



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 deployment in the 2011-13 timeframe. We are looking into LTE+ addressing ground realities (not necessarily LTE-A)
- It is our viewpoint, possible enhancements considering low mobility users (indoor / nomadic) should be made possible 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 for LTE-A, the following becomes essential
 - Reuse 1 deployment
 - Uniform data rates across the cells
 - Optimization for fixed and nomadic applications
 - Effective interference management needed

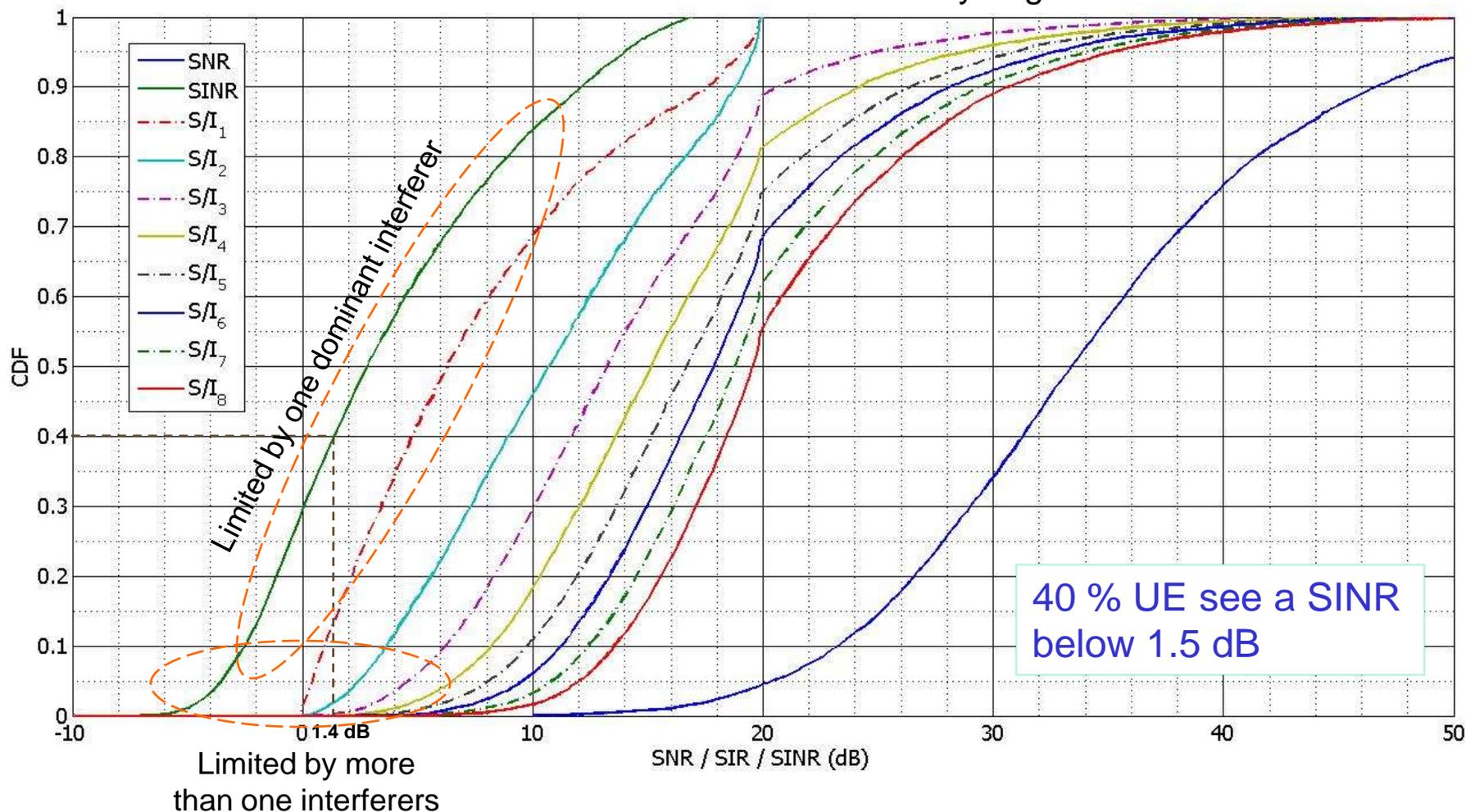
- Poor 'Low-SINR user' performance in reuse-1 networks
 - Severe co-channel interference (CCI)
 - Multiple CCI (up to 3-significant interferers)

- MIMO proposals not studied in the presence of interference

- Beamforming with 4 Transmit antennas offer additional gain over a 2 Transmit case

CDF of Signal Powers in a Reuse 1 System

Only large scale effects considered



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

$$y = hx_0 + \sum_{i=1}^N g_i x_i + n$$

System relation

$$\hat{x}_0 = wy$$

$$w = R_{xy} R_{yy}^{-1}$$

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

Precoding / precoding

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

Simpler MMSE receiver

Not so simple MMSE receiver

SFBC / SFBC

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

- Inference:

- MIMO design is not just about SNR improvement
- MIMO structure can be exploited for interference handling

Effects with Hybrid MIMO Schemes

Precoding / SFBC

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

Creates two interferers in the system

MMSE receiver implementation non-trivial

SFBC / Precoding

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

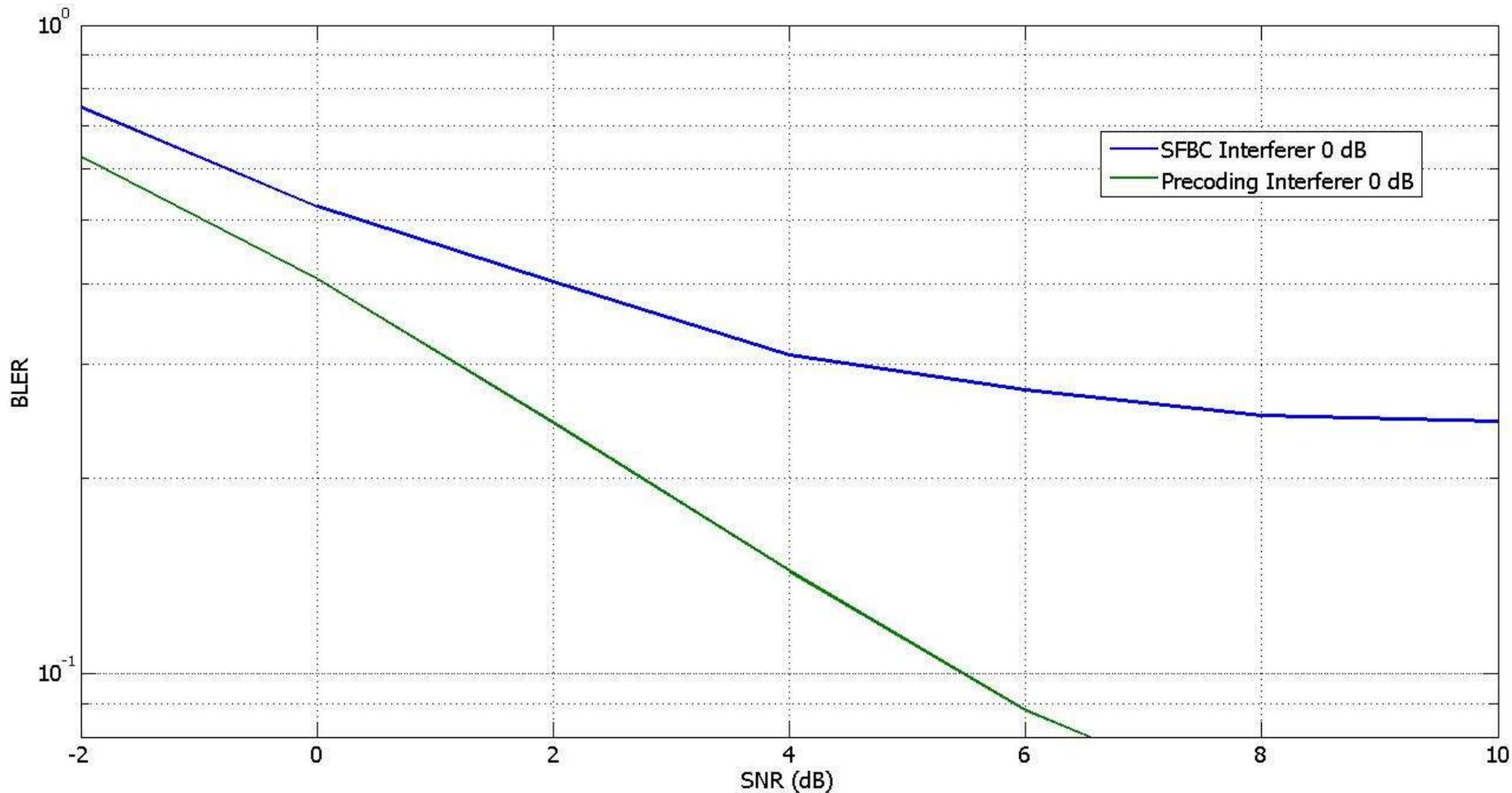
■ Inference:

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

Link Simulation Setup

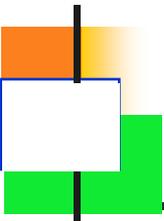
- EPA Channel model, 5 Hz Doppler
- MLS channel estimation
- QPSK modulation, MCS index 7
- 2 x 2 MIMO system
- No HARQ
- Feedback delay of 2 msec
- 10 MHz bandwidth and 2 GHz carrier frequency
- Other assumptions as per Rel-8 terminology

Simulation Performance



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

Regime of interest = 10% BLER



Use Cases

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

* 1 interferer assuming 2 Tx, can be 2 with 4 Tx antenna

- Inference:
 - 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 **symbol level synchronization** across cells
- Transmit signal processing using precoding matrices optimized for better inter cell behaviour seems promising
 - Distributed algorithm for inter base station cooperation
 - Precode to cause minimal interference
- Such techniques seem to complement FFR behaviour
 - Spatial interference coordination using precoding matrices ensures efficient MIMO usage

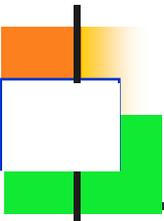
PMI Coordination

- Hadamard precoders used for closed loop precoding (Rel-8, 2Tx)
 - Simpler design and analogous to **phase beamforming**
 - Very effective mode of transmission when UE is Nomadic / Fixed

- Low SINR Cell-edge UEs get array-gain in addition to diversity

- With 2 Rx antennas, the MMSE receiver can handle 1 interferer

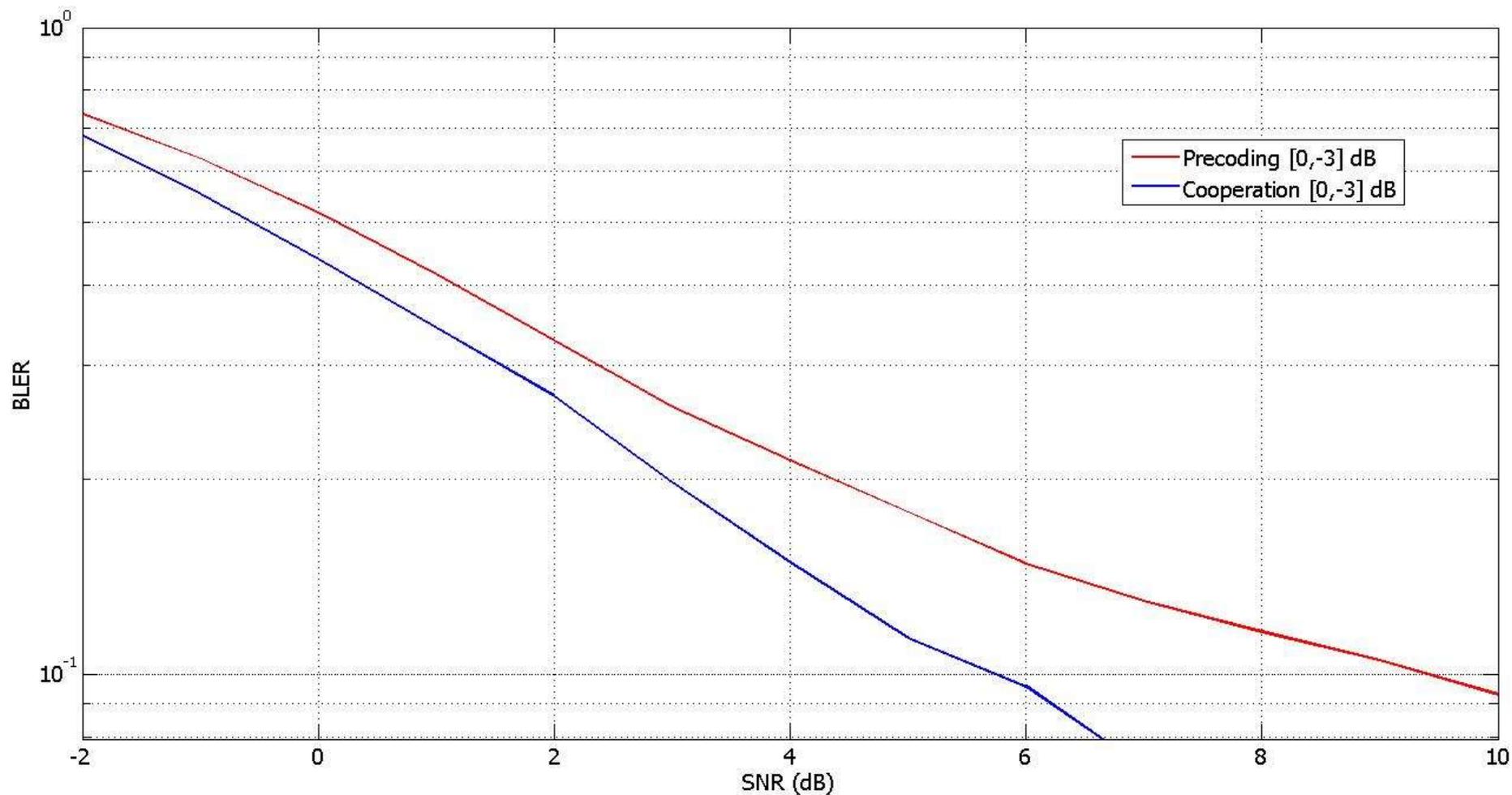
- **Use cooperation to minimize the impact of the other interferers**
 - eNB serving the cell edge UE selects the optimal precoding angle
 - Possibly the only option since **interference limited**
 - eNB's interfering will cooperate to minimize the interference
 - There are means to restore performance at high S(I)NR's



Simulation Setup

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

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

Performance Improvements

- 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**)
- Such coordination ends up loading the scheduler, which becomes inevitable
- The Rel-8 codebook needs to be extended to reap the true benefits of such coordination

Interference Handling in Legacy Systems

- At very low SINR, typically more than 2 significant interferers affect system performance
- Conventional technique for handling interference – randomization
 - Repeat information bits (eg. Rate 0.5, QPSK)

$$y_1 = h_1 x + g_{1i} x_i + n_1 \quad \text{Initial transmission}$$

$$y_2 = h_2 x + g_{2i} \tilde{x}_i + n_2 \quad \text{Re-transmission}$$

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

- 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

- Create multiple copies of transmit data across cells for the MMSE receiver processing
 - LTE baseline of 2 Rx antennas can handle 1 interferer
 - Repeat symbols across cells in a coordinated manner

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



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

$h_1(f)$ (pointing to h_1)
 $h_1(f+L) = \phi(h_1(f))$ (pointing to \cdot)

Use the OFDM property, adjacent RBs

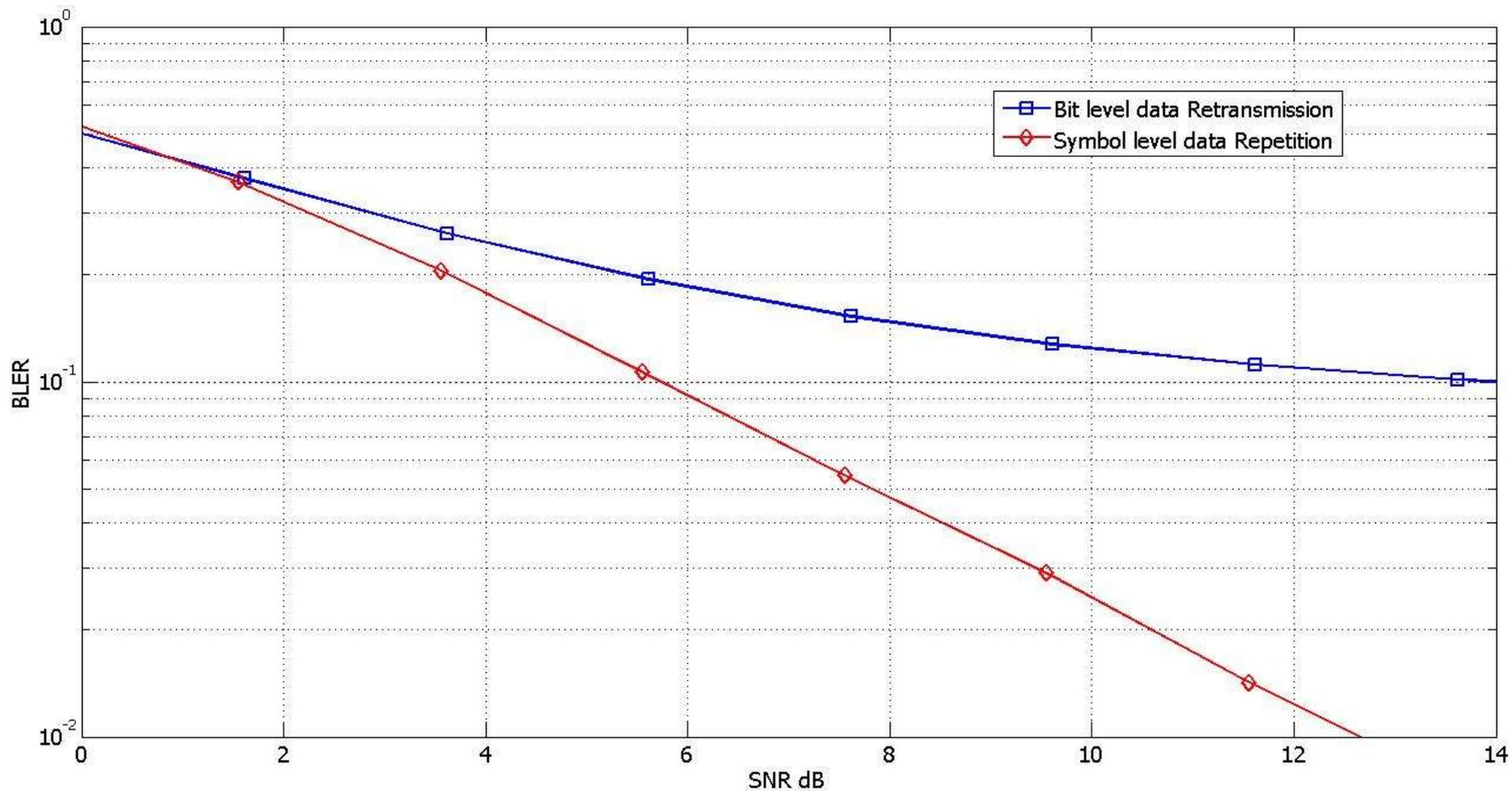
$$h_1(f)\phi(x) \Rightarrow \phi(h_1(f))x$$

ϕ Can be simpler functions like phase shift and conjugation

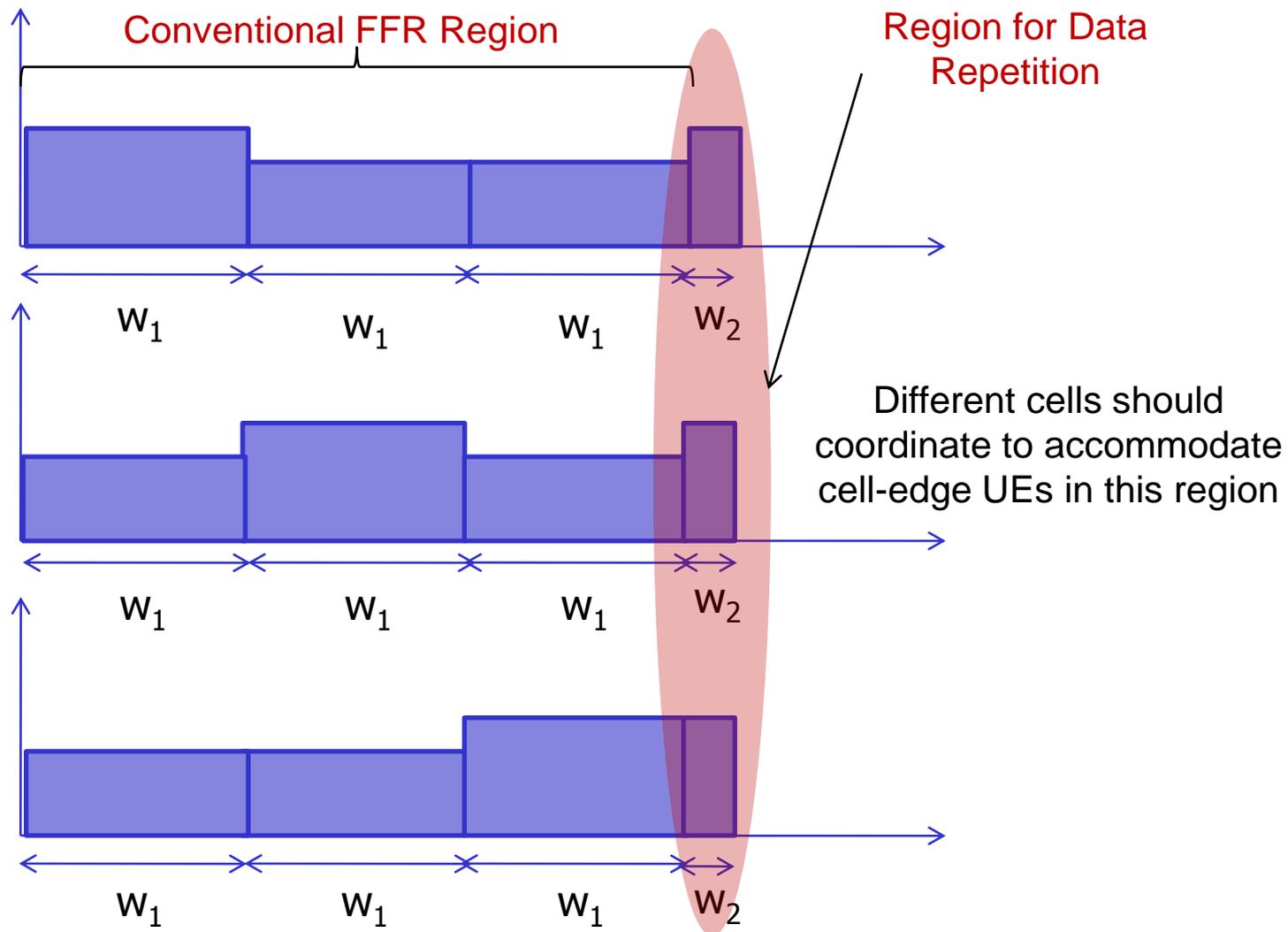
Simulation Setup

- 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 (Retransmission v. Repetition)



FFR Choice



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 via makes efficient usage of the receiver antennas
 - 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

1. TR 36.913 v8.0.0, "Requirements for Further Advancements for E-UTRA (LTE-Advanced)"
2. R1-083931, "Downlink coordinated transmission – Impact on specification", Ericsson, 3GPP RAN1 #54bis, Prague, Czech Republic, Sept 29- Oct 3, 2008
3. 3GPP TS 36.211 "Evolved Universal Terrestrial Radio Access (E-UTRA) Physical channels and modulation", V8.4.0
4. R1-084482, " Low-Complexity Precoding for LTE-A Collaborative MIMO: A Signal Leakage Approach", Mitsubishi Electric, 3GPP RAN1 #55, Prague, Czech Republic, Nov. 2008
5. REV-080050, CEWiT, "IMT Advanced Technical Requirements -- An India Perspective"
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