Time-Domain Compression of Complex-Baseband LTE Signals for Cloud Radio Access Networks

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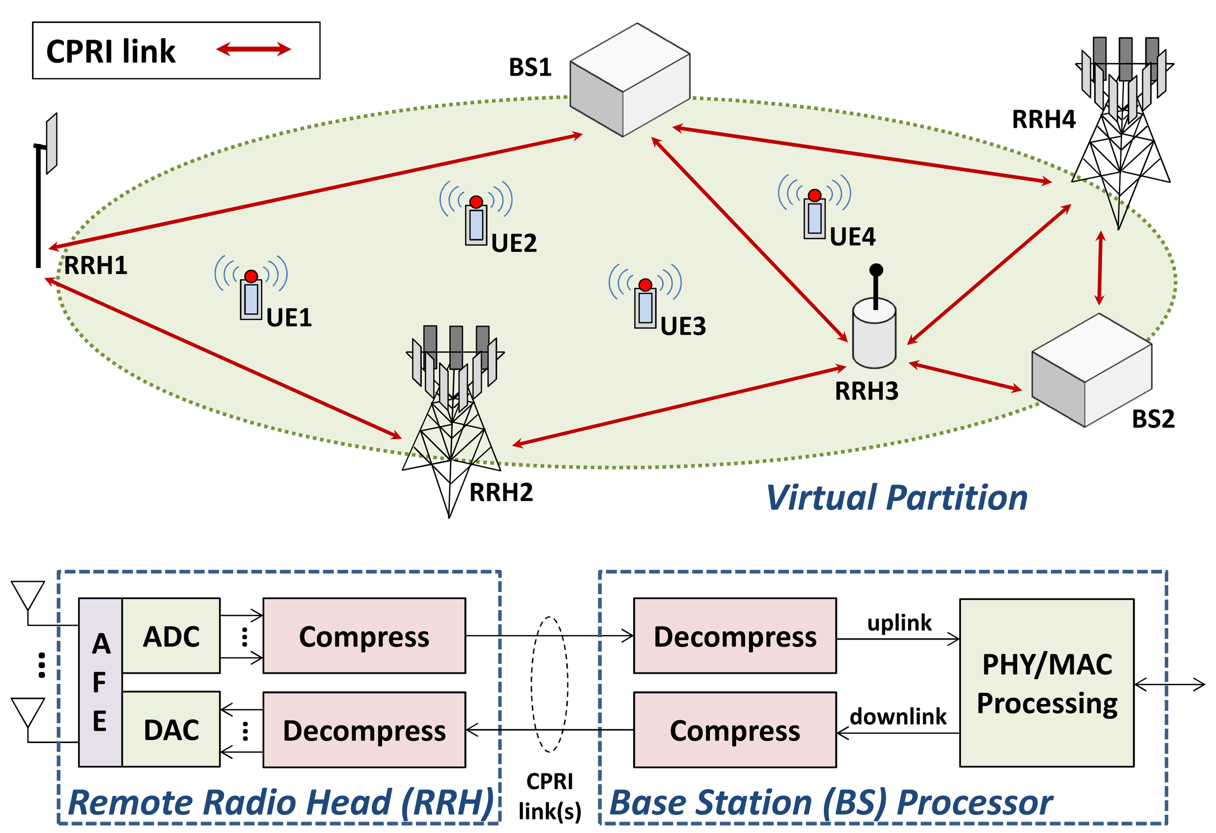
Objective: Achieve 5x compression of complex-baseband wireless signals to reduce cost of deployments for LTE-Advanced and Cloud-RAN.

Cloud Radio Access Networks (C-RANs)



C-RAN with CPRI Link Compression

Cloud Radio Access Networks (C-RANs)

- Increased energy-efficiency vs. traditional RANs
- Static coverage cells are virtualized
- Processing resources are shared in the cloud

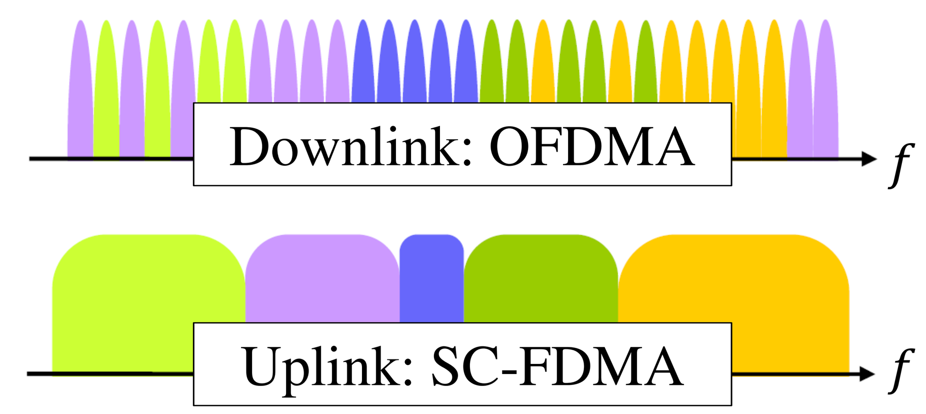
Common public radio interface (CPRI)

- Fiber or copper "backbone" of C-RANs
- Transports complex-baseband wireless samples between basestation (BS) processors and remote radio heads (RRHs)
- >90% of CPRI line bandwidth is used for complex-baseband sample transport

Available CPRI v5.0 Line Bit Rates

CPRI option	1	2	...	6	7
Bit rate (Gbit/s)	0.614	1.229	...	6.144	9.830

LTE-A Signal Structure



- Central Limit Theorem shows OFDMA and SC-FDMA samples converge to complex-Normal distribution:

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

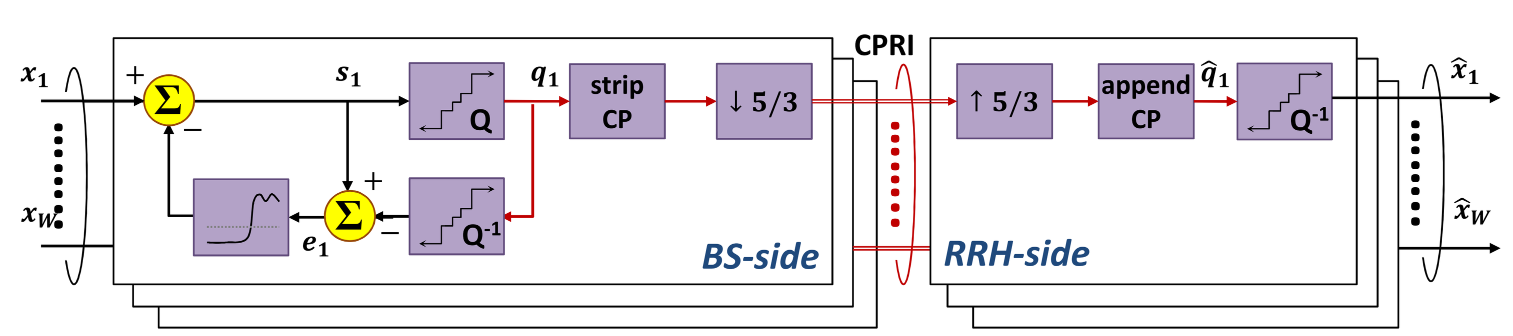
- Time-domain samples are not *i.i.d.* and are correlated due to 1.5× oversampling

Specifications for 5, 10, and 20 MHz LTE Signals

Channel bandwidth (MHz)	5	10	20
Frame duration (ms)	10		
Subframe duration (ms)	1		
Subcarrier spacing (kHz)	15		
Sampling frequency (MHz)	7.68	15.36	30.72
FFT size	512	1024	2048
Occupied subcarriers (incl. DC subcarrier)	301	601	1201
Guard subcarriers	211	423	847
Number of resource blocks	25	50	100
Occupied channel bandwidth (MHz)	4.515	9.015	18.015
OFDM symbols/subframe	7/6 (short/long CP)		
CP length (short CP) (μs)	5.2 (symbol 0)/ 4.69 (symbols 1-6)		
CP length (long CP) (μs)	16.67		

Figure taken from TSI, *LTE in a Nutshell*

Our Approach



Compression in LTE-A MIMO Downlink

Lloyd-Max Quantization

- Minimizes the mean-squared error for a given probability density function
- Can be designed for polar and rectangular complex-Gaussian distributions
- For an L-level quantizer, quantization levels can be derived in closed-form:

Rectangular: $\hat{x}_q = \frac{N\sigma}{\sqrt{2\pi}}\left[e^{-\frac{1}{2}t_q^2} - e^{-\frac{1}{2}t_{q+1}^2}\right] \qquad q = 0, 1, ..., L-1$

Polar: $\hat{x}_q = \sqrt{2\pi\sigma^2}L\left\{\left[\mathrm{erf}\left(\frac{t_{q+1}}{\sqrt{2\sigma^2}}\right) - \mathrm{erf}\left(\frac{t_q}{\sqrt{2\sigma^2}}\right)\right] - \left(t_{q+1}e^{\frac{t_{q+1}^2}{2\sigma^2}} - t_q e^{\frac{t_q^2}{2\sigma^2}}\right)\right\}$

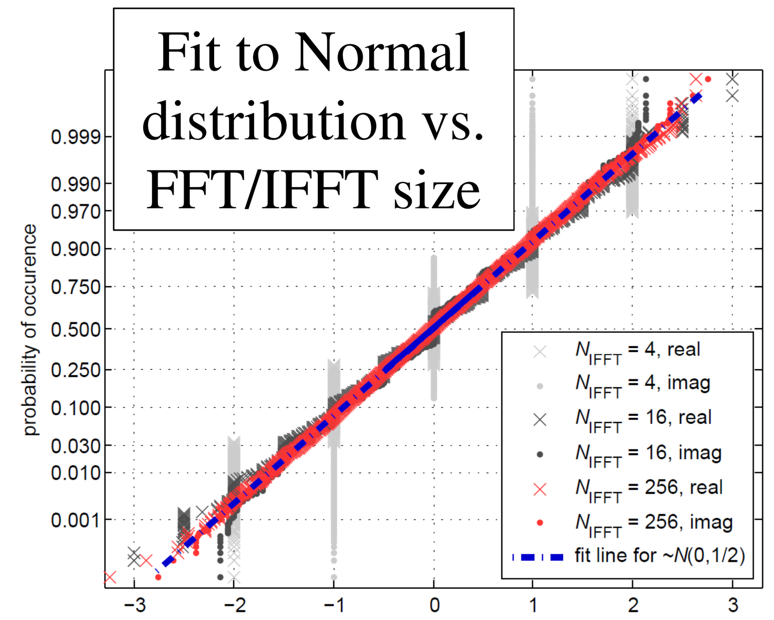
Noise Shaping

- Shape quantization noise to guard bands using recursive error-feedback
- Shaping filter is a fifth order IIR with flat response over passband

Resampling

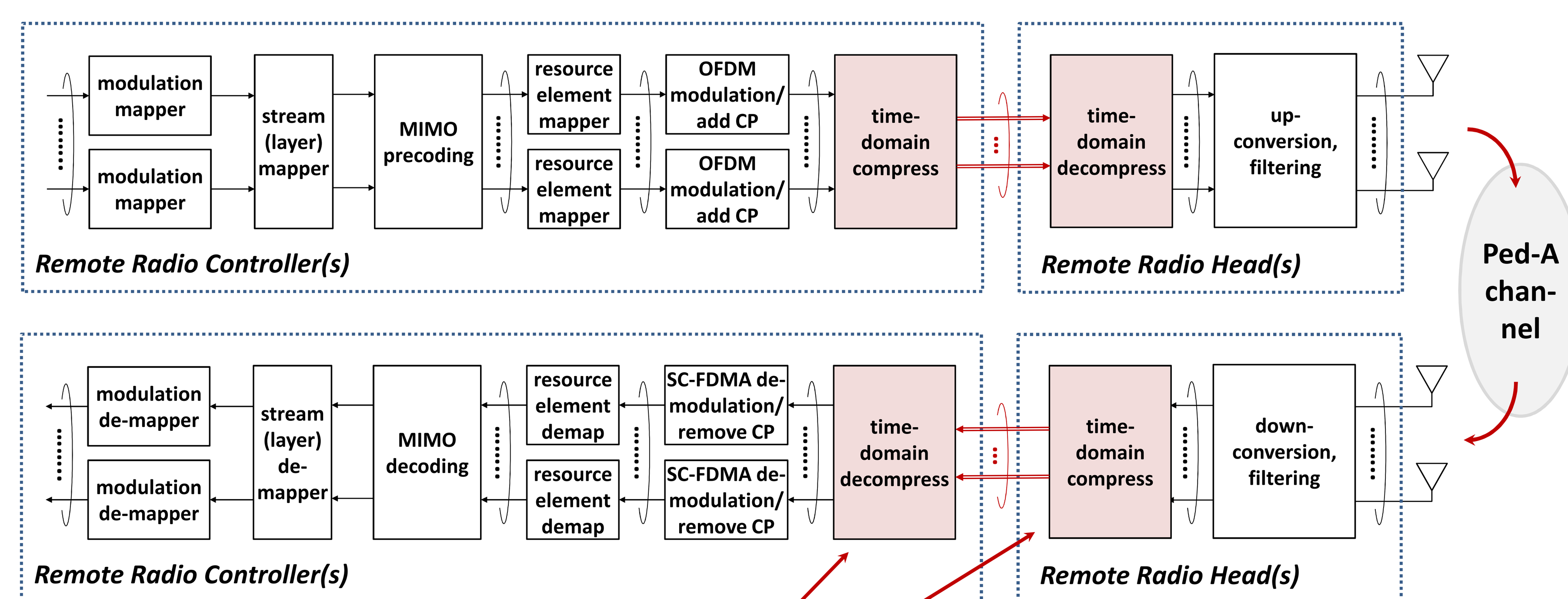
- After quantization, samples can be resampled to the Nyquist rate and cyclic prefix (CP) can be stripped

Fit to Normal distribution vs. FFT/IFFT size



Project website: http://users.ece.utexas.edu/~bevans/papers/2013/LTEcompression/

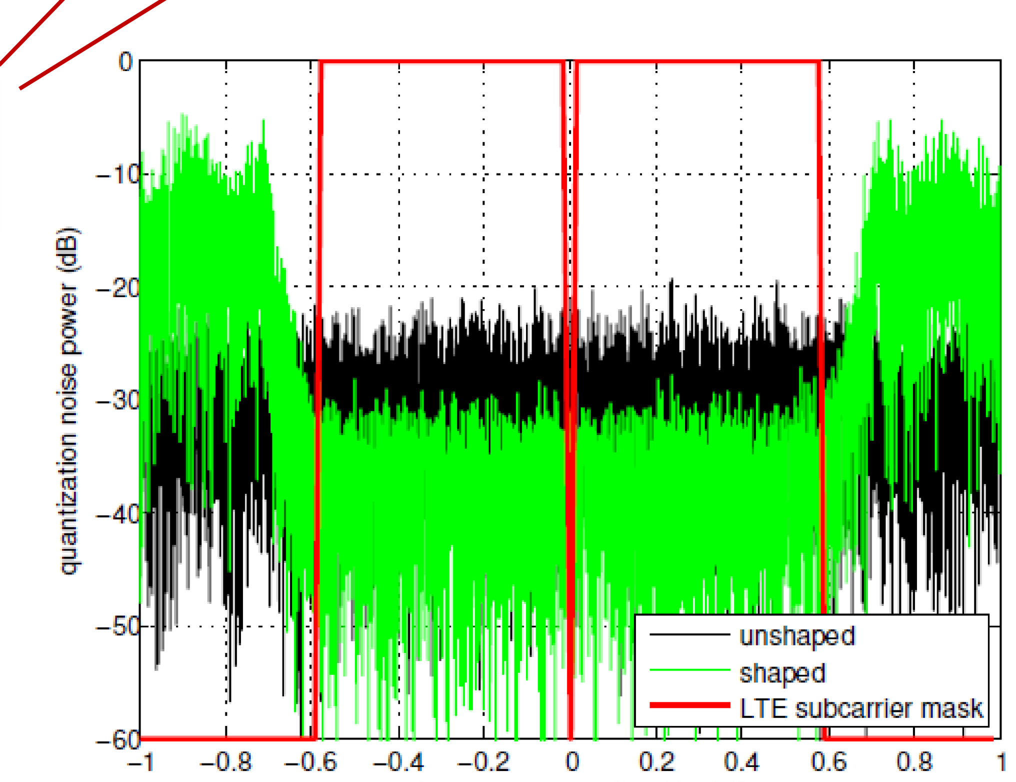
LTE Link-Level Simulator w/ Compression

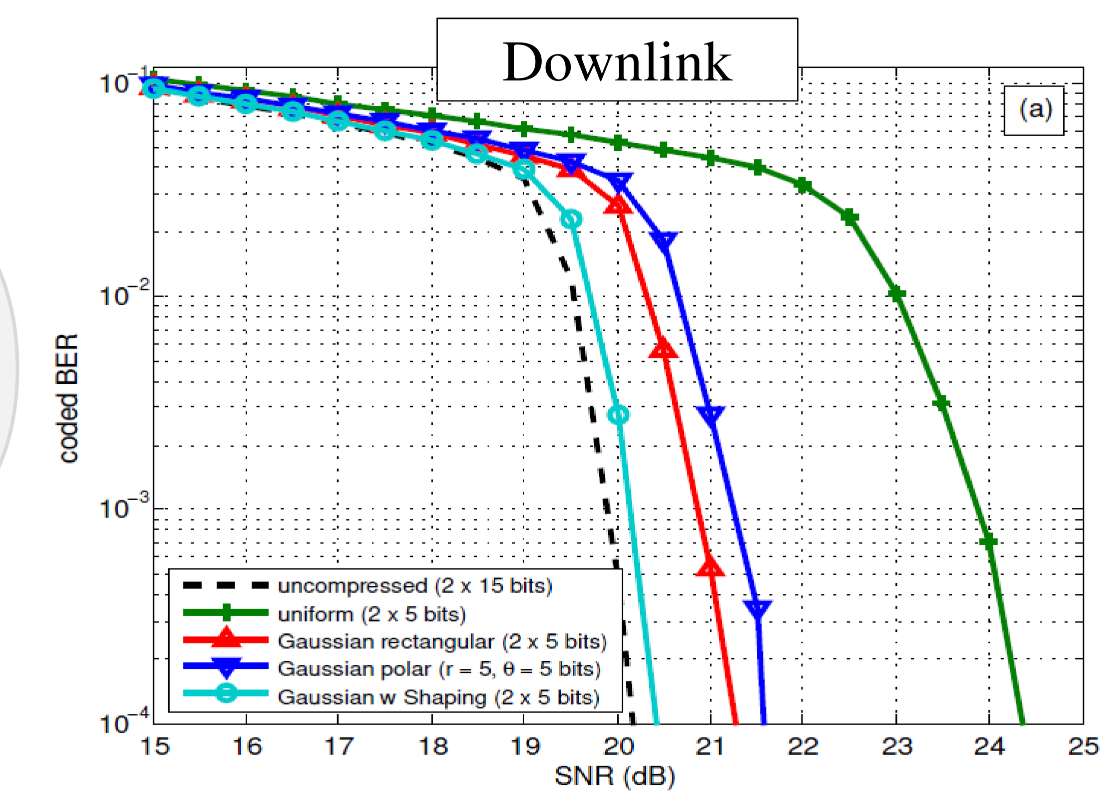


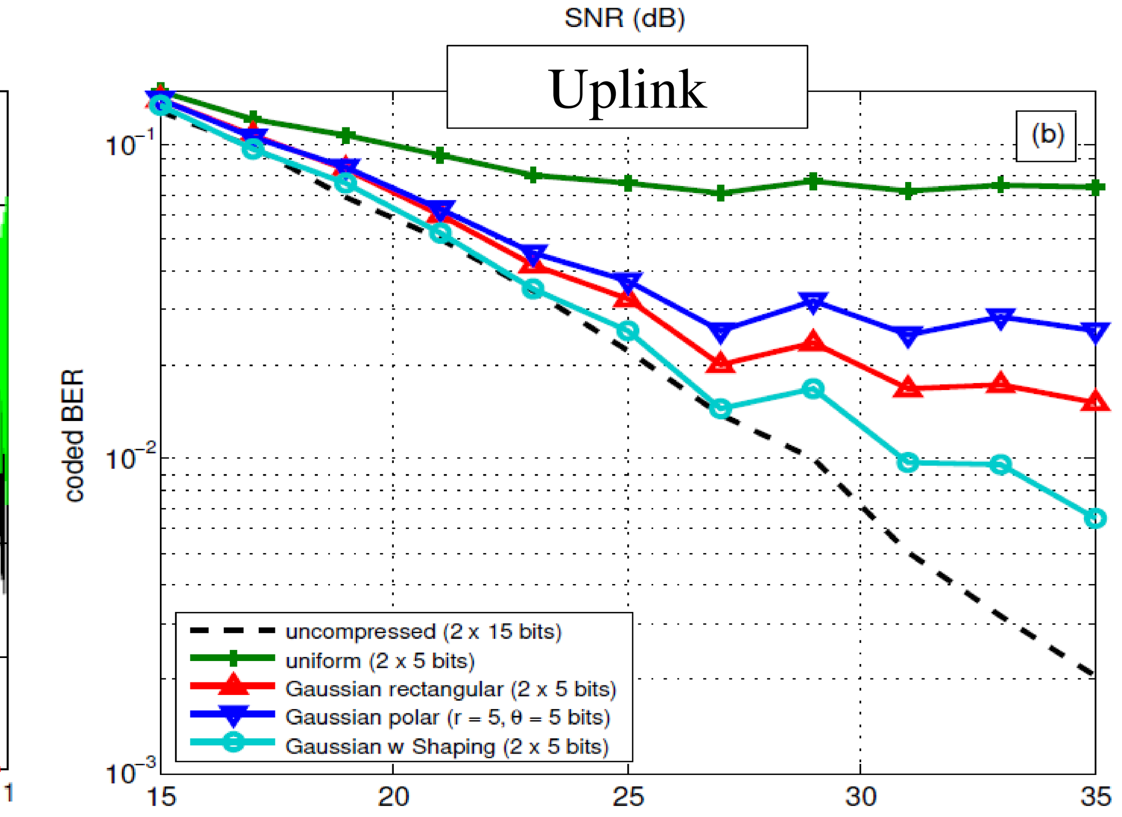
developed using Technical University of Vienna LTE link-level simulators

Compression introduced in link simulator here

- Reduce in-band quantization noise by **9 dB** due to noise shaping
- Achieve 3x compression from noise shaping and Gaussian quantization (see plots on far right)
- Resample and strip CP in downlink
- Achieve **5x** overall compression for downlink and uplink







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