Outdoor WiMAX Throughput Measurements

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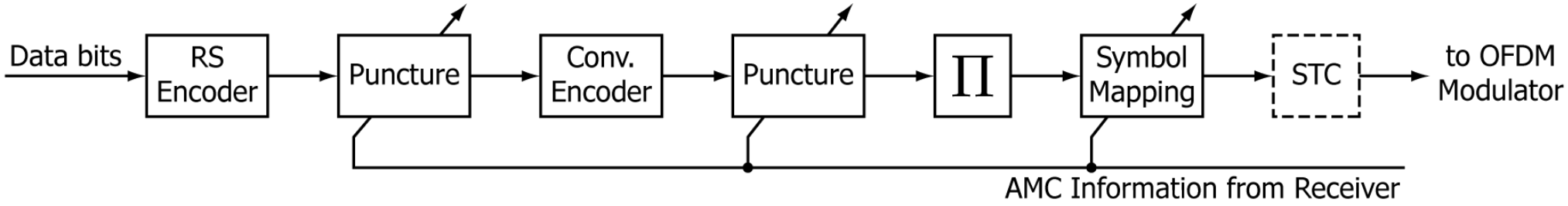
Outline

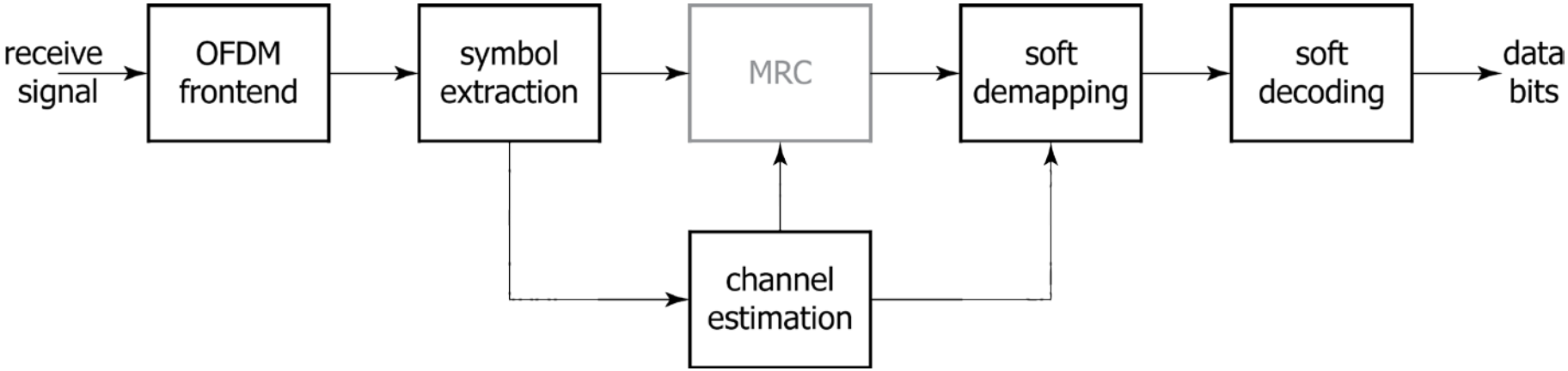
- WiMAX signal generation and reception
  - IEEE 802.16-2004 (Section 8.3) with OFDM physical layer
- Measurement setup
- Achievable and measured throughput
- Measurement results
- Enhancements
- Overall conclusions

TX Adaptive Modulation and Coding (AMC)

- Encoding
  - concatenated Reed-Solomon / convolutional code
  - puncturing depending on AMC information
  - optional block/convolutional Turbo coding
- Adaptive symbol mapping (2-PAM, 4-QAM, 16-QAM, 64-QAM)
- Optional Alamouti space-time coding



Receiver



- LS channel estimation
- max-log-MAP demapping

$$\mathrm{LLR}(b_k) \approx \max_{\mathbf{z}|b_k=1}\left(-\frac{1}{2}\frac{\|\mathbf{Hz}-\mathbf{r}\|_2^2}{\sigma_v^2}\right) - \max_{\mathbf{z}|b_k=0}\left(-\frac{1}{2}\frac{\|\mathbf{Hz}-\mathbf{r}\|_2^2}{\sigma_v^2}\right)$$

- soft Viterbi decoding

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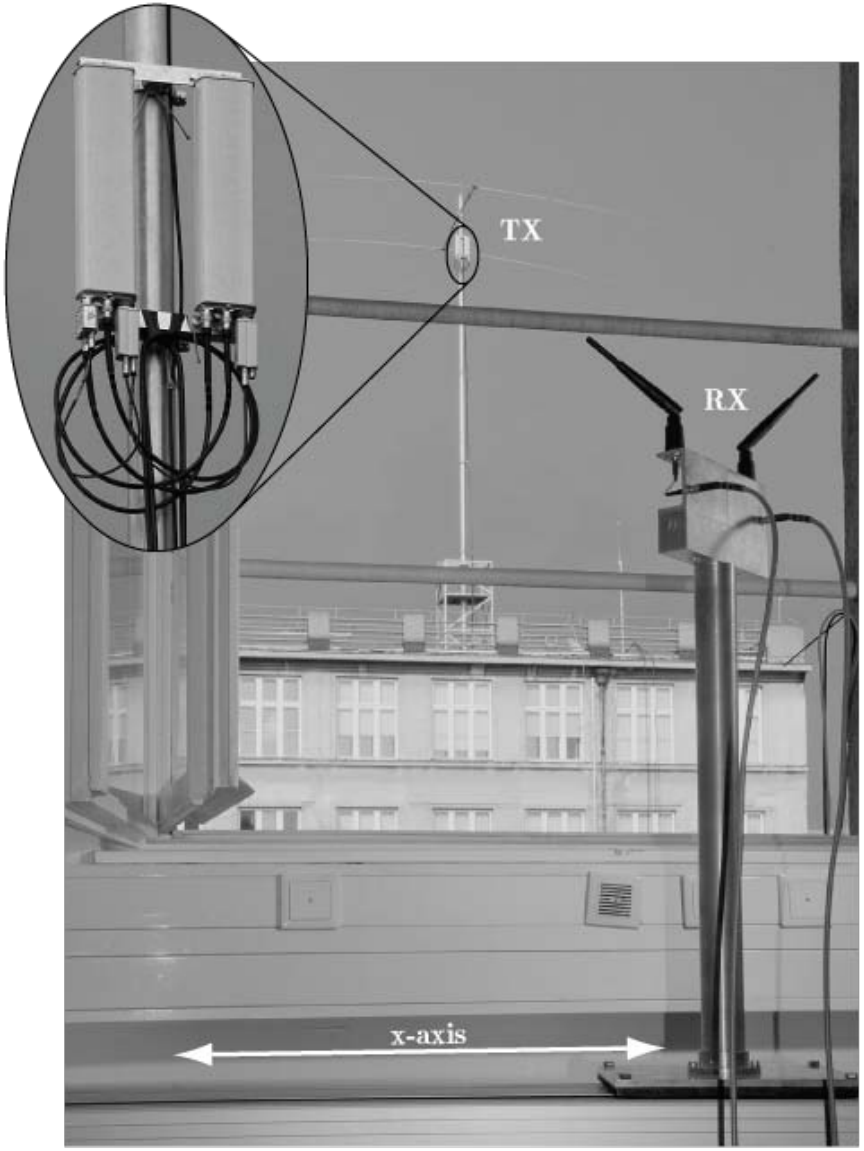
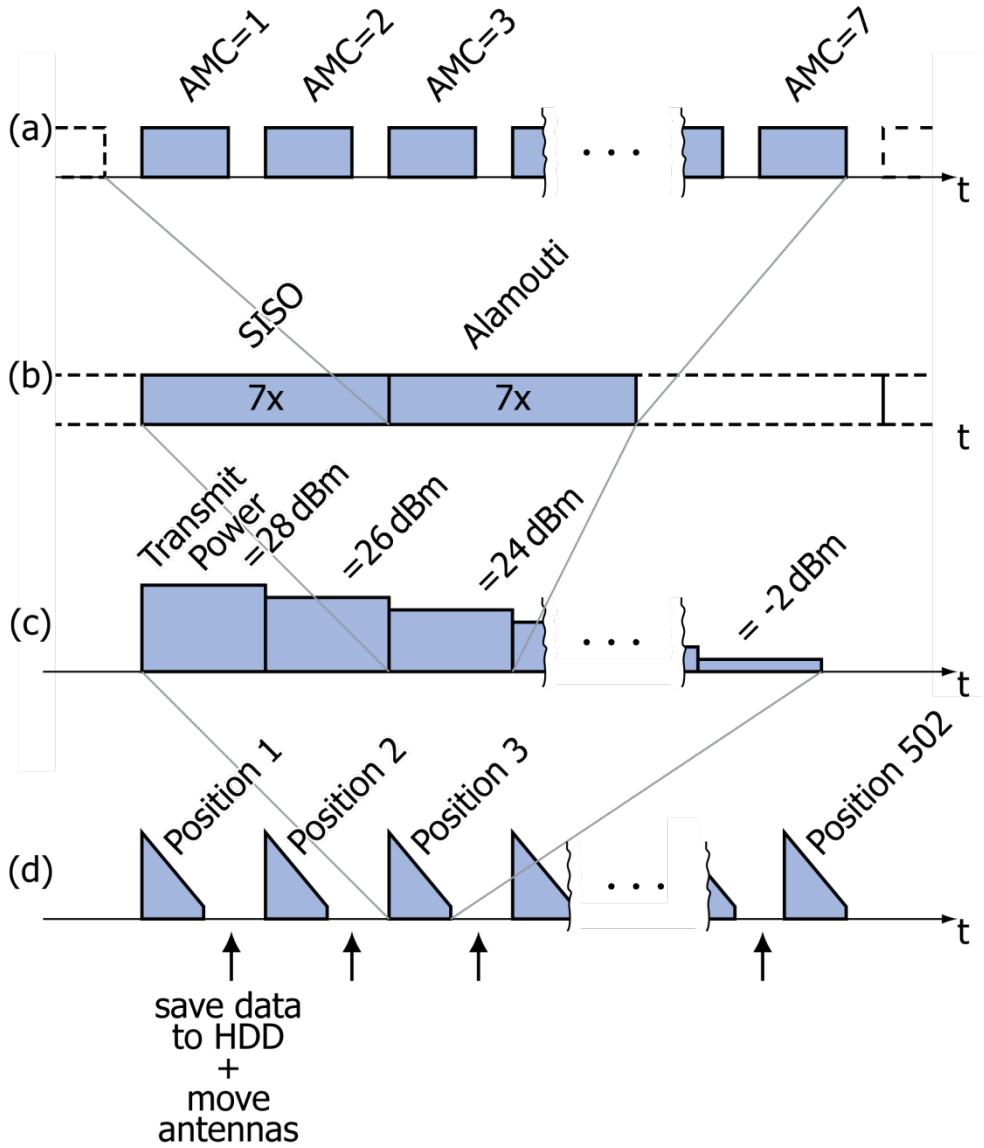
Measurement Setup

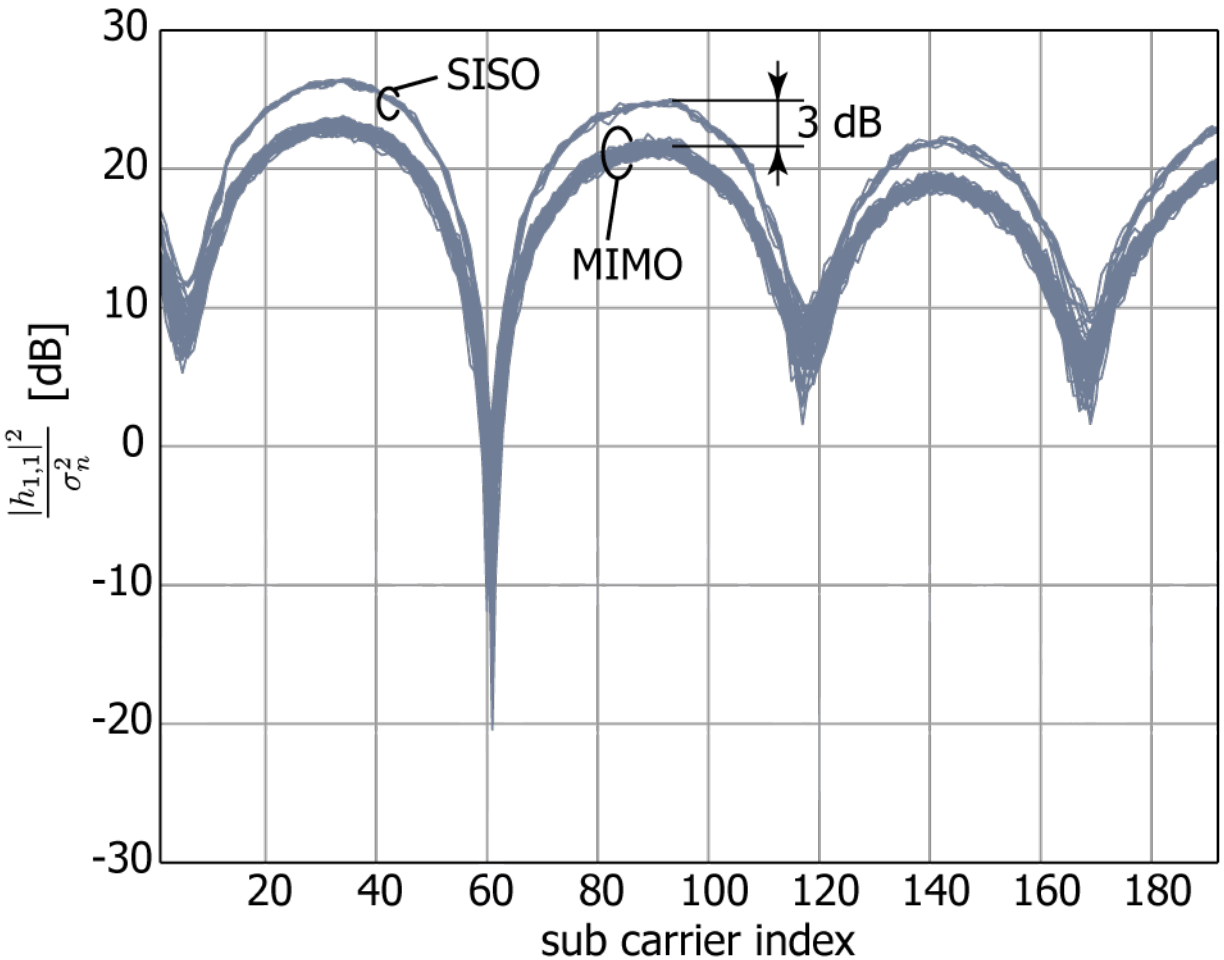
- 3 scenarios
  1. NLOS, outdoor-to-indoor
  2. NLOS, outdoor-to-outdoor
  3. LOS, outdoor-to-indoor
- Parameters
  - 2.503 GHz center frequency
  - 5 MHz channel bandwidth
  - Cyclic prefix 1/4
  - 256 carrier OFDM
  - TX antenna spacing 2.75 λ



Block Transmission



Measured Channel Coefficients at One Position



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Achievable Throughput (1)

Mutual information of the transmitted and received symbol at subcarrier k, at transmitter attenuation m, and for channel realization c is given by

$$I_k^{(c,m)} = \log_2 \left\{ \det \left(\mathbf{I}_{N_R} + \frac{1}{\sigma_n^2} \mathbf{H}_k^{(c,m)} \mathbf{H}_k^{(c,m)\mathsf{H}} \right) \right\}$$

Averaging over the channel realizations and summing over the subcarriers yields

$$I_{\mathsf{sum}}^{(m)} = \frac{1}{N_{\mathsf{RXpos}}} \sum_{c=1}^{N_{\mathsf{RXpos}}} \sum_{k=1}^{192} I_k^{(c,m)}$$

Achievable Throughput (2)

Achievable throughput

$$D_{\text{achievable}}^{(m)} = \frac{1}{1+G} \cdot \frac{1/T_s}{256} \cdot \frac{N_{\text{data}}}{N_{\text{OFDM}}} \cdot I_{\text{sum}}^{(m)}$$

G ... cyclic prefix ratio
T_s ... sampling time
N_{data} ... number of OFDM data symbols per frame
N_{OFDM} ... total number of OFDM symbols per frame

Evaluation of Measured Throughput

- Based on a “perfect” feedback method
  - Possible since all AMC schemes were transmitted over the same channel
- Best throughput at receive antenna position c

$$D_{\text{best}}^{(c,m)} = \max_{i \in \mathcal{I}} R_i (1 - P_i^{(c,m)})$$

- Here, $P_i^{(c,m)} \in \{0, 1\}$ is a frame error indicator, R_i is the data rate of the i-th AMC scheme
- The average throughput of one scenario at transmitter attenuation m is given by

$$D_{\text{best,avg}}^{(m)} = \frac{1}{N_{\text{RXpos}}} \sum_{c=1}^{N_{\text{RXpos}}} D_{\text{best}}^{(c,m)}$$

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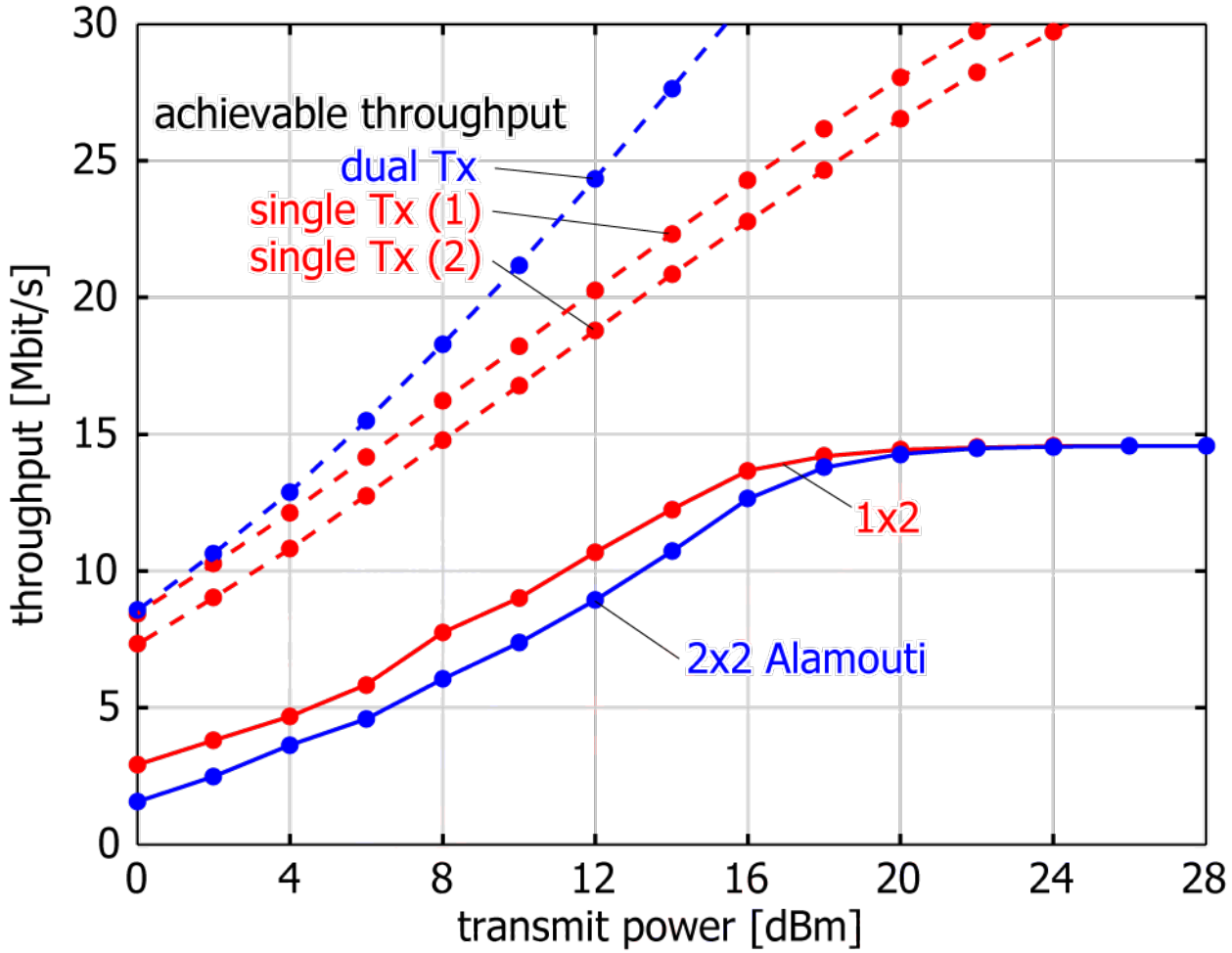
Two Receive Antennas: LOS outdoor-to-indoor



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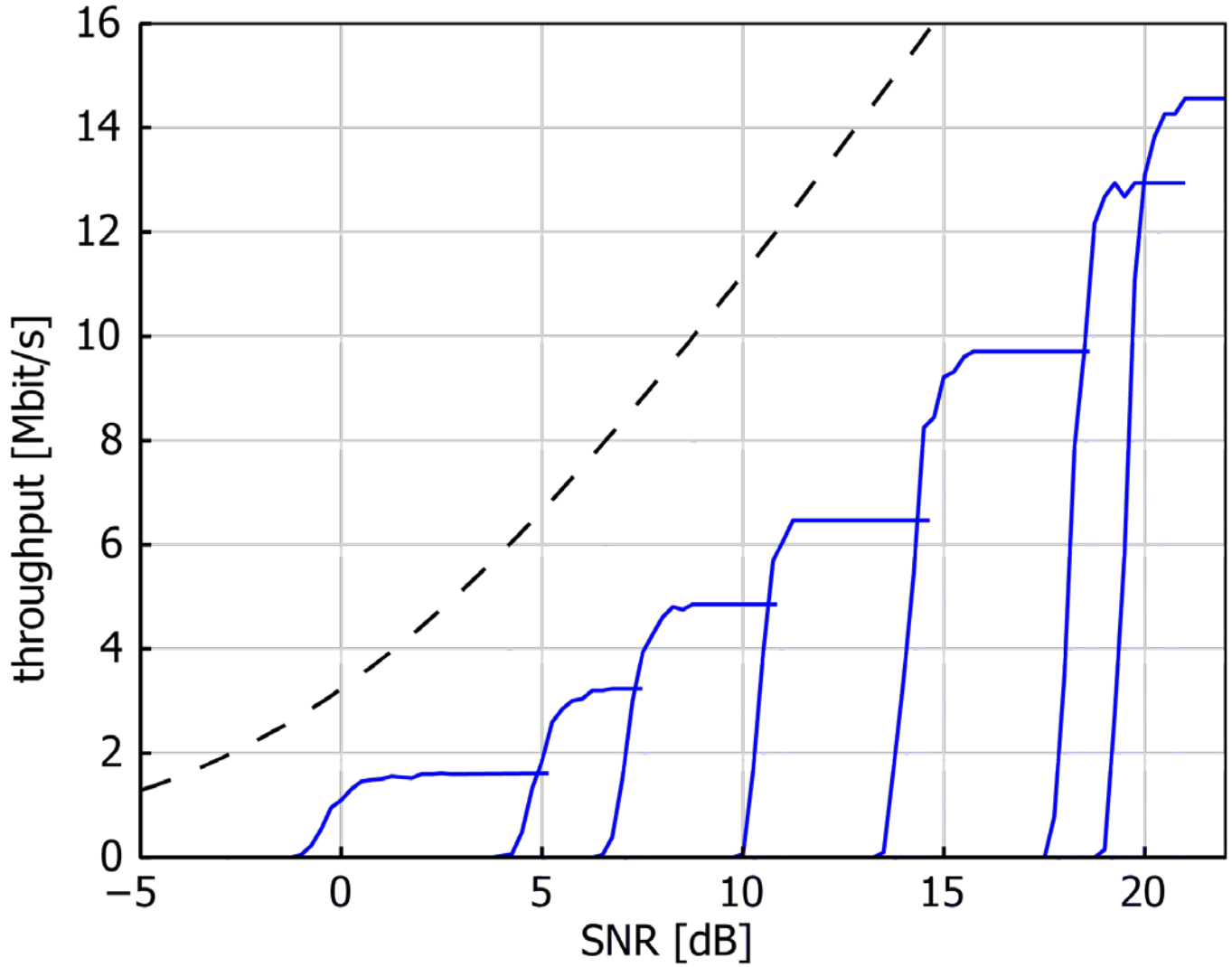
WiMAX Reed-Solomon Convolutional Coding (AWGN Channel)



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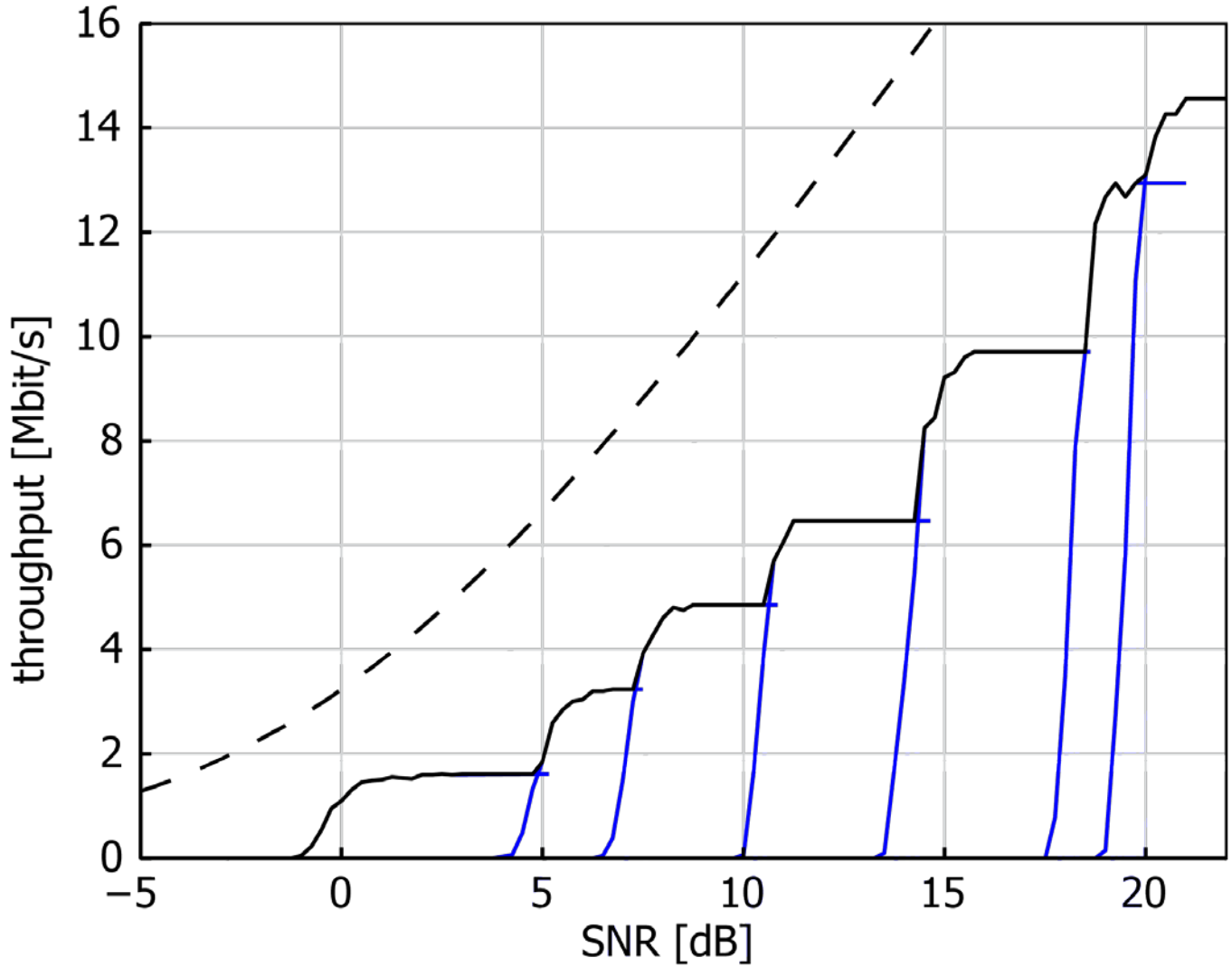
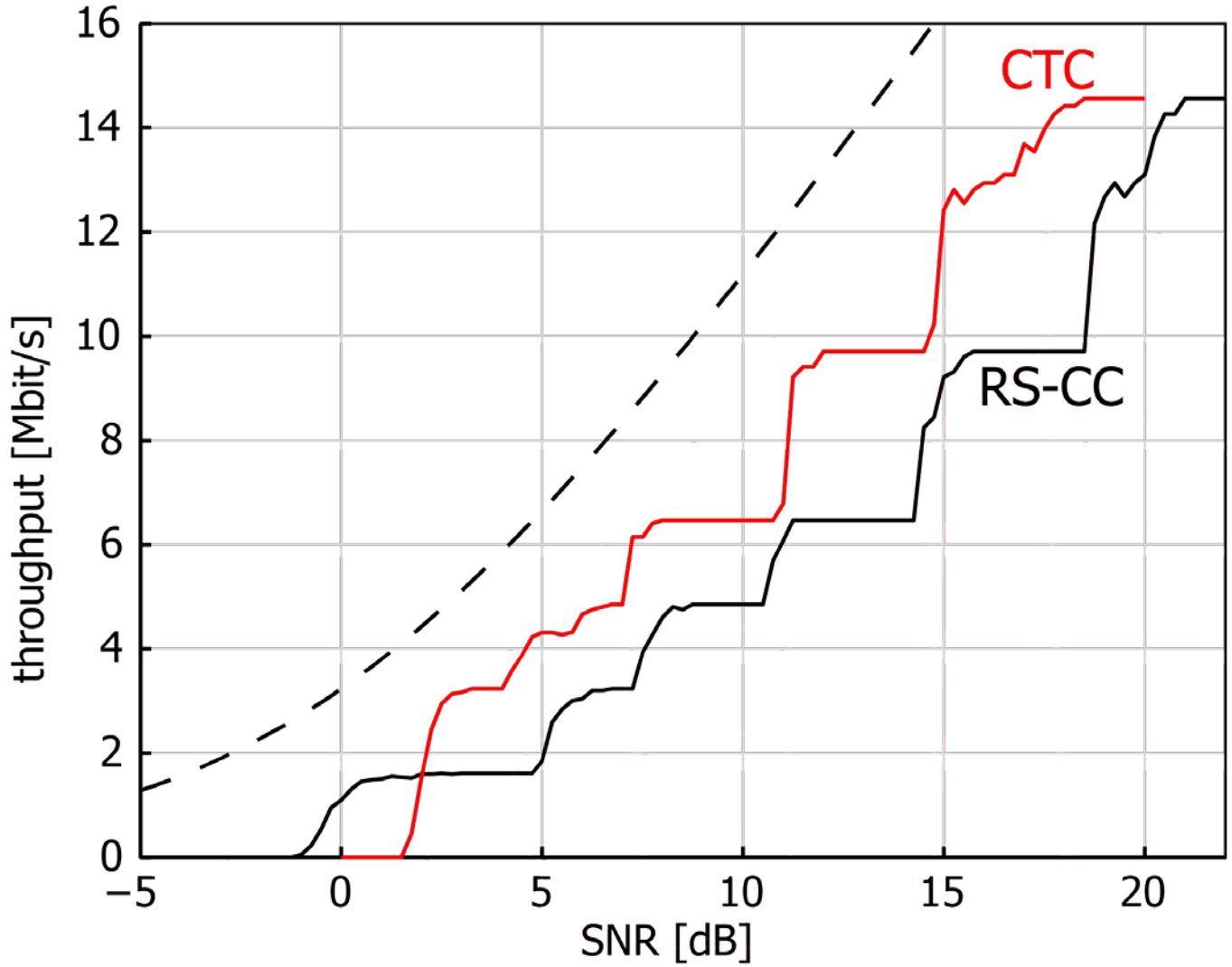
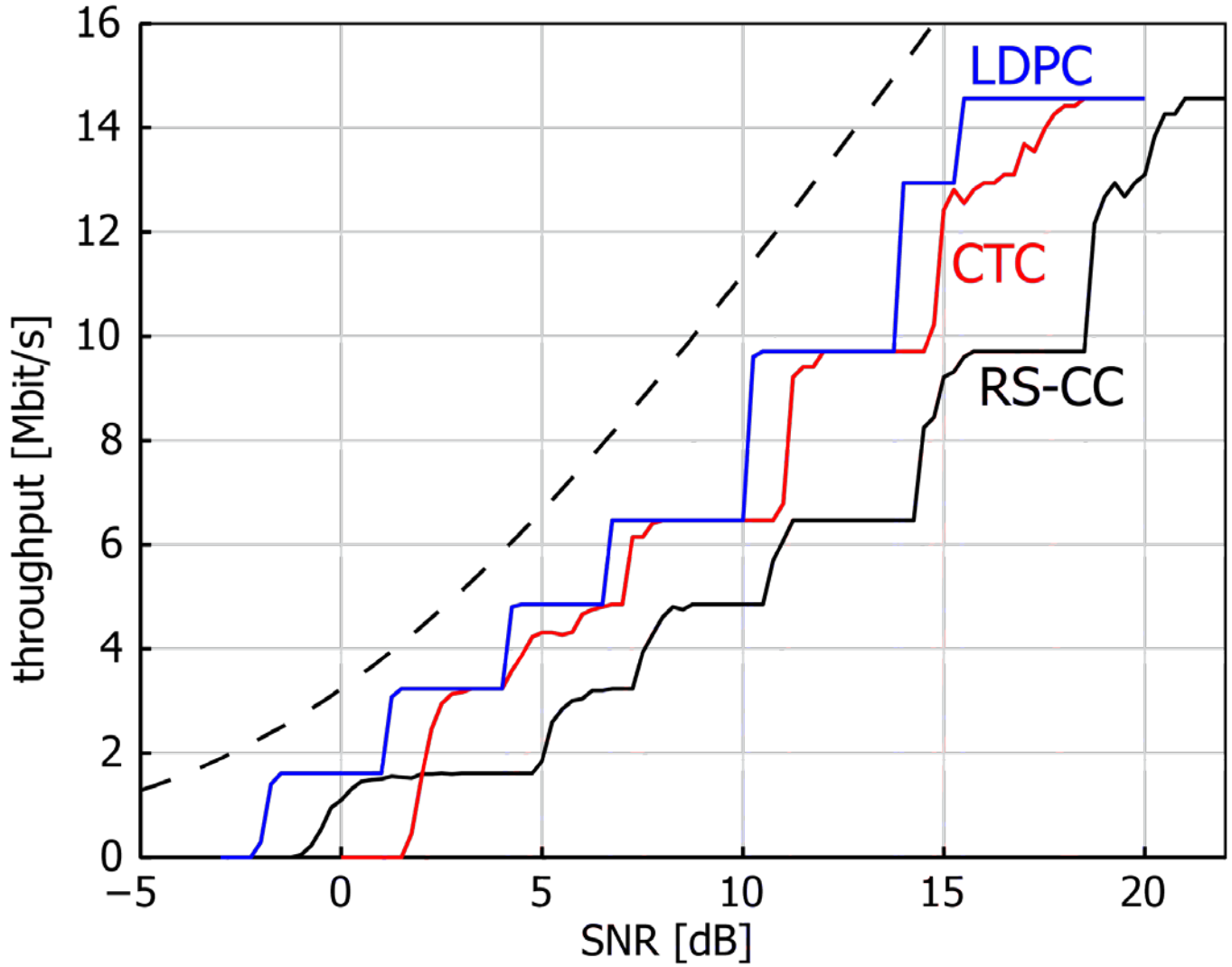


WiMAX Convolutional Turbo Coding (AWGN Channel)



Low Density Parity Check Coding (AWGN Channel)



LS and LMMSE Channel Estimation

System model: $\mathbf{r}^{(n_r)} = \mathbf{T}^{(n_t)}\mathbf{h}^{(n_r,n_t)} + \mathbf{v}^{(n_r)}$

LS channel estimator: $\hat{\mathbf{h}}^{\mathrm{LS}} = \left(\mathbf{T}^{\mathrm{H}}\mathbf{T}\right)^{-1}\mathbf{T}^{\mathrm{H}}\mathbf{r} = \frac{1}{4}\mathbf{T}^{\mathrm{H}}\mathbf{r}$

LMMSE channel estimator:

$$\hat{\mathbf{h}}^{\mathrm{LMMSE}} = \arg\min_{\hat{\mathbf{h}}} \mathrm{E}\left\{\|\hat{\mathbf{h}} - \mathbf{h}\|_2^2\right\} = \mathbf{R}_{\mathbf{hr}}\mathbf{R}_{\mathbf{rr}}^{-1}\mathbf{r}$$

$$\begin{aligned}\hat{\mathbf{h}}^{\mathrm{LMMSE}} &= \mathbf{R}_{\mathbf{hh}}\mathbf{T}^{\mathrm{H}}\left(\mathbf{T}\mathbf{R}_{\mathbf{hh}}\mathbf{T}^{\mathrm{H}} + \mathbf{R}_{\mathbf{vv}}\right)^{-1}\mathbf{r} = \\ &= \mathbf{R}_{\mathbf{hh}}\left(\mathbf{R}_{\mathbf{hh}} + \frac{\sigma_v^2}{4}\mathbf{I}\right)^{-1}\hat{\mathbf{h}}^{\mathrm{LS}} = \mathbf{F}\hat{\mathbf{h}}^{\mathrm{LS}}.\end{aligned}$$

The channel correlation matrix can be estimated as

$$\mathbf{R}_{\mathbf{hh}} = \mathrm{E}\left\{\mathbf{h}\mathbf{h}^{\mathrm{H}}\right\} \approx \hat{\mathbf{R}}_{\mathbf{hh}} = \frac{1}{N_{\mathrm{c}}}\sum_{i=1}^{N_{\mathrm{c}}}\hat{\mathbf{h}}^{(i)}\hat{\mathbf{h}}^{(i)\mathrm{H}} \qquad N_{\mathrm{c}} > N = 100$$

ALMMSE Channel Estimation

Channel can be partitioned in the frequency domain:

$$\mathbf{h} = \left[\mathbf{h}_1^{\mathrm{T}}, \ldots, \mathbf{h}_M^{\mathrm{T}}\right]^{\mathrm{T}} \quad \text{with} \quad \mathbf{h}_m = \left[h_{L(m-1)+1}, \ldots, h_{L(m-1)+L}\right]^{\mathrm{T}}$$

Estimate mean covariance matrix of size $L \times L$:

$$\hat{\mathbf{R}}_{\mathbf{hh}}^{(L)} = \mathrm{E}\left\{\mathbf{h}_m \mathbf{h}_m^{\mathrm{H}}\right\} \triangleq \frac{1}{M N_{\mathrm{c}}} \sum_{i=1}^{N_{\mathrm{c}}} \sum_{m=1}^{M} \mathbf{h}_m^{(i)} \mathbf{h}_m^{(i)\mathrm{H}} \qquad M N_{\mathrm{c}} > L$$

For $L{=}10$ we obtain

$$M = \left\lfloor \frac{N}{L} \right\rfloor = \left\lfloor \frac{100}{10} \right\rfloor = 10 \quad \rightarrow \quad N_{\mathrm{c}} \geq 1$$

Now, calculate a filter matrix from the estimated covariance:

$$\mathbf{F}^{(L)} = \hat{\mathbf{R}}_{\mathbf{hh}}^{(L)} \left(\hat{\mathbf{R}}_{\mathbf{hh}}^{(L)} + \frac{\sigma_v^2}{4}\mathbf{I}\right)^{-1}$$

ALMMSE Channel Estimation

This filter can now be used to improve the accuracy of the LS channel estimate:

$$\hat{h}_n^{\mathrm{ALMMSE}} = \begin{cases} \mathbf{F}_n^{(L)} \cdot \left[\hat{h}_1^{\mathrm{LS}}, \ldots, \hat{h}_L^{\mathrm{LS}}\right]^{\mathrm{T}} & n \leq \frac{L+1}{2} \\ \mathbf{F}_{\lceil \frac{L+1}{2} \rceil}^{(L)} \cdot \left[\hat{h}_{n-\lfloor \frac{L-1}{2} \rfloor}^{\mathrm{LS}}, \ldots, \hat{h}_{n-\lceil \frac{L-1}{2} \rceil}^{\mathrm{LS}}\right]^{\mathrm{T}} & \text{otherwise} \\ \mathbf{F}_{L+n-N}^{(L)} \cdot \left[\hat{h}_{N-L+1}^{\mathrm{LS}}, \ldots, \hat{h}_N^{\mathrm{LS}}\right]^{\mathrm{T}} & n \geq N - \frac{L-1}{2} \end{cases}$$

SNR Gain of Improved Channel Estimators over the LS Estimator

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

Conclusions and Outlook

- A huge SNR loss between the measured and the achievable data throughput is caused by
  - the inferior (convolutional) channel coding and
  - by too simple channel estimation techniques (like LS)
- Enhanced channel coding schemes yield up to 5dB SNR gain
- LMMSE channel estimation gains ~2 dB in the case of 2x2 Alamouti transmission
- Future work:
  - Evaluate new measurement data of MIMO WiMAX
  - Capacity analysis for MIMO High Speed Downlink Packet Access

Thank you for your attention.

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