R1-083732: Comparison between SC-FDMA and OFDMA for LTE-Advanced Uplink

RAN WG1 Meeting #54 bis

Prague, Czech Republic , September 29th – October 3th, 2008

Agenda Item 11

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Motivation and contents

In this slide set performance and complexity of SC-FDMA and OFDMA in LTE-Advanced Uplink are analyzed and conclusions are made. Various system aspects are taken into account including UL SU MIMO, CL precoding, Cubic Metric and receiver architectures.

Outline of the presentation:

- **Uplink SU-MIMO performance and receiver complexity comparison btw. OFDMA and SC-FDMA**
- **Performance comparison btw. OFDMA and SC-FDMA with closed-loop antenna diversity**
- **System-level comparison btw. OFDMA and SC-FDMA in CASE 1**
- **Link Budget 2x20 MHz**
- **Conclusion**

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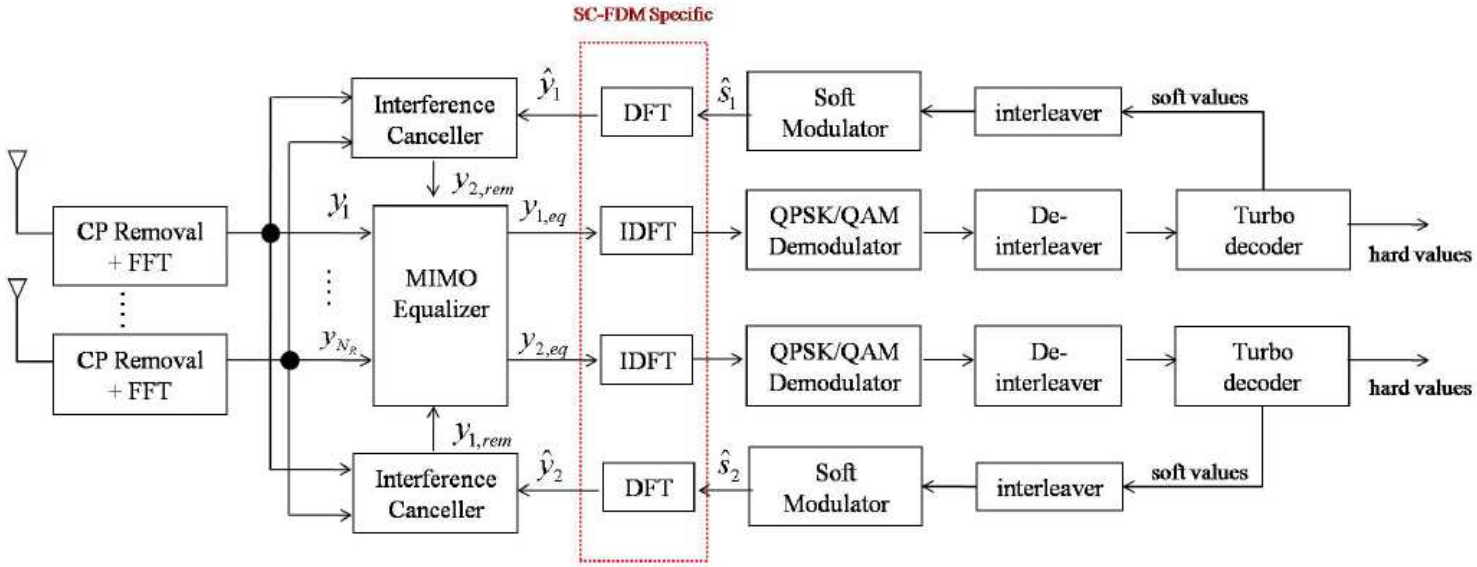
1. SU-MIMO Receiver : Iterative SIC receiver utilizing soft decision metric

- Turbo equalizer performs joint IPI and multistream equalization by utilizing an iterative loop between decoding and equalization.



- Only difference between OFDMA and SC-FDMA is an additional DFT/IDFT.
- The contribution of DFT/IDFT to total receiver complexity is about 15 %.
- MIMO receivers needed anyhow for both SC-FDMA and OFDMA due to MU-MIMO!
  - In addition to complexity/performance comparison between OFDMA and SC-FDMA also the cost of having both type of receiver should be considered.

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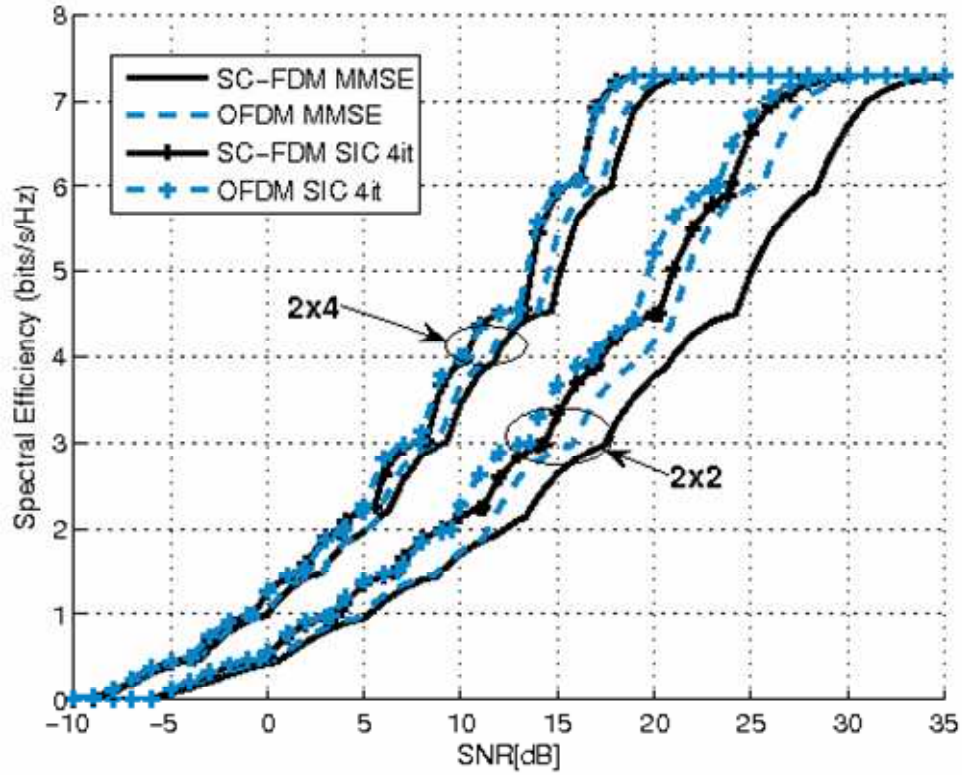
1.1 Performance comparison between SC-FDMA and OFDMA



Dual codewords, SCM channel

- With 2x4 the performance of SC-FDMA with Turbo SIC is equal to that of OFDMA.
- With 2x2 OFDMA performs slightly better even with Turbo SIC.

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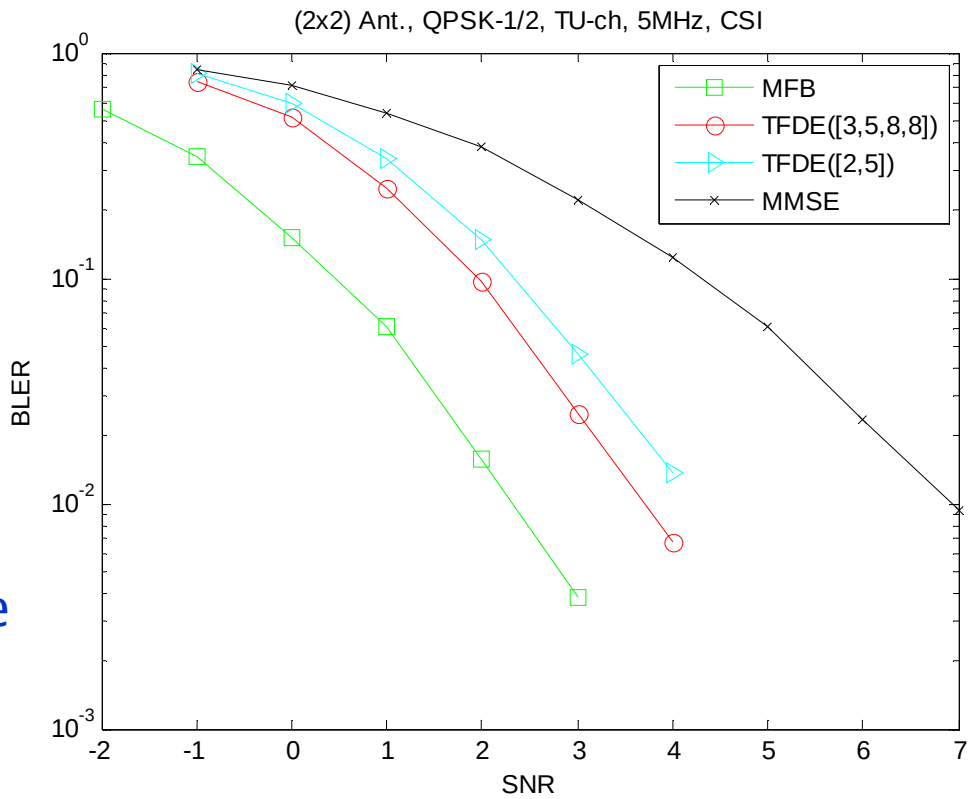
1.2 Complexity of iterative SIC receiver

- Complexity depends on the number of iterations in IC stage as well as on the number of turbo decoding iterations.
- When looking at the different contributors of complexity in the receiver, the turbo decoding is a major factor. Generally, decoding is many times more complex than equalization.
- By reducing the number of turbo decoding iterations for each turbo equalizer iteration, the overall increase in receiver complexity can be kept very low.
- Above example shows that most of gain can be obtained by using only one IC stage iteration with 2 turbo decoding iterations and 5 iterations after IC stage.
  - Total complexity about 2xMMSE.



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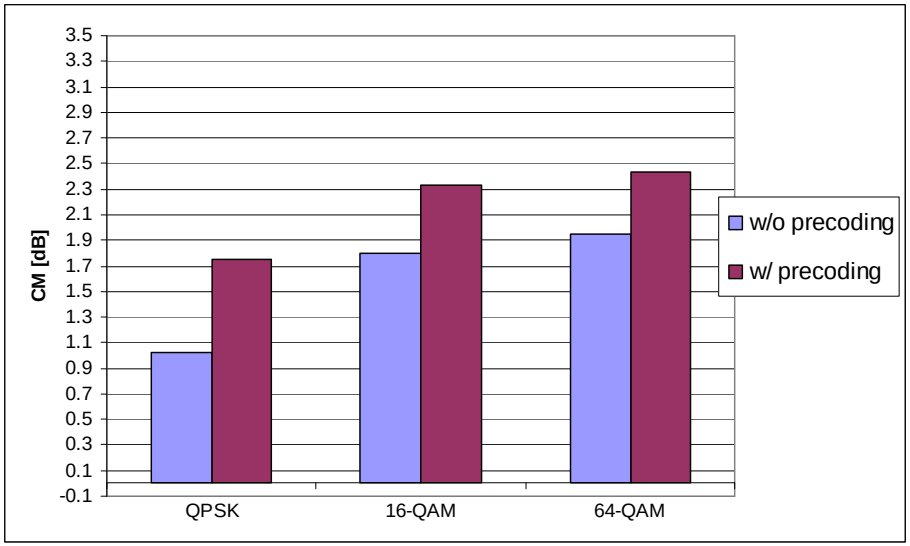
1.3 Cubic metric of precoded MIMO

- Rel'8 downlink codebook assumed
  - Spatial (open loop) MIMO included to the codebook.
- Actual precoding causes
  - over 1 dB CM increase for QPSK
  - below 1dB CM increase for 16-QAM / 64-QAM
- The gain from pre-coding in the uplink is not obvious and should be studied.



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2. Closed-loop antenna diversity

- In this section the performance of single stream precoding is shown for both OFDMA and SC-FDMA.
- The single stream precoding is made frequency selective in order to show that frequency domain processing can be as well applied for SC-FDMA signal.
- Otherwise we note that the system level gain from frequency selective precoding should be carefully analyzed before it is accepted to specification.
  - For example, the gain could be small with frequency domain scheduling.

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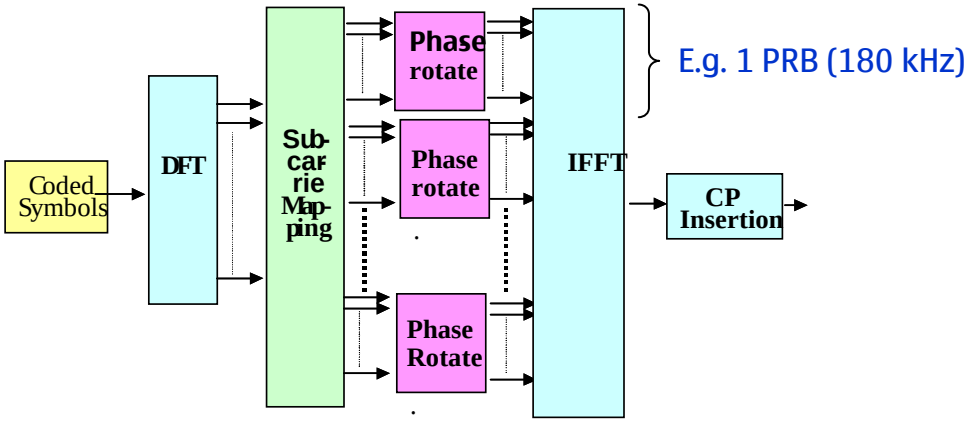
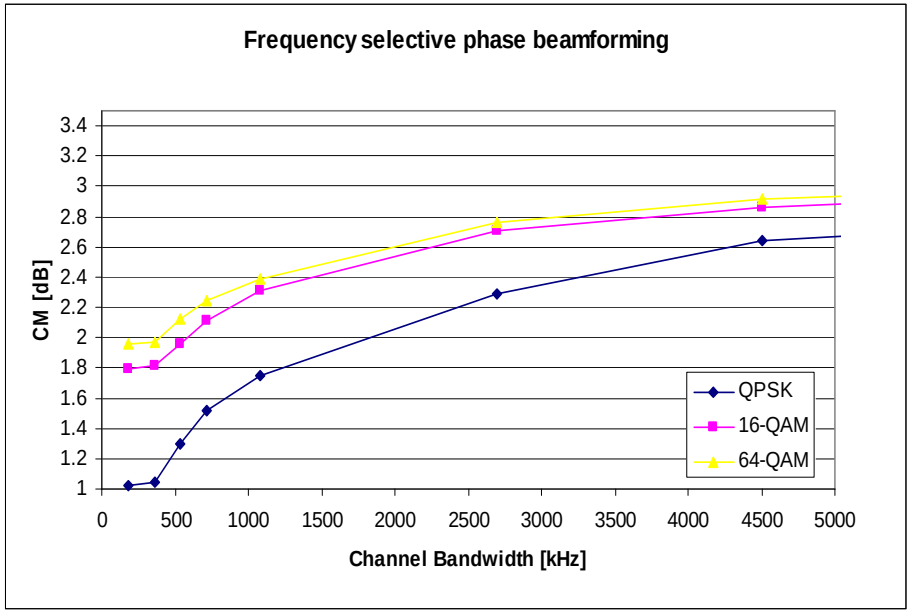
2.1. Closed-loop antenna diversity techniques

- The frequency selective single-stream precoding can be utilized for both OFDM and SC-FDMA.



- When it is utilized for SC-FDMA, the CM of second antenna signal is increased.
- CM degradation can be indirectly controlled via PRB allocations / CL commands.



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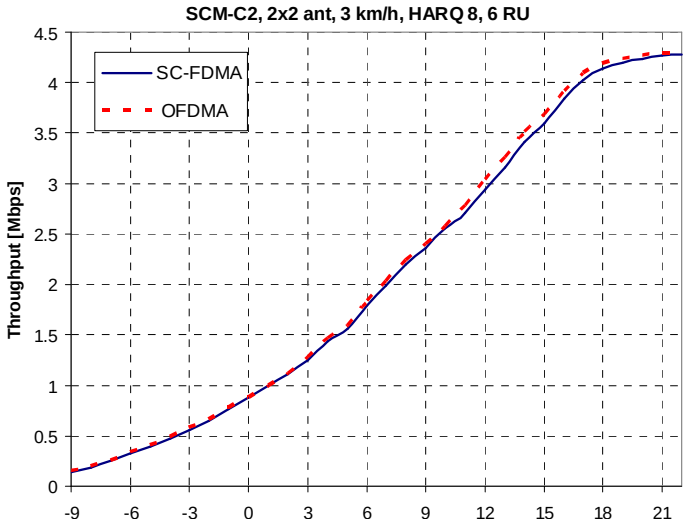
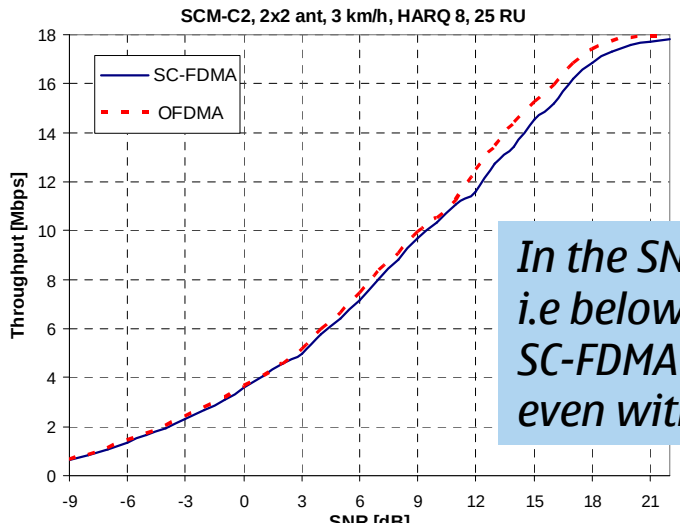
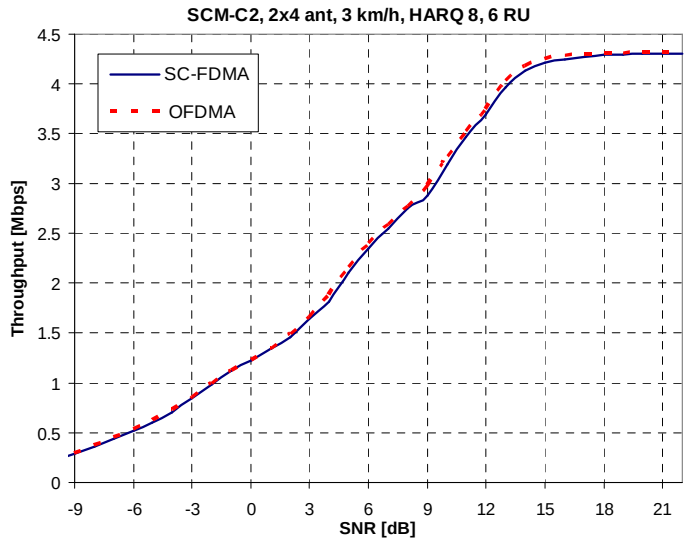
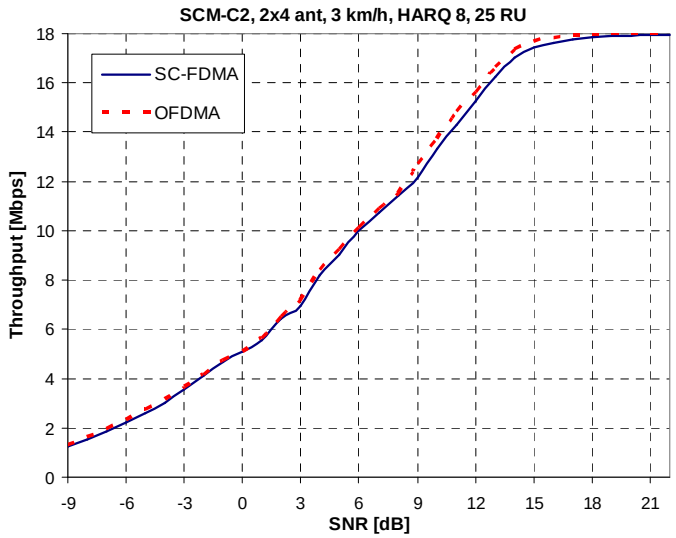
2.1 Performance comparison between OFDMA and SC-FDMA with CL antenna diversity (MMSE receiver)





In the SNR range of interest, , i.e below 6 dB, OFDMA and SC-FDMA perform equally even with an MMSE receiver!





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3. System performance evaluation

- In this section we benchmark the system level performance gain obtained from OFDMA in the CASE 1.
- We assume antenna setup 1x2, 10 MHz bandwidth and 10 UEs.
- Proportional Fair scheduling
- Fast link adaptation was used with fixed bandwidth for all users.
- Interference over thermal (IoT) probability at 20 dB was limited to 5%.

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3.1 System simulation parameters

Description	Settings
Number of cells	19 sites with 3 cells.
Carrier center freq.	2.0 GHz
ISD	500 m
System bandwidth	10 MHz (BE)
Effective bandwidth	9 MHz (BE)
Number of active UEs per cell	10 Users for BE traffic, UEs are uniformly distributed
Shadow fading	8 dB std Shadow correlation between sites 0.5, between sectors 1.0,Correlation distance 50 m
Penetration loss	20 dB
Velocity, fast fading	3 km/h, Jakes
Channel	SCM-C with correlations for spatial channels
Link to system model	UL AVI (realistic channel estimation)
Allocations	PRB resolution, 12 sub-carriers on each
Sub-carrier spacing	15 kHz
Cell selection	Best cell selected with 0 dB margin
Multiple access	SC-FDMA, OFDMA
UE transmission power	Max 24 dBm
Power dynamics of UEs at the eNB	17 dB
Reference Symbol overhead	DMRS 2 LB per PRB per sub-frame 1 SRS per sub-frame (max full bandwidth)
Control channel overhead	4 PRBs for BE (8% overhead)
Tx-Rx scheme	1x2 with ideal Maximal Ratio Combining (MRC) at the eNB
Receivers	MRC
Channel sounding measurement error model	Zero mean i.i.d. Gaussian measurement error with 1 dB standard deviation in the decibel SINR domain for each group of 1xPRB
Power control	Open loop power control
HARQ	8 synchronous, non-adaptive HARQ channels with maximum 8 transmissions.

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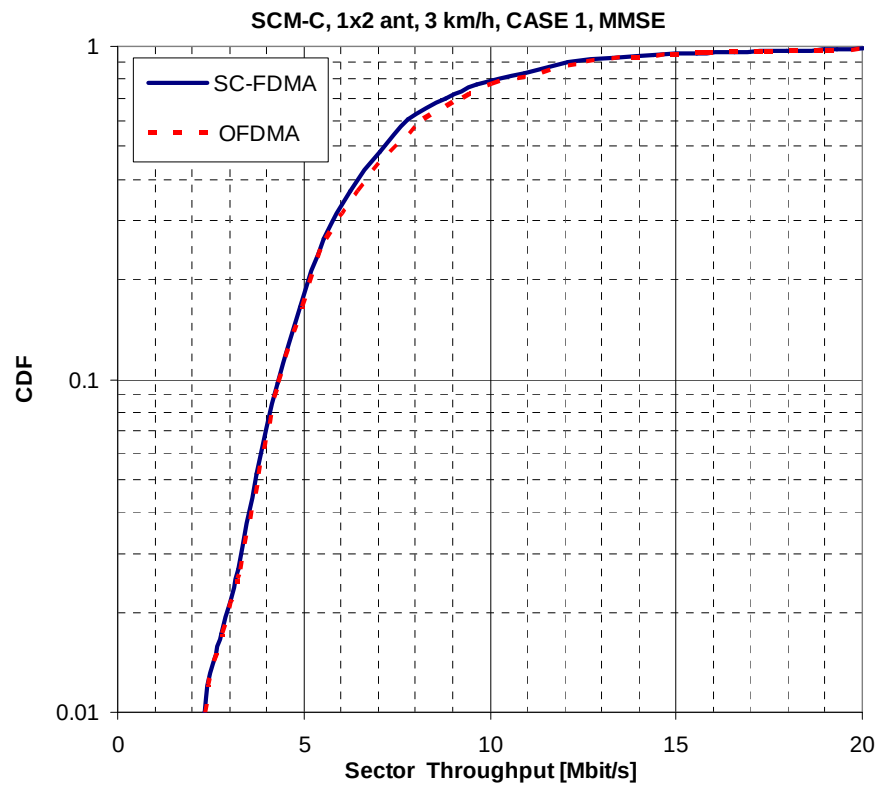
3.2 Sector throughput CASE 1 / 10 UE, 10 MHz

- CASE 1 is an interference-limited scenario.
- OFDMA gain in terms of average sector throughput is 3 %.
  - Zero gain in cell edge.
- OFDMA can give about 3% gain in the interference-limited case because of better equalization.
  - There are is some (few percent) gain available also from more flexible frequency usage. This is not considered in this study because the same techniques could as well be utilized for clustered SC-FDMA.



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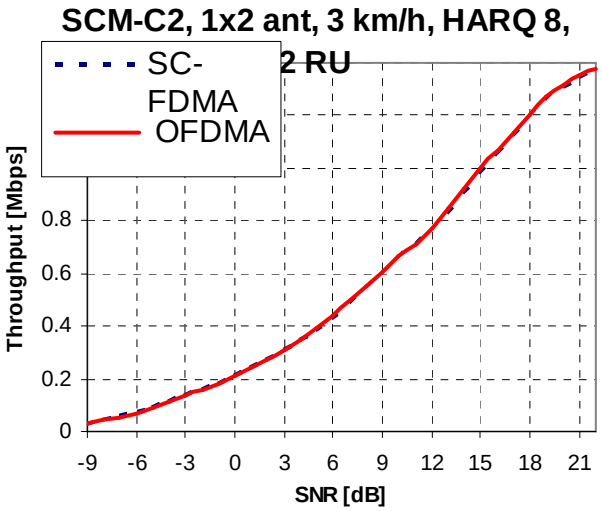
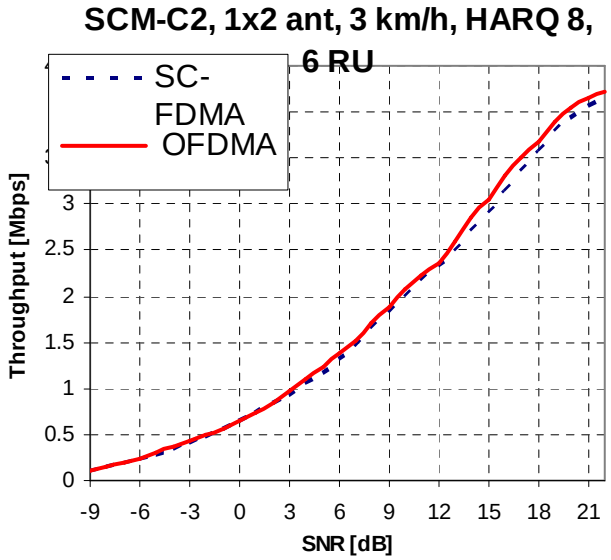
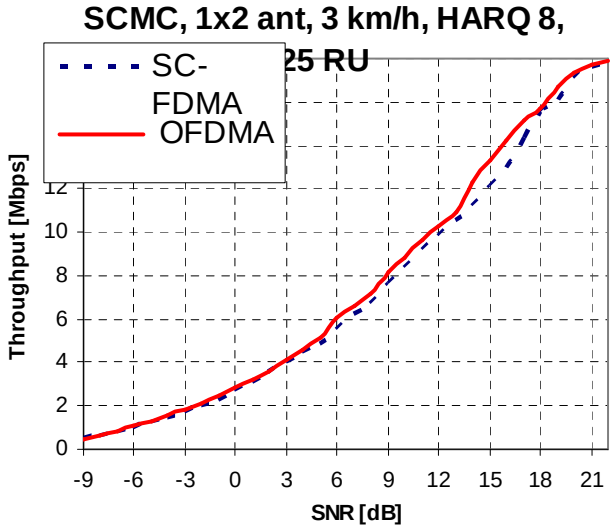
3.3 Link performance with MMSE receiver







In the SNR range of interest, i.e. below 12 dB, there are not signicant difference between SC-FDMA and OFDMA

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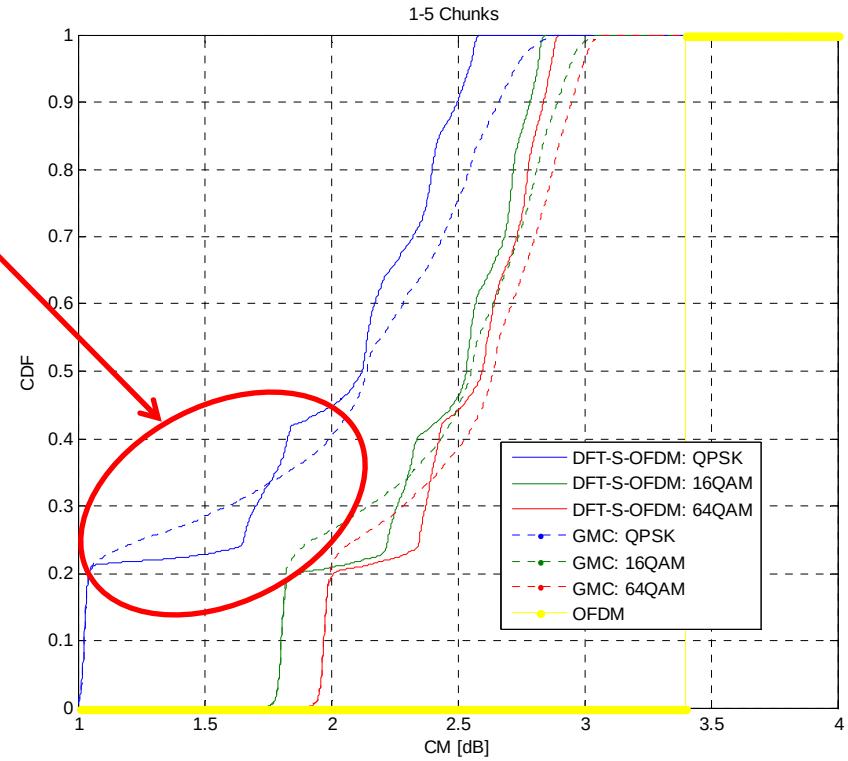
4. Link budget: OFDMA vs. NxSC-FDMA (2x20 MHz)

- Assuming 2x20 MHz UL BW allocation there is still significant difference in QPSK modulation:
  - 2x20 MHz SC-FDMA has 1.2-2.4 dB* higher TX power than OFDMA.
  - Clustered 2x20 MHz DFT-S-OFDMA has 1.5-1.7 dB* higher TX power than OFDMA.
- If SC-FDMA is not extended to support BW>20 MHz, it results in coverage loss:
  - Coverage loss exists especially for bit rates higher than 10 Mbit/s (QPSK/20 MHz).

In noise limited conditions, 2xSC-FDMA (40 MHz) gives about 25-56% higher cell edge bit rate than OFDMA!

Case: Number of clusters is equally distributed between 1-5, cluster size is equally distributed between 180kHz- 18MHz [R1-082609].



*We assume assume that LTE-Advanced UE with 1 TX antenna has PA sized to 24 dBm/QPSK, CM=1 dB as in Rel'8.

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5. Conclusion

We do not see compelling reasons to introduce OFDMA to LTE-Advanced:

- SU-MIMO
  - With iterative turbo SIC, the receiver complexity is similar:
    - MIMO receiver is needed already in Rel'8 in order to get full benefits of MU-MIMO.
  - With 2x2 OFDMA when SNR > 10 dB (16/64 QAM), OFDMA gives about 1-10 % (depending ECR) higher througput than SC-FDMA; with QPSK the performance is similar.
  - With 2x4 the performance is equal.
- Closed-loop antenna diversity
  - Even with an MMSE receiver, OFDMA and SC-FDMA have equal performance with both 2x2 and 2x4.
- System performance 1x2
  - In interference limited situation CASE 1 with MMSE, OFDMA gives 3 % higher average spectrum efficiency, no difference in cell edge performance.
  - In power limited situation, the achievable cell-edge bit rate of OFDMA is smaller than SC-FDMA, hence there seems to be no system performance reasons to introduce OFDMA for single antenna case.
- Cell edge bit rate in noise limited situation / cubic metric
  - Even with carrier aggregation, the cubic metric difference between OFDMA and NxSC-FDMA is still significant and needs to be considered.
  - For example, in noise limited situation, assuming aggregation level 2 and single antenna transmission, NxSC-FDMA (40 MHz) with QPSK gives still 1.2-2.4 dB lower CM resulting in 25-56 % higher cell edge bit rate than OFDMA.
- Cubic metric / power efficiency is still an issue with OFDMA.
  - Even with MIMO, since UE PAs will be optimized for half power with two PAs => MIMO transmission will be limited by cubic metric, i.e. only single stream can be provided in power-limited case (with SC-FDMA).

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