Efficient Interference Handling with Cooperative MIMO

Centre of Excellence in Wireless Technology
(CEWiT India)

Agenda Item:12.3
Discussion / Decision

Prevailing Scenario

- Consolidated view point of CEWiT and BWCI (Broadband Wireless Consortium of India)*
- India will likely see LTE deployments in the 2011-13 timeframe
- It is in our viewpoint that possible enhancements considering low mobility users (indoor / nomadic) should be made to Rel-8 Spec
  - If a UE becomes a 'low SINR user', it continues to remain so unless the environment changes
  - From the operator view point it is necessary to offer a sustained data rate

- This document is an exposition to possible enhancements, starting with the Rel-8 framework

Prevailing Scenario (2)

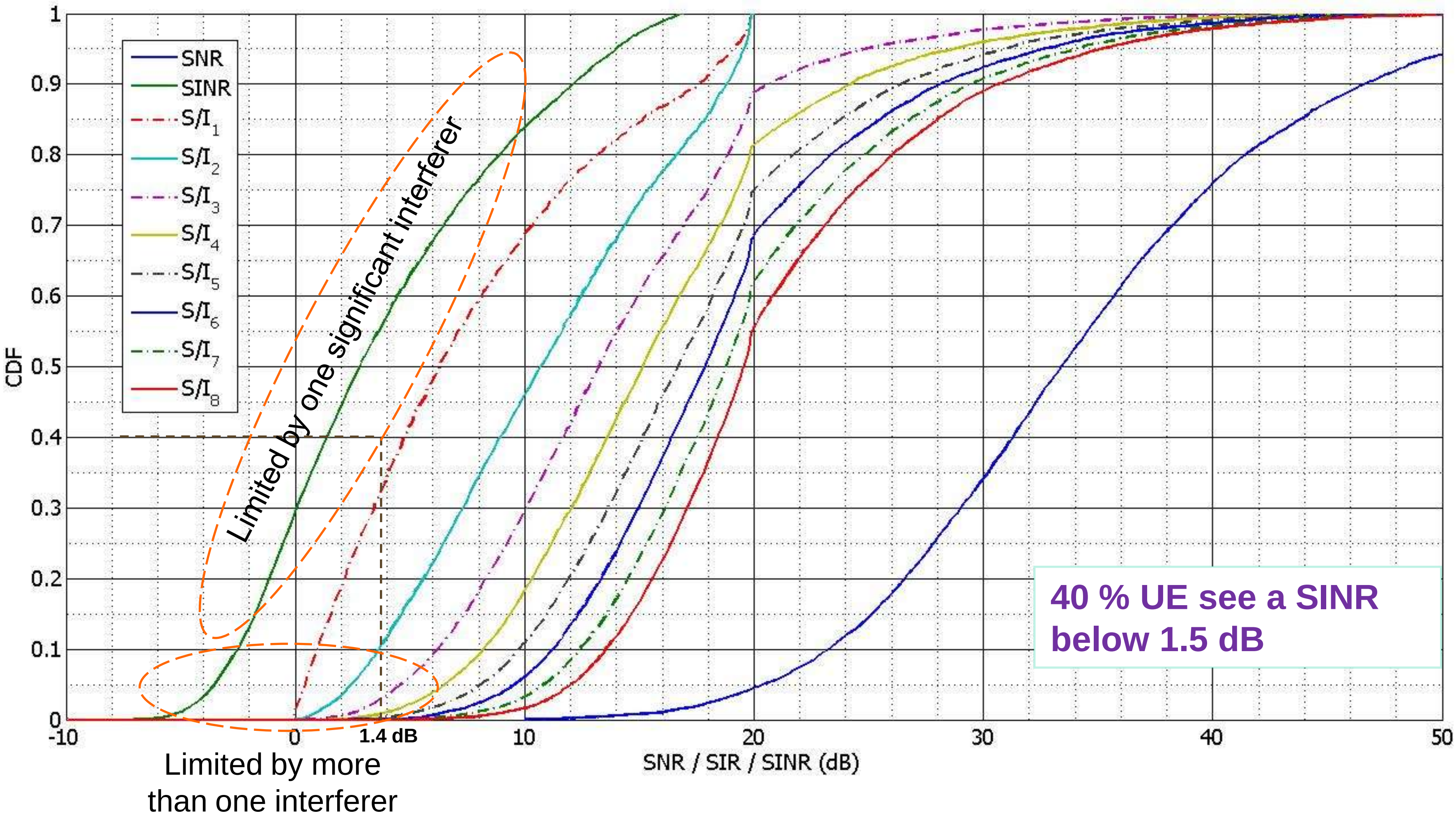
- Based on the requirements, the following become essential
  - Reuse 1 deployment
  - Uniform data rates across the cells
  - Optimization for fixed and nomadic applications

- Poor ‘Low-SINR user’ performance in reuse-1 networks
  - Severe co-channel interference (CCI)
  - Multiple CCI (up to 3-significant interferers)

- Effective interference management techniques needed

CDF of Signal Powers in a Reuse 1 System

Only large scale effects considered



40 % UE see a SINR below 1.5 dB

Prevailing Scenario (3)

- Techniques practiced for handling interference
  - Fractional frequency reuse
    - Better edge performance, trading over in cell performance
  - Interference randomization via data repetition

- Known fact: With N receiver antennas, N-1 interferes can be handled
  - MMSE receivers show very good performance

$$y = \enclose{circle}{h} x_0 + \sum_{i=1}^{N} g_i x_i + n$$

System relation

$$\hat{x}_0 = wy \qquad w = \enclose{circle}{R_{xy}} R_{yy}^{-1}$$

MMSE relation and equalizer weight

  - With a baseline 2 Rx antenna at UE, 1 interferer can be effectively handled
  - Limitations on the UE performance due to hybrid traffic in the network

Effects with Similar MIMO Schemes

Simpler MMSE receiver

Precoding / precoding

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x_0 + \begin{bmatrix} g_{11} \\ g_{12} \end{bmatrix} x_i + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

Not so simple MMSE receiver

SFBC / SFBC

$$\begin{bmatrix} y_1(n) \\ y_1^*(n+1) \\ y_2(n) \\ y_2^*(n+1) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{12}^* & -h_{11}^* \\ h_{13} & h_{14} \\ h_{14}^* & -h_{13}^* \end{bmatrix} \begin{bmatrix} x_{01} \\ x_{02} \end{bmatrix} + \begin{bmatrix} g_{21} & g_{22} \\ g_{22}^* & -h_{21}^* \\ g_{23} & g_{24} \\ g_{24}^* & -h_{23}^* \end{bmatrix} \begin{bmatrix} x_{11} \\ x_{12} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}$$

Effects with Hybrid MIMO Schemes

Precoding / SFBC

Creates two interferers in the system

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x_0 + \begin{bmatrix} g_{11}x_{11} \\ g_{12}x_{12} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

MMSE receiver implementation non-trivial

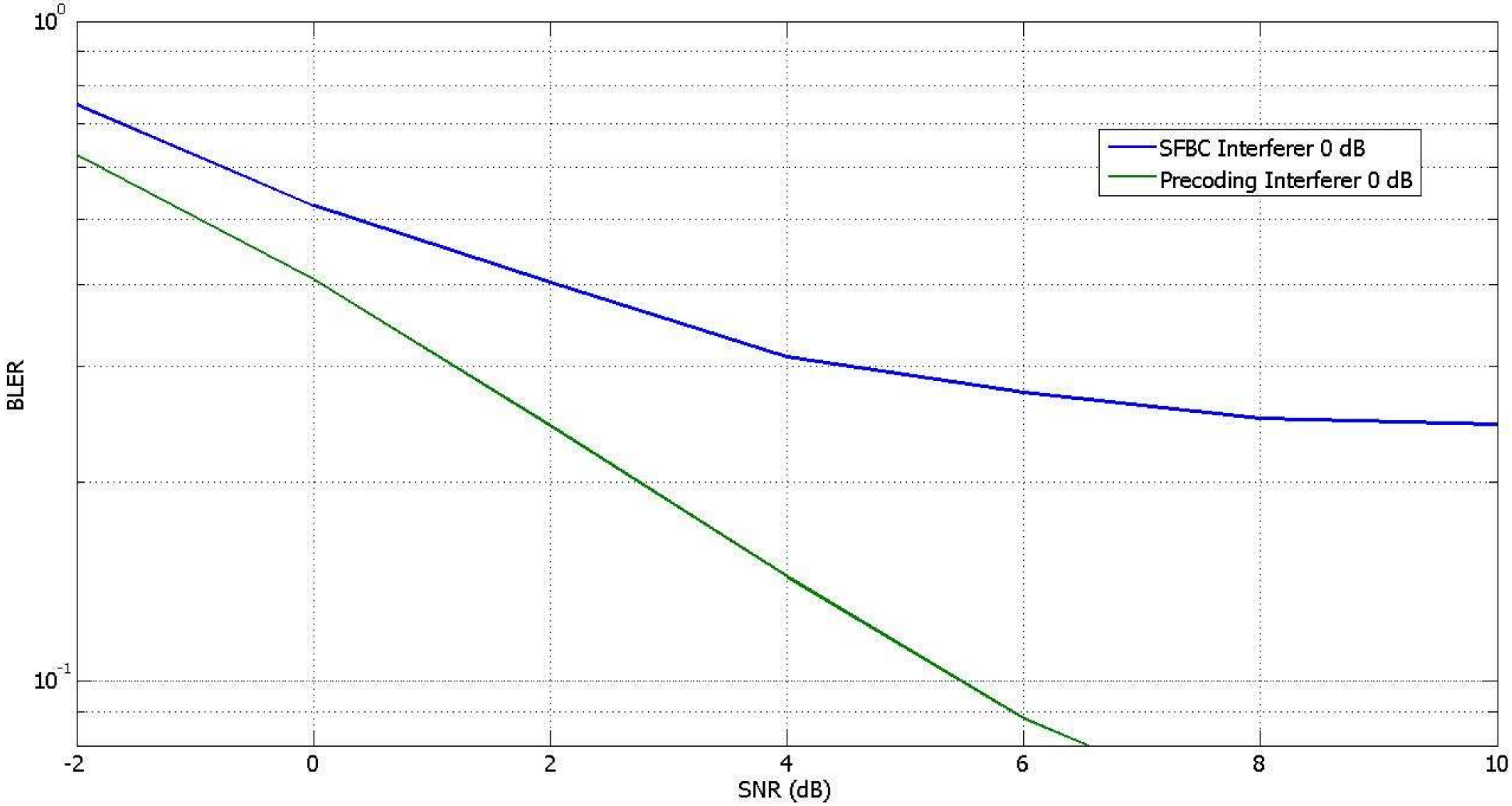
SFBC / Precoding

$$\begin{bmatrix} y_1(n) \\ y_1^*(n+1) \\ y_2(n) \\ y_2^*(n+1) \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{12}^* & -h_{11}^* \\ h_{13} & h_{14} \\ h_{14}^* & -h_{13}^* \end{bmatrix} \begin{bmatrix} x_{01} \\ x_{02} \end{bmatrix} + \begin{bmatrix} \left(g_{21} + e^{j\theta} g_{22}\right) x_{11} \\ \left(g_{21} + e^{j\theta} g_{22}\right)^* x_{12}^* \\ \left(g_{21} + e^{j\theta} g_{22}\right) x_{11} \\ \left(g_{21} + e^{j\theta} g_{22}\right)^* x_{12}^* \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}$$

Link Simulation Setup

- EPA Channel model, 5 Hz Doppler
- MLS channel estimation
- QPSK modulation, MCS index 7
- 2 x 2 MIMO system
- No HARQ
- Feedback delay of 2 msec
- 10 MHz bandwidth and 2 GHz carrier frequency
- Other assumptions as per Rel-8 terminology

Simulation Performance



SNR = Signal / (Rest of Interf. + Noise)

Regime of interest = 10% BLER

Use Cases

- Inference:
  - Network level coordination, ensuring similar MIMO schemes superimposing over each other favours MMSE interference cancellation

Signal	Interference*	MMSE Rx. Performance
Single stream	Single stream	Optimal, Simple
SFBC	SFBC	Optimal, Not so simple
Single stream	Dual stream	Sub optimal, two interferers
Single stream	SFBC	Sub optimal due to covariance structure
SFBC	Single / dual stream	Sub optimal due to covariance structure

  - Virtual single stream transmission schemes are effective with MMSE Rx
  - Single stream open-loop transmission mode complementing closed-loop single-stream transmission needed
    - Overlap with high mobility user, erroneous feedback, etc.

Cooperative Precoding

- System performance improvement using antenna arrays of close vicinity eNBs
- Any MIMO scheme should be simple and not assume tighter centralized control across cells
  - Jitter is tolerable, with marginal degradation from ideal cases

- Transmit signal processing using precoding matrices optimized for better inter cell behaviour seems promising
  - Precode to cause minimal interference
  - Distributed algorithm for inter base station cooperation

- Such techniques seem to complement FFR behaviour
  - Spatial interference coordination using precoding matrices ensures efficient MIMO usage
  - Very effective mode of transmission when UE is Nomadic / Fixed

Cooperative Precoding (2)

- The gains due to cooperative precoding should not be at the expense of a in-cell user behavior
  - With 2 Rx antennas, a MMSE receiver can handle 1 interferer

- Use cooperation to minimize the impact of the other interferers
  - eNB serving the low SINR cell edge UE selects the optimal precoding angle
    - UE enjoys array-gain advantage
    - Possibly the only option since interference limited

  - eNB's interfering will cooperate to minimize the interference
    - There are means to restore performance at high S(I)NR's

Simulation Setup

- EPA Channel model, 5 Hz Doppler
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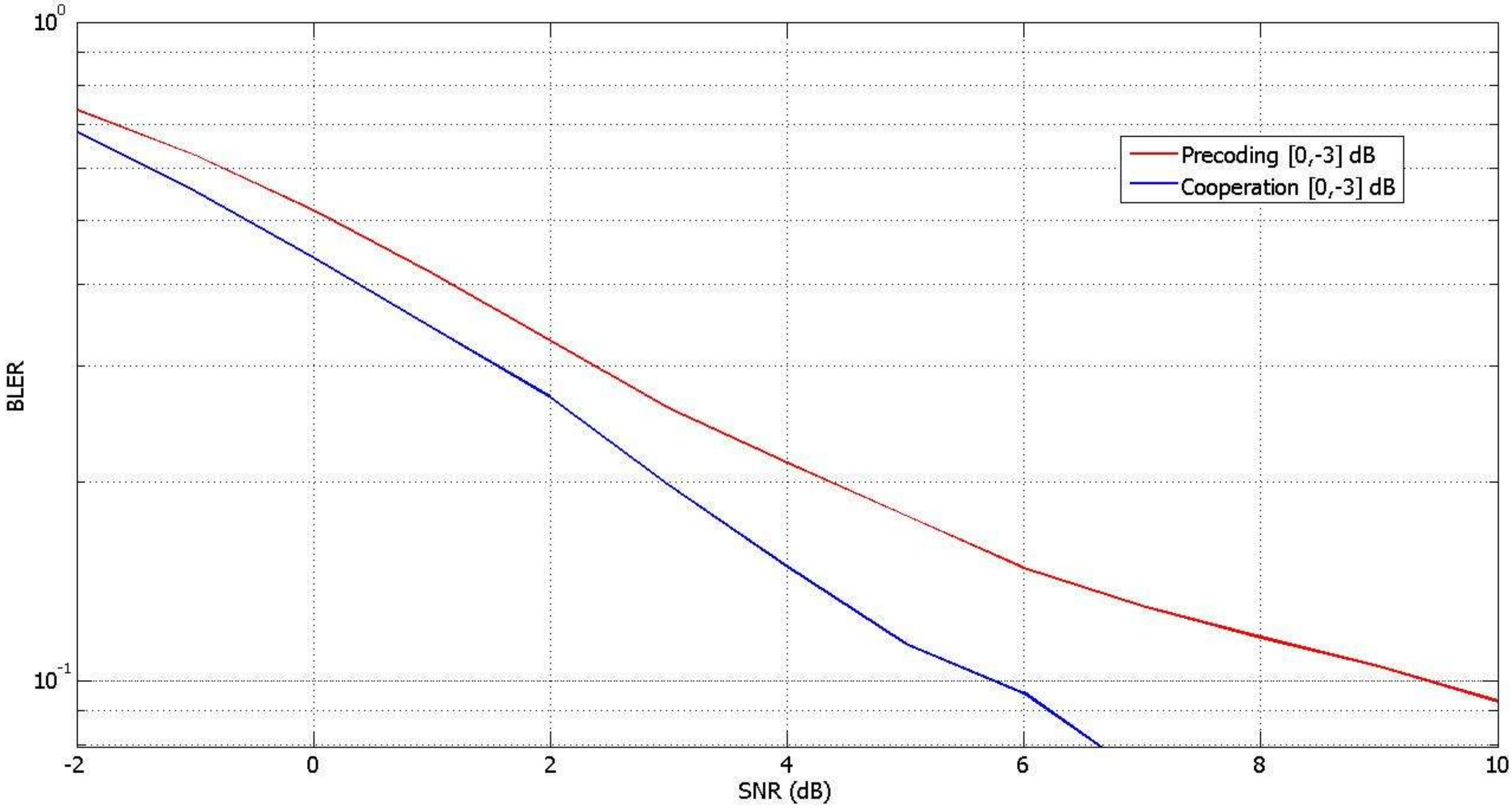
Simulation Performance



When 4 antennas are used for transmission, up to 3 interferers can be handled by the MMSE capable receiver

Regime of interest = 10% BLER

Use Cases

- PMI Coordination benefits comes from efficient information sharing across cooperating elements
- Initial results indicate significant improvements for low SINR users
  - 15 -20 % improvement for low SINR users
  - Same or upto 5 % improvement for in cell users (medium SINR users)
  - The scheduler needs to be 'cooperation aware' to reap these gains
- True benefits of such coordination comes when the options are high
  - Codebook size may need a revisit
- It is necessary that the co-variance estimate made by the MMSE receiver are accurate
  - Needs UE specific RS
  - Possible scenarios need further study

Interference Handling in Legacy Systems

- At very low SINR, UE typically sees more than 2 significant interferers
- Conventional technique for handling interference
    - FFR (tries to minimize interference and make it noise like)
    - Repeat information bits (eg. Rate 0.5, QPSK)

$$y_1 = h_1 x + g_{1i} x_i + \qquad + n_1$$

Initial transmission

$$y_2 = h_2 x + \qquad + g_{2i} \tilde{x}_i + n_2$$

Re-transmission

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x + \begin{bmatrix} g_{1i} x_i \\ g_{2i} \tilde{x}_i \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

- Coherent combining assumes interference to have white noise behaviour
    - Helps to improve the S(I)NR, but does not permit interference mitigation
    - Bit level repetition is spectrally inefficient

IC @ Cell-edge with Rx Processing

- LTE baseline of 2 Rx antennas can handle 1 interferer

$h_1(f)$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x + \sum_i \begin{bmatrix} g_{1i} \\ g_{2i} \end{bmatrix} x_i + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \Rightarrow \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \\ . \\ . \end{bmatrix} x + \sum_i \begin{bmatrix} g_{1i} \\ g_{2i} \\ . \\ . \end{bmatrix} x_i + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix}$$

Use the OFDM property, adjacent RBs

$h_1(f+L) = \phi(h_1(f))$

$$h_1(f)\phi(x) \Rightarrow \phi(h_1(f))x$$

Φ Can be simpler functions like phase shift and conjugation

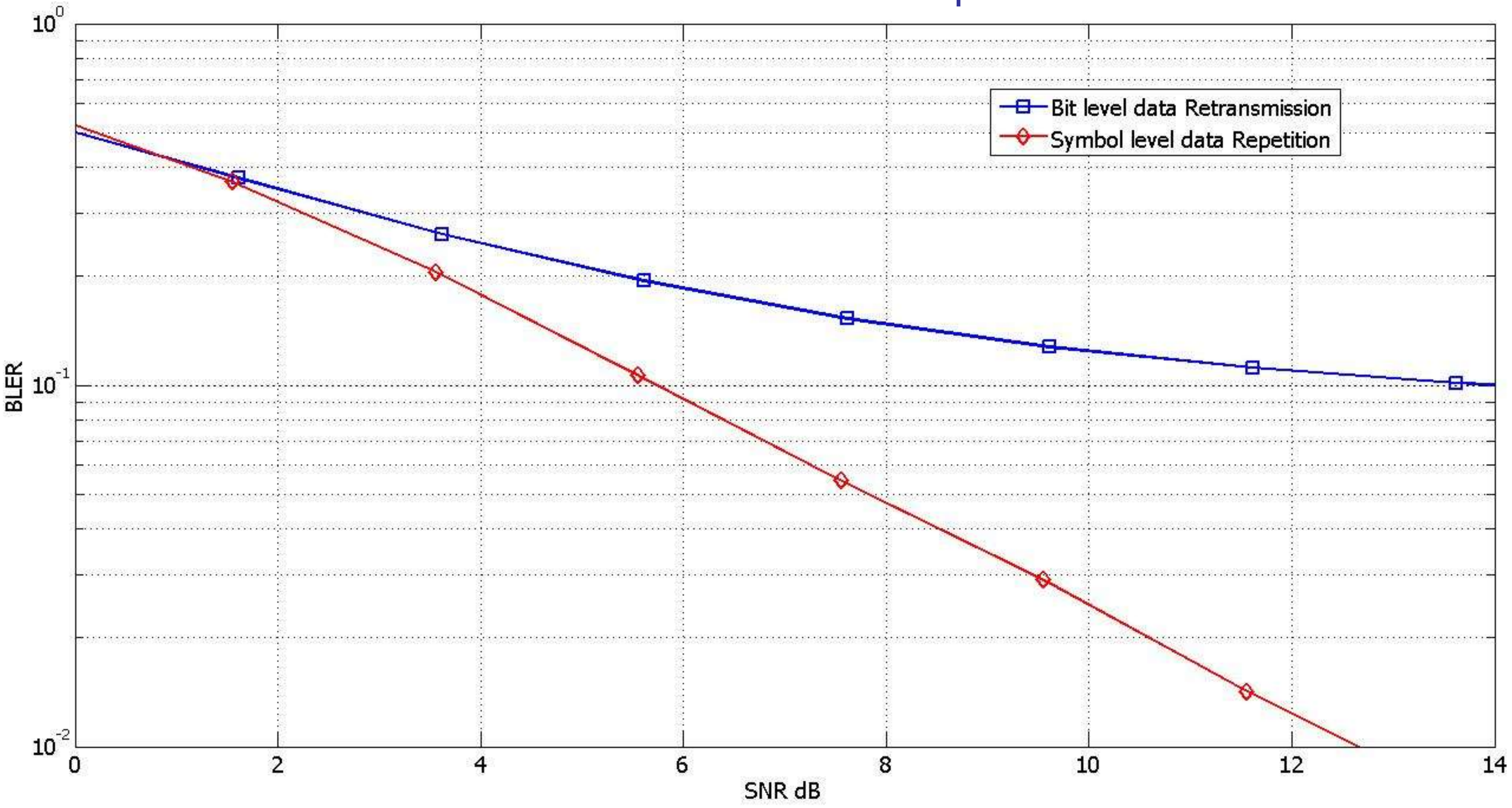
- Create multiple copies of transmit data across cells for the MMSE receiver processing
  - Repeat symbols across cells in a coordinated manner

Simulation Setup

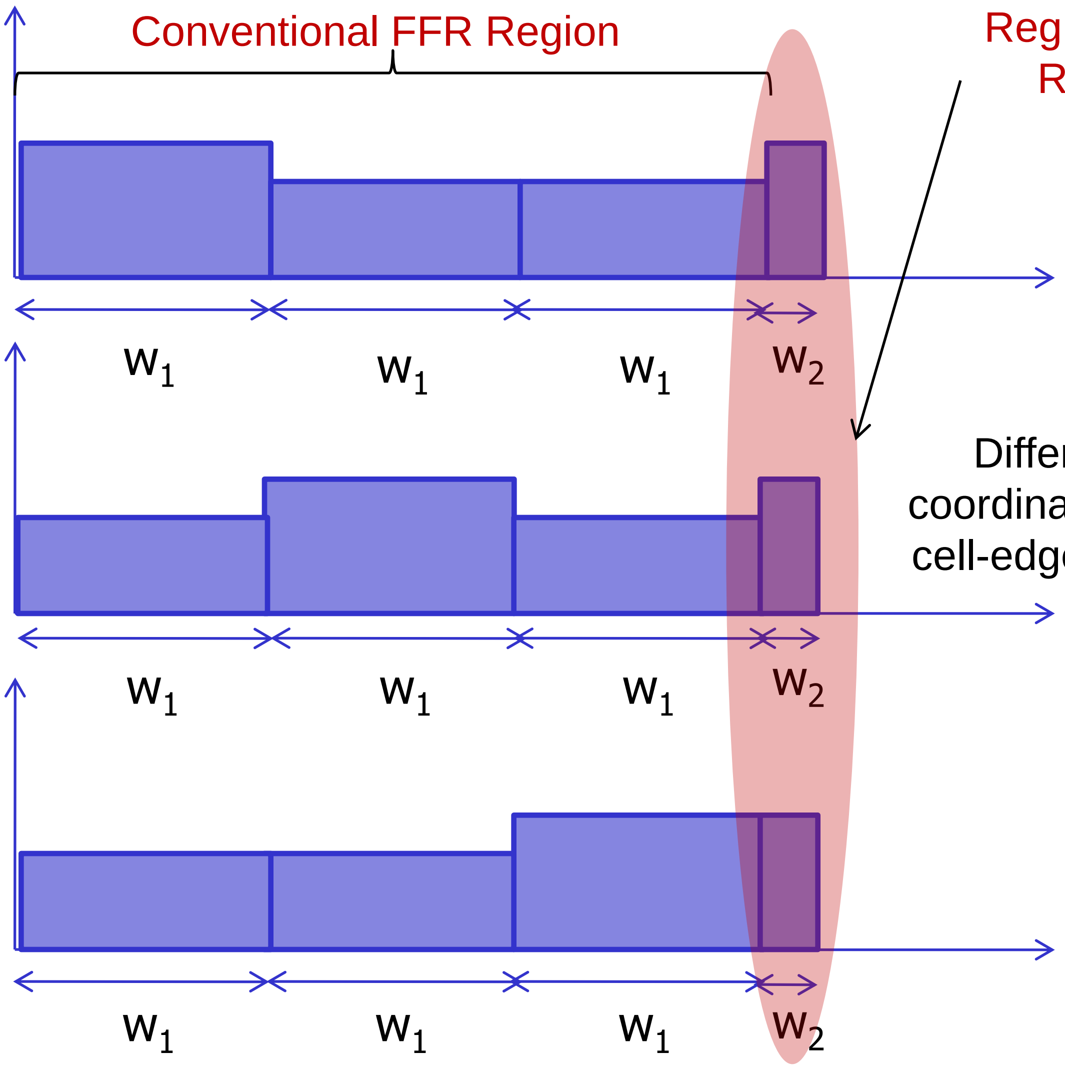
- Three interferers at [0, -2, -4] dB S/I_i
- EPA channel model, 5 Hz Doppler
- 2 x 2 MIMO scheme
- MCS index 7 (rate ~0.533, QPSK)
- No HARQ
- 10 MHz bandwidth and 2 GHz carrier frequency
- Other assumptions as per Rel-8 terminology

Simulation Performance

Randomized Retransmission v. Coordinated Repetition



FFR Choice



Region for Data Repetition

Different cells should coordinate to accommodate cell-edge UEs in this region

Conclusions

- Interference plays a limiting role in cellular performance improvement and effective interference management is needed for low Doppler use cases
- Complementing FFR, MMSE receiver processing makes efficient usage of the receiver antennas
  - Network level coordination to transmit similar MIMO schemes show merit
  - Virtual single antenna transmission streams prove vital in such cases
- Intra eNB cooperation using precoding matrices when using single stream transmission can help medium to low SINR users
- Coordinated data repetition can improve the performance of very low SINR users

References

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