Optimization of Feedback use in Wireless Networks

Olav Tirkkonen

Department of Communications and Networking (Comnet),
Helsinki University of Technology, Finland

Collaborators: Sergio Lembo, Helka-Liina Määttänen, Kalle Ruttik, Chia-Hao Yu,
Karol Schober, Risto Wichman

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Outline

- Three kinds of physical layer feedback
  - Precoding
  - CQI
  - HARQ
- Main Characteristics of FB Methods
- Value of Precoding FB bit
  - Orthogonalization & Grassmannian BF
- Value of CQI FB bit
- Joint FB Analysis
  - CQI + HARQ

Physical Layer Feedback

Physical layer feedback used at least for three purposes:

- Precoding feedback for multiantenna systems
  - direct the multiantenna beam towards the receiver configuration at the transmitter
- Channel Quality Indication (CQI) feedback
  - for Adaptive Modulation and Coding (AMC) and channel-dependent scheduling
  - receiver feeds back SINR (FDD) or interference information (TDD), or suggests the best Modulation and Coding Scheme (MCS) to be used.
- ACK/NACK feedback, related to a Hybrid ARQ retransmission protocol

As well as

- Combinations of these
- Multistream MIMO transmissions: Multilayer complexity
- Frequency selective feedback

Feedback Partitioning

- Feedback information needs to be transmitted on the opposite link direction

- Fundamental law of FB resource scarcity:

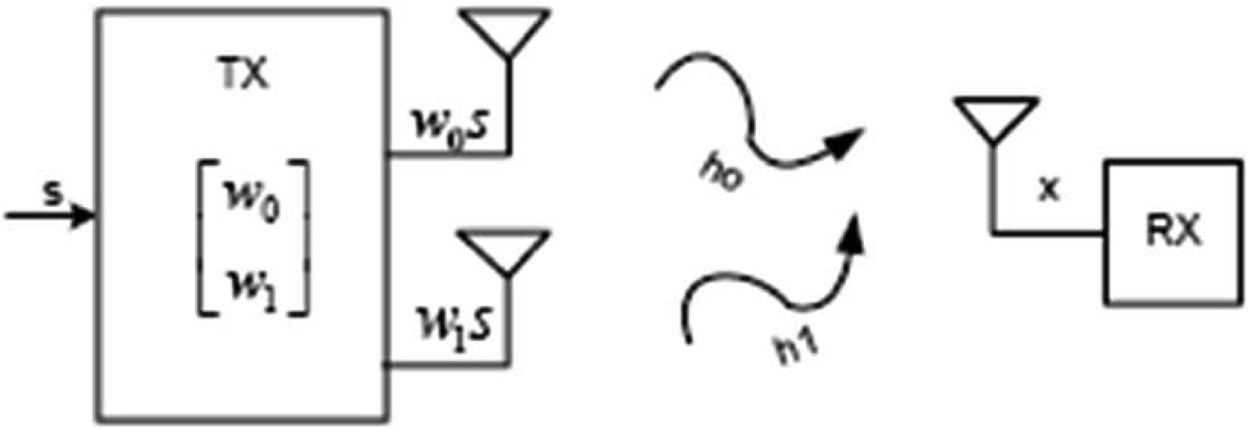
  There is never space for all the feedback you want

  - e.g. in LTE, typical users should survive with 10 bits

- Questions to address:
  - What is the value of a FB bit?
  - How to use the few FB bits you can afford?

Main Characteristics of FB Methods

Principle of Precoding

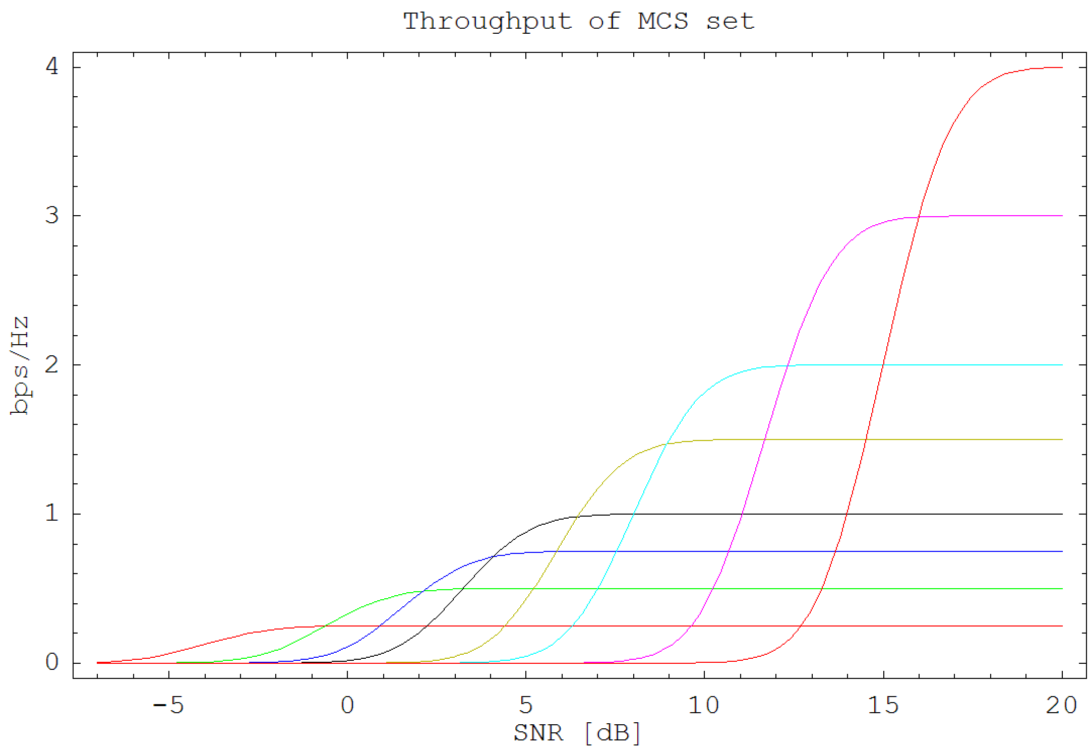


- Weight transmitted symbols from different antennas
- Target: to combine favourably at Rx

Precoding FB for beamforming

- Gain from beamforming: increasing the SNR of a link
- Simplest metric works: SNR gain
  - with perfect BF, 1 Rx, absolute SNR gain is N_t
  - with quantized FB, fractions of this
- SNR gain can be used to evaluate expected throughput on the capacity level
- Example: 2 Tx, 1 Rx (Narula & al.)
  - 1 bit: SNR gain 1.5
  - 2 bit: SNR gain 1.82
- In multistream MIMO, less straight forward.
  - metric: multistream capacity or throughput
  - depends on receiver

Basis of CQI: An MCS set



AMC performance

- Gain from AMC: tuning the transmission method to channel condition (CQI)
- Metric: Expected throughput
  - typically analyzed assuming a fixed MCS set
- Use of Information theory:
  - Shannon capacity: infinite MCS, infinite length codes
    - with finite MCS, achievable capacity can be assessed
  - Performance of finite length codes can be addressed with random coding bounds $\longrightarrow$ throughput measure
    - tight bound at high SNR
    - assuming low BLER requirement, viable approach
    - with no or high BLER requirement, not viable
- For finite MCS and generic SNR, better modeling of code performance is needed $\Rightarrow$ S. Lembo's talk

HARQ performance

- Gain from HARQ: possibility to use more aggressive MCS selection to meet a BLER target
  - BLER operation point becomes high
  - info theoretical modeling (Random coding etc) does not apply
- Metric: Expected throughput
- Performance of HARQ usually addressed by simulation
  - fixed MCS set

Value of Precoding FB bit

MIMO Precoding with Linear Receiver

- Linear MIMO Precoding: beamforming for multistream MIMO:

$$\mathbf{y} = \mathbf{H}\mathbf{W}\mathbf{x} + \mathbf{n}$$

- Capacity with linear receiver as a function of k-stream post-processing signal-to-interference-noise ratio γ_k

$$C = \sum_{k=1}^{N_s} \log_2(1+\gamma_k)$$

$$\gamma_k = \frac{1}{[\gamma \mathbf{W}^H \mathbf{H}^H \mathbf{H}\mathbf{W} + a\mathbf{I}_{N_s}]^{-1}_{k,k}} - a$$

MIMO Precoder Partitioning

- Precoder partitioning [Määttänen & al. WCNC 2008]

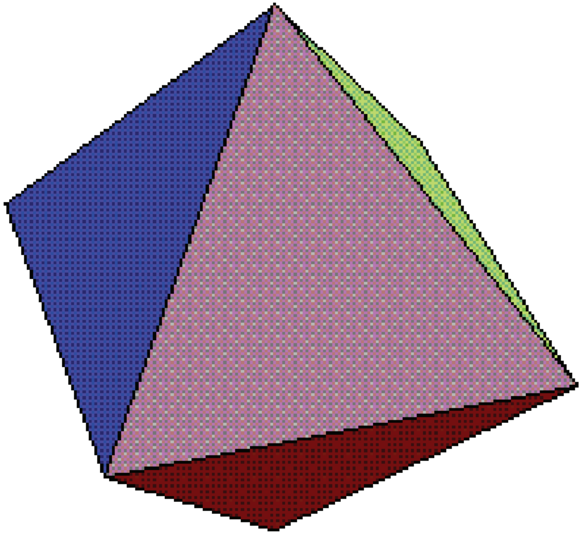
$$\underset{N_t \times N_s}{\mathbf{W}} = \underset{N_t \times N_s}{\mathbf{G}} \underset{N_s \times N_s}{\mathbf{O}} .$$

- $\mathbf{G}$ is Grassmannian part of precoder
  - Target: minimize power transmitted into null space
  - Oblivious to cross-talk (interference) between streams
- $\mathbf{O}$ is orthogonalization part of precoder
  - Target: minimize cross-talk
  - Value depends on receiver
- With finite FB, the precoding spaces need to be quantized
  - Grassmannian line packing problem for $\mathbf{G}$
  - Packing problem on flag manifold up to antenna permutation for $\mathbf{O}$

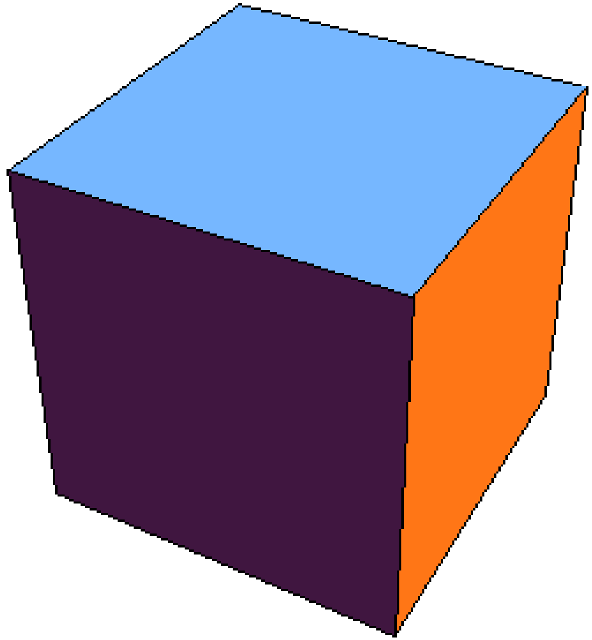
Example: Two Tx Antennas

- Grassmannian part is the two-sphere S^2
- Orthogonalization part is the upper hemisphere of S^2
- Grassmannian beamforming codebooks are unconstrained packings on S^2
- Orthogonalization codebooks are antipodal packings on S^2
  - The two streams may be permuted without loss of generality.
  - Permutations correspond to antipodal points on sphere
- With a small number of bits, best orthogonalization codebooks are Platonic solids

Platonic Solids: 6 & 8 Vertices



Octahedron



Cube

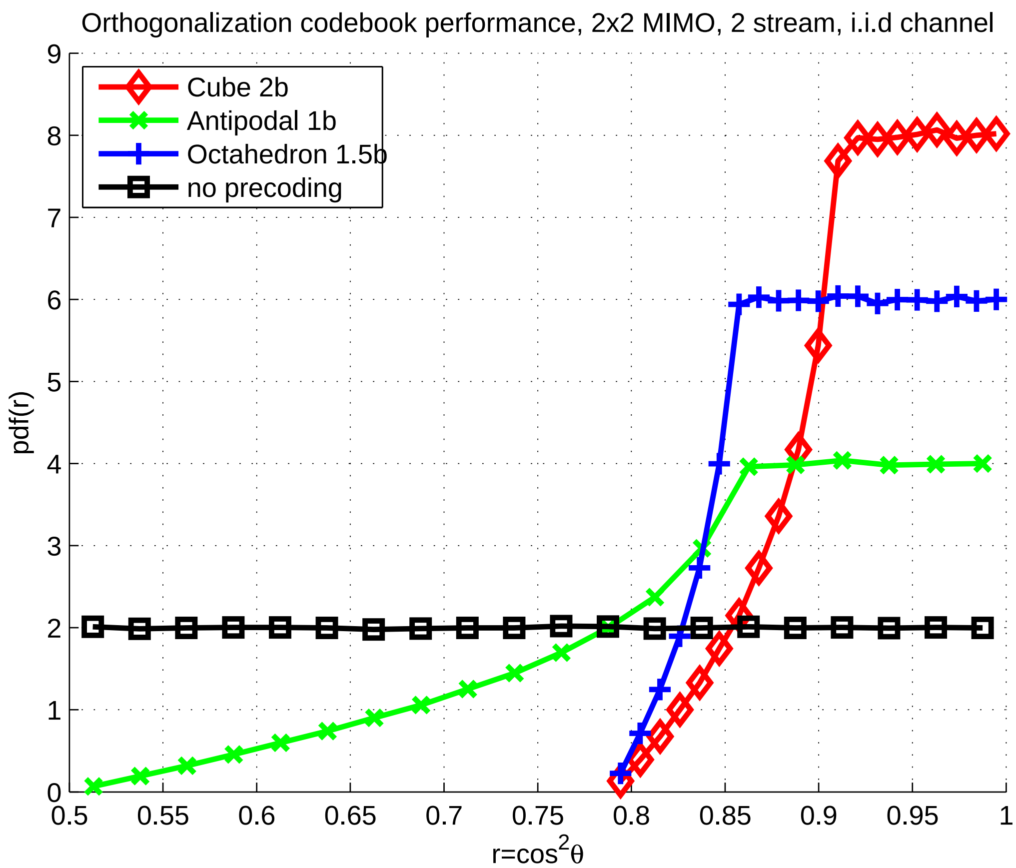
Platonic Solid Codebooks

$$c = \sqrt{1 - s^2} = 0.8881$$

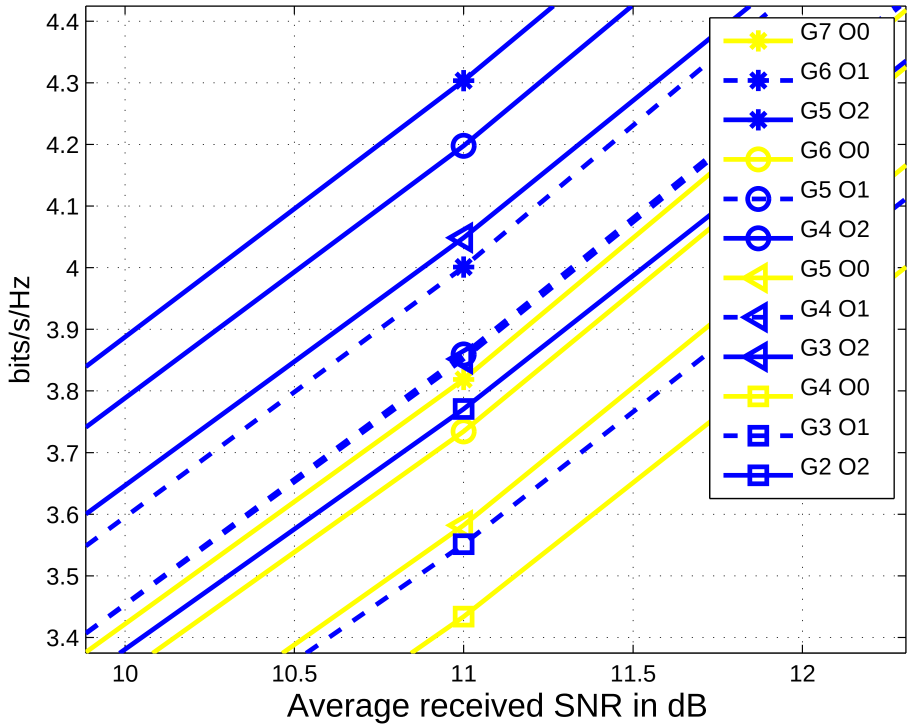
n	Octahedron	Cube
1	$\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$	$\begin{pmatrix} c & s(1-\jmath) \\ s(-1-\jmath) & c \end{pmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$	$\begin{pmatrix} c & s(1+\jmath) \\ s(-1+\jmath) & c \end{pmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ \jmath & -\jmath \end{pmatrix}$	$\begin{pmatrix} c & s(-1-\jmath) \\ s(1-\jmath) & c \end{pmatrix}$
4		$\begin{pmatrix} c & s(-1+\jmath) \\ s(1+\jmath) & c \end{pmatrix}$

- Octahedron CB is used in LTE

Orthogonalization performance



Grassmann vs. Orthogonalization FB

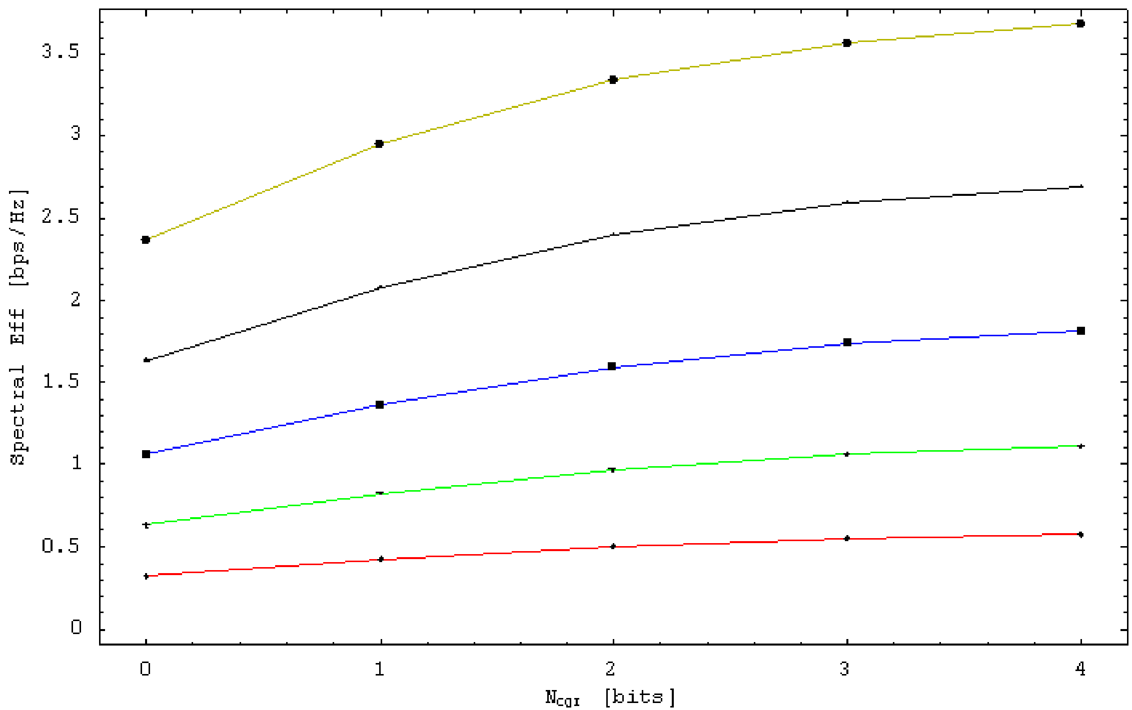


- Strong correlation, Zero Forcing receiver
- Significant gain from proper FB partitioning

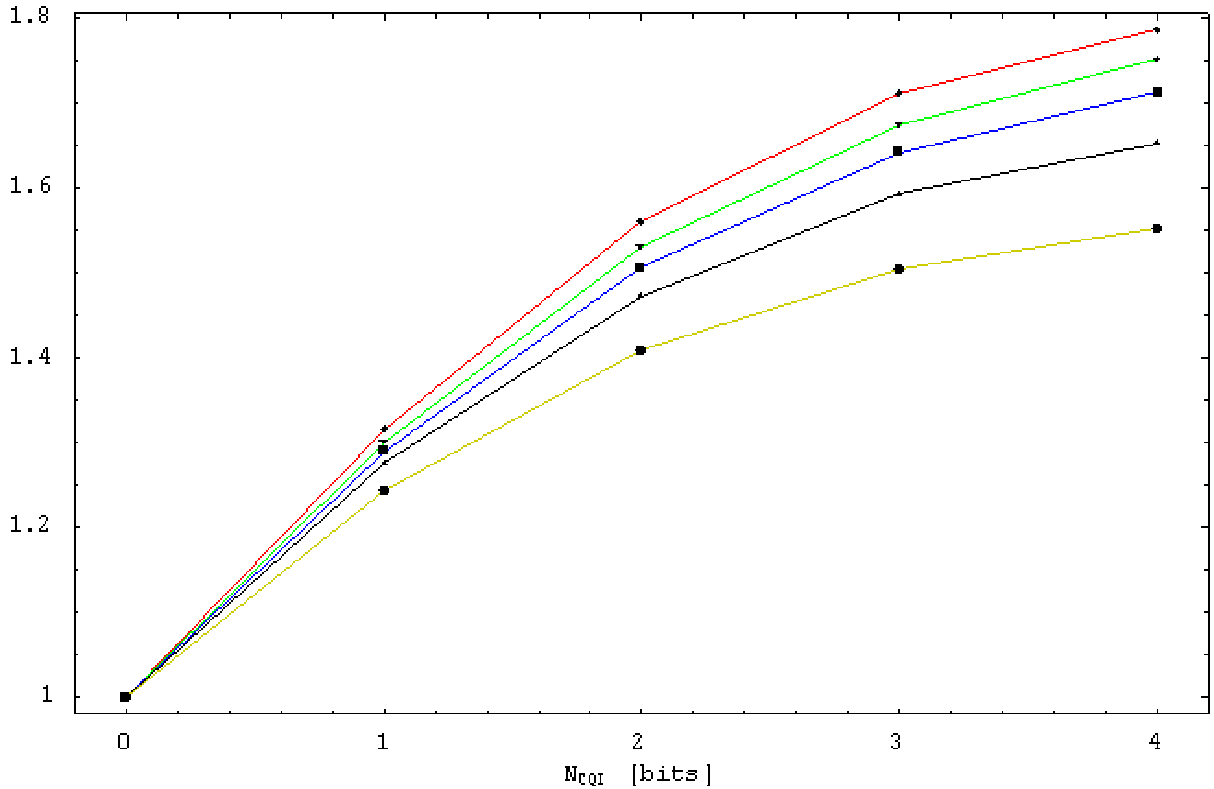
Value of CQI FB bit

Absolute Value of CQI Bit

- With an analytic handle on performance with different rates, optimal MCS sets can be designed [Yu & al., WPMC 2008]
- Example:
  - 1 Tx, 1 Rx, Rayleigh fading
  - CQI FB optimized to average SNR $\gamma_0 = 0, 4, 8, 12, 16$dB



Relative Value of CQI Bit

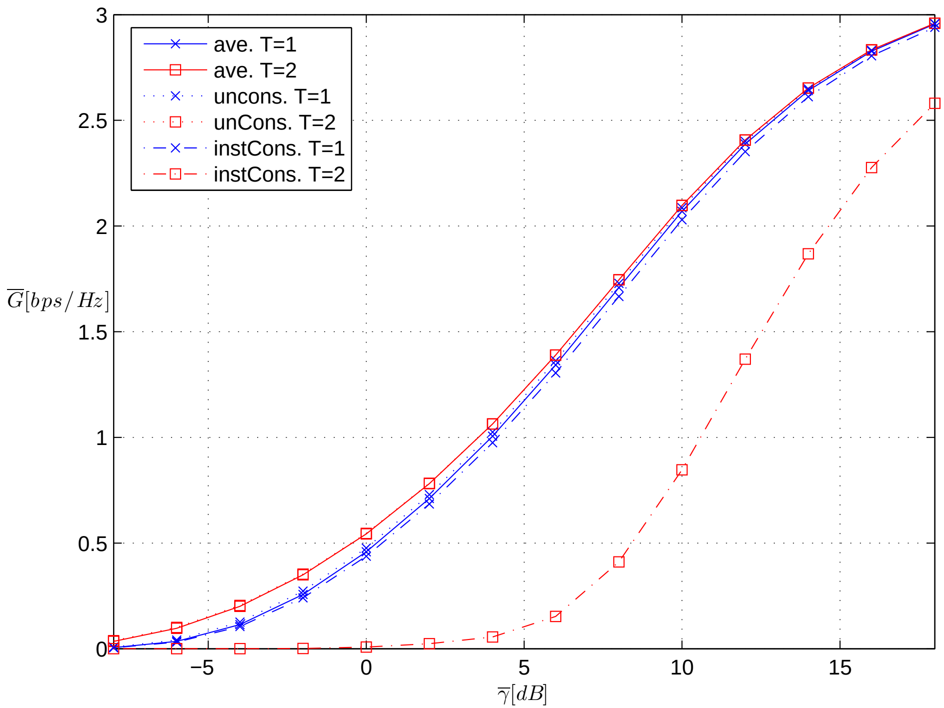


- The relative gain is larger in low SNR
- MIMO scenario ⇒ H. Määttänen's talk

Joint FB Analysis

CQI+HARQ Analysis

- With analytic performance model, joint AMC–HARQ performance can be addressd
  - analytic equations for switching points (requiring numerical solutions)



Summary

- Discussed three kinds of feedback: precoding, CQI, ACK/NACK
- To partition feedback, expected throughput metric only possible
- To make optimality statements, analytical model of FEC needed
- Work in progress: joint FB analysis and partitioning

Thank You!

- Questions?
- Comments?