{Tx}}) = I_{a}(P_{\text{Tx}}) - D_{m}(P_{\text{Tx}}); \quad L_{i}\%(P_{\text{Tx}}) = 100 \cdot \frac{I_{a}(P_{\text{Tx}}) - D_{m}(P_{\text{Tx}})}{C'(P_{\text{Tx}})}
\]
Throughput Losses [P4]

Channel State Information loss

Design loss

Implementation loss
2x2 LTE OL Measurement with 10MHz Bandwidth

- [P1-P4]
4x4 LTE OL Measurement with 10MHz Bandwidth

- [P1-P4]
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: \( \alpha \) given by proportion of pilots

<table>
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<td>1.19</td>
<td>2.38</td>
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</table>

\[ \rightarrow \text{LTE} \]
\[ \rightarrow \text{LTE A} \]

- 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

\[
\begin{align*}
\text{maximize} & \quad \tilde{C}(p_{\text{off}}, D_t, D_f) \\
\text{subject to} & \quad N_d\sigma_d^2 + N_p\sigma_p^2 \leq \text{constant} \\
& \quad B(D_f, D_t) \leq \text{constant}
\end{align*}
\]

\[p_{\text{off}} = \frac{\sigma_p^2}{\sigma_d^2}.\]
High Mobility: Coherent Transmission [H4-H7]
As if interference from neighbor cells would not be enough....
Interference and its Mitigation [I2]

- Does M2M change traffic?

Startup
Regular
Alarm
Silent
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

- 4G LTE will keep us busy for some time....
With help from...
Available now!
Testbed References


LTE High Mobility


LTE Performance


LTE Interference


Matrix Indicator for 3GPP UMTS/LTE" ITG Workshop on Smart Antennas, Bremen Feb. 2010

Scalable Complexity"; ITG Workshop on Smart Antennas, Bremen; Feb. 2010

[L5] Q. Wang, C. Mehlführer, M. Rupp: "Carrier Frequency Synchronization in the Downlink of
3GPP LTE"; Int. Symposium on Personal, Indoor and Mobile Radio Communication (PIMRC),
Istanbul, Turkey; Sept. 2010.


