Quantised Massive Multi User Mimo Ofdm Uplink Using Combiners

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ABSTRACT

Coarse quantization at the Base Station (BS) of a massive Multi-User (MU) Multiple-Input Multiple-Output (MIMO) wireless system provides significant power and cost savings. Coarse quantization also enables significant reductions of the raw analog-to-digital converter data that must be transferred from a spatially separated antenna array to the baseband processing unit. This project investigates the uplink using combiner performance of a quantized massive MU-MIMO system that deploys Orthogonal Frequency-Division Multiplexing (OFDM) for wideband communication.

INTRODUCTION

The effects of coarse quantization at the Base-Station (BS) on the performance of uplink data transmission in a massive Multi-User (MU) Multiple Input Multiple Output (MIMO) system. To enable reliable communication over frequency-selective channels, we develop new methods for (optimal) channel estimation and data detection for the case when massive MU-MIMO is combined with Orthogonal Frequency-Division Multiplexing (OFDM).

This model includes coarse quantization in the analog-to-digital converters (ADCs) at the in-phase and quadrature outputs of each radio-frequency (RF) chain at the BS side.

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Benefits of Quantized Massive MIMO

In conventional multiple-antenna BSs, each RF port is connected to two high-precision ADCs (typically, the in-phase and the quadrature signal components are quantized with resolutions exceeding 10 bit). Scaling such architectures to massive MIMO with hundreds or thousands active antenna elements would result in prohibitively high power consumption and hardware costs, especially for systems operating in the millimeter-wave frequency bands. Since the power consumption of an ADC scales roughly exponentially in the number of quantization bits [1], reducing the precision of the ADCs provides an effective means to accommodate a massive array of active antenna elements, while—at the same time—keeping the power consumption and system costs within desirable limits. Furthermore, the use of low-precision ADCs allows for a relaxation of the quality requirements on the RF circuitry (e.g., low-noise amplifiers, oscillators, and mixers), which enables a further reduction in both the power consumption and system costs. The underlying reason is that RF circuitry needs to operate at precision levels “just above” the quantization noise floor. Apart from power and cost reductions, coarsely quantized massive MIMO also reduces the amount of bits per second that needs to be transferred from the antenna unit (usually located on top of the cell tower) to the baseband processing unit (usually located at the bottom of the cell tower). The deployment of low-precision ADCs at the BS mitigates this data-transfer bottleneck.

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Relevant Prior Art

Massive MU-MIMO promises to increase the spectral efficiency at reduced signal-processing complexity compared to that of conventional, small-scale MIMO systems, and is therefore considered to be a key technology for next-generation wireless systems [2], [3]. Most theoretical results on the performance of the massive MU-MIMO uplink are for the scenario where the base-station is equipped with infinite precision ADCs. The performance impact of low-precision ADCs has been analyzed only recently

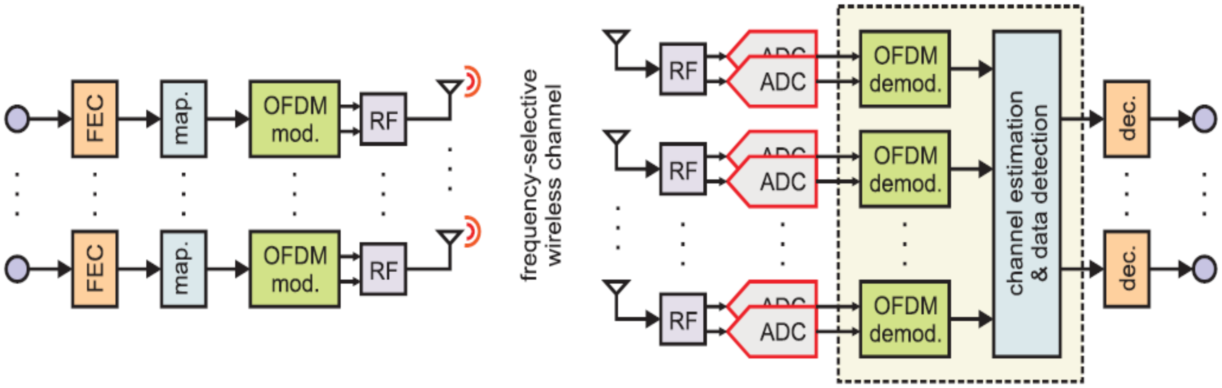


Fig. 1. Overview of the considered quantized massive MU-MIMO-OFDM uplink system. Left: *U* single-antenna user terminals; right: massive MIMO base station with *B* _ *U* antennas and coarse quantization in the analog-to-digital converters (ADCs). The proposed system includes OFDM to simplify communication over frequency-selective, wideband channels.

PROPOSED METHODS :

User terminal (Transmit side):

During the training phase, the data and the pilot tones contain QPSK training symbols that are known to the BS; the guard tones remain unused. During the data-transmission phase, each user encodes its information bits using a forward error correction (FEC) channel code and maps the coded bits.For a given OFDM symbol, the frequency domain transmit vector of each user terminal , which is compactly described by the vector, is converted into the time domain using inverse DFT. the time-domain signals are transmitted simultaneously and in the same frequency band

Base station (Receiver side) :

Each of the antennas at the BS receive a noisy mixture of time-domain user data. Specifically the unquantised time domain received vector at antenna , after removal of the cyclic prefix. The time-domain received vector at each antenna is quantized and then passed to the channel-estimation/data-detection unit.

During the data-transmission phase, the data-detection unit generates LLR values for each coded bit of each user, on the basis of the channel estimates and of the quantized received vectors. The resulting (approximate) information is used to perform decoding.

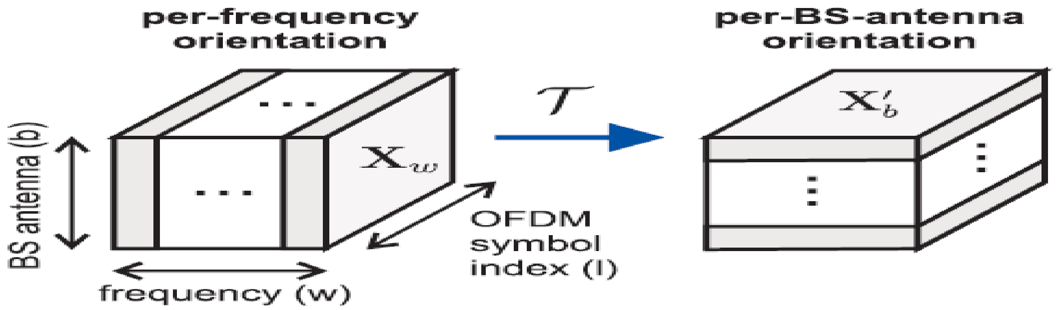
Map channel estimation :

To minimize the negative log-likelihood of the quantized data, given prior information on the channel matrices to be estimated.

MMSE Data detection :

convex-optimization problem involves not only all subcarriers, but also all antennas

Mapping between frequency orientation and base station antenna:



Quantised Massive MU-MIMO-OFDM:

We consider a coded MU-MIMO-OFDM uplink system that employs spatial multiplexing. consists of *independent single-antenna users* communicating with a BS having $B \geq U$ *receiver antennas*. We consider a frame-based OFDM transmission.

We furthermore assume that communication is effected in two phases:

- (i) a training phase *(which enables the training of every* channel coefficient at least once) followed by (ii) a data transmission phase.

Training phase:

During the training phase, the channel-estimation unit generates estimates, for all OFDM tones

The time domain received vector at each antenna is quantised according to :

$$q_b = Q(y_b)$$

And then passed to the channel-estimation/data-detection unit.

Data-transmission phase:

During the data-transmission phase, the data-detection unit generates LLR values for each coded bit of each user, on the basis of the channel estimates and of the quantized received vectors. The resulting (approximate) information is used to perform decoding on a user basis.

Quantization:

The in-phase and quadrature components of an RF-chain's outputs are typically converted to the digital domain using a pair of ADCs. After a sample-and-hold stage, the analog time-domain sample *is mapped onto a finite-cardinality* quantization according *scalar quantizer and is* the complex-valued quantization alphabet.
scalar quantizers that operate independently on the in-phase (real) and on the quadrature (imaginary) part of each sample. we frequently apply the quantizer to a vector/matrix, with the understanding that quantization is applied entry-wise to the vector/matrix.

Mismatched quantization model:

- First mismatched quantization model
- Second mismatched quantization model

First mismatched quantization model:

• Exact quantization model often leads to computationally expensive numerical algorithms that require high arithmetic precision.
• By "mismatched quantization model," we mean that algorithms for channel estimation and data detection are developed on the basis of a quantized input output relation that does not match the exact one given in Obviously, such a mismatch yields an error-rate performance loss

Second mismatched quantization model:

• A second mismatched quantization model which yields a significant complexity reduction for channel estimation and data detection The key idea is to replace the noise vector,whose entries are independent but not identically distributed.

• For the second mismatched quantization model the MAP channel estimation and the MMSE data detection problems simplify drastically. Specifically, after a DFT operation at the receiver.

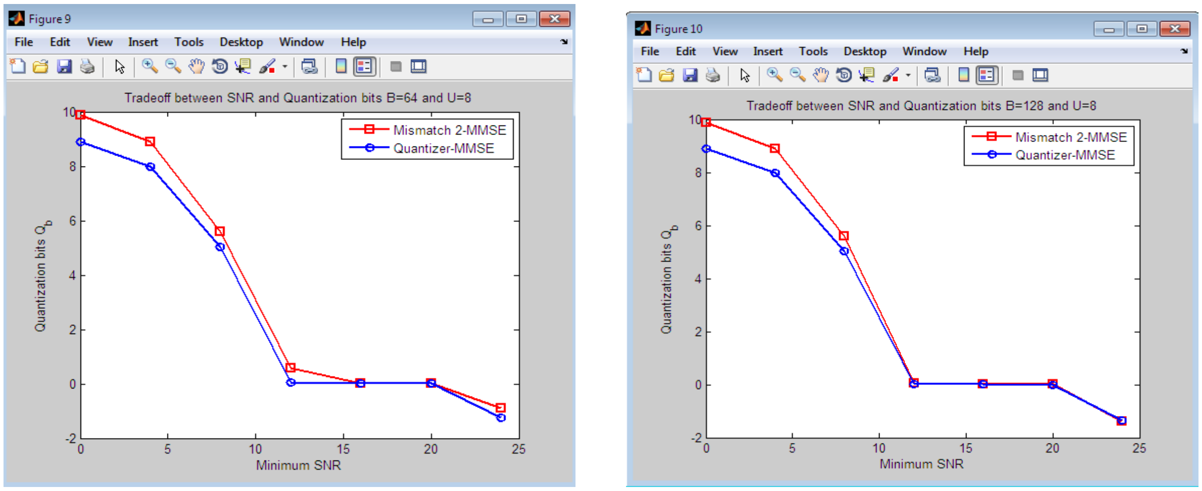
- 16 BS antennas and 8 users (corresponding to a BS-antenna-to-user ratio of 2). We see that “Quantizer” outperforms both “Mismatch 1” and “Mismatch 2”. The system is not able to reach a PER of 1%. “Mismatch 2” outperforms both “Quantizer” and “Mismatch 1”; this is because in “Mismatch 2” it is possible to compute the post-equalization SNR values for output computation

- Increasing the number of BS antennas to 32 (corresponding to a BS-antenna-to-user ratio of 4), enables “Quantizer” and “Mismatch 2” to achieve a similar SNR operating point . *This shows that the* LLR approximation is accurate for such a BS-antenna-to-user ratio. In this regime, one should use the “Mismatch 2” receiver architecture as it does not entail a complexity increase compared to conventional algorithms for infinite-precision MU-MIMO-OFDM systems. For lower values of *Qb, however, “Quantizer” significantly outperforms* “Mismatch 2” (we do not show “Mismatch 1” as it exhibits similar performance to

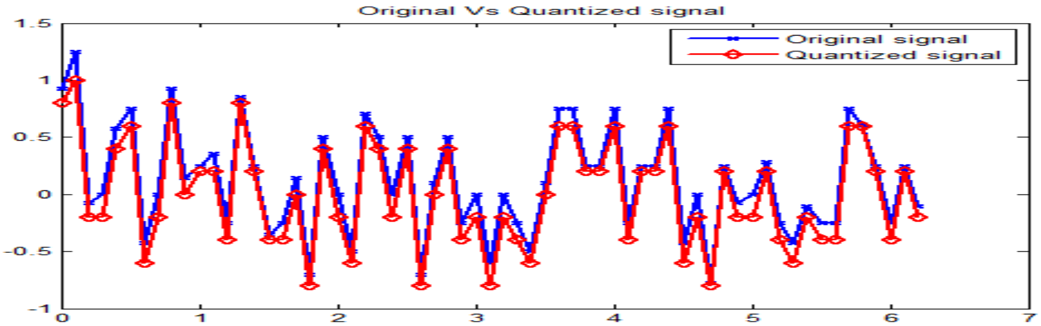
RESULTS SUMMERY:

“Quantizer”). Also note that with “Quantizer,” we are now able to achieve 1% PER for only two quantization bits (i.e., *Qb* = *2).*

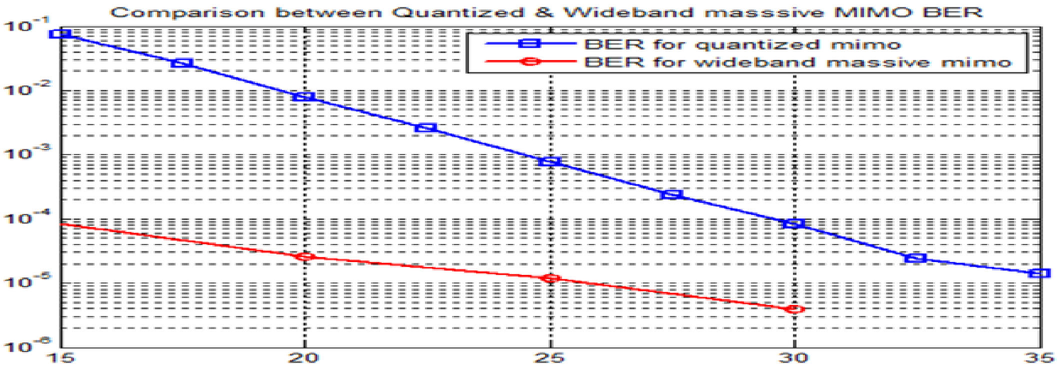
- Further increasing the BS-antenna-to-user ratio to 8 and 16, respectively, “Mismatch 2” delivers the same performance as “Quantizer.” In addition, we see that for both receiver architectures, *Qb* = *4* yields an SNR gap to the infinite-precision ADC case of only 0*.25 dB. Furthermore, the SNR* is less than 1 dB. All these observations have far reaching consequences for quantized massive MU-MIMO-OFDM systems with BS-antenna-to-user ratio exceeding 8. In particular, we see that the simple and low-complexity “Mismatch 2” receiver architecture achieves near-optimal performance with only 4 bit precision at virtually no complexity increase in baseband processing compared to infinite-precision MU-MIMO-OFDM systems



Tradeoff between SNR and Quantization bits B=16 and U=8



Original Vs Quantized signal



Comparison between Quantized & wideband massive MIMO BER

Conclusion:

Simulation results show that the use of four-bit ADCs is sufficient to achieve near-optimal performance in massive MU-MIMO-OFDM systems having a BS-antenna-to-user ratio of eight or higher. This comes at no additional costs in terms of baseband-processing complexity, compared to infinite-precision systems. Results imply that coarse quantization enables low-cost and low-power massive MU-MIMO-OFDM system implementations that achieve near optimal performance

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