# Compression of Complex Baseband LTE Signals


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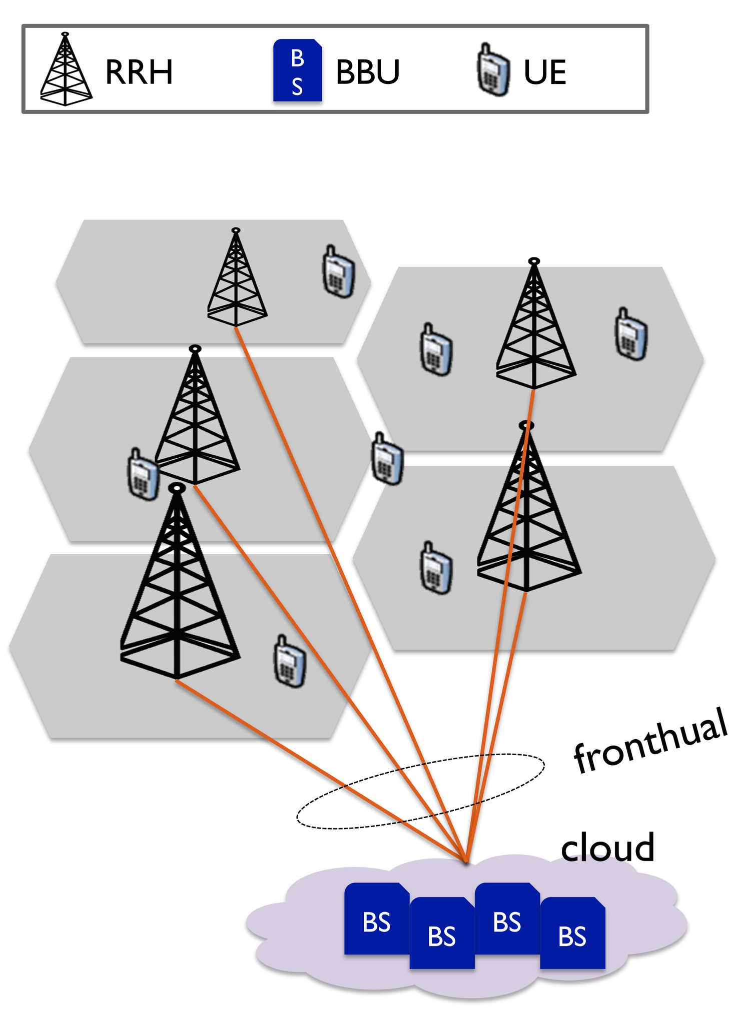
## Motivation

I




Cloud-RAN Model

***Cloud Radio Access Networks (C-RANs)***

- Increase energy efficiency vs. traditional RANs
- Support growing mobile traffic
- Share processing resources in the cloud
- Separate remote radio heads (RRHs) and baseband processing units (BBUs)

***Common Public Radio Interface (CPRI)***

- Uses optical fiber link between RRH and BBU
- Transports complex-baseband wireless samples
- Needs expensive link to support high data rates

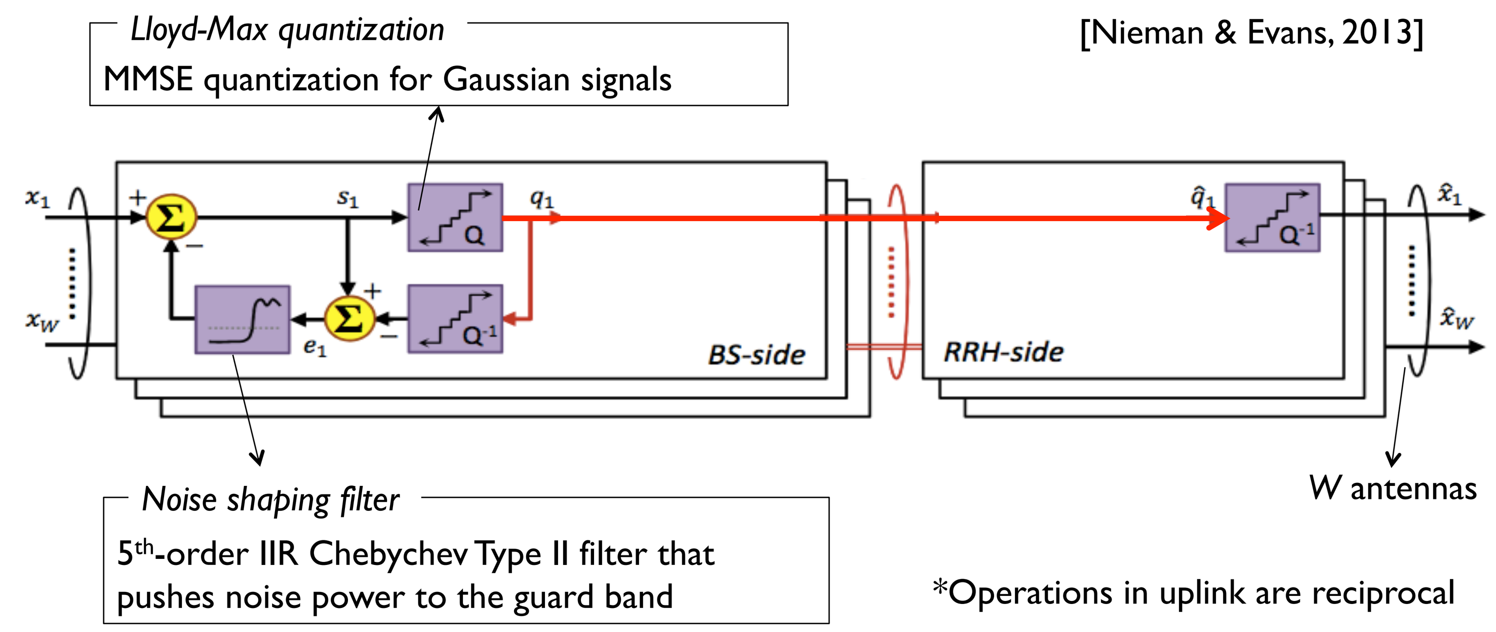
**Data compression is necessary**

**CPRI Data Rates per Sector**

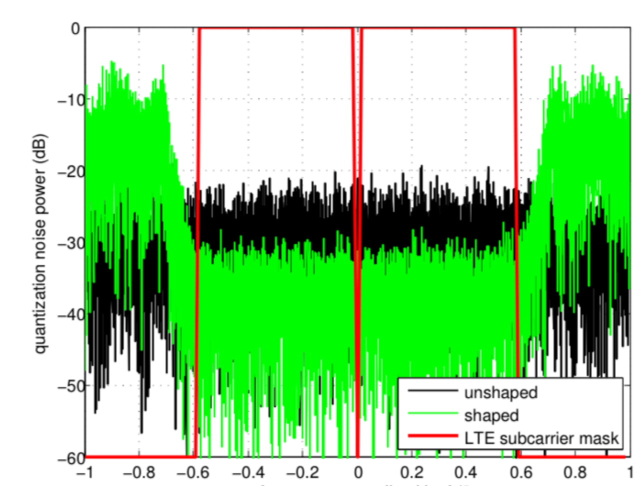
| MIMO Antenna | LTE Bandwidth | |
|---|---|---|
| | 10MHz | 20MHz |
| 2 x 2 | 1.2288 Gbps | 2.4576 Gbps |
| 4 x 2 (4 x 4) | 2.4578 Gbps | 4.9512 Gbps |
| 8 x 2(8 x 4, 8 x 8) | 4.9512 Gbps | 9.8304 Gbps |

## Single Antenna Compression

III




*Operations in uplink are reciprocal



Noise Shaping Effect

***Lloyd-Max Quantization***

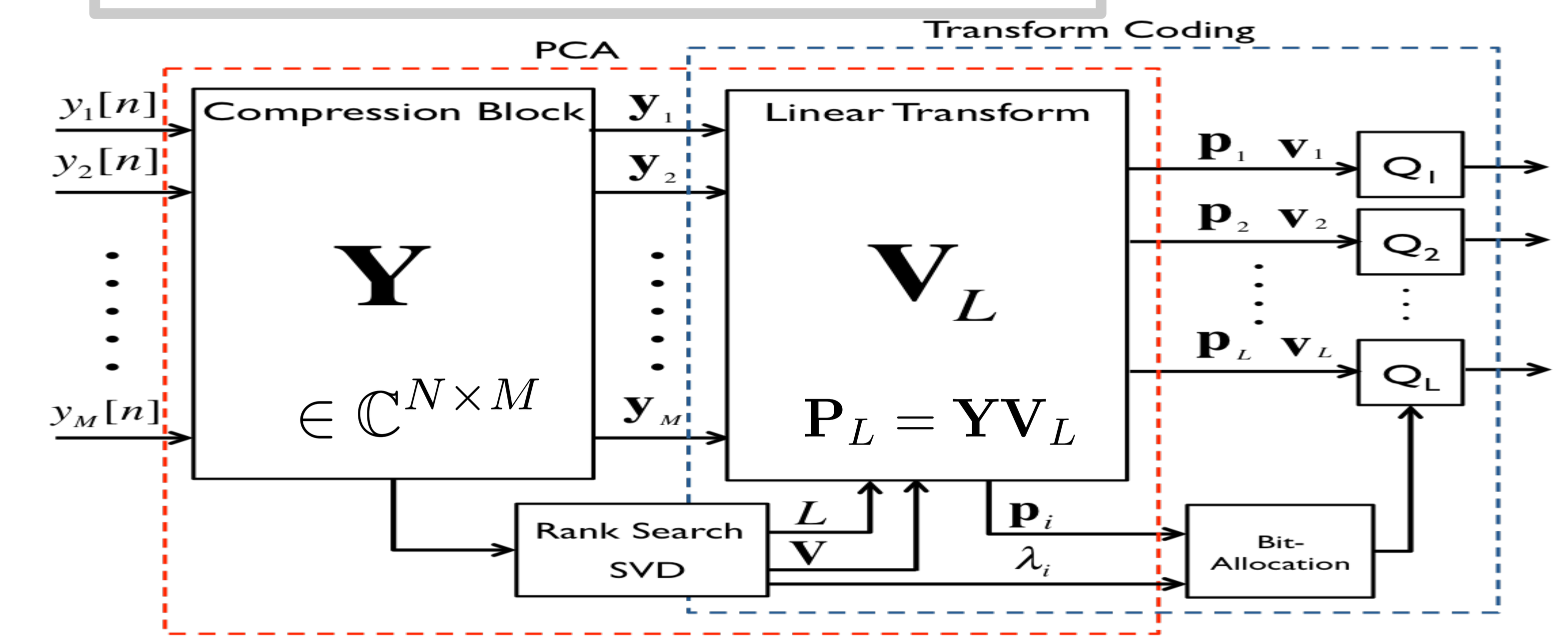
- Minimizes MSE for a probability density function
- Derives quantization levels in closed-form

***Noise Shaping***

- Shapes quantization noise to guard band
- Uses recursive error-feedback
- Increases SQNR

## Multi-Antenna Compression

V




***Principal Component Analysis (PCA)***

- *Low-rank approximation:* $\tilde{\mathbf{Y}} = \mathbf{U}_L \Sigma_L \mathbf{V}_L^H$
- Dimensionality reduction: $M/L$
  - *M* is # antennas
  - *L* is # users x channel state dimension
- *SNR gain due to denoising:* $G_{\mathrm{dB}} = 10\log_{10}\frac{M}{L}$

***Transform Coding with Bit Allocation***

- Performs individual quantization $\mathbf{p}_i$ and $\mathbf{v}_i$
- Minimizes overall weighted mean-squared error
- Uses a simple greedy algorithm

***Compression Rates (CR)***

- PCA – Dimension Reduction

$$CR_{\mathrm{DR}} = \frac{MN}{L(M+N)}$$

- Transform Coding – Bit Allocation

$$CR_{\mathrm{BA}} = \frac{L\, b_{\mathrm{SD}}}{\sum_{i=1}^{L} b_i}$$

- Overall Compression Rate

$$CR_{\mathrm{DRBA}} = \frac{MN\, b_{\mathrm{SD}}}{(M+N)\sum_{i=1}^{L} b_i + b_{\mathrm{QSI}}}$$

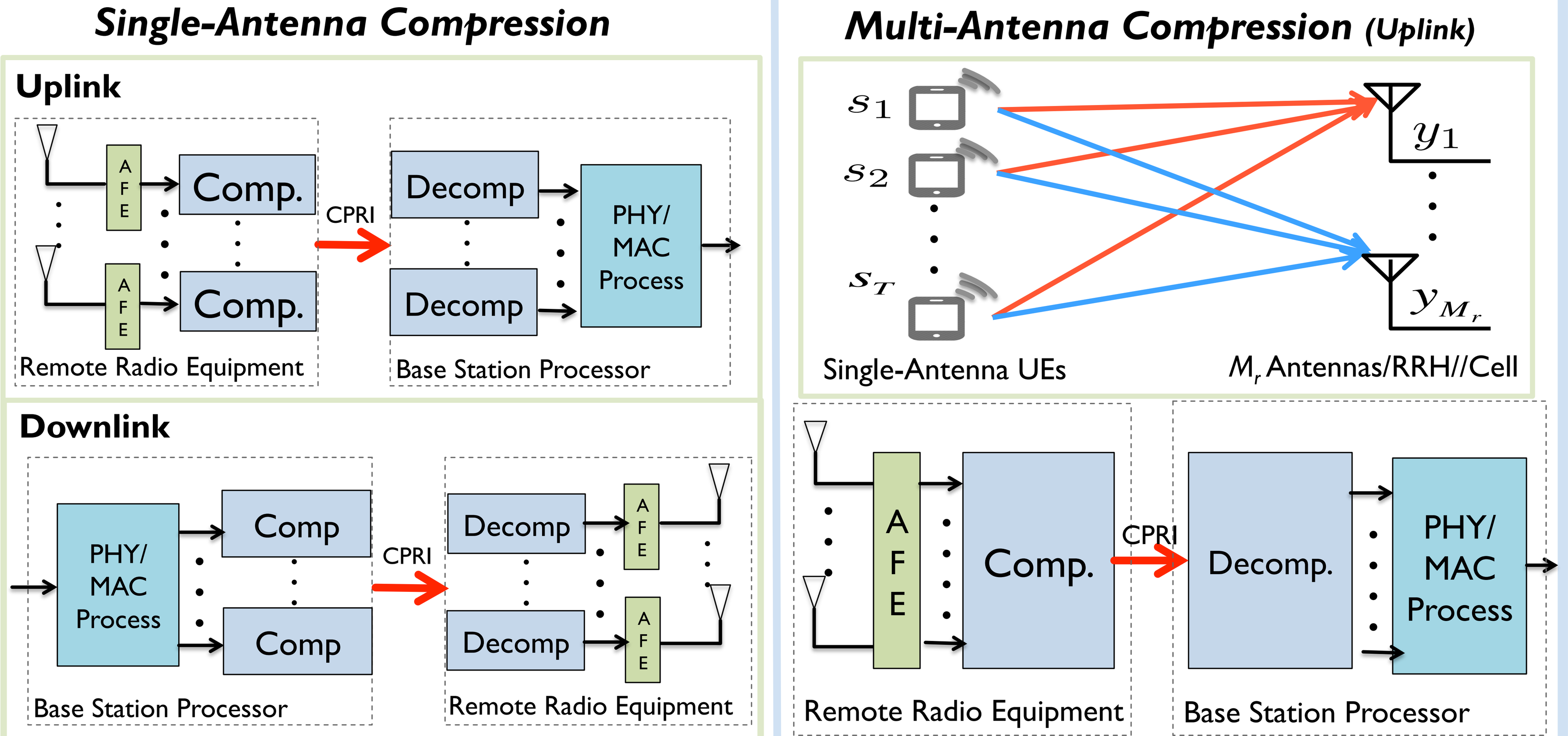
$$b_{\mathrm{QSI}} = L(2b_{\mathrm{SD}} + \log_2 b_{\mathrm{SD}}) + \log_2 M$$

## System Model

II

***Single-Antenna Compression***

***Multi-Antenna Compression (Uplink)***




- Signals (I/Q samples)

$$\left.\begin{array}{l}\sqrt{N}\mathrm{Re}\left(\left[\frac{1}{N}\sum_{k=0}^{N-1} X_k \omega_N^{kn}\right]-\mu\right)\\ \sqrt{N}\mathrm{Im}\left(\left[\frac{1}{N}\sum_{k=0}^{N-1} X_k \omega_N^{kn}\right]-\mu\right)\end{array}\right\} \xrightarrow{d} \mathcal{N}(0,\sigma^2/2).$$

IFFT of M-QAM Symbols; Central Limit Theorem

**Intuition** "Non-Linear Quantization"

- Received Signals

$$y_m[n] = \sum_{t=1}^{T} s_t[n] * h_{m,t}[n] + v_m[n]$$

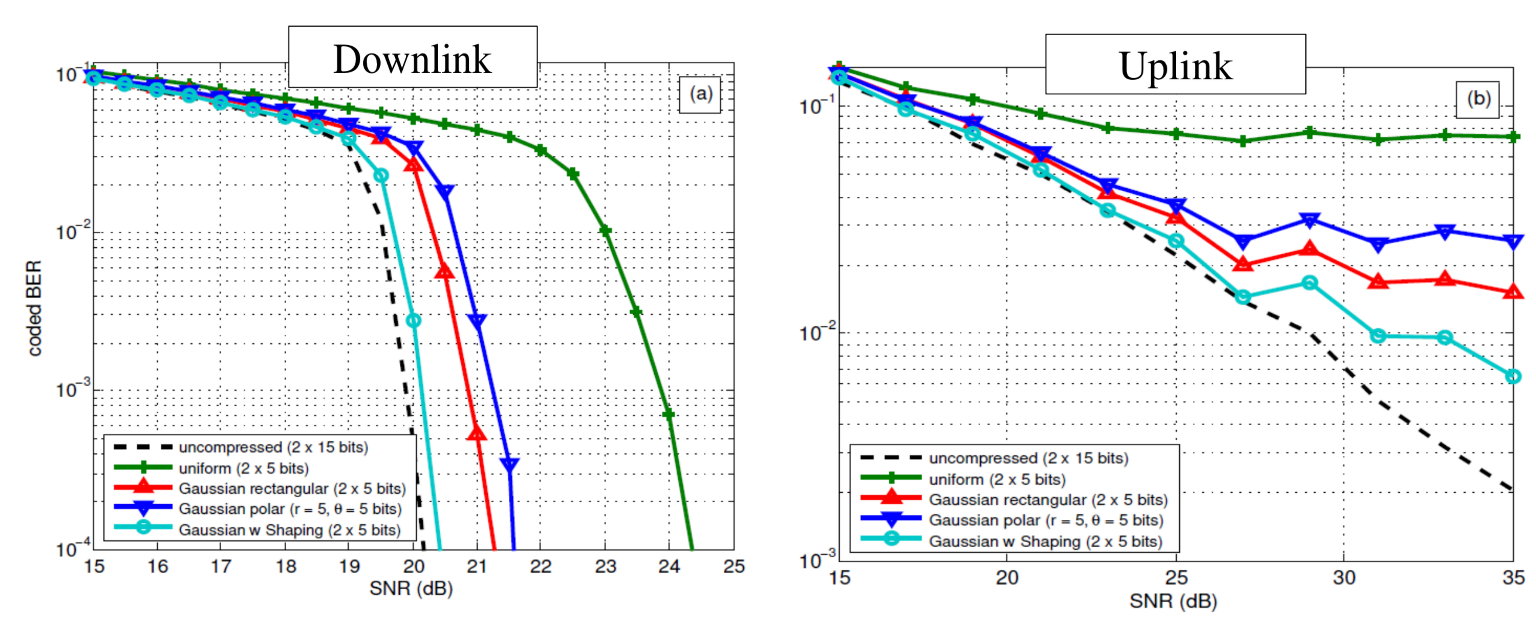
$$m \in \{1,2,\cdots,M_r\}, \quad n \in \{1,2,3,\cdots\}$$

- Small cell size & Multi-Antenna RRH
  ⇨ Correlated Received Signals

**Intuition** "Exploit space-time correlation"

## Validation & Contribution 1

IV




Channel Quality Index (CQI) = 15
Bandwidth = 5 MHz
Ped.A Channel

Channel Quality Index (CQI) = 15
Bandwidth = 1.4 MHz
Ped.A Channel

***Contributions***

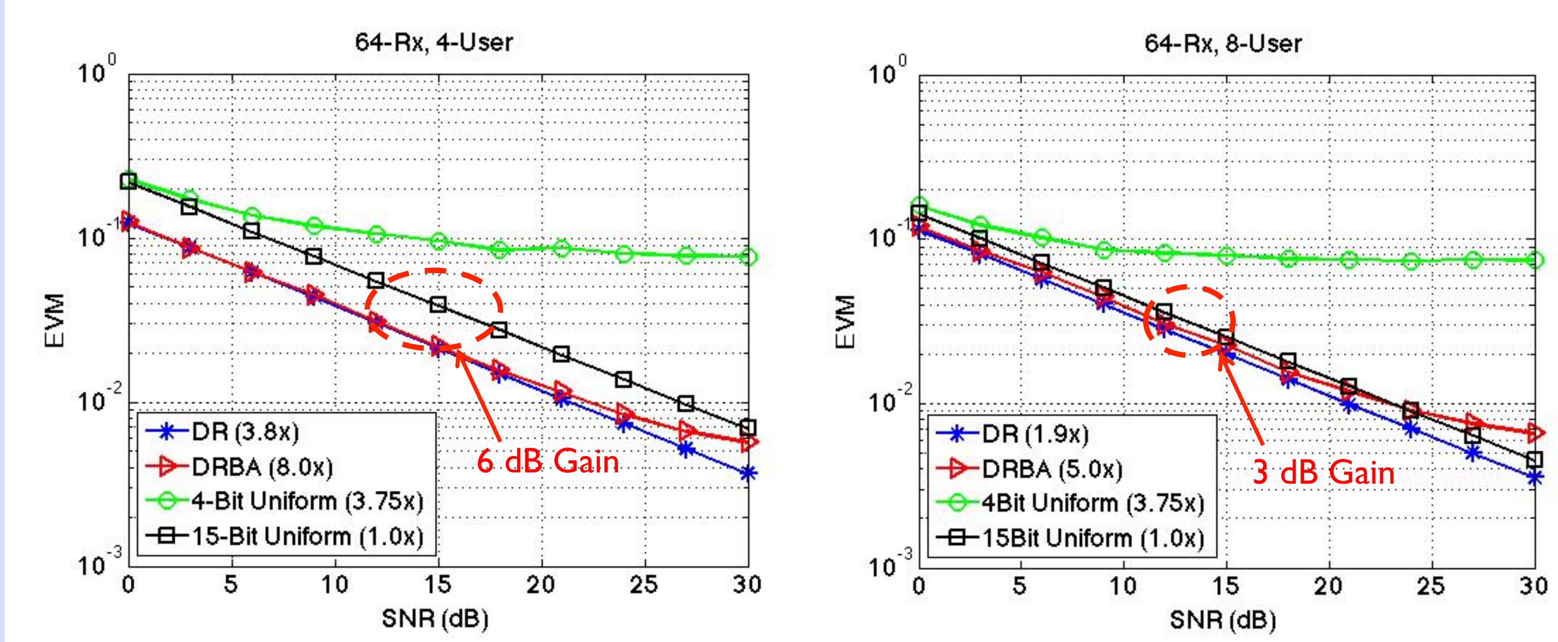
- Achieves 3x compression
- Keeps an error vector magnitude (EVM) < 2%

***Limitations***

- Cannot increase compression rate as the number of antennas increases

## Validation & Contribution 2

VI




*15-Bit Uniform: Non-Compression Case

10MHz Channel Bandwidth w. Ped.A channel model
4 / 8 Users - 12 / 6 blocks each (total 48/50)
64-QAM Modulation
$M_r = 64$, $N_b = 1096$ (1024 + 72 CP)

***Contributions***

- Achieves **8.0x / 5.0x** *compression* for 64-antenna cases with 4 / 8 users
- Achieves **6dB / 3 dB** *SNR gain* – EVM improvement
- Satisfies EVM Requirement for 64-QAM (< 8%)

***Limitations***

- Compression ratio depends on # antennas, # users & channel state dimension
- Low rank matrix is necessary for high compression ratio


http://users.ece.utexas.edu/~bevans/projects/mimo/index.html

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