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SC-FDM for Single User MIMO LTE-A Uplink

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Outline

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- SC-FDM for MIMO LTE-A Uplink
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  - → performance with precoded transmission
- Conclusions and future work

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Introduction

3GPP radio access

2003-2004	2006-2007		2009-2010	2012-2015+
WCDMA	HSDPA	HSUPA	LTE	**LTE-A**
384 kbps DL	14 Mbps peak	5.7 Mbps peak	100 Mbps peak DL	**1 Gbps peak DL**
128 kbps UL			50 Mbps peak UL	**500 Mbps peak UL**

DL improvements to WCDMA

UL improvements to WCDMA

→ New access technology

WCDMA: 5 Mhz BW

LTE: up to 20 Mhz BW

LTE-A: up to 100 Mhz BW

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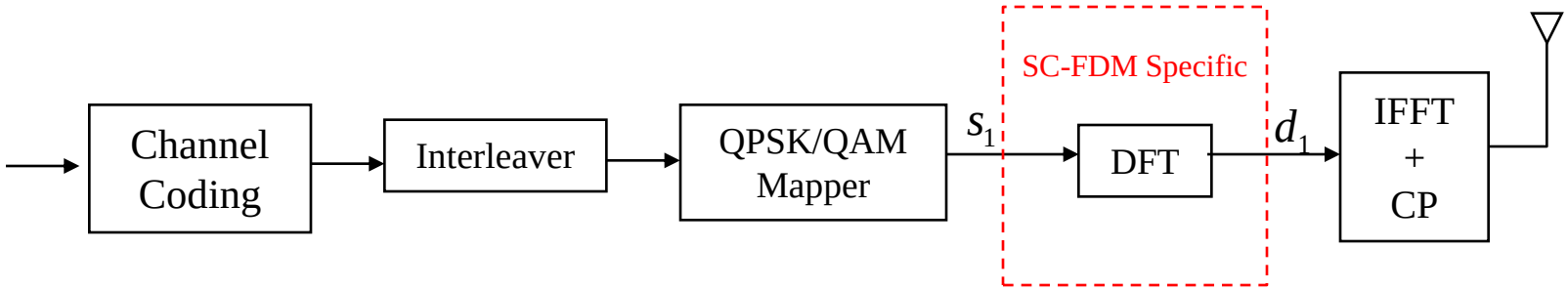
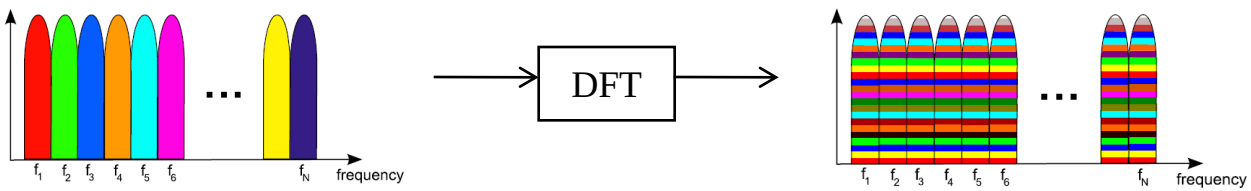
Introduction

LTE		LTE-Advanced	
Downlink	Uplink	Downlink	Uplink
OFDM	SC-FDM	OFDM	**SC-FDM**
SISO 2x2 MIMO 4x4 MIMO	SISO 1x2 SIMO	SISO 2x2 MIMO 4x4 MIMO 8x8 MIMO	SISO **2x2 MIMO** **4x4 MIMO**

SC-FDM as DFT-spread-OFDM

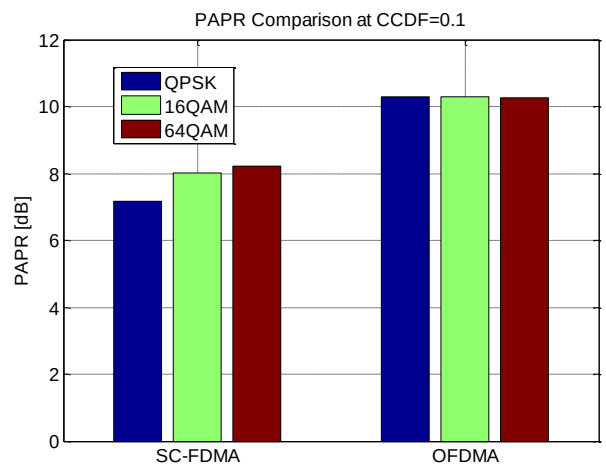


Each data symbol is spread over all the subcarriers by the DFT block.



Main Advantages

- Low PAPR →
- Higher robustness to the doppler shift and the phase noise than OFDM
- Frequency diversity →better uncoded results than OFDM
- Efficient multipath mitigation → as OFDM
- Single Tap equalization → as OFDM



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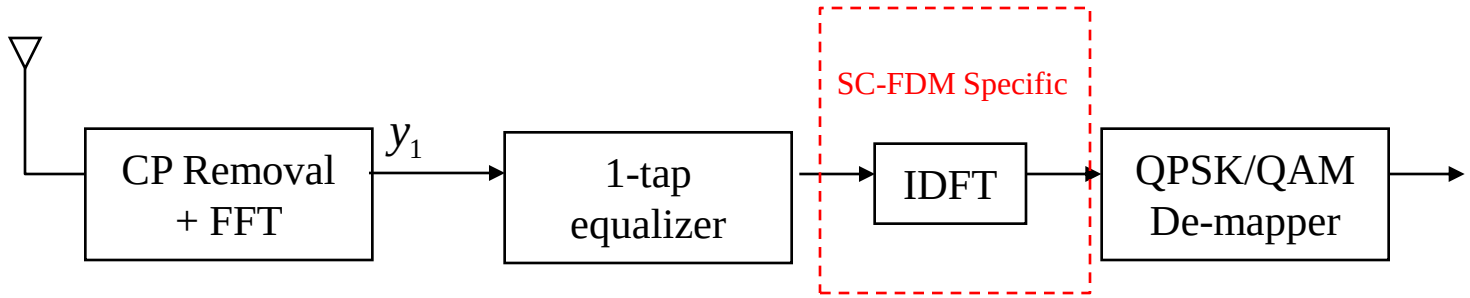
SC-FDM as DFT-spread-OFDM

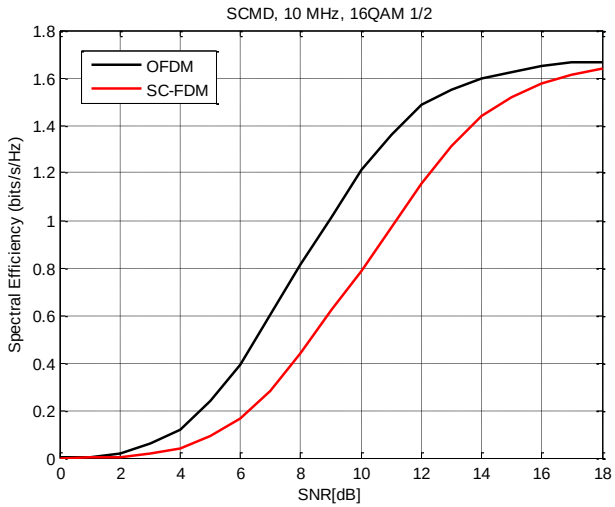
Drawback

- Noise enhancement in the linear receiver



The IDFT block spreads the noise contribution in the faded subcarriers, which is enhanced by the equalizer, over the whole bandwidth.

→ Link level performance gap with OFDM.



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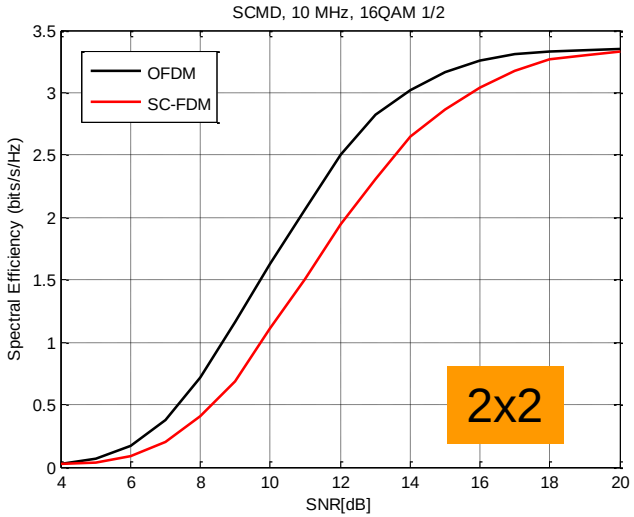
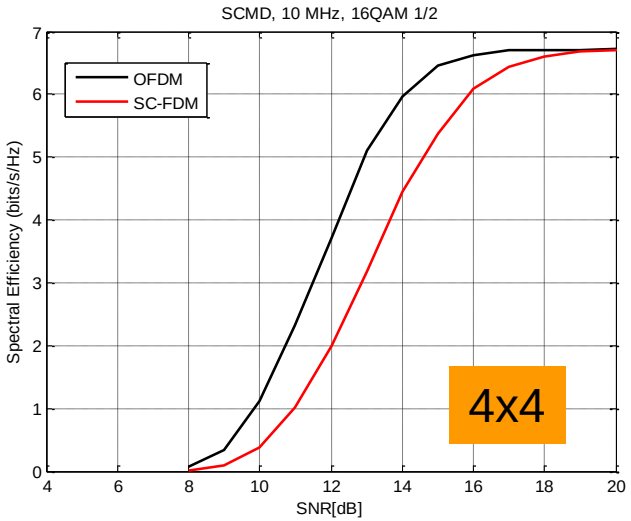
SC-FDM for LTE-A Uplink

- Single User MIMO techniques are expected to take place in LTE-A Uplink.
- The performance losses due to the noise enhancement persists in a 2x2 and 4x4 system.





- However, the MIMO transmission can be exploited to reduce the noise enhancement.
  - **Diversity techniques**
  - **Turbo detection**

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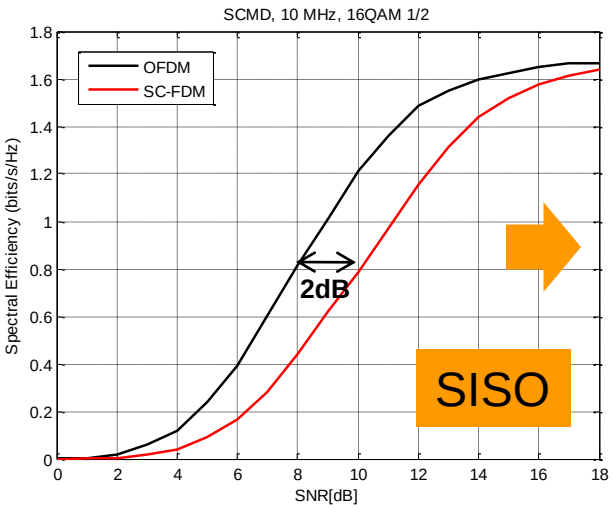
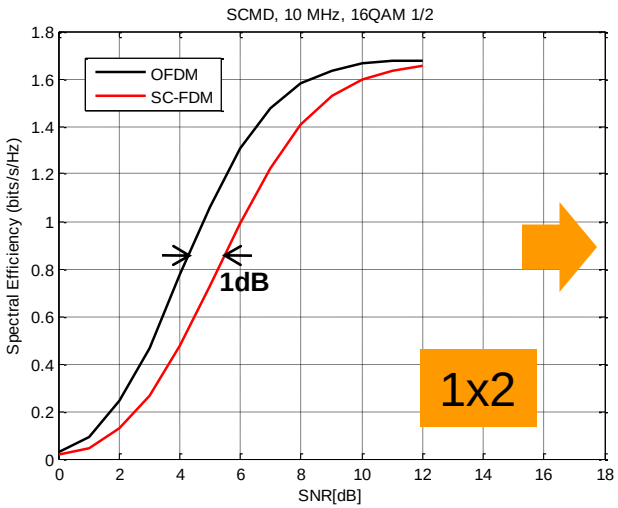
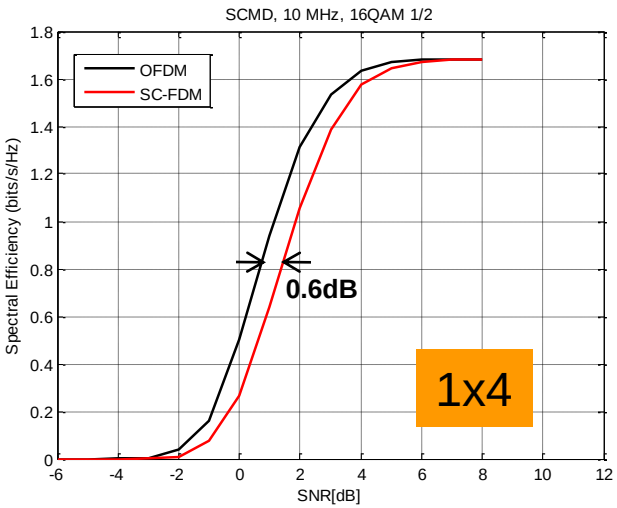
SC-FDM for LTE-A Uplink: diversity

- The increase of the diversity branches allows to average the channel seen at the receiver, smoothing the deep fades and thus reducing the noise enhancement.
- We can obtain diversity gain by adding further receiving antennas, by using Alamouti codes or channel aware closed loop transmission.







SC-FDM for LTE-A Uplink: turbo detection

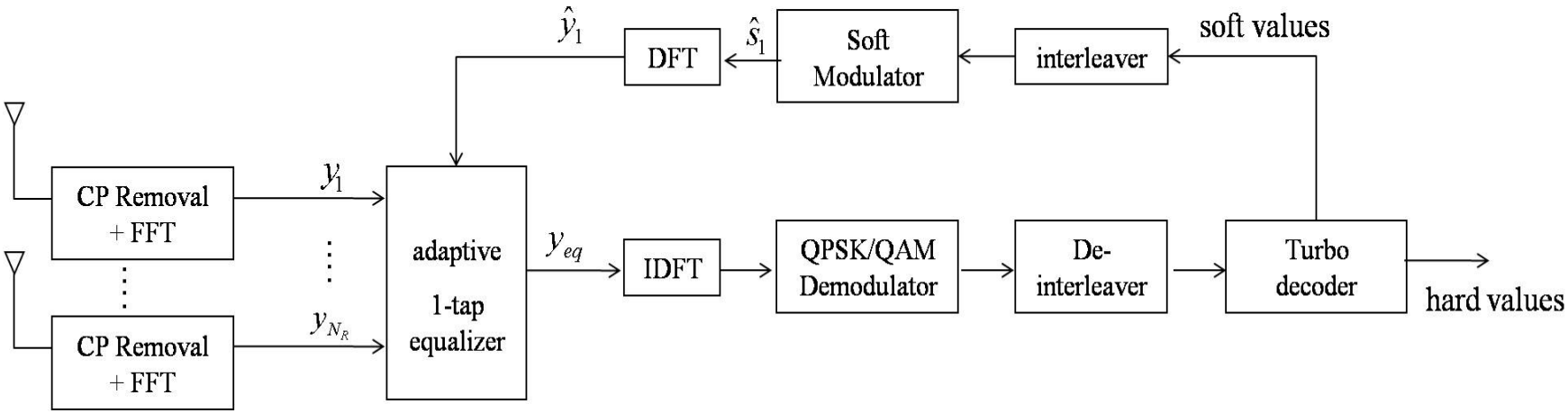
- The turbo receiver aims at reducing the noise enhancement of SC-FDM by performing iteratively the detection process.

→ **single stream turbo receiver**: it adapts iteratively the equalizer coefficients depending on the variance of the estimated sequence in the previous iteration.

→ **multi-stream turbo receiver**: it performs parallel or successive interference cancellation.

SC-FDM for LTE-A Uplink: turbo detection

- Single Stream turbo receiver (turbo equalizer, TEQ)



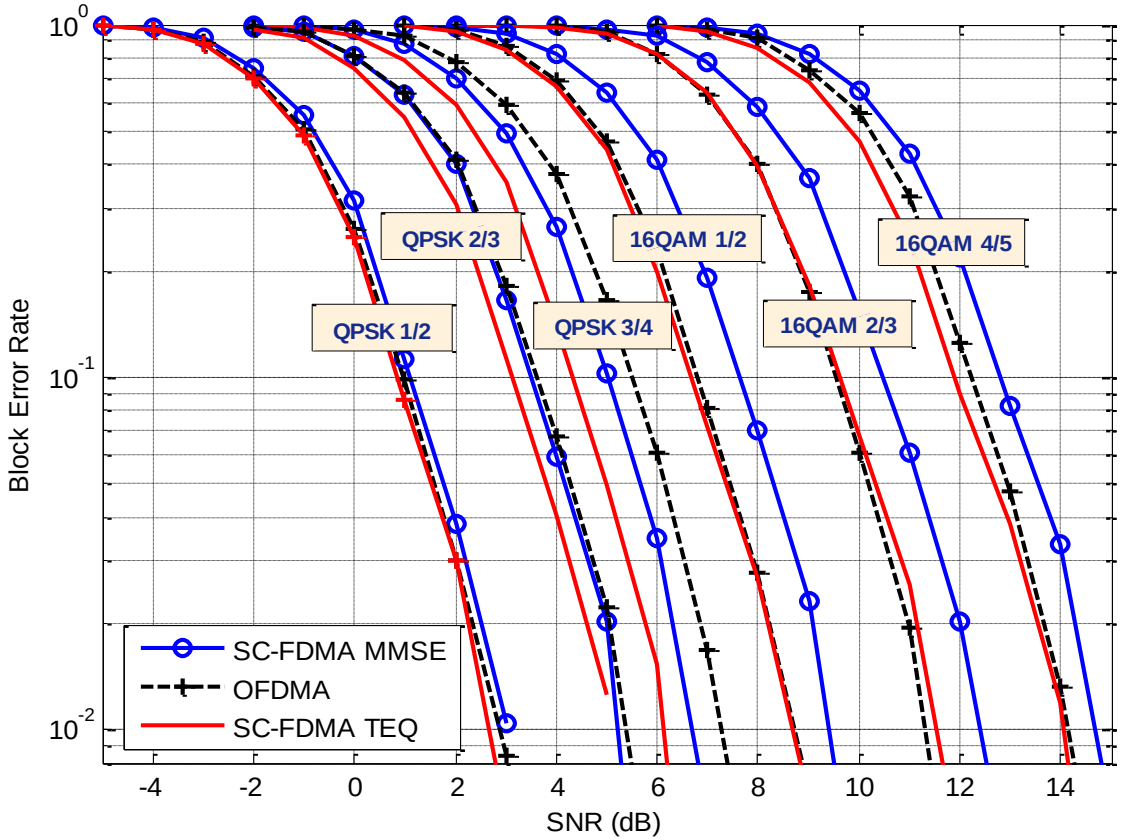
The adaptive equalizer includes in the detection process a previous estimate of the transmitted data sequence, and adapts the coefficients depending on its variance.

Forward coefficients $C_{ff,k}^{(1)} = \frac{\sigma_s^2}{1+\beta\sigma_{\hat{s}}^2} \frac{H_{1,k}^*}{\left(\sigma_s^2 - \sigma_{\hat{s}}^2\right)\left(\left|H_{1,k}\right|^2 + \left|H_{2,k}\right|^2\right) + \sigma_w^2}$ $C_{ff,k}^{(2)} = \frac{\sigma_s^2}{1+\beta\sigma_{\hat{s}}^2} \frac{H_{2,k}^*}{\left(\sigma_s^2 - \sigma_{\hat{s}}^2\right)\left(\left|H_{1,k}\right|^2 + \left|H_{2,k}\right|^2\right) + \sigma_w^2}$

Feedback coefficient $C_{ff,b} = H_{1,k} C_{ff,k}^{(1)} + H_{2,k} C_{ff,k}^{(2)} - 1$

SC-FDM for LTE-A Uplink: turbo detection

- Single Stream turbo receiver

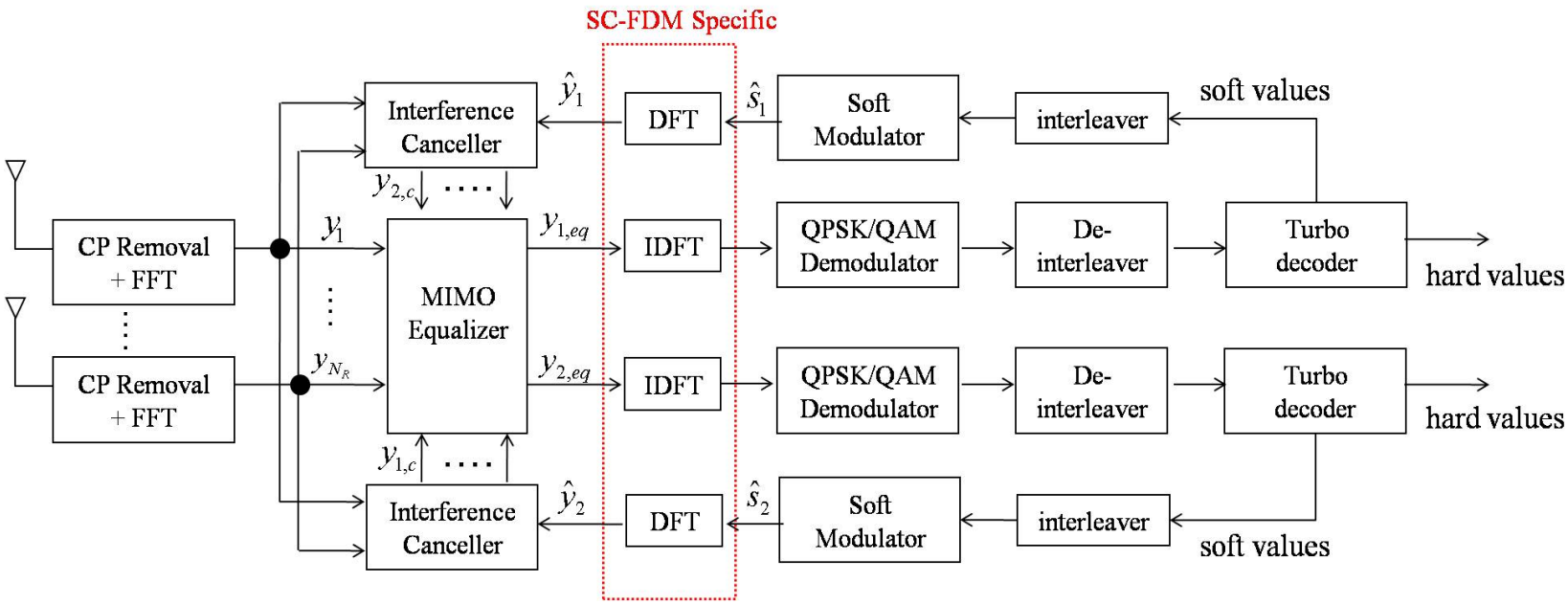


SC-FDM TEQ receiver allows to overcome the performance gap with OFDM.

SC-FDM for LTE-A Uplink: turbo detection

- Multi-Stream turbo receiver

The turbo receiver aims at reducing the interstream interference by including in the detection process a previous estimate of the transmitted data sequences.



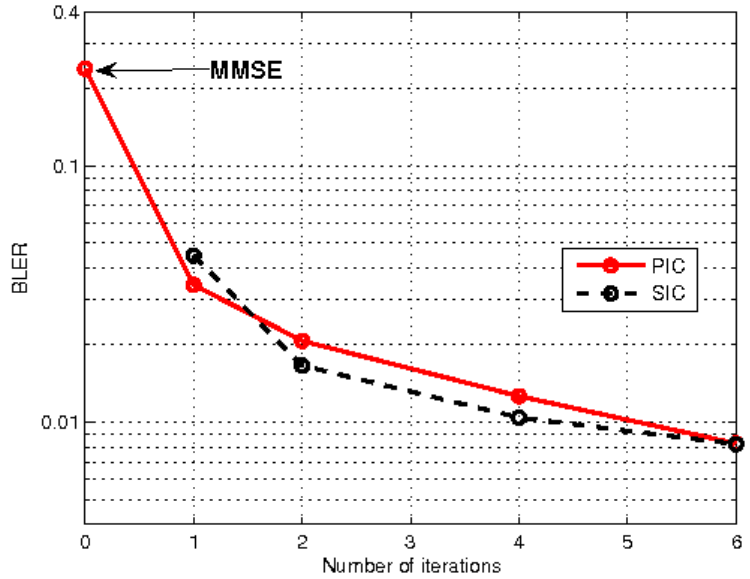
SC-FDM for LTE-A Uplink: turbo detection

- Two approaches are widely considered:

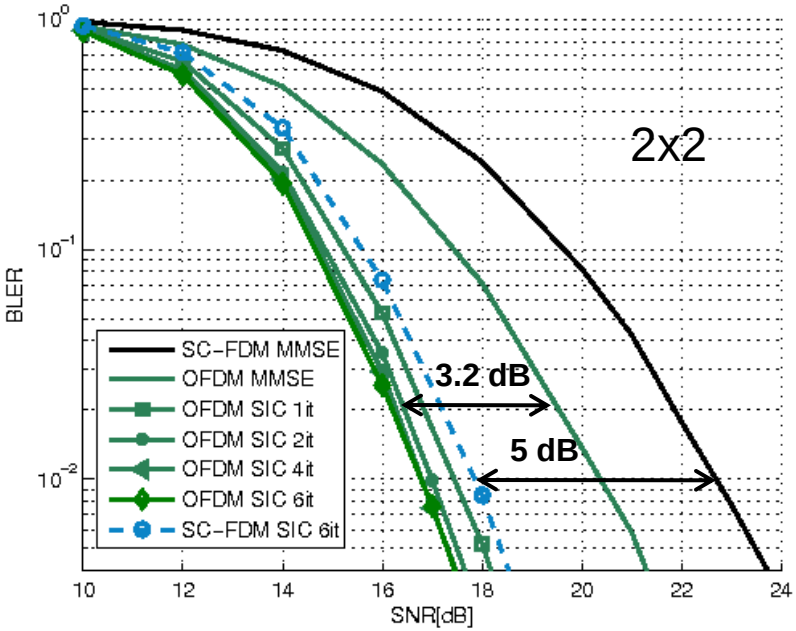
  - Parallel Interference Cancellation (PIC): both CWs are detected and re-encoded for the interference cancellation.

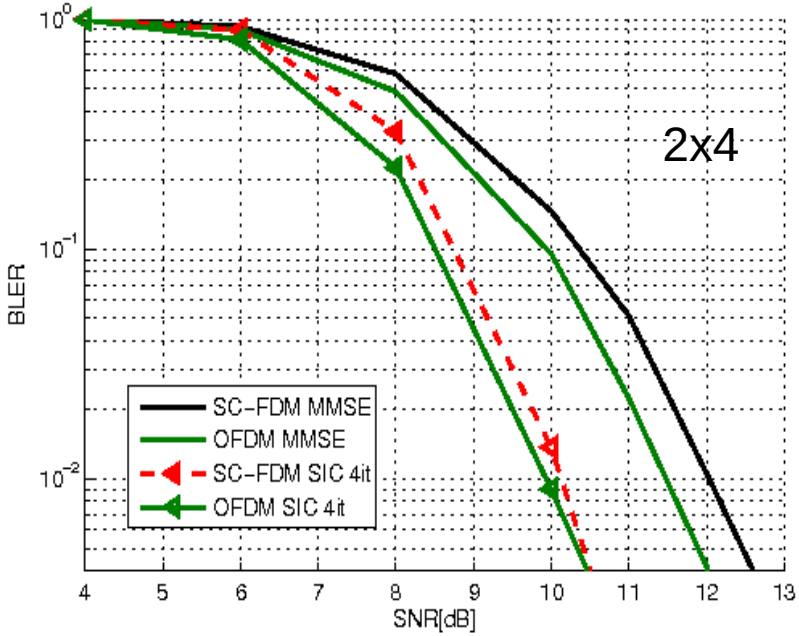
  - Successive Interference Cancellation (SIC): only the most reliable CW is detected and fed back for the interference cancellation.

- The SIC approach has been shown to converge faster than PIC after the first iteration.



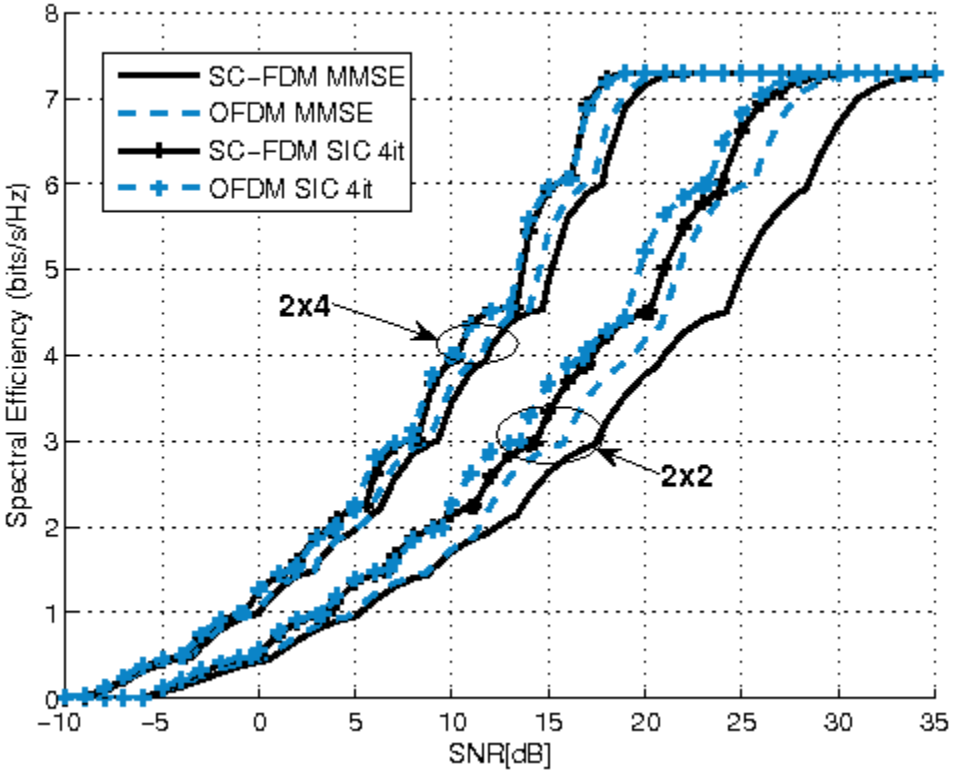
SC-FDM for LTE-A Uplink: turbo detection





- SC-FDM shows higher relative gain than OFDM.
- **The removal of the interstream interference reduces the noise enhancement of SC-FDM.**
- The performance gap between OFDM and SC-FDM is further reduced in a 2x4 configuration.

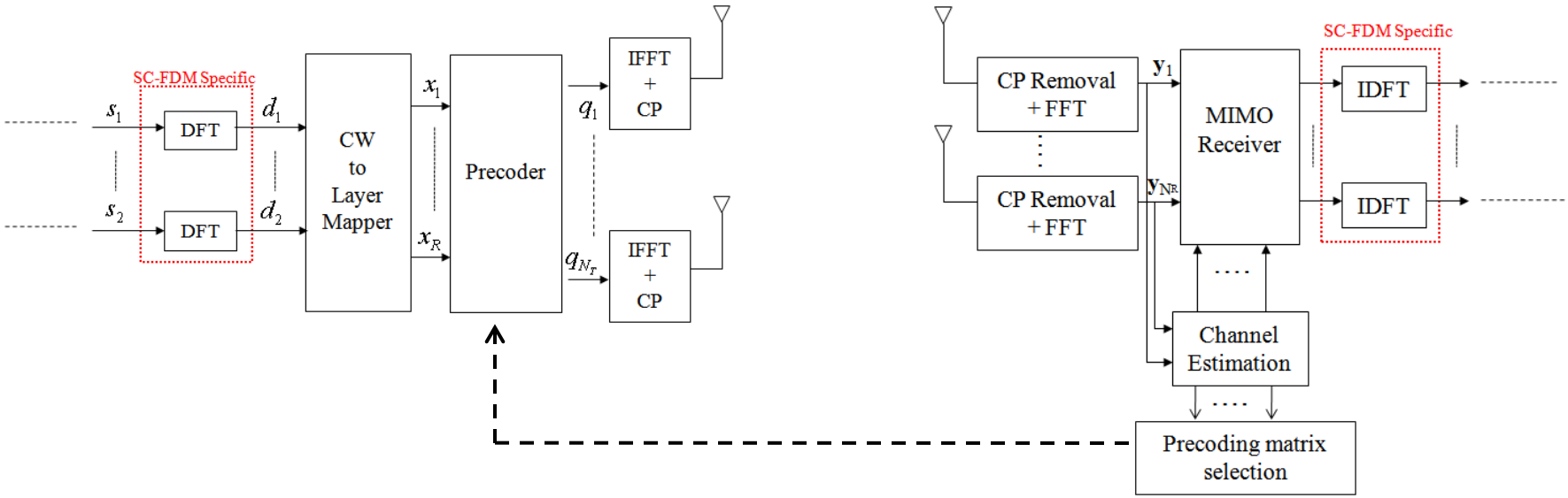
SC-FDM for LTE-A Uplink: turbo detection



- For low SNRs, OFDM performs as good as SC-FDM for both linear and iterative detection.
- The performance gap is relevant for high order MCSs, where the higher relative gain of the turbo receiver for SC-FDM is evident.
- OFDM and SC-FDM tend perform similarly in a 2x4 antenna system.

SC-FDM for LTE-A Uplink: precoded transmission

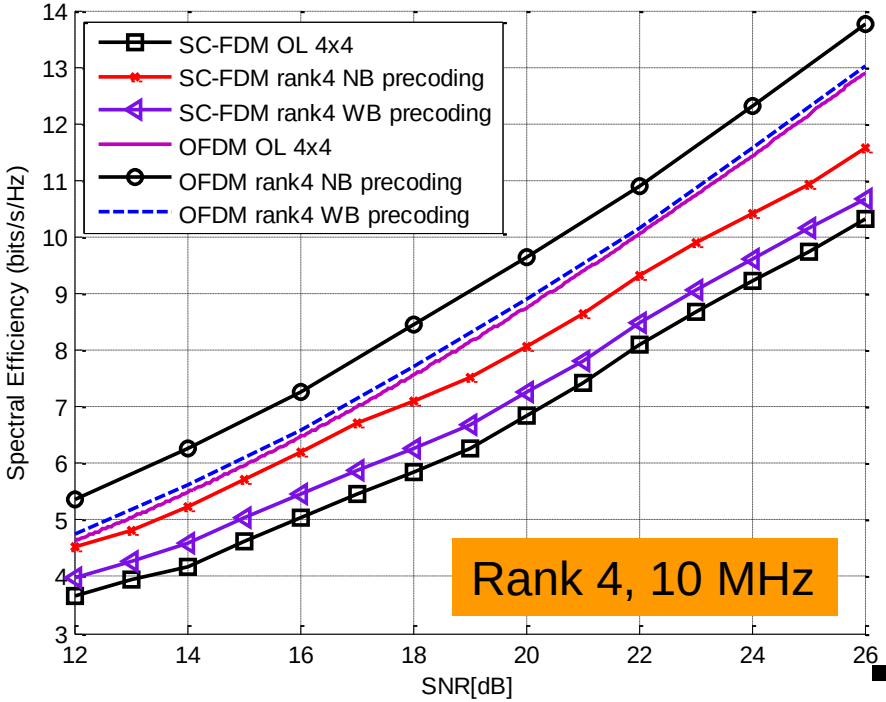
- Release 8 enabled the channel-aware precoded multirank transmission for the downlink.



- The feasibility of precoded multirank transmission should be evaluated even for the uplink of LTE-A.

SC-FDM for LTE-A Uplink: precoded transmission

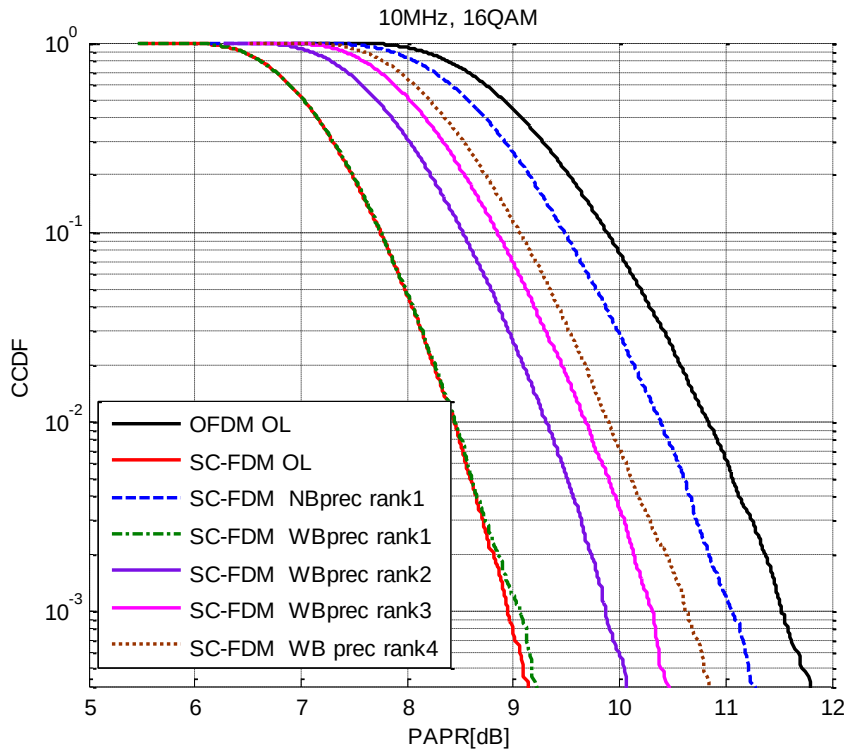
- We refer to narrowband precoding (NP) when the selection of the precoding matrix is made per subcarrier, and wideband precoding (WP) when it is made over the whole bandwidth.



For high rank transmission, the performance gain over open loop (OL) transmission is consistent for NB precoding, but is reduced for WB precoding.
However, the gain of WP precoding is still consistent for rank 1 transmission.

R	Gain over OL $R \times 4$			
	NB precoding		WB precoding	
	SC-FDM	OFDM	SC-FDM	OFDM
1	4 dB	3.5 dB	2.5 dB	2.2 dB
2	2.8 dB	2 dB	1 dB	0.4 dB
3	2.6 dB	1.8 dB	1 dB	0.3 dB
4	2.4 dB	1.4 dB	0.9 dB	0.2 dB

SC-FDM for LTE-A Uplink: precoded transmission



- The PAPR of SC-FDM signals is severely affected by the NB precoding.
- WB precoding has not impact on rank 1 transmission.
- Higher ranks are still affected by the WB precoding.

Since WB precoding rank 1 transmission shows significant spectral efficiency gain while preserving the low PAPR property of SC-FDM, it becomes a good candidate for a practical scheme where small feedback overhead is required.

Conclusions

- SC-FDM exploits similar benefits to OFDM and keeps low PAPR of the transmit signals.
- The diversity techniques reduce the performance losses due to the noise enhancement in the linear receiver.
- The turbo receiver shows higher relative gain for SC-FDM than for OFDM.

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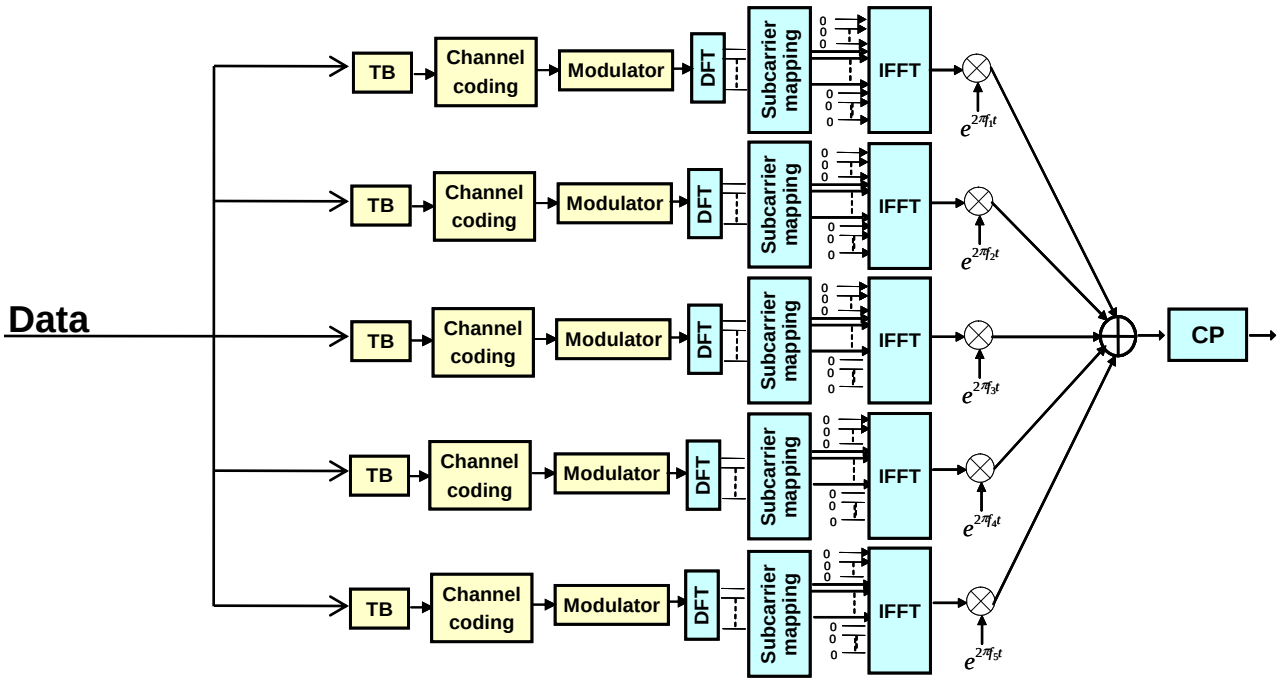
- Closed loop MIMO is a suitable option for low rank transmission.

SC-FDM has been selected as uplink modulation and coding scheme for the upcoming LTE-A standard.

Future work

- Impact of the turbo receiver on the precoded transmission.
- Comparison of Release 8 codebook with SVD-based codebook.
- **”Enhanced SC-FDM” investigation for multicarrier transmission.**



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Any Questions?