The Performance of 3G and 4G Cellular Systems

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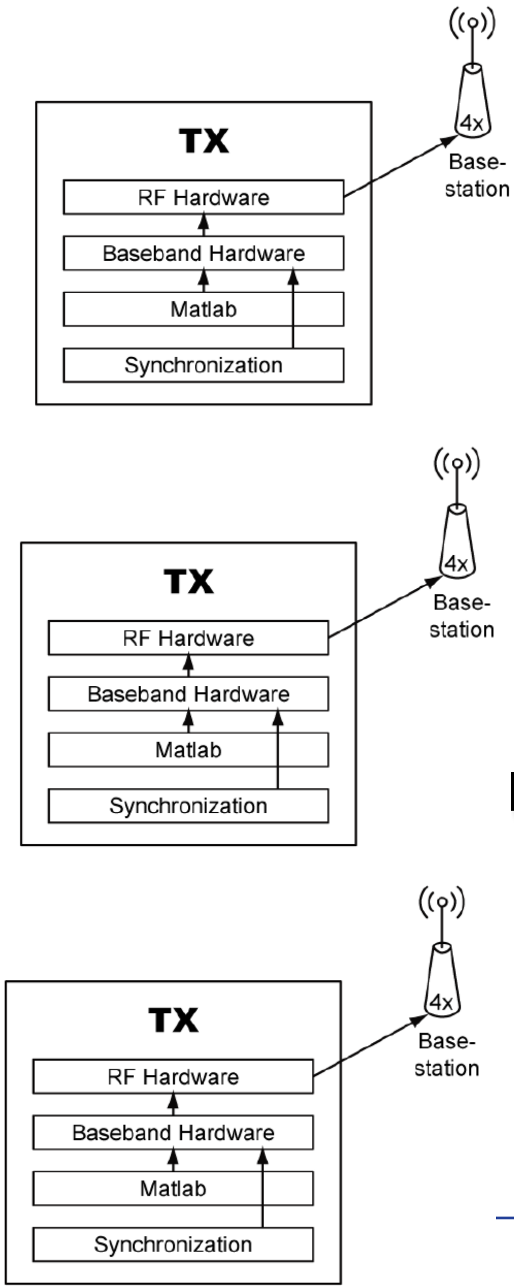
Evaluating MIMO radio communication

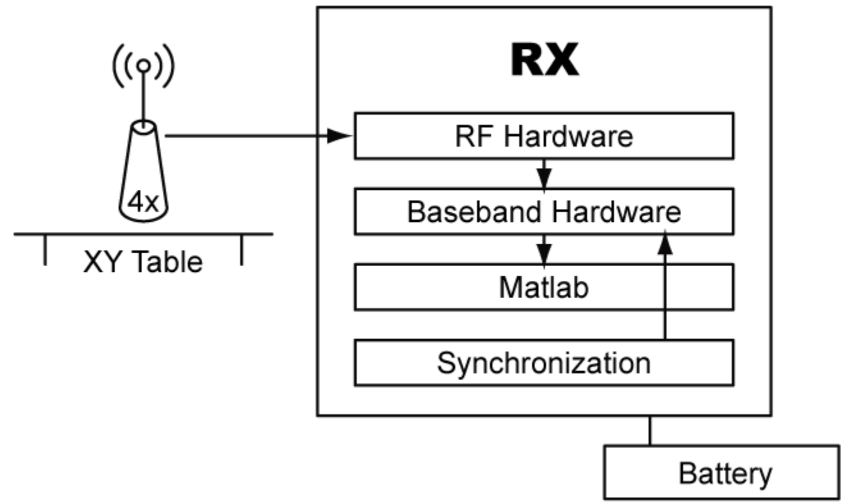
- theoretically
- by pure simulation
- by channel sounding
- utilizing a testbed
- utilizing a prototype
- using the final product

degree of realism

effort

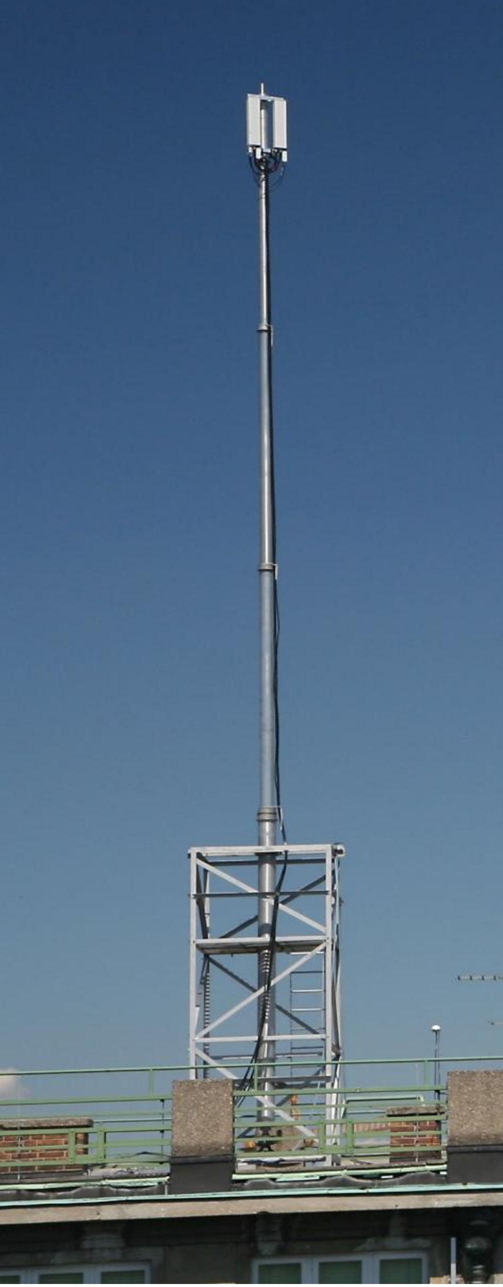
MIMO Testbed [T1,T2]





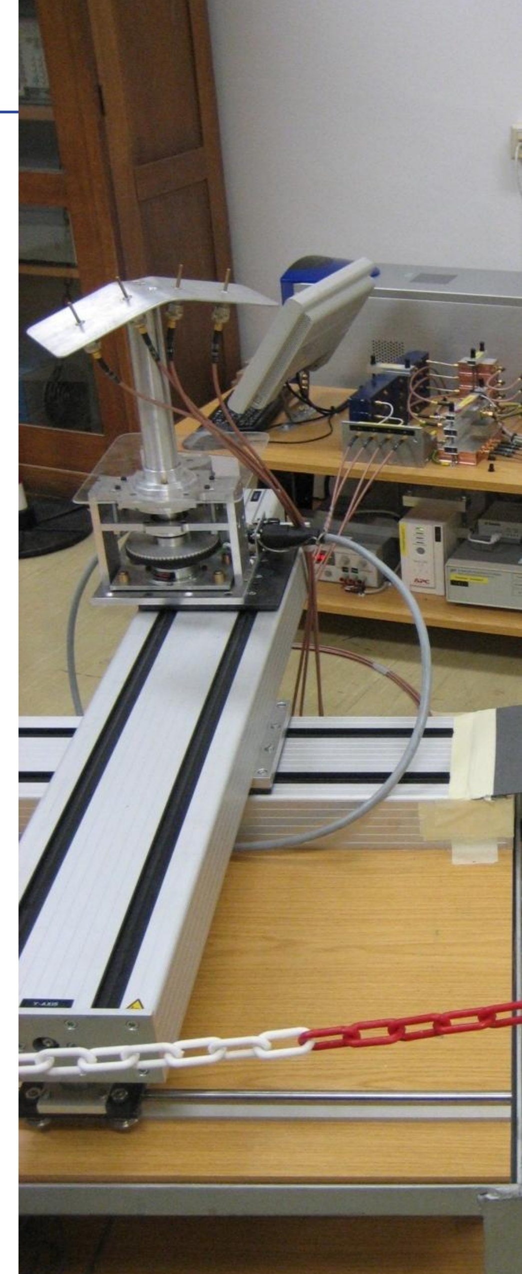
Data is created and evaluated in Matlab ...

Number of Antennas:	**4x4**	**→12x4**
Bandwidth:	**5 MHz**	**→20MHz**
Center Frequency:	**2.5 GHz**	



MIMO Testbed [T1,T2]

- **MIMO WiMAX 802.16-2004**
  OFDM physical layer
  - including channel coding and decoding
  - SISO and MIMO
- **MIMO HSDPA (TxAA, DTxAA)**
  CDMA physical layer
  - including channel coding and decoding
  - SISO and MIMO
- **MIMO LTE (new)**
  - also MU, multi BS



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Experimental MIMO Testbed: THE MOVIE

- Movie only in the orignal presentation included

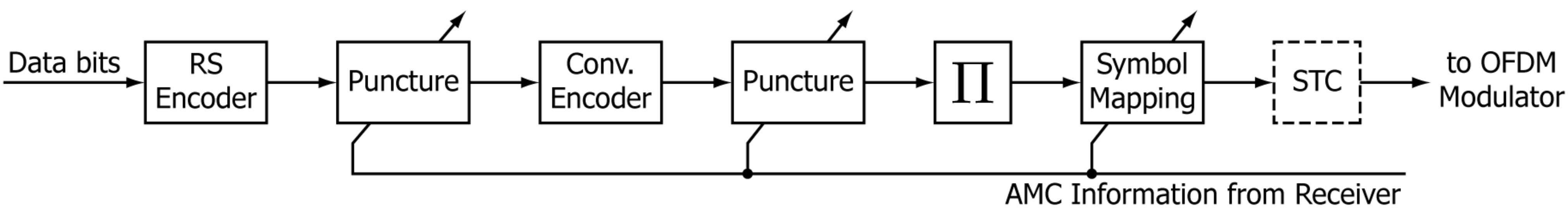

The Vienna Wireless Testbed 2011

Outline

- MIMO Testbed
- WiMAX in Brief
  - Losses in WiMAX
- HSDPA in Brief
  - signal generation and reception
- LTE in Brief
- Comparisons HSDPA vs. WiMAX
- Further Comparisons to LTE
- Conclusion

Adaptive Modulation and Coding (AMC)

- Encoding
  - concatenated Reed-Solomon / convolutional code
  - puncturing depending on AMC information
  - optional block/convolutional turbo coding
  - Alternatively: LDPC coding
- Adaptive symbol mapping
- Optional Alamouti space-time coding

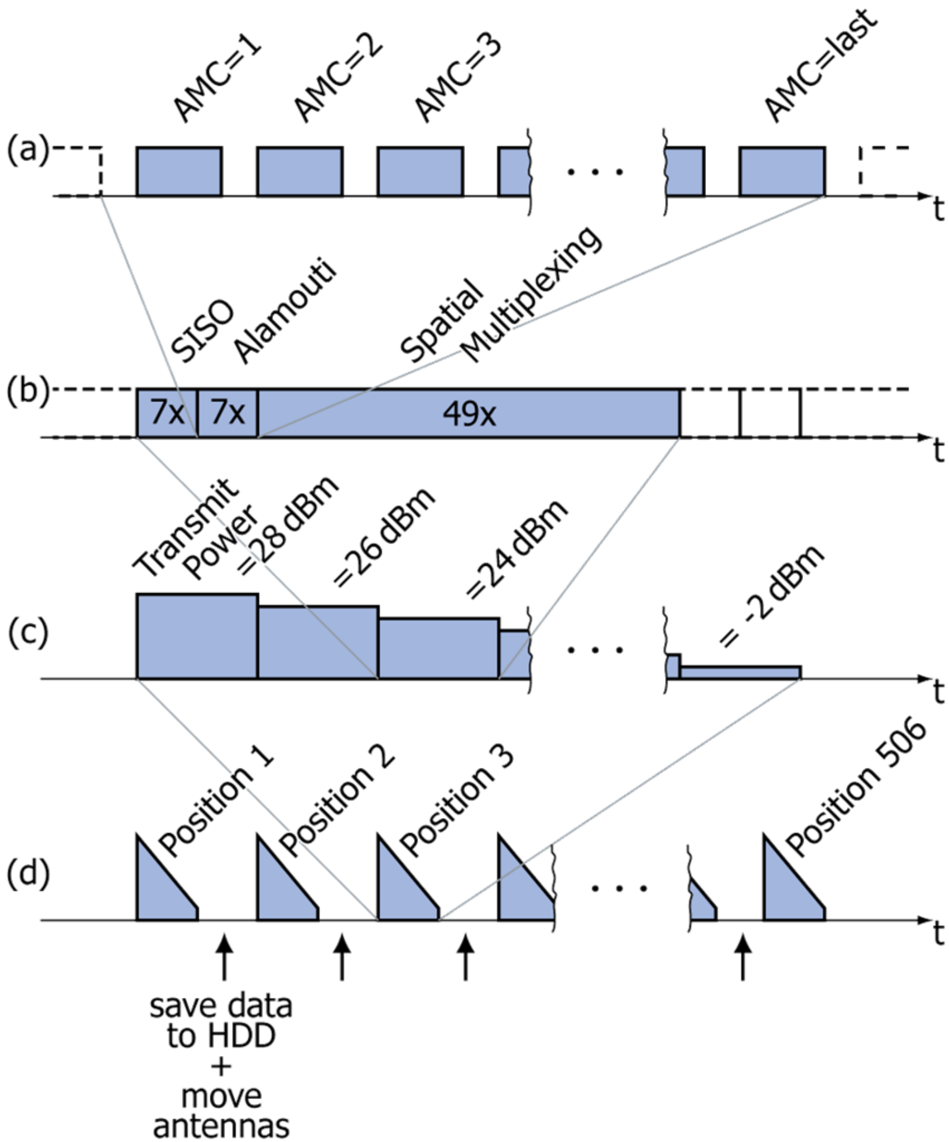


Adaptive Modulation and Coding (AMC)

AMC value	Modulation	RS Code Rate	CC Rate	Overall Code Rate
1	2-PAM	1	1/2	1/2
2	4-QAM	3/4	2/3	1/2
3	4-QAM	9/10	5/6	3/4
4	16-QAM	3/4	2/3	1/2
5	16-QAM	9/10	5/6	3/4
6	64-QAM	8/9	3/4	2/3
7	64-QAM	9/10	5/6	3/4

3bit feedback

Block Transmission [W2]



1. SIMO, 7 AMC schemes, 3 bit feedback
2. MIMO with Alamouti, 7 AMC schemes, 3 bit feedback
3. MIMO with spatial multiplexing, **same** coding scheme on both antennas, 3 bit feedback
4. MIMO with spatial multiplexing, **individual** coding schemes on both antennas, 6 bit feedback

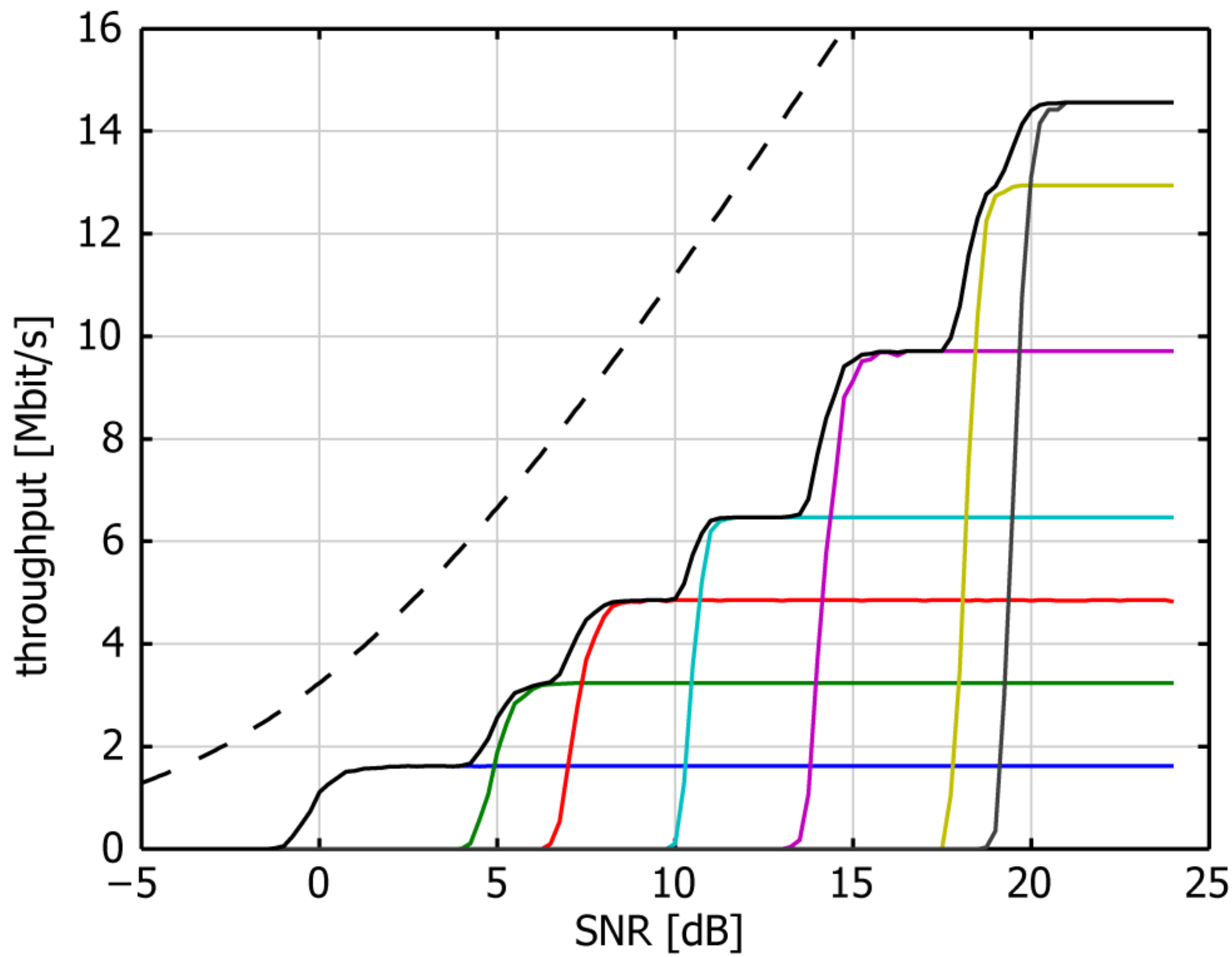
Losses

- WiMAX does not reach Shannon bound because of
  - Channel estimation losses
  - Coding losses

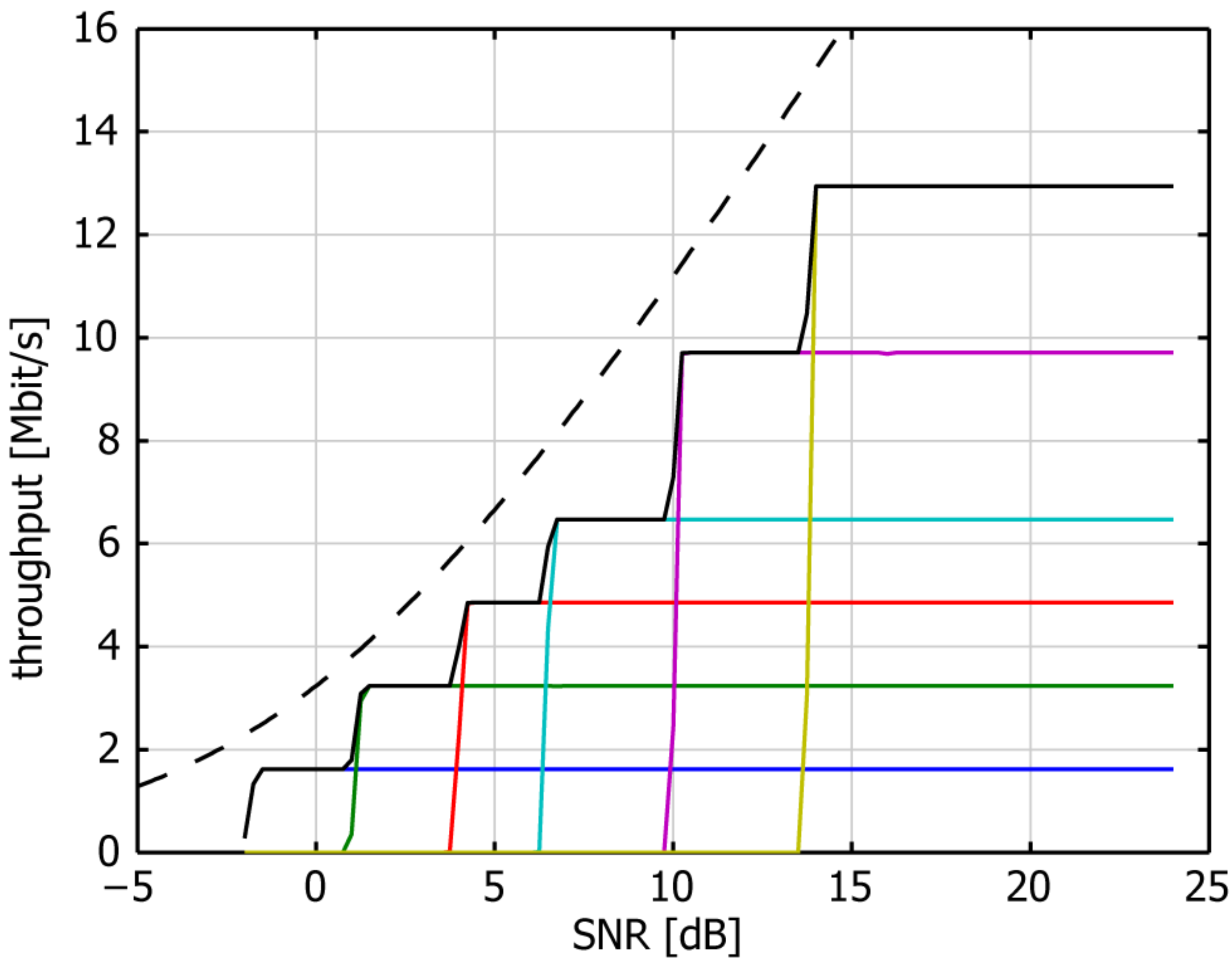
- SNR Gain of Improved Channel Estimators over the LS Estimator [W1]

Scenario 1	LMMSE	genie-driven
1x1 SISO	0.6 dB	1.2 dB
2x1 Alamouti	1.8 dB	2.9 dB
1x2 SIMO	0.5 dB	1.2 dB
2x2 Alamouti	1.9 dB	3.2 dB
2x2 Spatial Multiplexing (3 bit)	1.4 dB	2.4 dB
2x2 Spatial Multiplexing (6 bit)	1.1 dB	2.2 dB

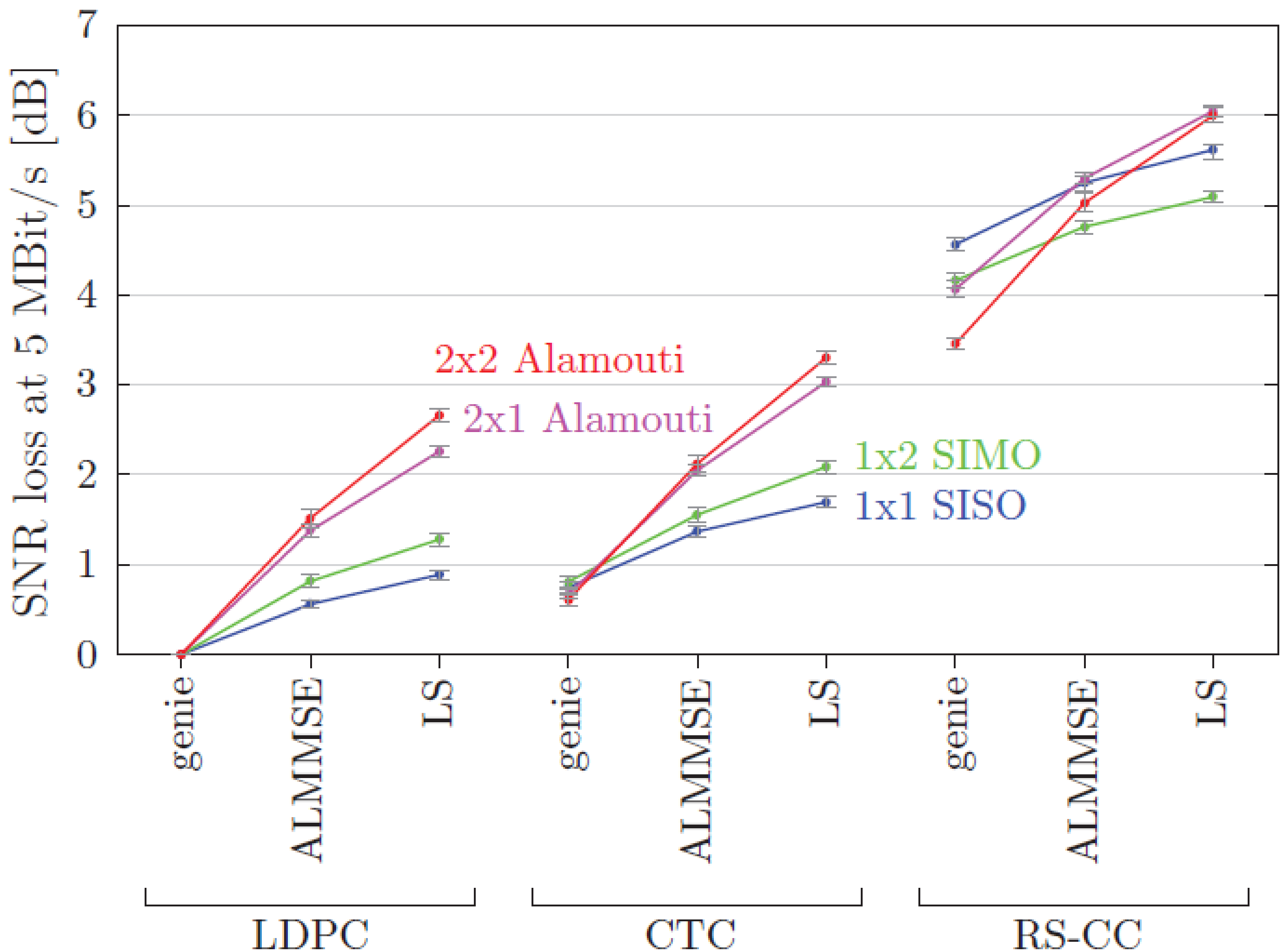
AWGN Performance of the Reed Solomon-Conv.Coder



AWGN Performance of LDPC codes



Losses in WiMAX



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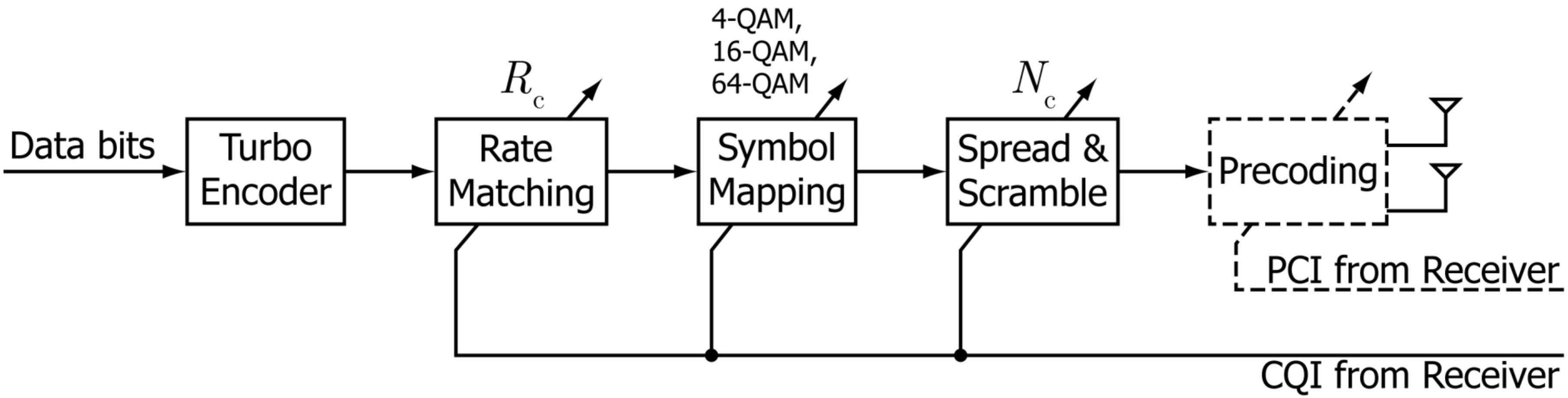
HSDPA Overview:
Adaptive Modulation and Coding (AMC)



- Channel adaptation is performed by means of
  - a Channel Quality Indicator (CQI) and
  - a Precoding Control Indicator (PCI) when two transmit antennas are available

CQI: 30 values=5bit/15 values=4bit for DTxAA
PCI: 2 bit/4bit for DTxAA

Significantly more Feedback

- HSDPA Parameters: CQI,PCI

- Measurement not possible with quasi-static assumption
  - Mini receiver solution (computes the post equalization SINR)

- HDSPA Losses:
  - channel estimation,
  - successive interference cancellation required due to non–orthogonal synch codes
  - High self interference

SINR Estimation in Minireceiver [H5,C6,C9]

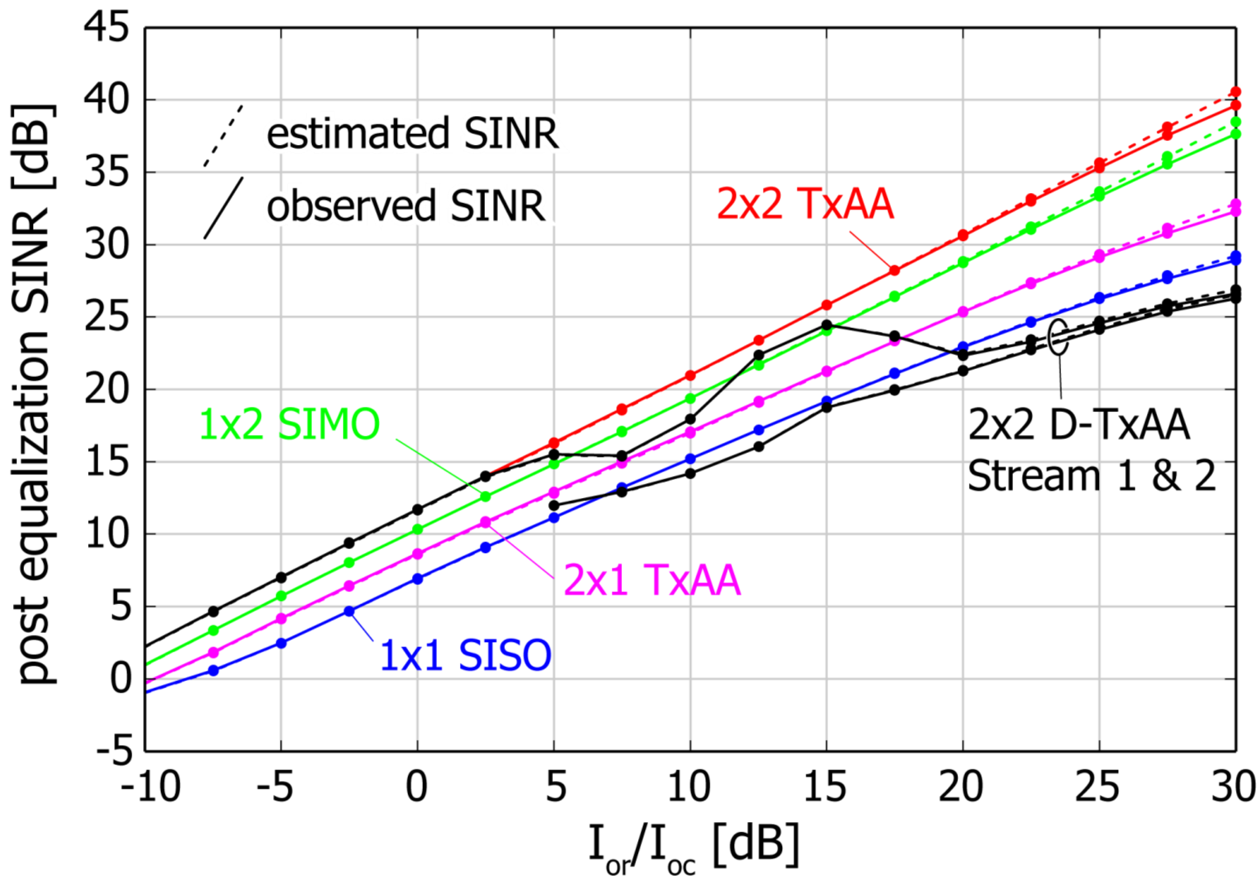
$$\mathrm{SINR}_{\mathrm{est}} = \frac{P_s}{\sigma_{n'}^2 + P_{\mathrm{ISI}} + P_{\mathrm{INT}}}$$

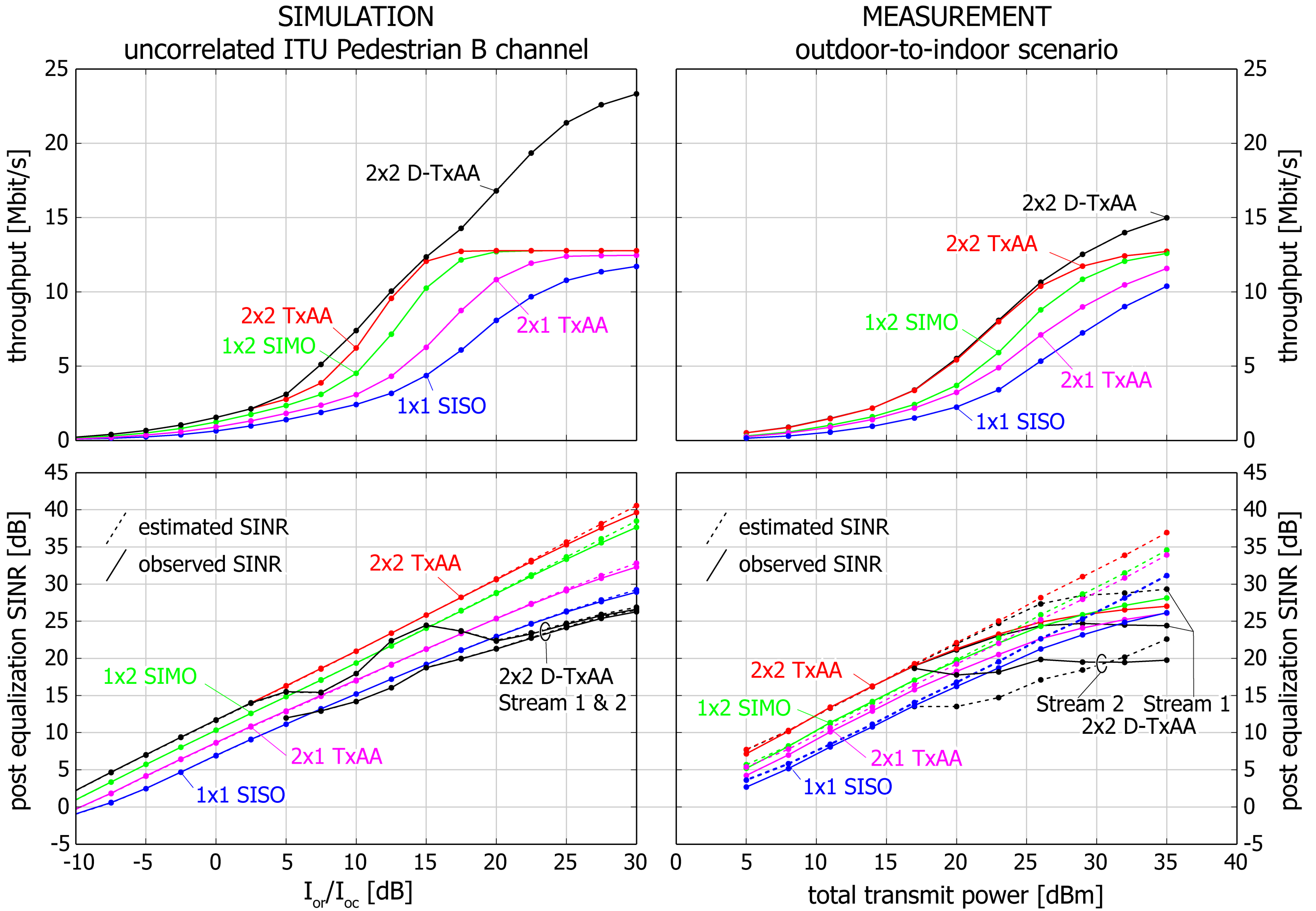
The post equalization SINR is given by

- the signal power P_s
- the noise at the output of the equalizer $\sigma_{n'}^2$
- the remaining inter-symbol interference P_{ISI}
- the interference caused by spatially multiplexed streams sharing the same scrambling and spreading codes P_{INT}

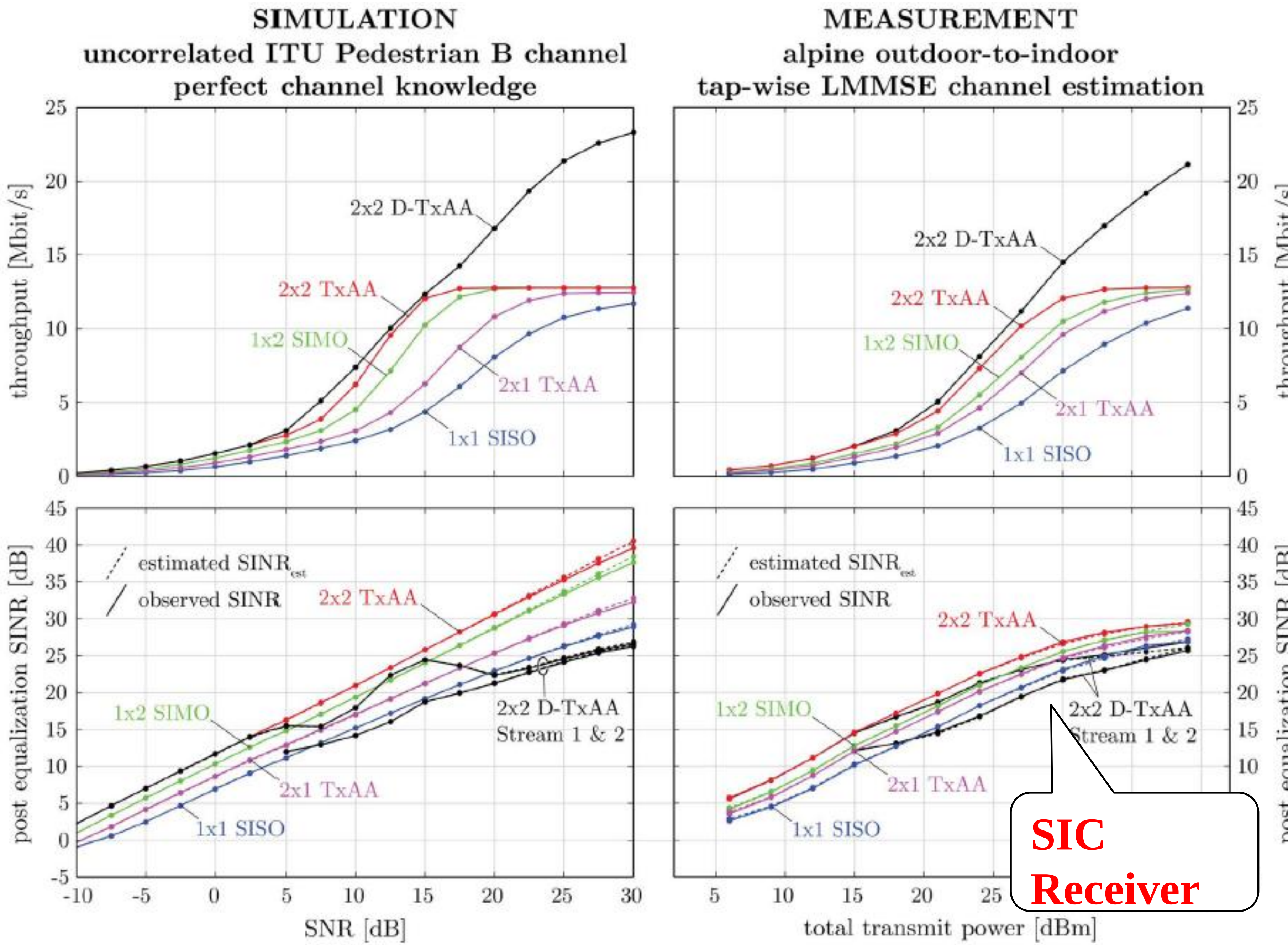
SINR is calculated for all possible precoding vectors and mapped to the supported CQI values. The precoding vector maximizing the transport block size is selected.

Verification of the SINR Estimation in the Simulation [H5,C9]





SIMULATION
uncorrelated ITU Pedestrian B channel
MEASUREMENT
outdoor-to-indoor scenario
throughput [Mbit/s]
2x2 D-TxAA
2x2 TxAA
1x2 SIMO
2x1 TxAA
1x1 SISO
post equalization SINR [dB]
estimated SINR
observed SINR
2x2 D-TxAA
Stream 1 & 2
Stream 2
Stream 1
I_{or}/I_{oc} [dB]
total transmit power [dBm]



SIMULATION
uncorrelated ITU Pedestrian B channel
perfect channel knowledge
MEASUREMENT
alpine outdoor-to-indoor
tap-wise LMMSE channel estimation
throughput [Mbit/s]
2x2 D-TxAA
2x2 TxAA
1x2 SIMO
2x1 TxAA
1x1 SISO
post equalization SINR [dB]
estimated SINR_est
observed SINR
2x2 D-TxAA
Stream 1 & 2
SNR [dB]
total transmit power [dBm]
SIC Receiver

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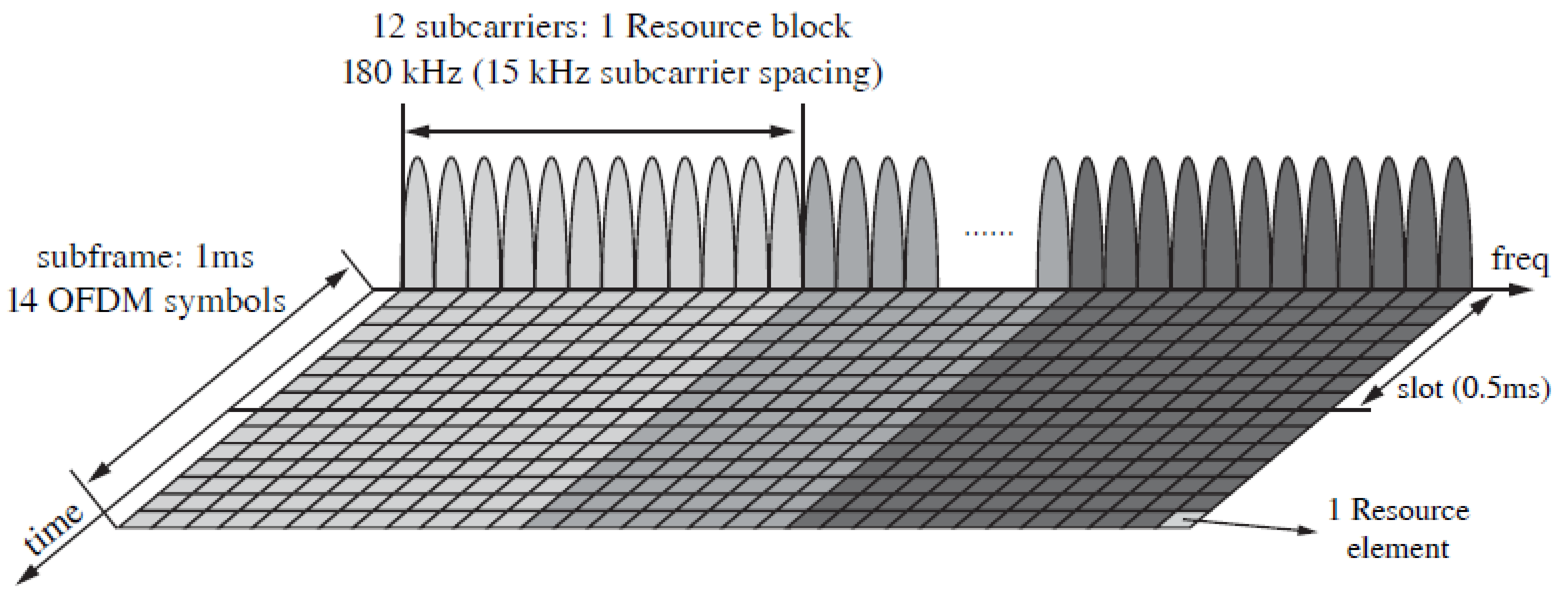
LTE in Brief [L1,L2,…,L14]

- Similar to WiMAX, LTE is an OFDM system



- It offers AMC by
  - CQI (15 values=4bit/31 values =5 bit)
  - PMI (15 values=4bit)
  - RI (2 bit)
  - →Minireceiver required again

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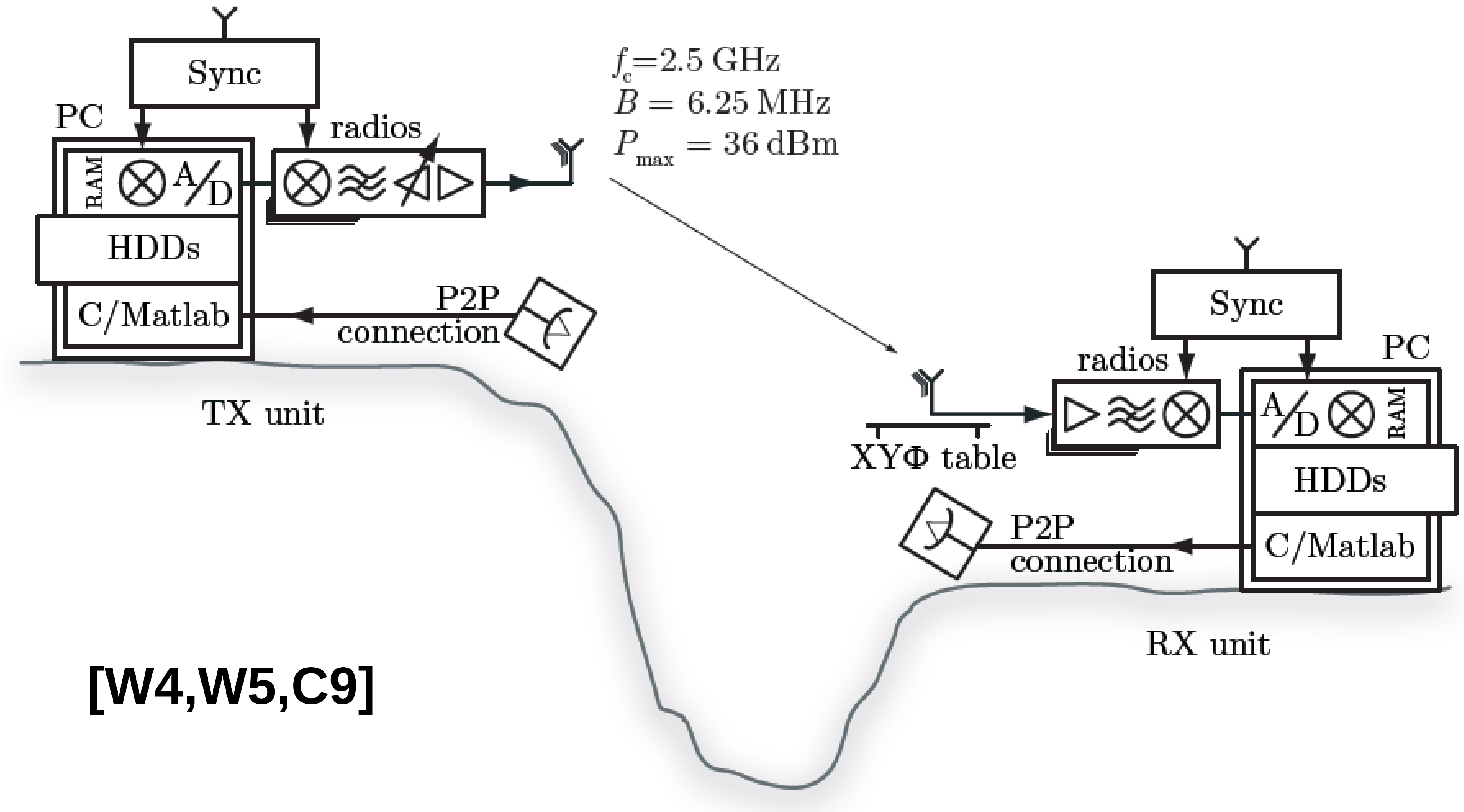
Two Measurement Campaigns: Alpine and Urban



[W4,W5,C9]

Two Measurement Campaigns: Alpine and Urban

Two Measurement Campaigns: Alpine and Urban

[C1,C2,C3,C4,C5,C6,C7,C8,C9]

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)

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

Throughput Losses

- Channel State Information (CSI) Loss:

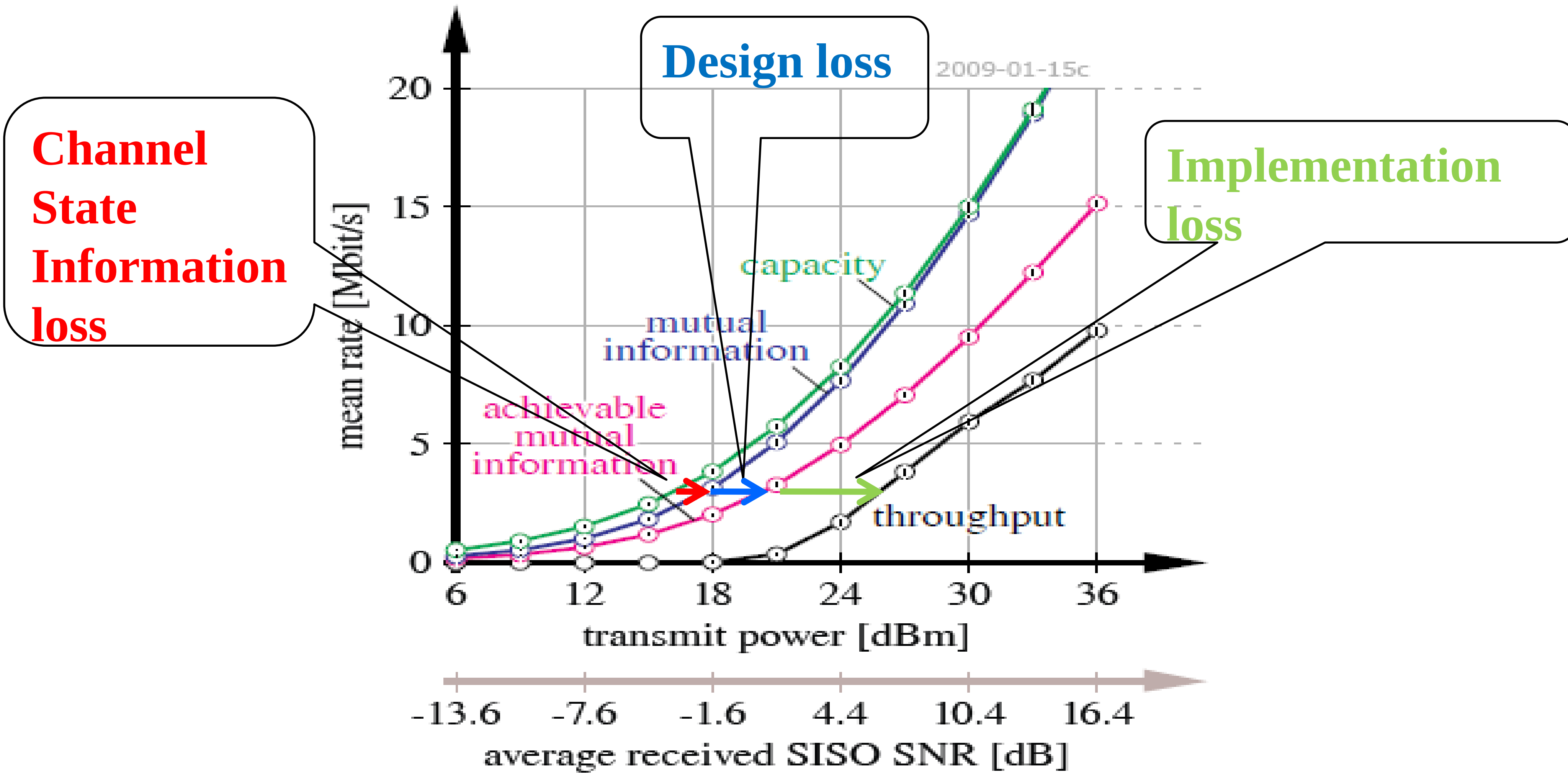
$$L_{\mathrm{CSI}}(P_{\mathrm{Tx}}) = C(P_{\mathrm{Tx}}) - I(P_{\mathrm{Tx}}); \quad L_{\mathrm{CSI\%}}(P_{\mathrm{Tx}}) = 100 \cdot \frac{C(P_{\mathrm{Tx}}) - I(P_{\mathrm{Tx}})}{C(P_{\mathrm{Tx}})}$$

- Design Loss

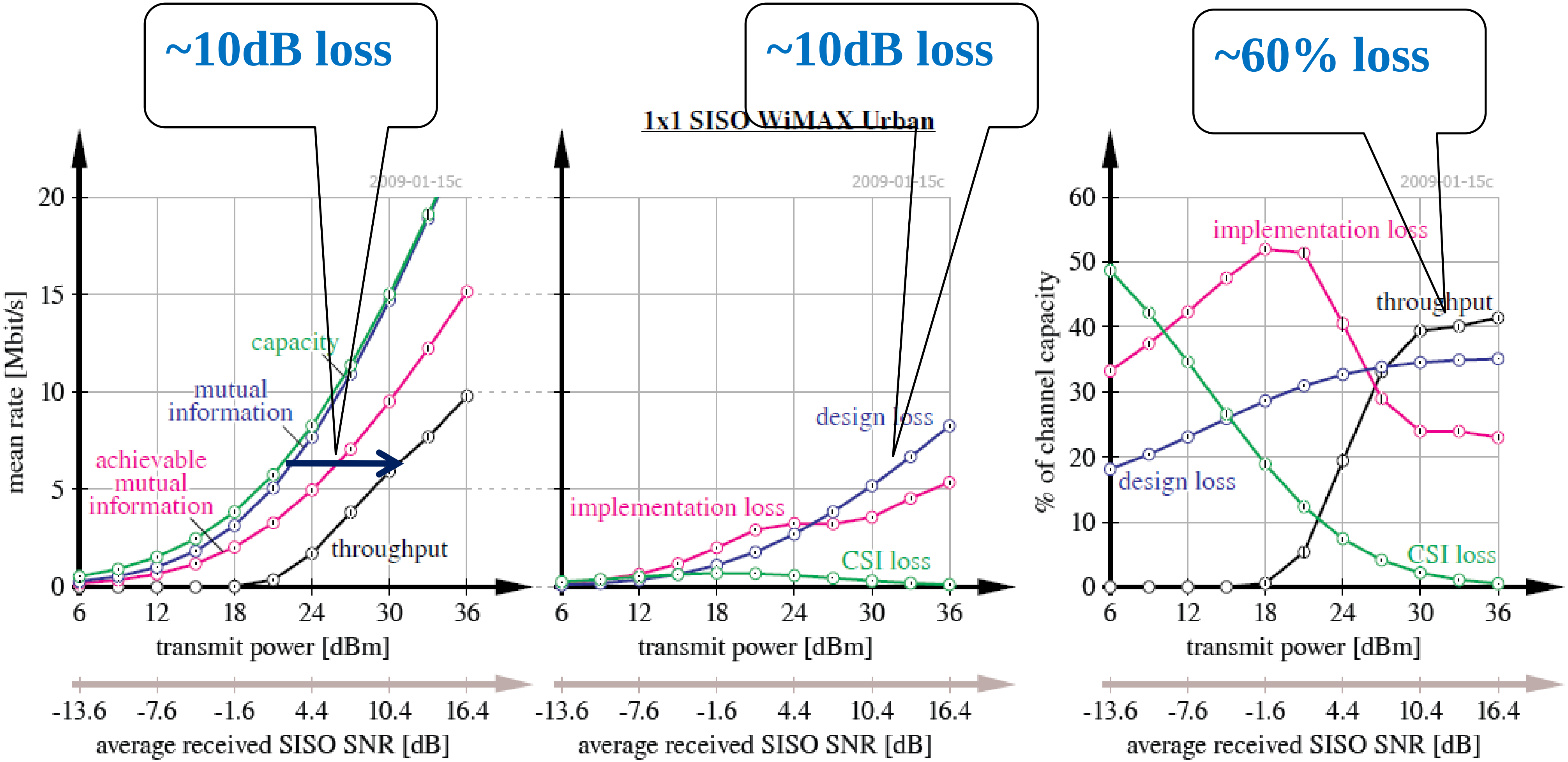
$$L_{\mathrm{d}}(P_{\mathrm{Tx}}) = I(P_{\mathrm{Tx}}) - I_{\mathrm{a}}(P_{\mathrm{Tx}}); \quad L_{\mathrm{d\%}}(P_{\mathrm{Tx}}) = 100 \cdot \frac{I(P_{\mathrm{Tx}}) - I_{\mathrm{a}}(P_{\mathrm{Tx}})}{C(P_{\mathrm{Tx}})}$$

- Implementation Loss

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


Channel State Information loss
Design loss
Implementation loss
2009-01-15c
capacity
mutual information
achievable mutual information
throughput
mean rate [Mbit/s]
0
5
10
15
20
6
12
18
24
30
36
transmit power [dBm]
-13.6
-7.6
-1.6
4.4
10.4
16.4
average received SISO SNR [dB]

Performance Comparisons



Absolute Losses [C6,C9]

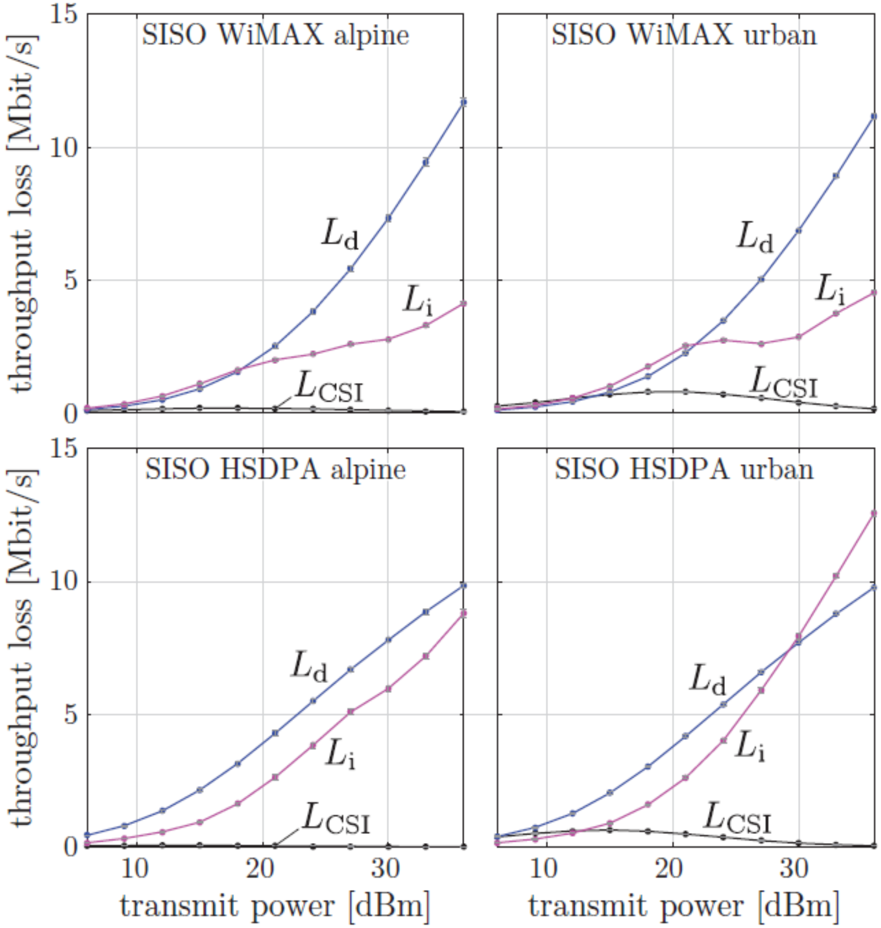


Fig. 2. Throughput losses of the SISO WiMAX and the SISO HSDPA systems in the alpine (ID "2008-09-23") and the urban environments (ID "2009-01-15c").

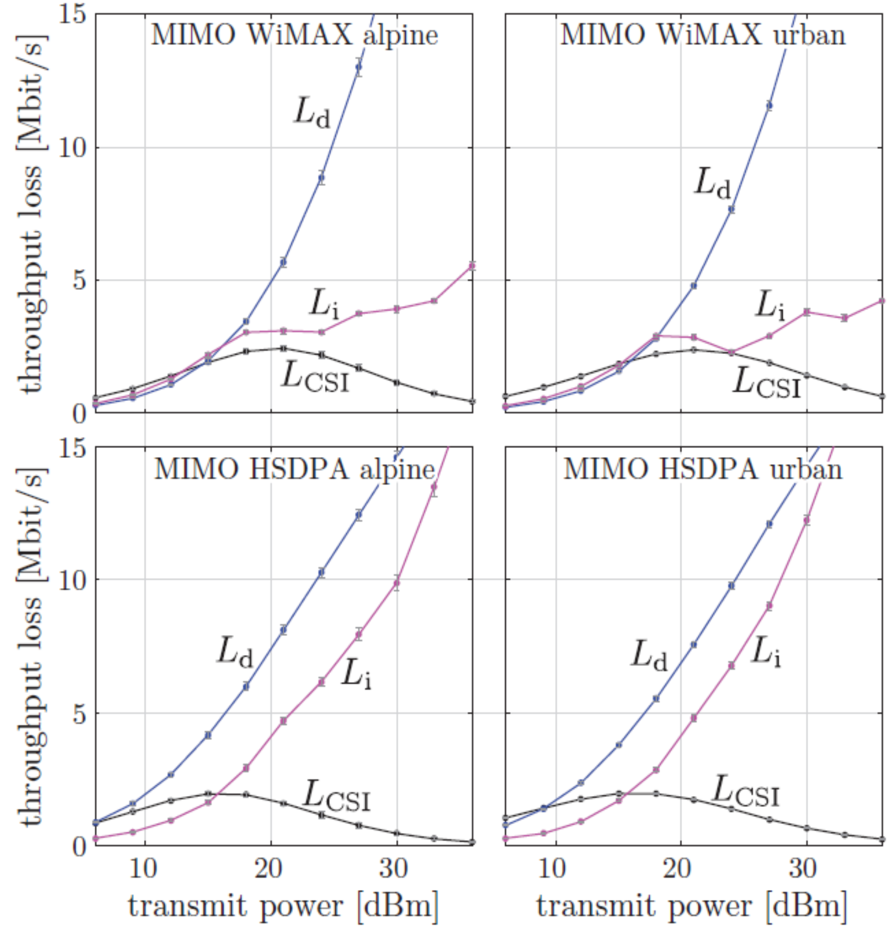
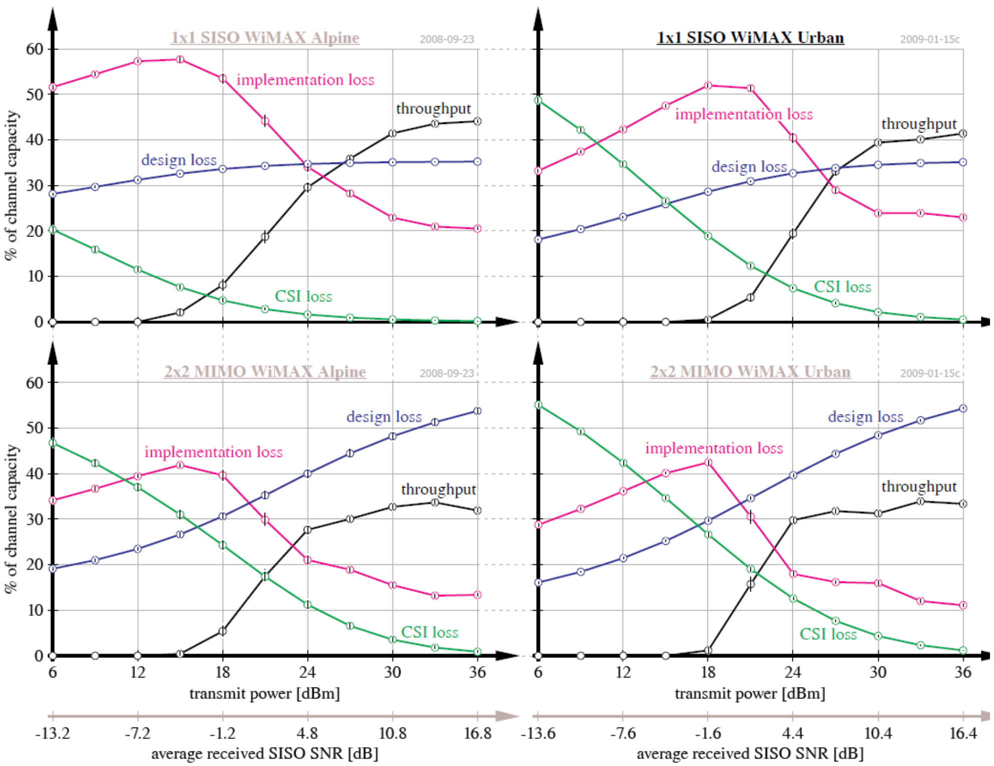


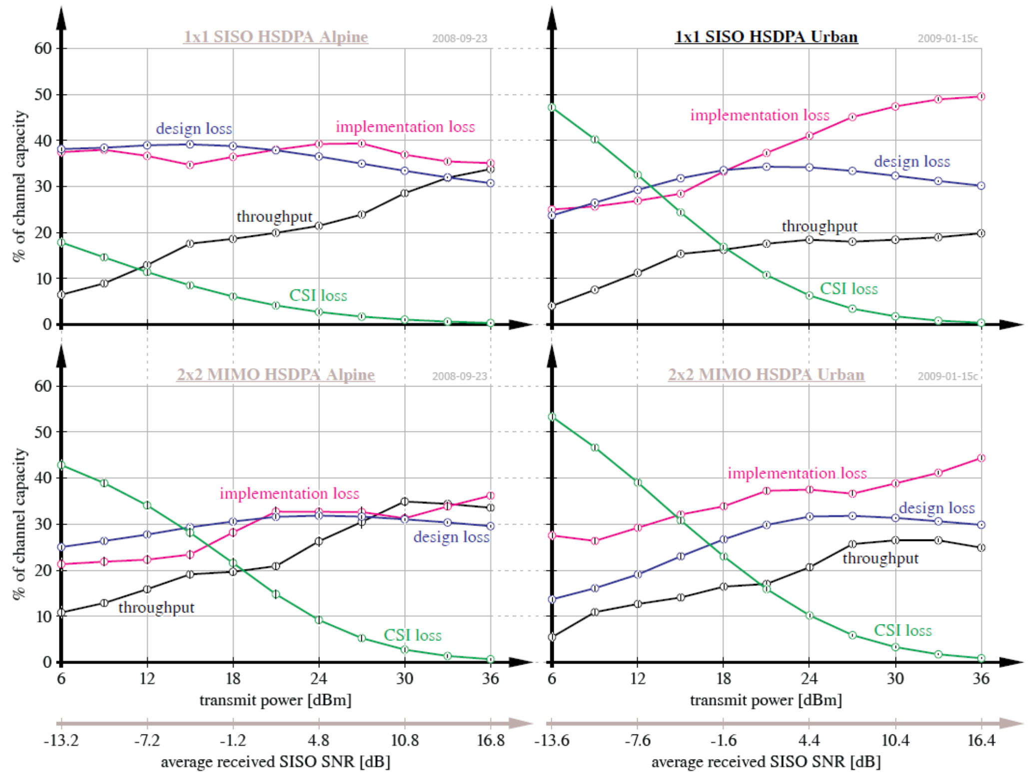
Fig. 3. Throughput losses of the MIMO WiMAX and the MIMO HSDPA systems in the alpine (ID "2008-09-23") and the urban environments (ID "2009-01-15c").

Relative Losses [C8,C9]

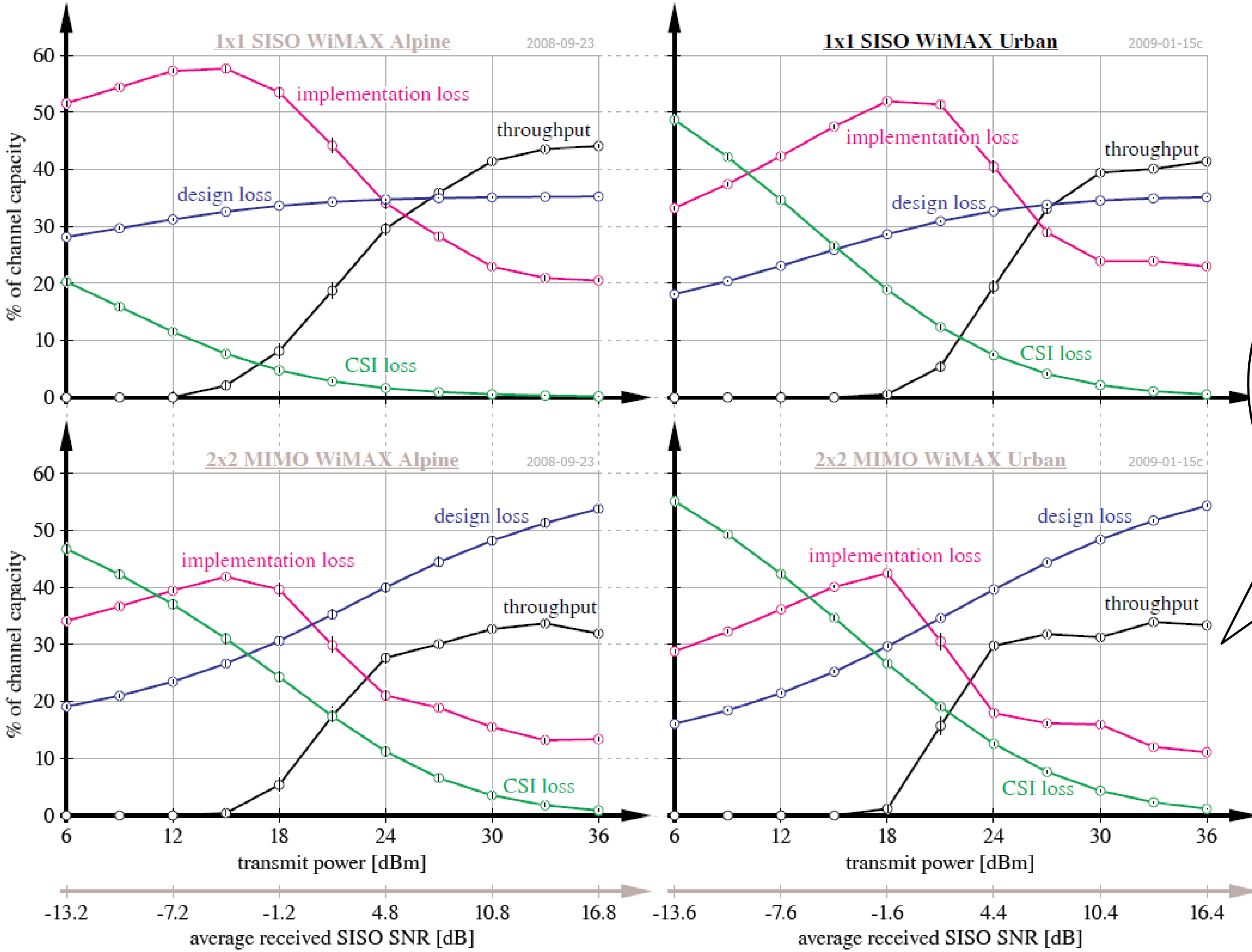
- WiMAX



HSDPA



Relative Losses: WiMAX [C8,C9]



No difference between Urban and Alpine

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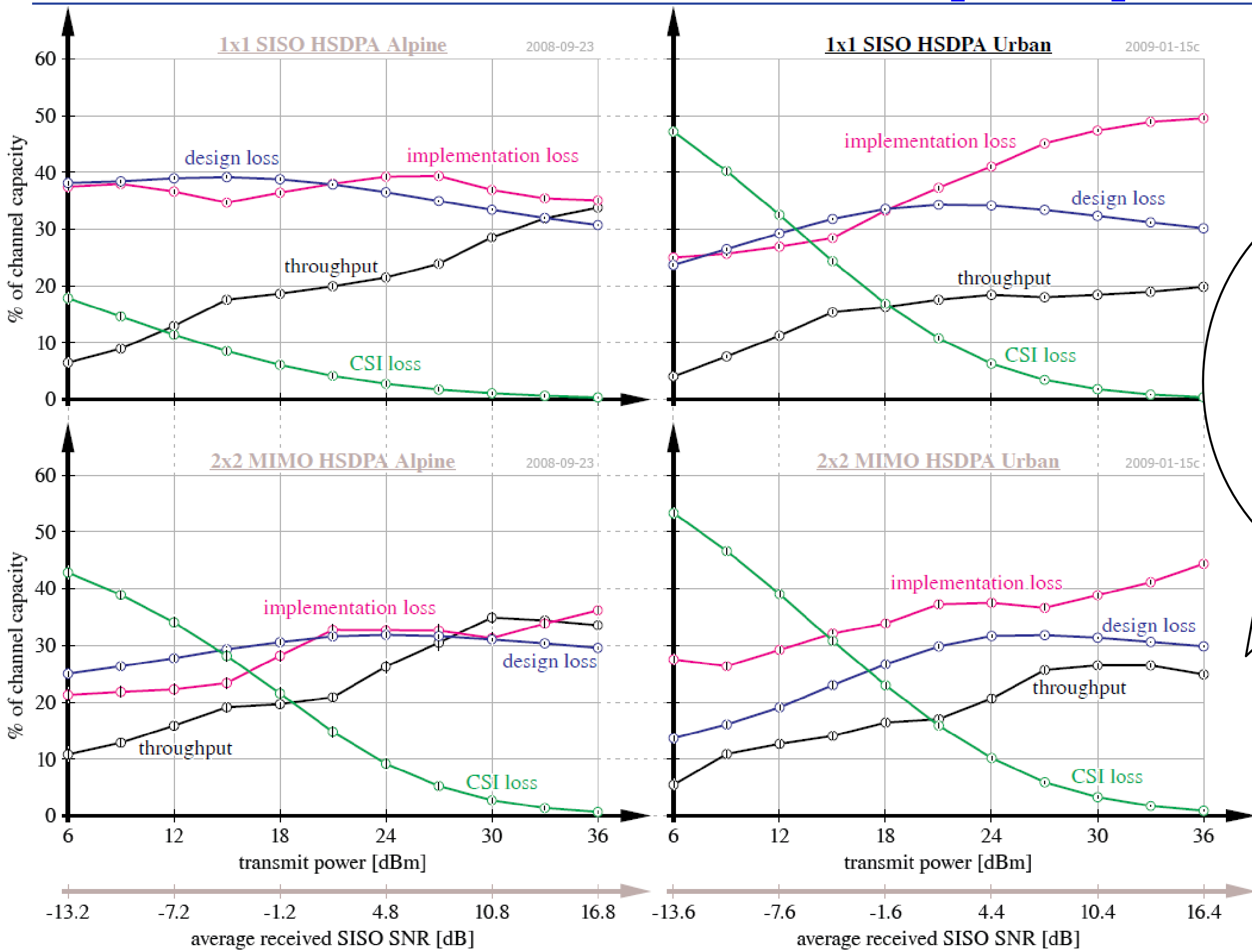
Relative Losses HSDPA [C8,C9]



Difference between Urban and Alpine due to RMS Delay spread

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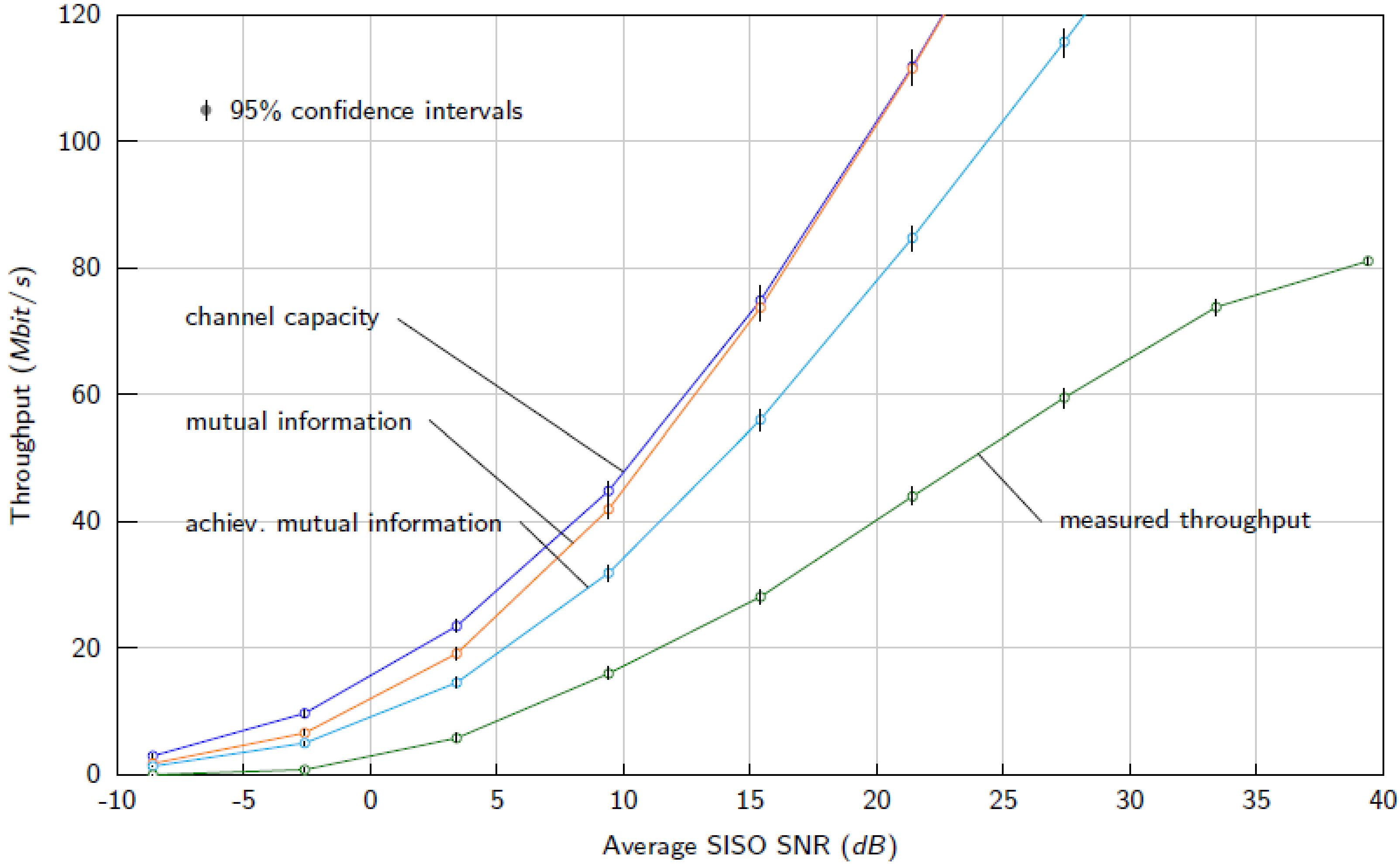
Vienna LTE Simulators [L1-L20]

- You can find below the links to each one of the LTE simulators:
-
- **LTE Downlink Link Level Simulator**
- **LTE Downlink System Level Simulator**
- **LTE Uplink Link Level Simulator**
- Now Available:
- **LTE-Advanced Downlink Link Level Simulator**
- Since 2009 >23,000 downloads

2x2 LTE OL Measurement with 10MHz Bandwidth

- Crossploarized antennas



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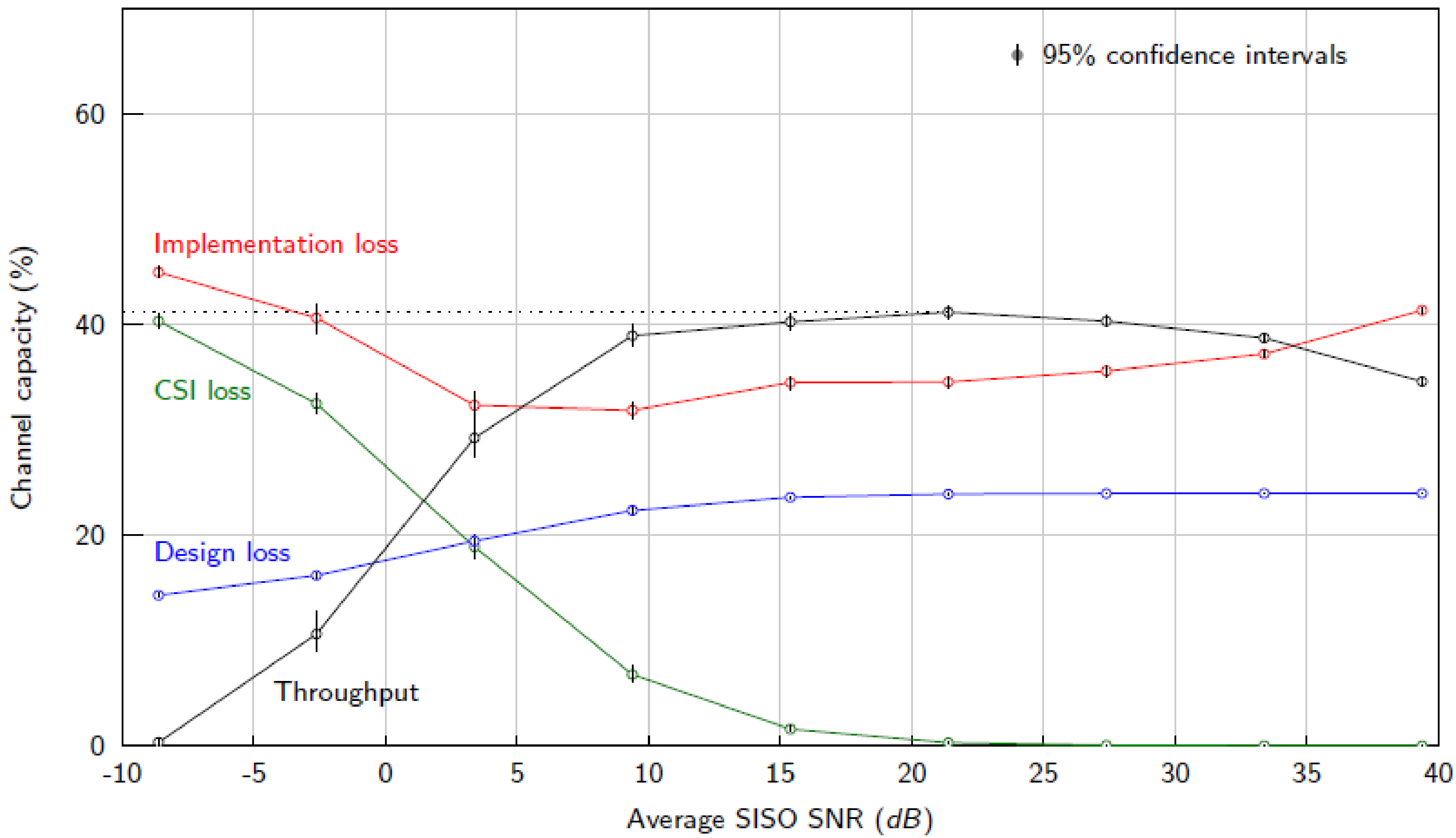
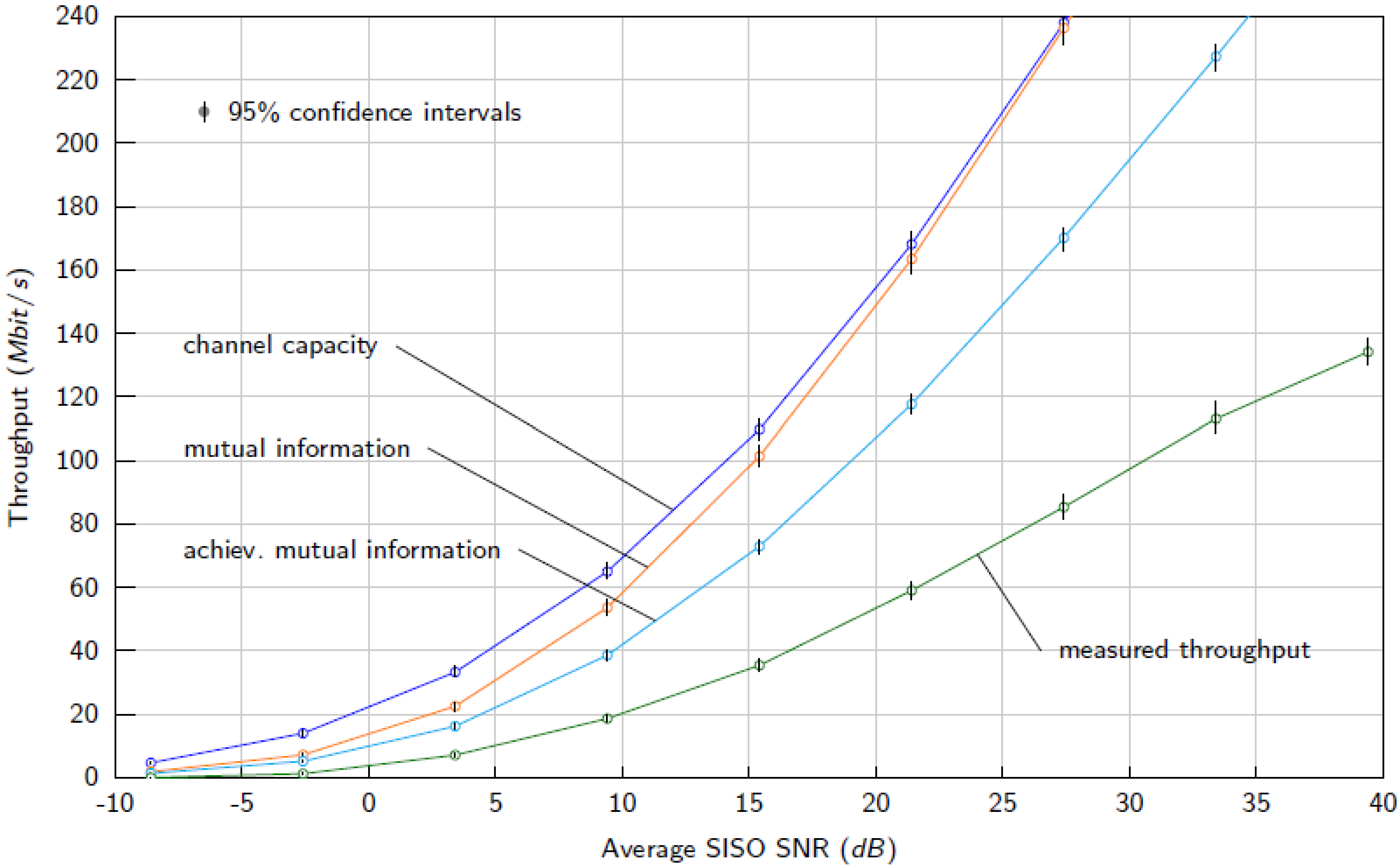
2x2 LTE OL Measurement with 10MHz Bandwidth



4x4 LTE OL Measurement with 10MHz Bandwidth



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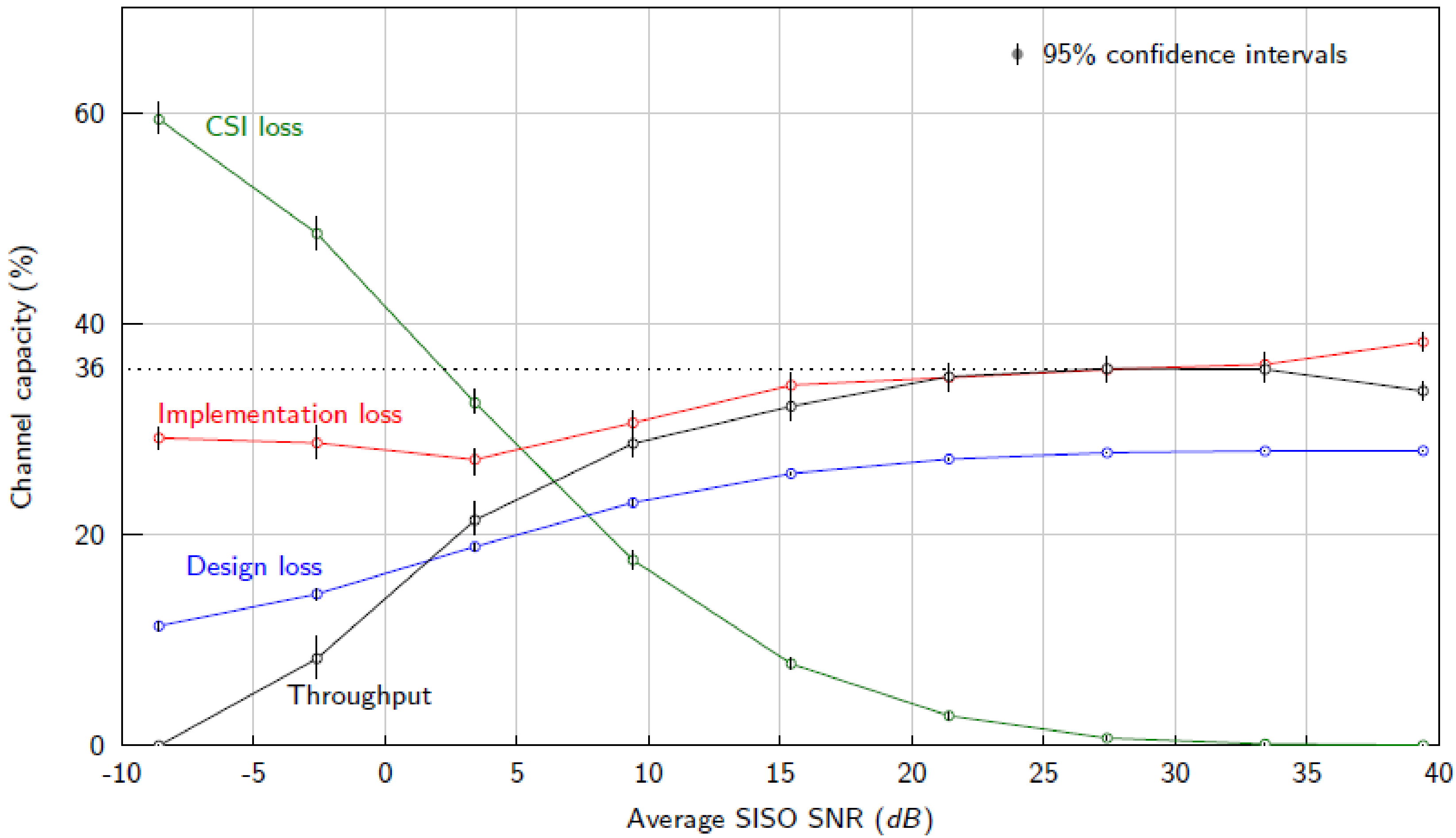
4x4 LTE OL Measurement with 10MHz Bandwidth

- 4x4 MIMO [L13,L14]



Maximum OLSM Throughput 10MHz Bandwidth

- 2x2 LTE
- **41%**

- 4x4 LTE
- **36%**

- 8x8 LTE
- **31%** (predicted)

Conclusion

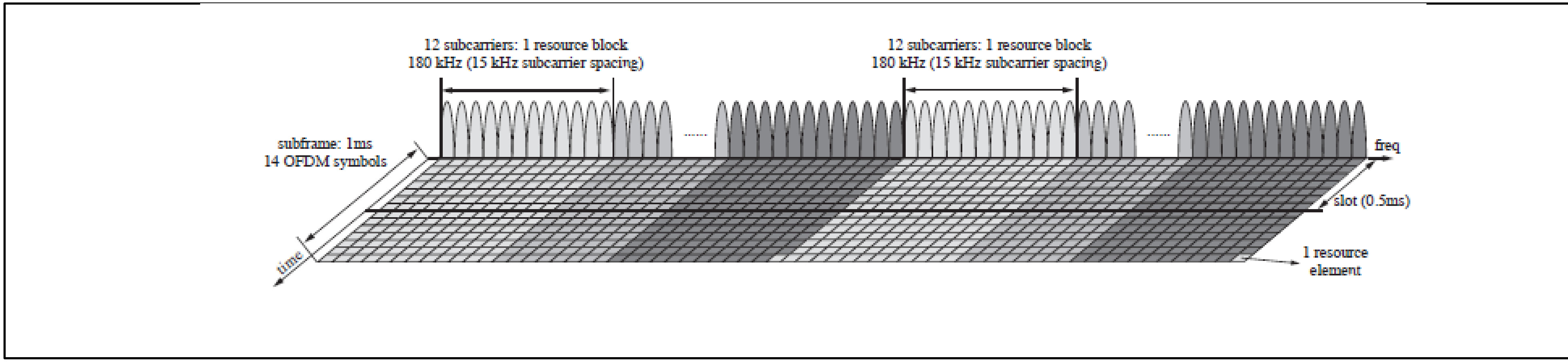
- WiMAX and HSDPA are ~10dB off from the Shannon Bound!
  Less than half of the potential throughput is achieved.
- Channel estimation loss: an overemphasized loss!
  - Channel knowledge at transmitter is mostly irrelevant
- Design loss: a political loss!
  - Standards have not been treated scientifically yet
- Implementation loss: an unavoidable loss!
  - Need of accurate implementation models as design loss depends on them!

- **LTE is not expected to be much better!**

- **In particular LTE MIMO is not efficient!**

Improvements

- Gain 25% throughput by using the entire spectrum
  Synchronise base stations!

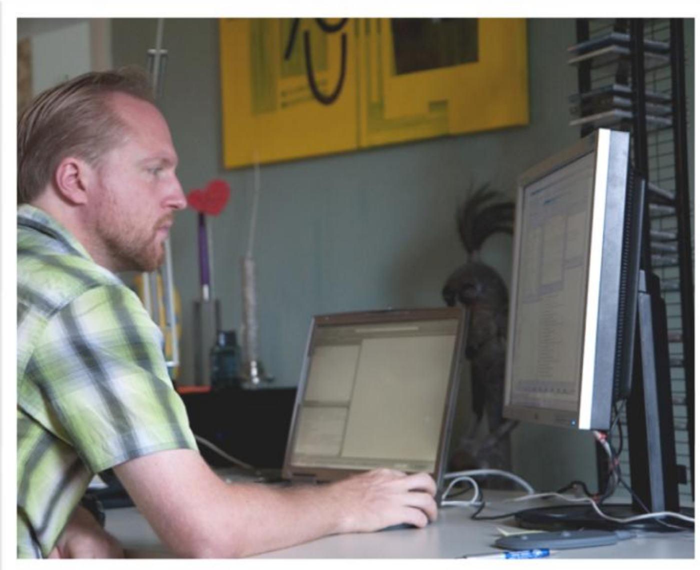


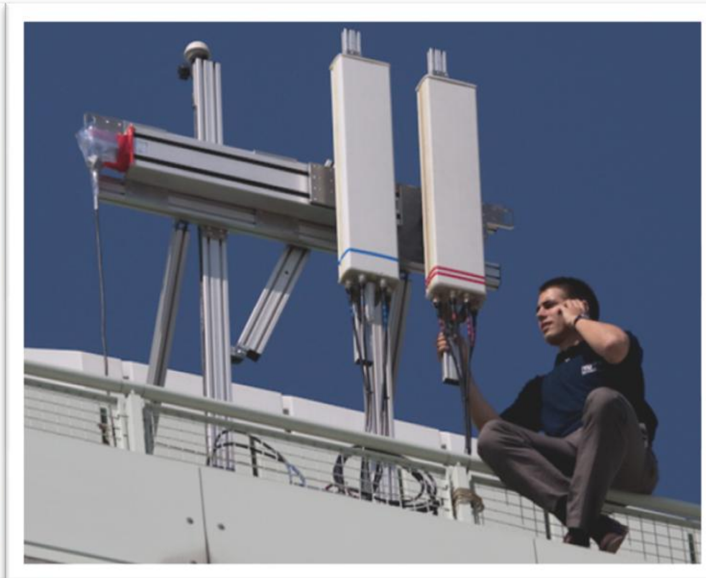
- Gain 13% throughput by switching to differential encoding→no pilots

- Gain a lot % throughput by utilising MIMO the right way:
  Does anybody know how???

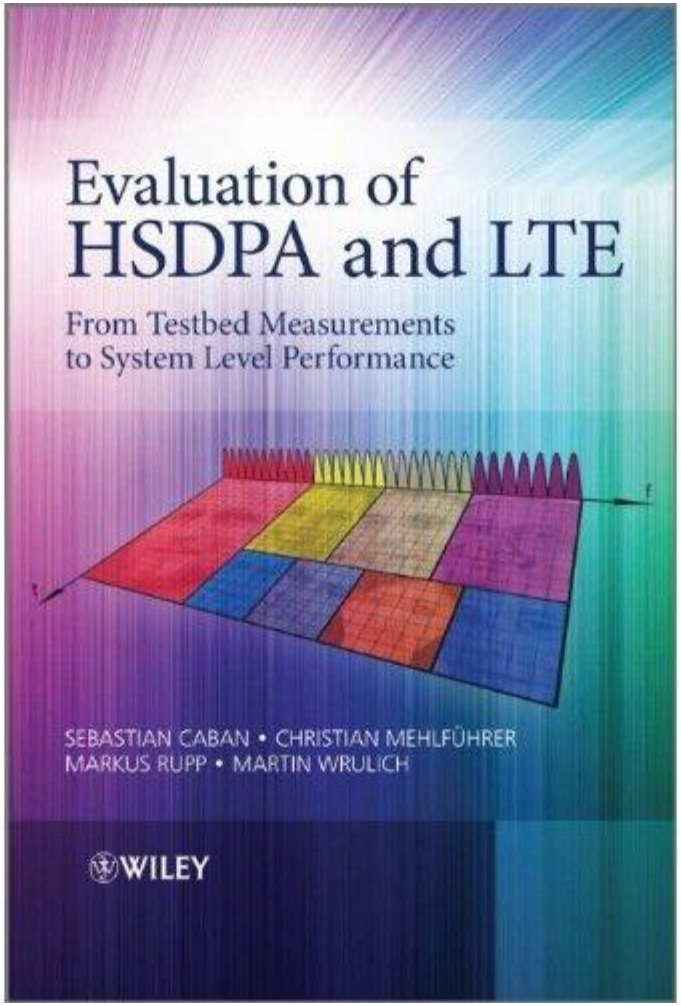
Thank you for your attention.

http://www.nt.tuwien.ac.at/





With help from…



Available now!

Testbed References

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[T3] Thomas Kaiser, Andreas Wilzeck, Martin Berentsen, Markus Rupp, "**Prototyping for MIMO Systems - an Overview,"** in Proc. 12th European Signal Processing Conference (EUSIPCO 2004), Vienna, Austria, pp. 681-688, Sept. 2004, http://publik.tuwien.ac.at/files/pub-et_8809.pdf.

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HSDPA References

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[H3] Christian Mehlführer, Martin Wrulich, Markus Rupp, "**Intra-cell Interference Aware Equalization for TxAA HSDPA**," in Proc. IEEE International Symposium on Wireless Pervasive Computing (ISWPC 2008), pp. 406-409, Santorini Greece, http://publik.tuwien.ac.at/files/pub-et_13749.pdf.

[H4] Christian Mehlführer, Sebastian Caban, Markus Rupp, "**Measurement based evaluation of low complexity receivers for D-TxAA HSDPA**," in Proc. 16th European Signal Processing Conference (EUSIPCO 2008), Lausanne, Aug. 2008. http://publik.tuwien.ac.at/files/PubDat_166132.pdf

[H5] Christian Mehlführer, Sebastian Caban, Martin Wrulich, and Markus Rupp, "**Joint Throughput Optimized CQI and Precoding Weight Calculation for MIMO HSDPA**," 42nd Asilomar Conference on Signals, Systems and Computers, 2008, Pacific Grove, CA, USA, Oct. 2008. http://publik.tuwien.ac.at/files/PubDat_167015.pdf

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WiMAX References

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OFDM Frame Structure

- 3 OFDM symbols preamble
  1. Synchronization
  2. Channel estimation
  3. Control information
- Subcarrier distribution
  - 192 data subcarriers
  - 8 pilot subcarriers
  - 1 zero DC subcarrier
  - 55 guard band subcarriers
  - ! 256 total