Cutting Edge at the Cell Edge

Interference Mitigation in Emerging Broadband Wireless Systems

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Acknowledgments

CEWiT Research Staff

- Kiran Kuchi
- Klutto Milleth
- Vinosh B. James
- R. Vinod
- M.S. Padmanabhan
- V. Ganesh
- M.K. Dileep
- B. Dhivagar

IIT Madras

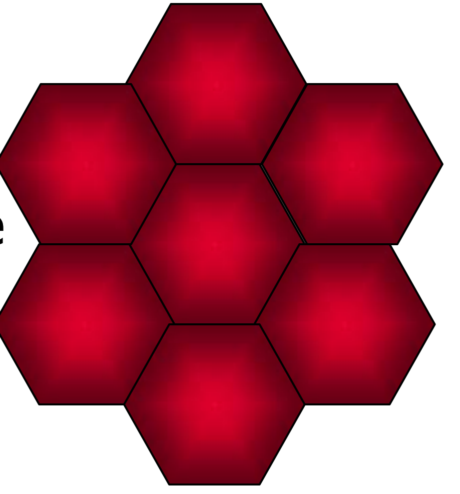
- K. Giridhar

Key Aspects of Emerging 4G technologies

- LTE/LTE-A as well as 802.16e/m based on OFDM
  - Scalable (3-20) bandwidth, typically 10-20 MHz
    - Multi-Band aggregation up to 100 MHz
  - 4x2 MIMO typical, 8x4 possible
  - 8-10 bps / Hz / site throughput
  - <5% users ~ 0.1 bps/Hz
  - Spectrum Re-use 1:1

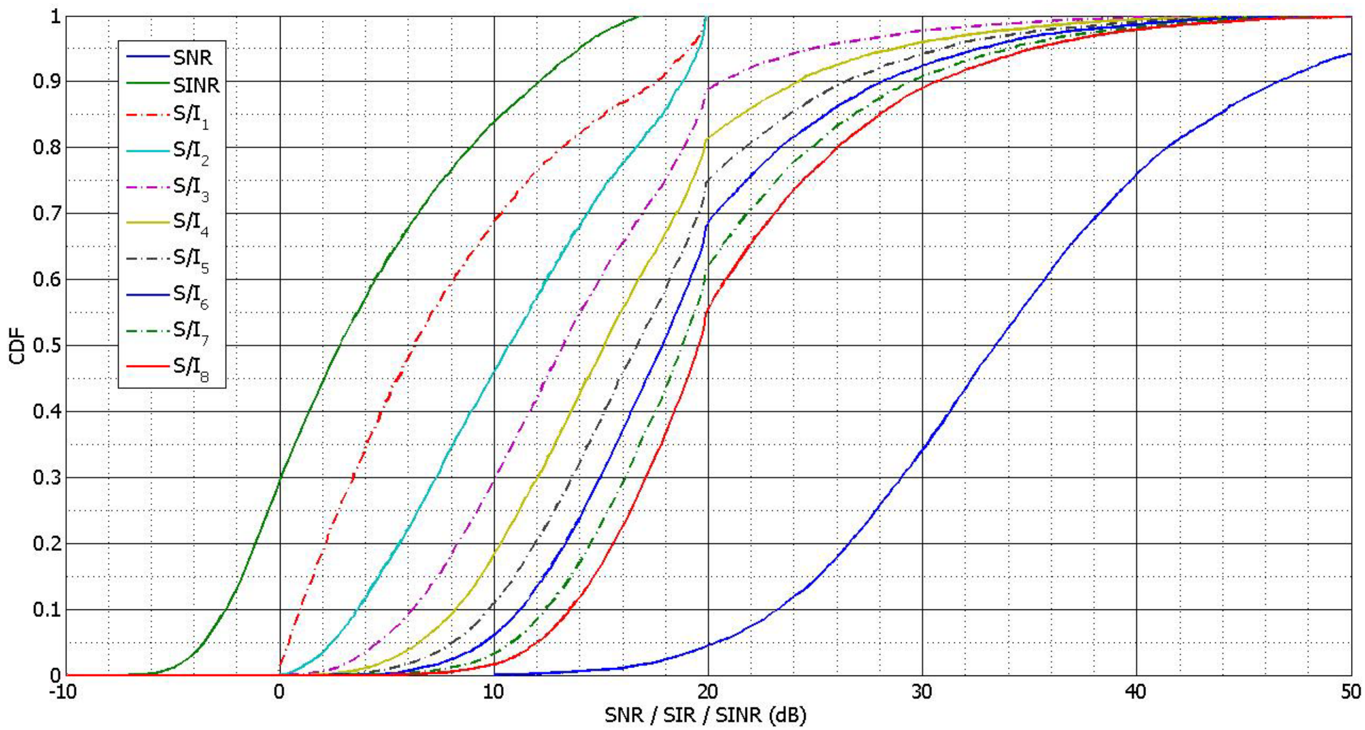
India: differences

- 85% users nomadic, in-building
  - Cell-edge users camp at cell-edge
- Cell-edge user also needs >512 kbps
  - Without consuming all the spectrum resource
- Cells as small as 200m radius
  - Increases cell-edge area
- In-building users distributed vertically
  - Stronger interference at higher floors (not captured in typical path loss models)



Frequency re-use 1:1

Distribution of SINR: 1:1 re-use



40% users below 2 dB, 30% below 0 dB!

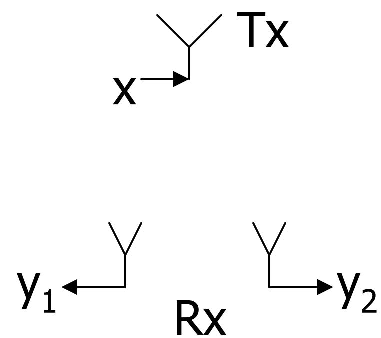
CEWiT in standards

- CEWiT's focus : significant improvement in cell-edge performance
  - With modest complexity in terminal
- CEWiT responsible for focus on nomadic, cell-edge user in LTE-A and 802.16m
- Several proposals in both standards

Vision: Make 4G (starting with 3G) do for broadband in India what 2G did for telephony

Interference mitigation options with 2 Rx antennas

- Assume single Tx antenna
- Receive two different copies



$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x + \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} u + \textbf{\textit{noise}}$$

- Can treat interference **g** *u* as white noise : Max. Ratio Combining (MRC) receiver: simple, poor performance
- Can detect *x* and *u* jointly assuming channels are known (estimated) : MLD receiver: complex, best
- Can treat **g** *u* as colored noise with known (estimated) statistics : ≡ MMSE receiver
  - Good compromise, linear receiver with modest complexity

MMSE Interference Cancellation

- With two antennas, can mitigate one strong interferer
  - Other background interference clubbed with noise
- With dominant interferers > 1, block error rate will floor
- Desired-signal channel parameters, and (dominant-)interference+noise covariance, estimated from respective pilots

Two Transmit Antennas: MIMO modes

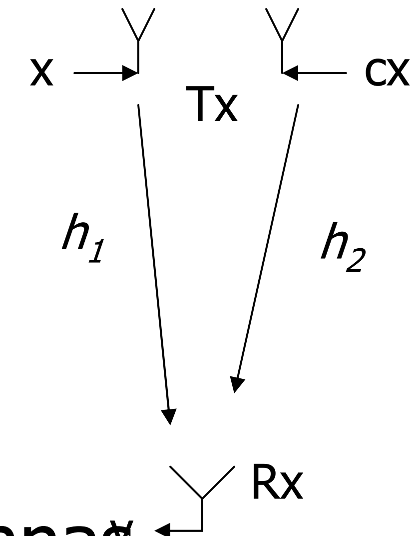
- Diversity mode: Alamouti code
  - Two symbols transmitted over two symbol durations (or two frequency tones)
  - Open-loop
- Beamforming mode
  - Closed-loop: feedback from terminal about channels used to co-phase tranmissions
  - Works well for nomadic / low mobility case
  - Gives array gain compared to open-loop

MIMO modes and MMSE IC

- In closed-loop beamforming (CLB) same symbol transmitted thru second antenna after rotation by *c*
- $y = (h_1+ch_2)x$: Tx appears as as single virtual antenna with channel h_1+ch_2

$\Rightarrow$ MMSE IC works well 2 Rx antennas if interferer is also using CLB

Alamouti code and CLB do not suit each other for IC



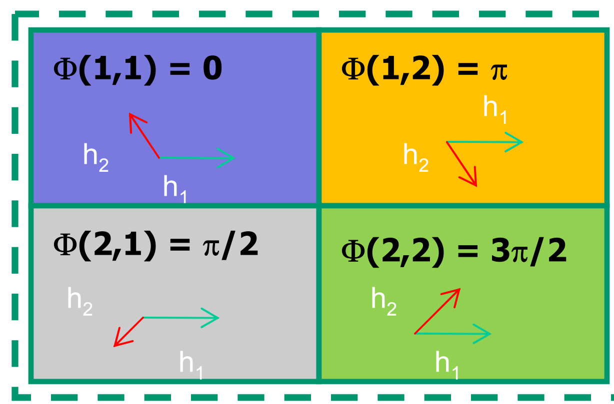
Strategy for enabling MMSE IC on D/L at cell edge

- Virtual single antenna diversity MIMO model as substitute for Alamouti codel
- Beamforming not only for array gain but also interference mitigation
  - Base station co-operation (Inter Cell Interference Cancellation
- Technique for commn. even at -3 dB SINR!

2D Phase Offset Diversity

- Symbols in each Resource Block (p tones x q symibols block) multiplied with a distinct phase rotation and transmitted through second antenna
- Code Block spans > 2 RBs
- Enable a code-block to see multiple effective channel realizations

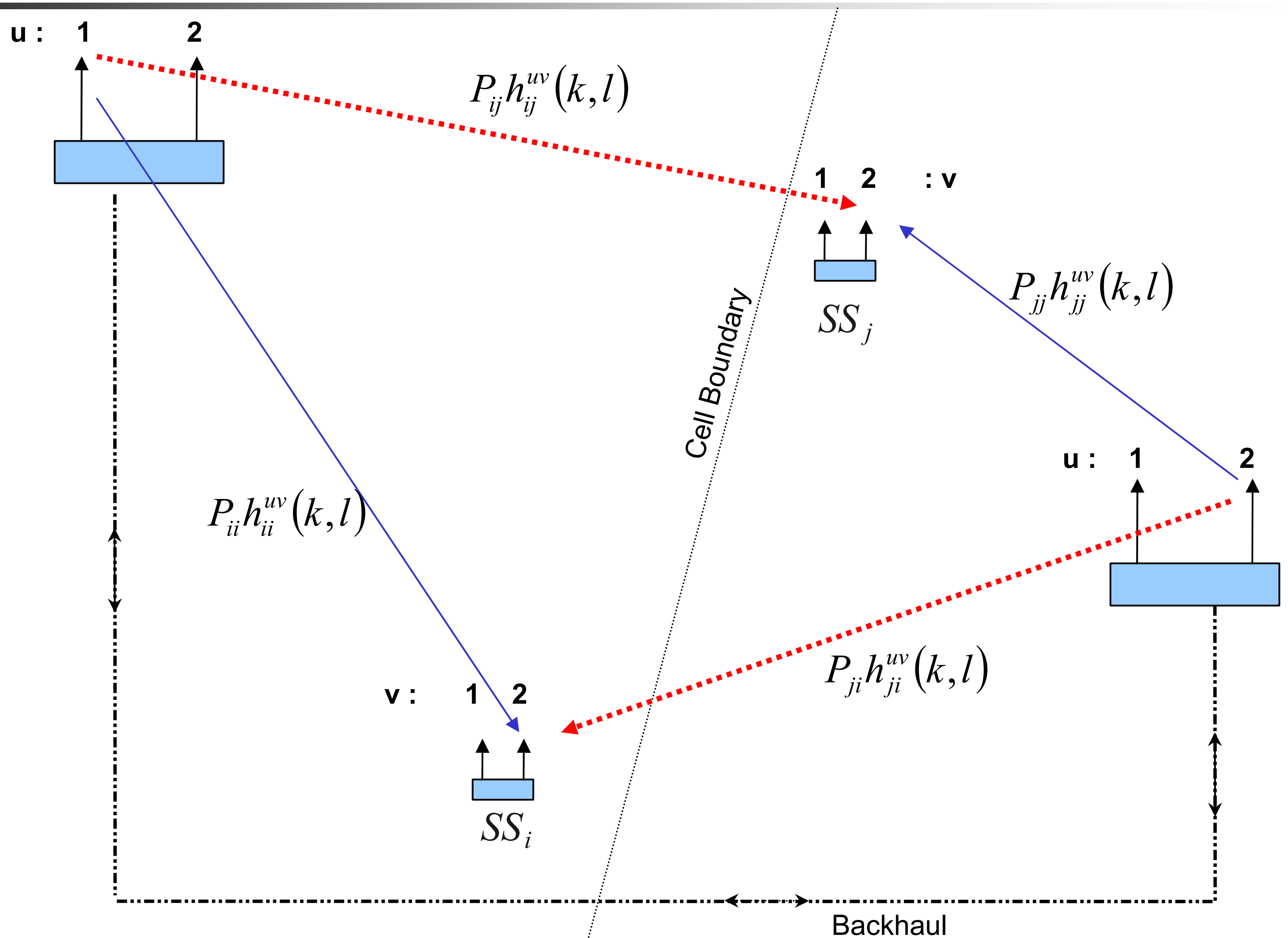
$$\begin{bmatrix} s_k \\ s_k e^{j\Phi(p,q)} \end{bmatrix} \begin{array}{l} \xrightarrow{Ant\ 1} \\ \xrightarrow{Ant\ 2} \end{array}$$



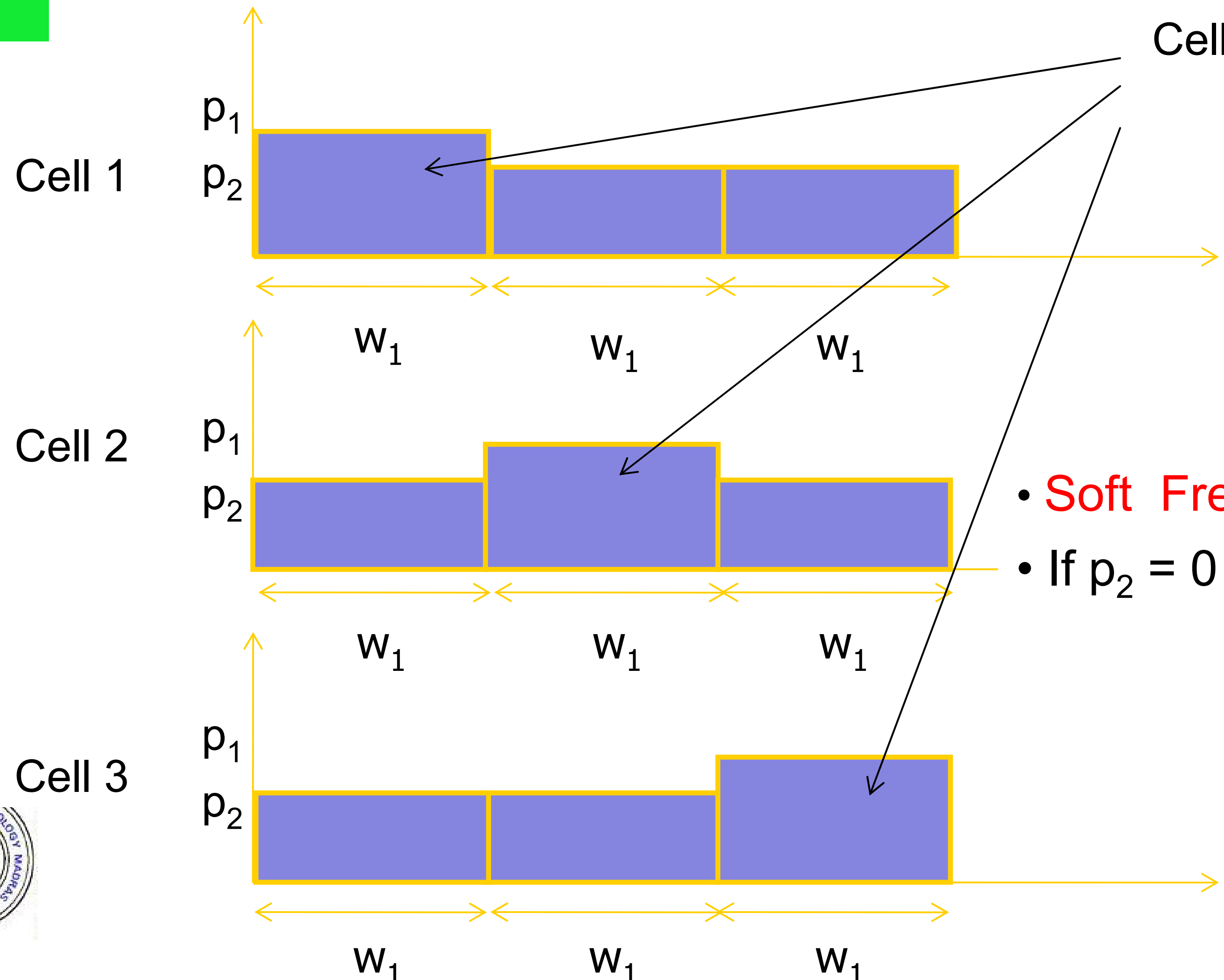
- Virtual single antenna channel
  - Enables MMSE IC
- Diversity performance similar to Alamouti code for Rate ½ modes
  - Rate ~ ½ not a constraint at cell edge

Included in 802.16m SDD Text

Inter-Cell Interference Cancellation (ICIC)

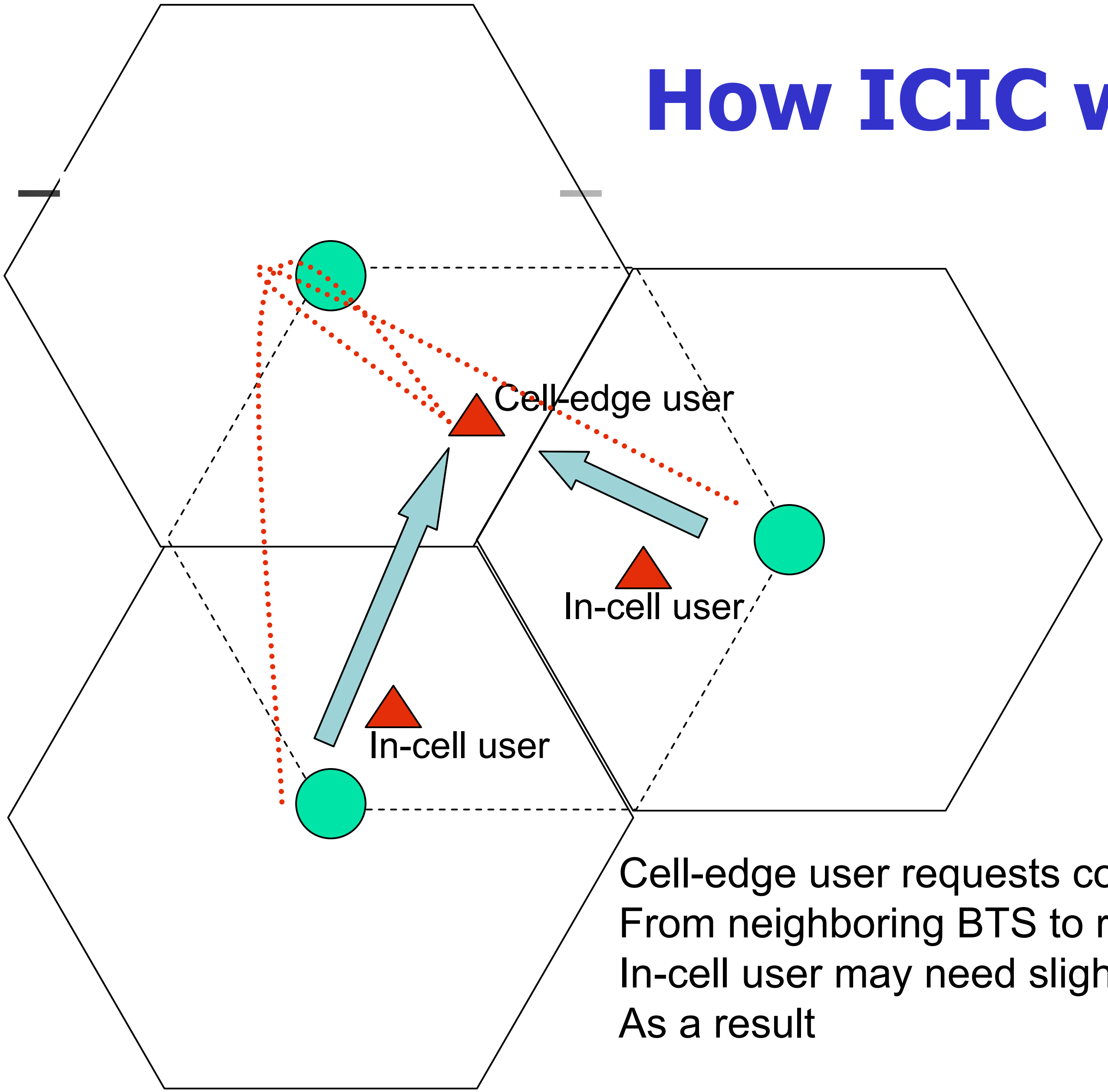


Fractional Frequency Reuse



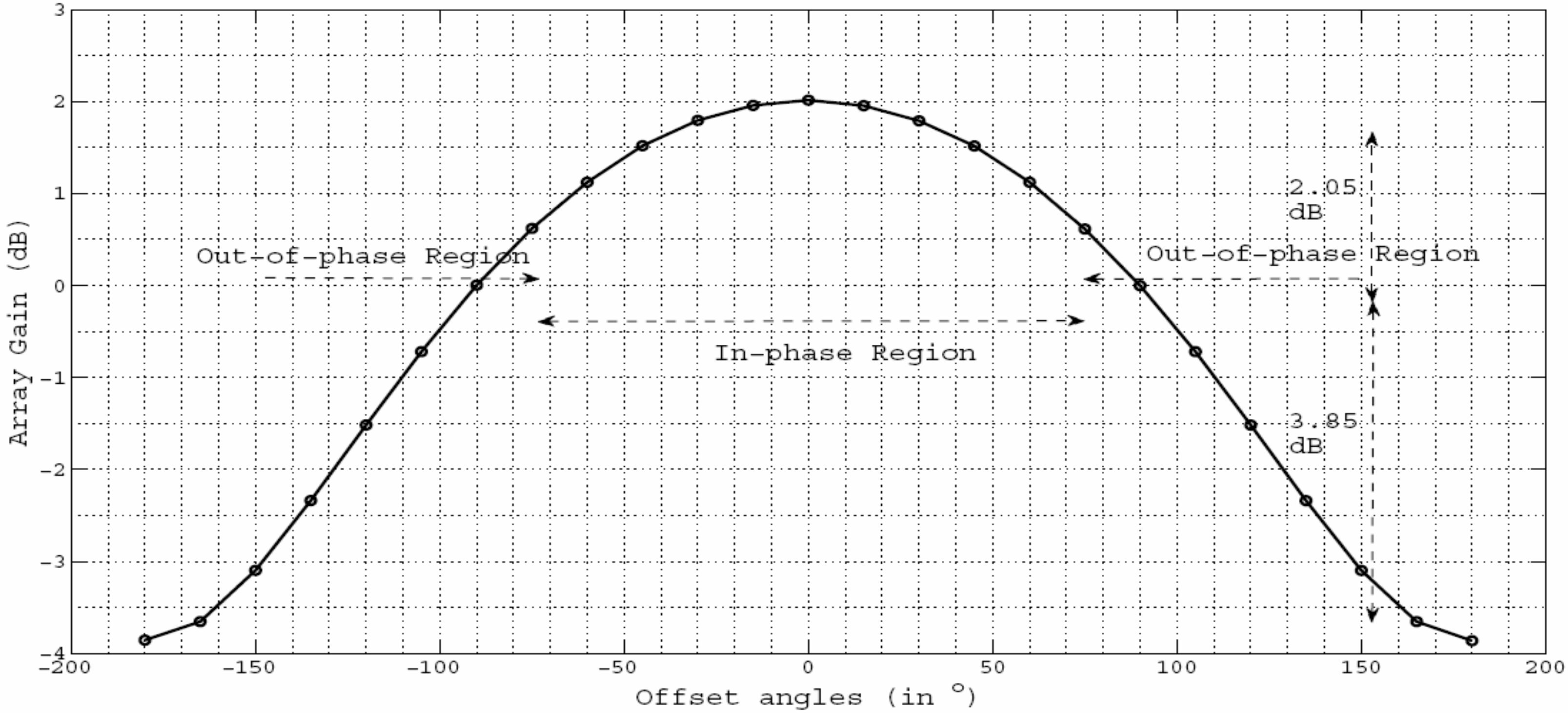
- Soft Frequency Reuse
- If $p_2 = 0 \Rightarrow$ 1:3 re-use

How ICIC works



Cell-edge user requests co-operation
From neighboring BTS to reduce interference
In-cell user may need slightly higher power
As a result

Array Gain vs. Offset from Optimal BF angle



BTS of in-cell user can offset in In-phase region if cell-edge use can benefit from "array loss" in interference

Benefits of ICIC

- Reduces interference "at source"
- Can compensate for loss in array gain for in-cell user by increasing power
- Works when closed-loop feedback is possible and BTS-BTS link has low latency
- Gives array gain over 2D-POD
- Virtual single antenna mode

$\Rightarrow$ MMSE IC possible

Negative-SINR Handling in Legacy Systems

- Conventional technique for handling very high interference and lowest FEC rate does not work
  - $\Rightarrow$ Repeat information bits (eg. Rate 0.5, QPSK) with randomization

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

Initial transmission

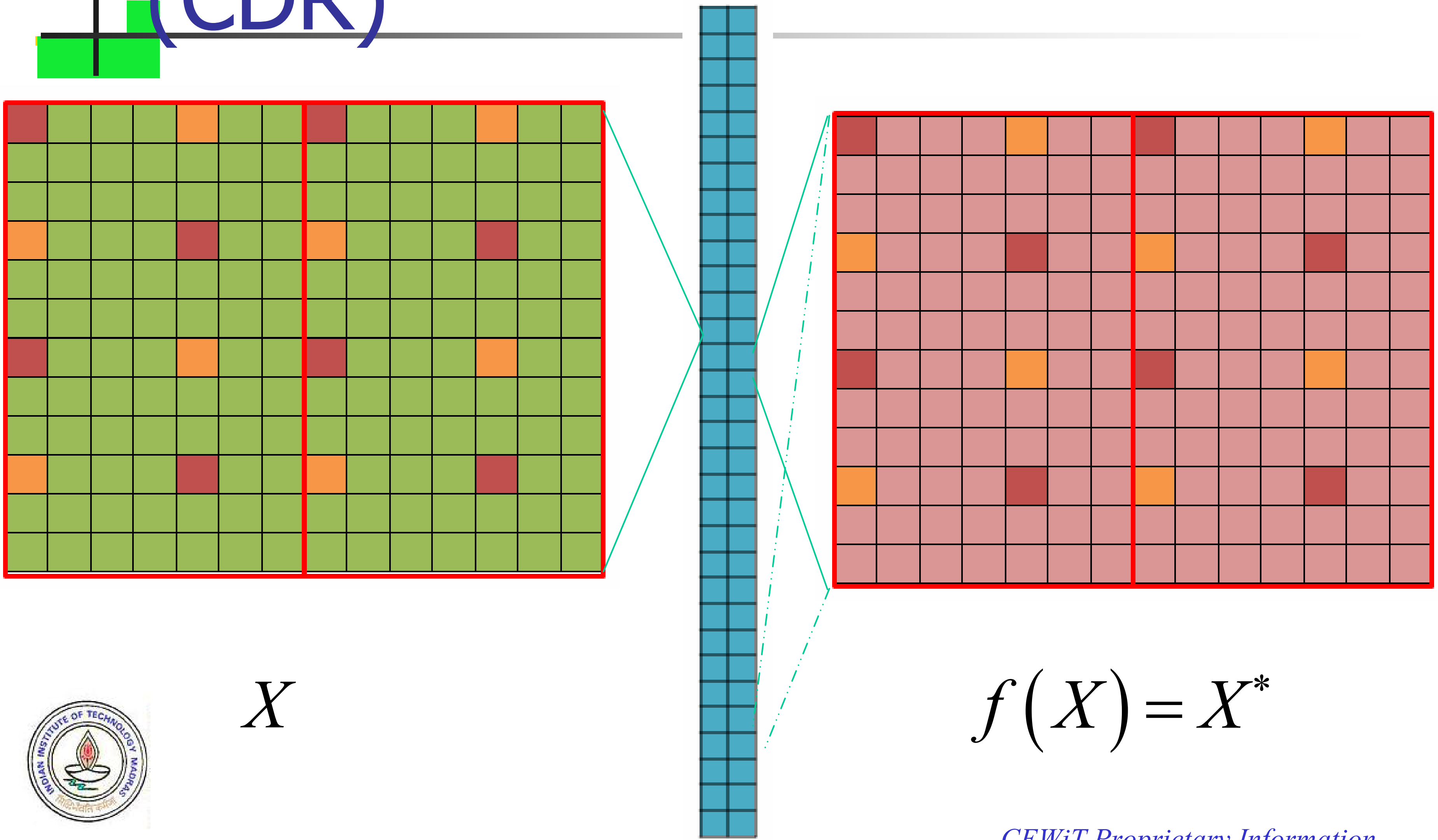
$$y_2 = h_2 x + \qquad + g_{2i} \tilde{x}_i + n_2$$

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 helps to improve the S(I)NR, but ignores structure in interference
- Bit level repetition is spectrally inefficient

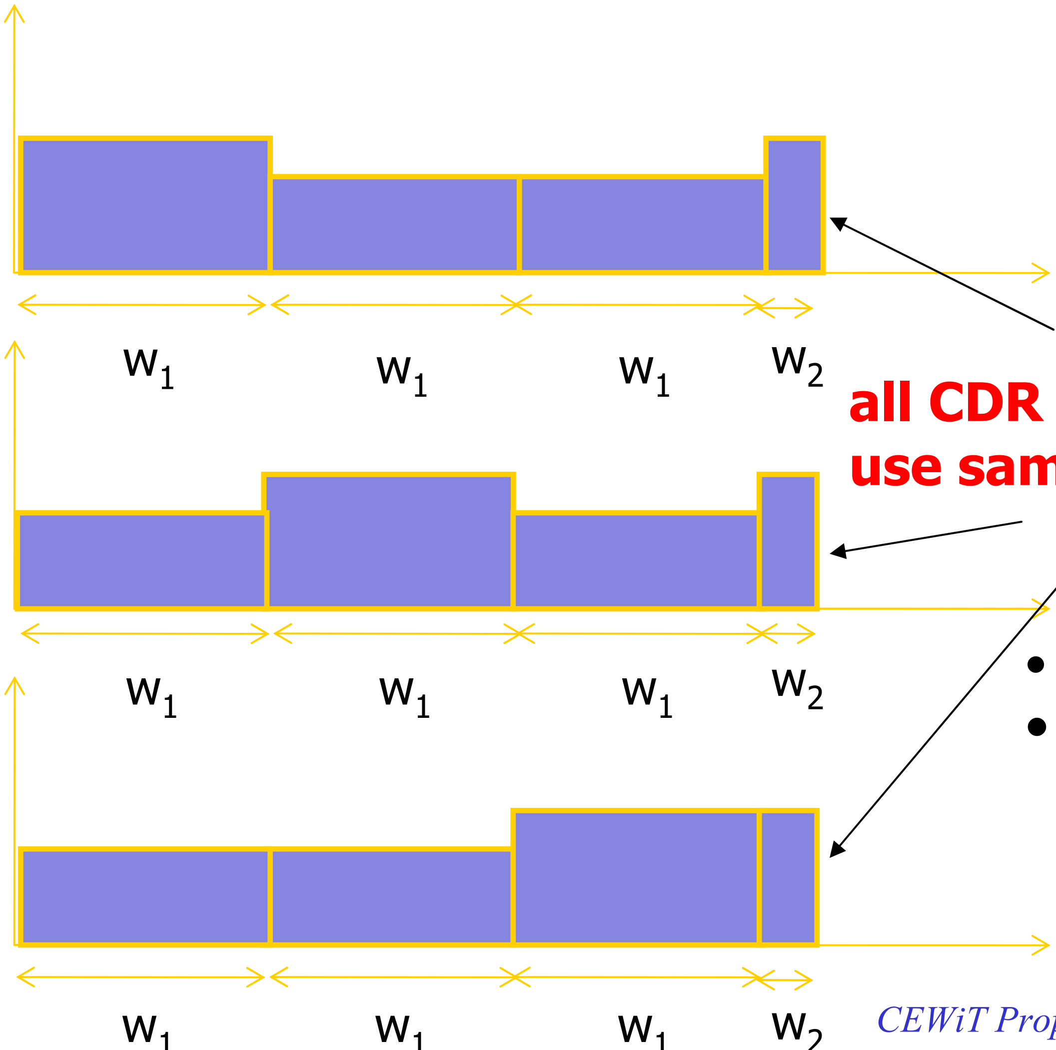
Conjugate Data Repetition (CDR)



X

$f\left(X\right)=X^{*}$

FFR Modification



all CDR users in 3 cells use same resources

- *Counter-intuitive*
- *because we want to exploit structure*

Benefits of CDR

- Rxvr conjugates second copy $[hx^*+gu^*+\ldots]^*$ to get $h^*x + g^*u + \ldots$
- Each Rx antenna generates second copy of every symbol + interference with *-ed channel parameters

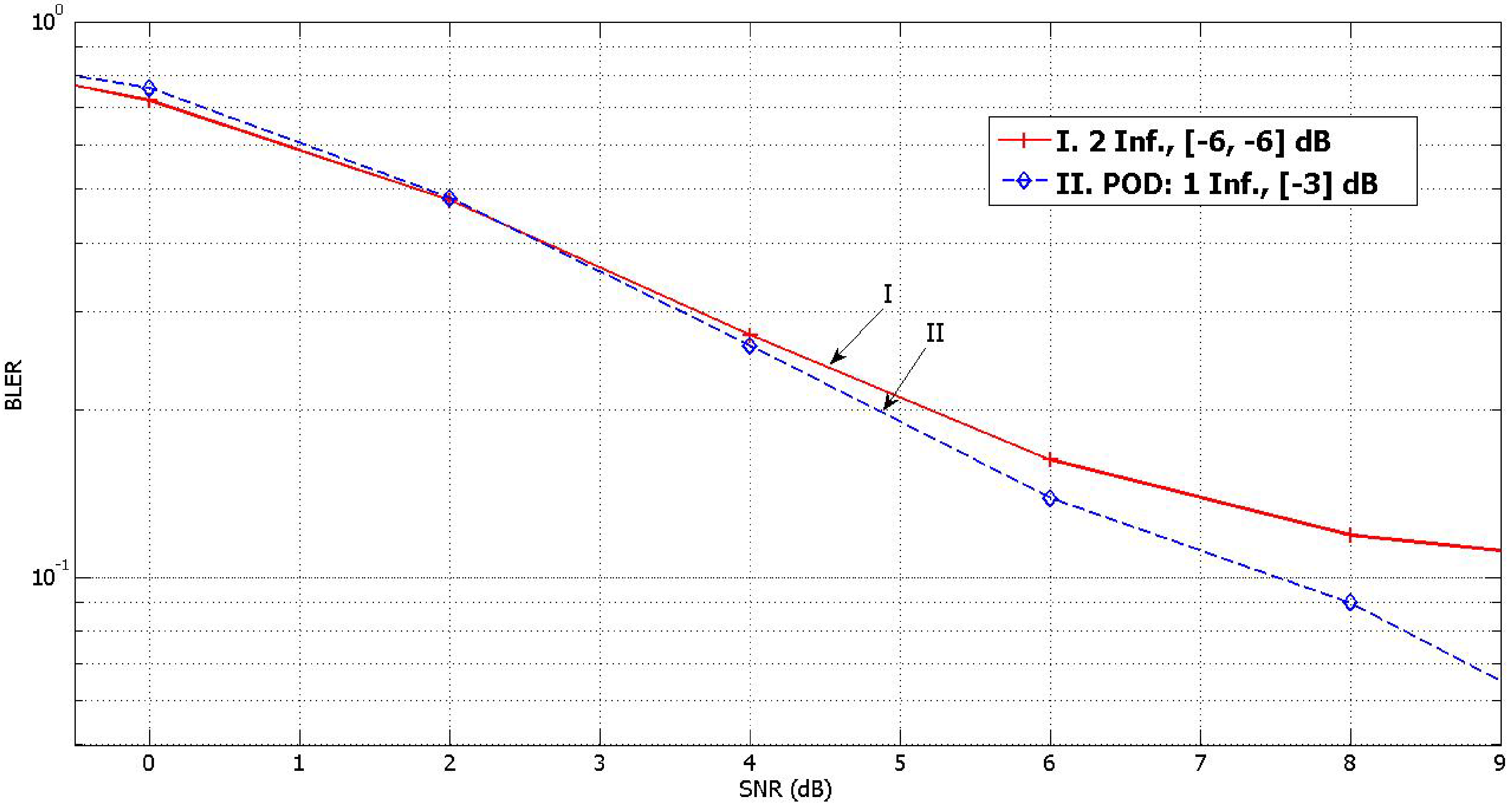
  $\Rightarrow$ independent channel $\equiv$ extra Rx antenudena!
- Two Rx antennas $\equiv$ 4 virtual antennas

  $\Rightarrow$ 3 dominant interferers can be mitigated
- Can be combined with 2DPOD or ICIC

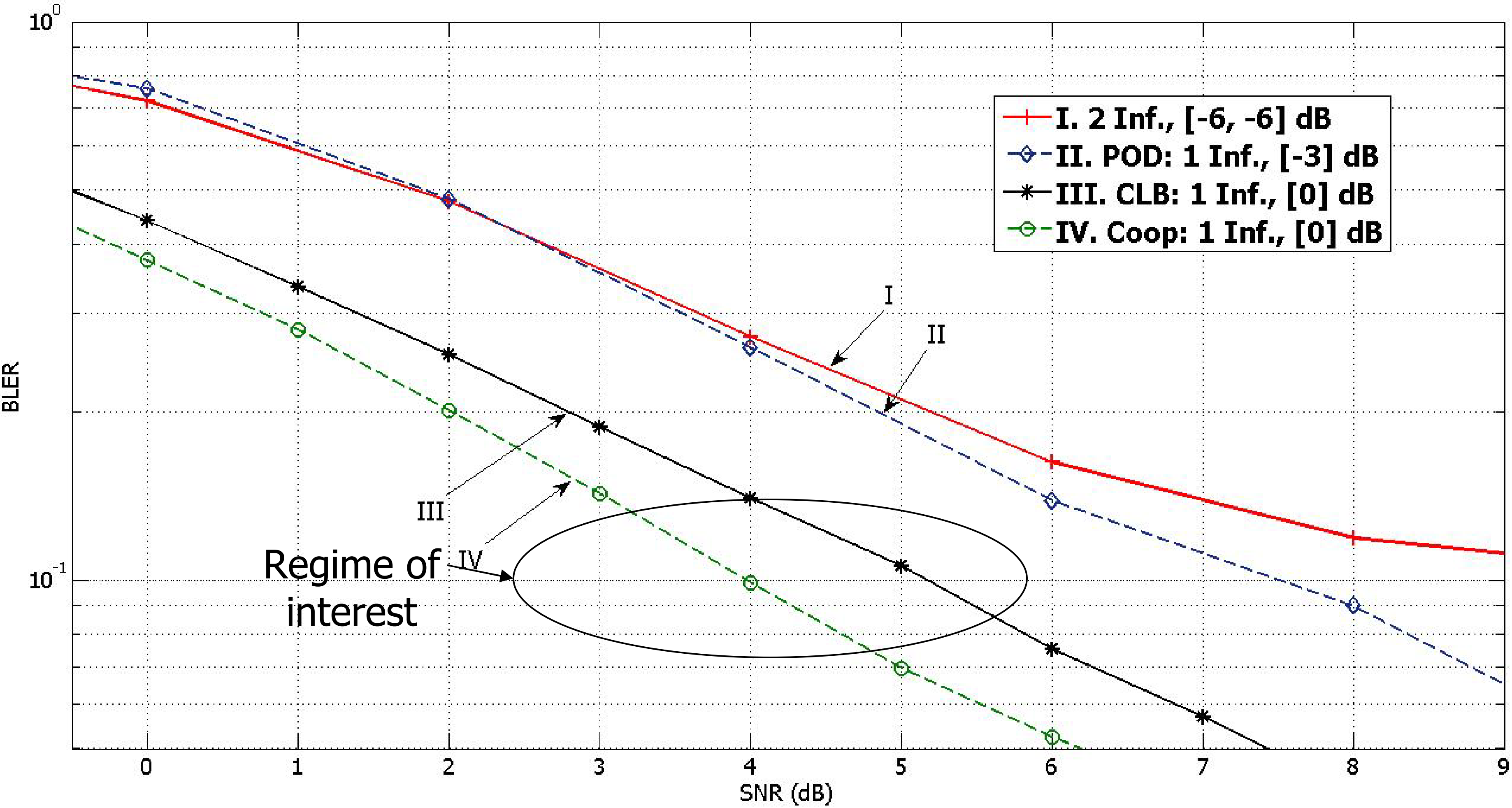
Expect to be included in SDD text next week

Operating Regime of Interest

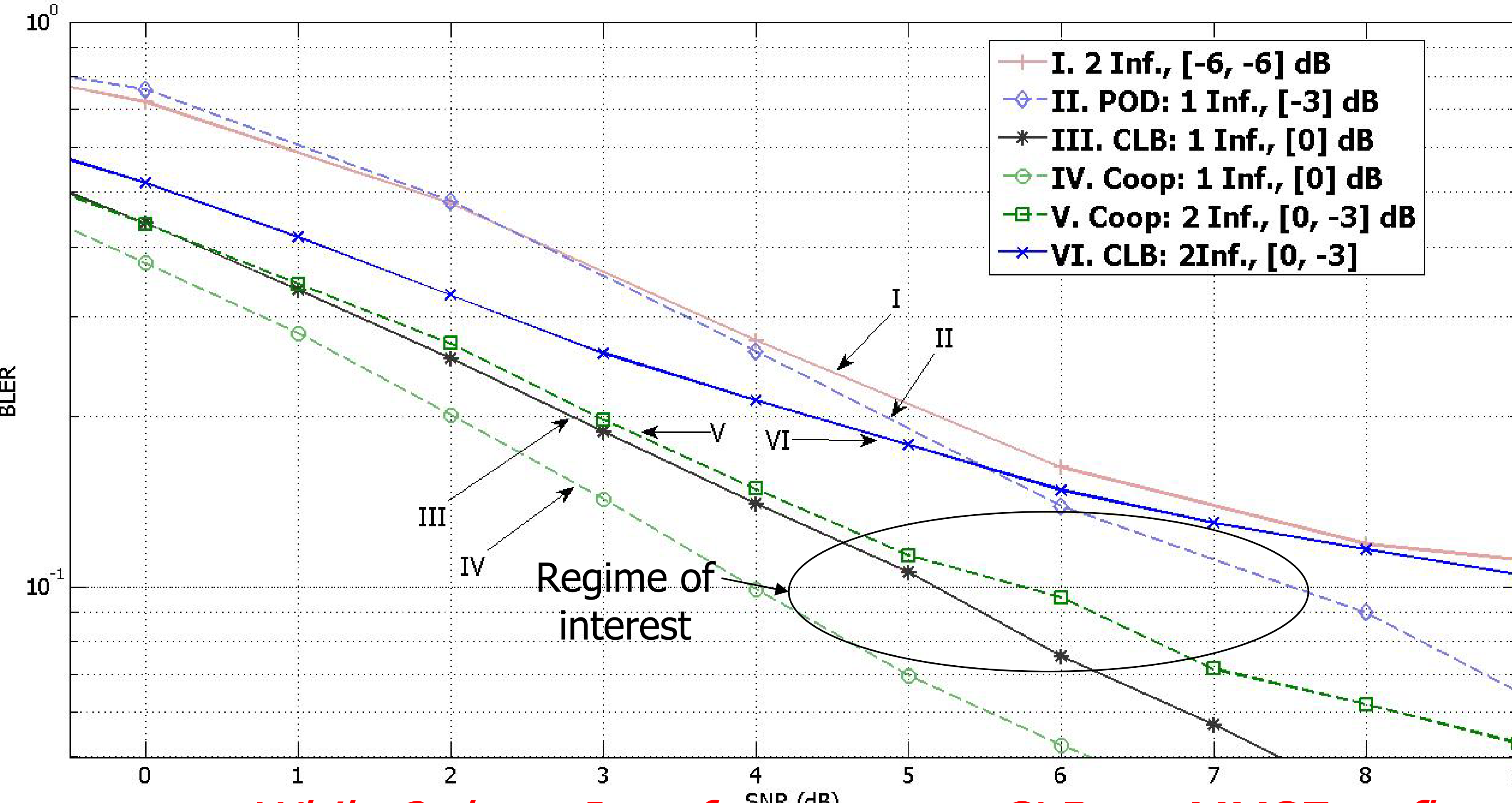
- For HARQ efficiency to be good, BLER < 10^{-1}
- For given set of dominant interferers, plot BLER vs. S"N"R where "N" is thermal noise + rest of background interference
- The RoI is when
  (i) "N" is smallest dominant interferer – few dBs
  (ii) BLER < 10^{-1}



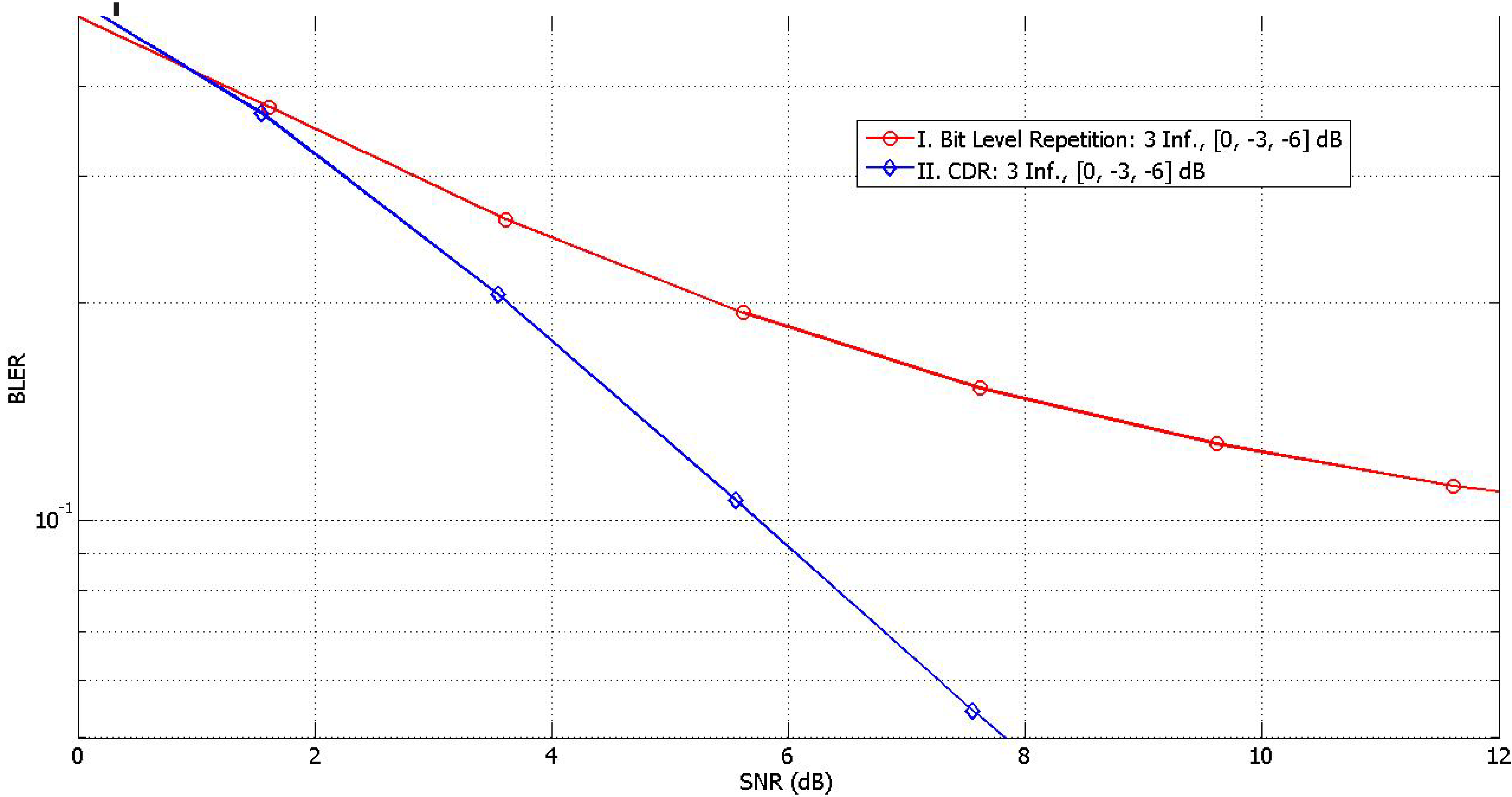
- *1 dominant interferer mitigated by MMSE IC* (II)
- *2 or more cause flooring* (I)



- *CLB+MMSE gives further array gain over 2DPOD* [III]
- *ICIC + MMSE gives further improvement with no loss to in-cell user* [IV]



- *While 2 dom. Interferers cause CLBs + MMSE to floor above 10^{-1},*
- *ICIC+MMSE floors at a lower BLER and lowers the curve into RoI*



- *CDR can handle 3 dominant interferers without flooring,*
- *and SINR < -3 dB*

Conclusions

- Can get significant traction in handling strong to severe interference at cell edge by enabling MMSE IC at Rxvr
  - O/L 2DPOD
  - C/L ICIC
  - CDR for negative SINR
- With 4 Tx antennas at BTS, can do more
- Being proposed actively at both 802.16m and LTE-A
  - Important for India