3G/4G Mobile Communications Systems

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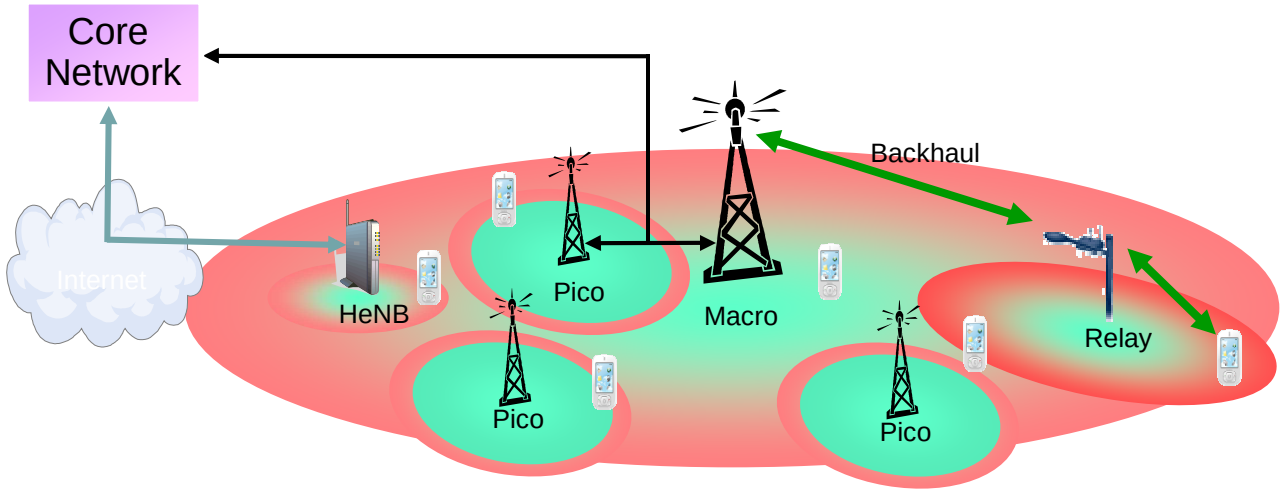
Chapter X: enhanced Inter Cell Interference Coordination in LTE

Enhanced Inter Cell Interference Coordination

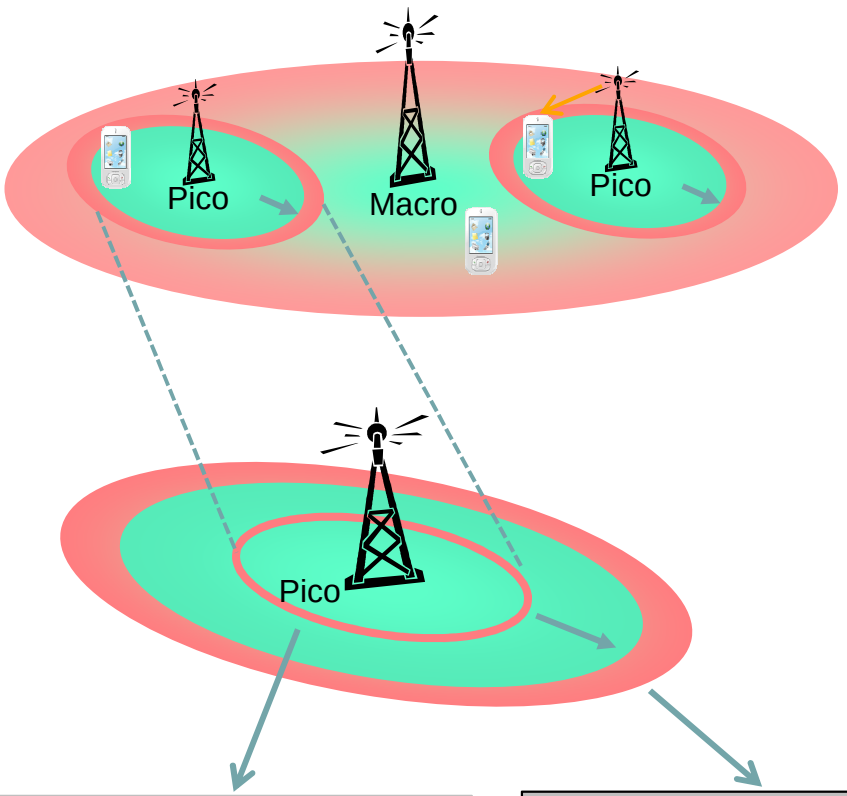
- The Next Deployment Step: Heterogeneous Networks
- Traffic Offload and Cell Range Expansion
- Interference Scenarios in Heterogeneous Networks
- Enhanced Inter Cell Interference Coordination (eICIC)
  - Almost Blank Subframes
  - X2 Coordination
- Interference Cancellation Receivers
  - CRS, PSS/SSS, PBCH
- Performance Gains of eICIC with IC receivers

Heterogeneous Networks

- Network expansion due to varying traffic demand & RF environment
  - Cell-splitting of traditional macro deployments is complex and iterative
  - Indoor coverage and need for site acquisition add to the challenge
- Future network deployments based on Heterogeneous Networks
  - Deployment of Macro eNBs for initial coverage only
  - Addition of Pico, HeNBs and Relays for capacity growth & better user experience
    - Improved in-building coverage and flexible site acquisition with low power base stations
    - Relays provide coverage extension with no incremental backhaul expense



Traffic Offloading from Macro to Pico Layer



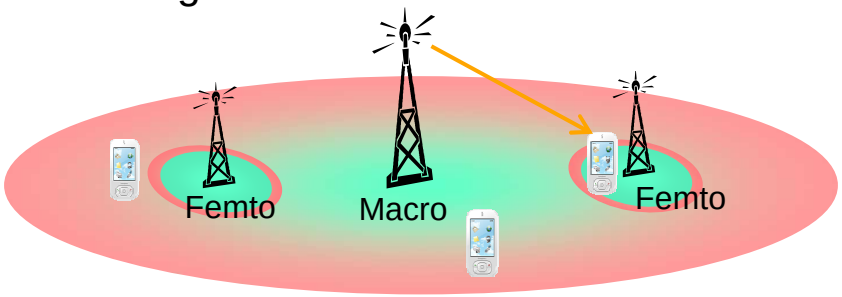
SIR = 0 dB at cell edge of regular coverage area

SIR < 0 dB at cell edge of expanded coverage area

- In homogeneous networks traffic is served by macro base stations
- Deploying pico cells offers capacity gains by traffic offloading
  - Traffic offloading: UEs are preferably served by the pico cell rather than the macro cell
- Advantages
  - Better load balancing between macro and pico layer improves network capacity and user
- How to achieve traffic offloading? Answer: Cell range expansion of the pico cell
  - The UE should connect to the pico cell even if the macro cell is stronger
  - Coverage area of the pico cell is artificially enlarged → Cell range expansion

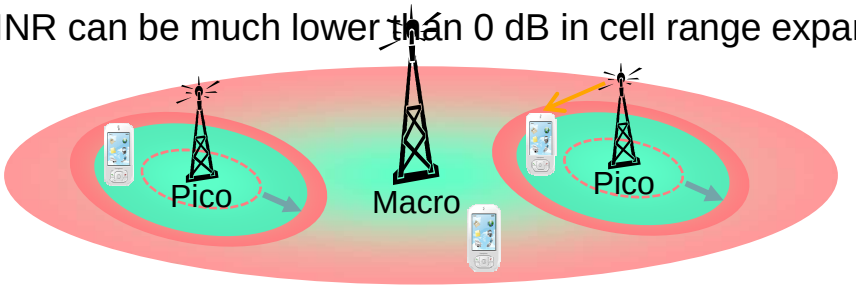
Downlink Interference Scenarios in HetNets

- UEs in close proximity to CSG femto cells if UE is not allowed to connect to
  - This results in strong interference from the CSG cell



Femto is the aggressor and macro the victim

- Macro-pico deployments with UEs operating in cell range expansion
  - Nominally, a UE associates with a base station with strong DL SINR
  - With cell range expansion, a UE can associate with a low power eNB
    - The DL SINR can be much lower than 0 dB in cell range expansion



Macro is the aggressor and pico the victim

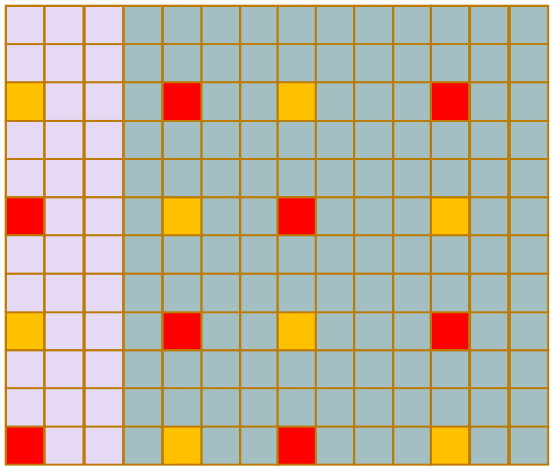
eICIC in LTE Rel-10/11 – Concept

- Enhanced interference management is needed to combat interference in HetNet co-channel deployments
  - Examples: CoMP, Coordinated Beamforming, eICIC

- eICIC is introduced in LTE Rel-10 and further enhanced in Rel-11
    - eICIC = **e**nhanced **I**nter **C**ell **I**nterference **C**oordination
    - FeICIC = **F**urther **e**nhanced **I**nter **C**ell **I**nterference **C**oordination

- eICIC consists of three design principles
  - Time domain interference management (Rel-10)
    - Severe interference limits the association of terminals to low power cells
  - Cell range expansion (Rel-10/11)
    - Time domain resource partitioning enables load balancing between high and low power cells
    - Resource partitioning needs to adapt to traffic load
  - Interference cancellation receiver in the terminal (Rel-11/12)
    - Ensures that weak cells can be detected
      - Inter cell interference cancellation for control signals (pilots, synchronization signals)
    - Ensures that remaining interference is removed
      - Inter cell interference cancellation for control and data channels (PDCCH/PDSCH)

Almost Blank Subframes in eICIC (Rel-10)



RS antenna port 1 resource element

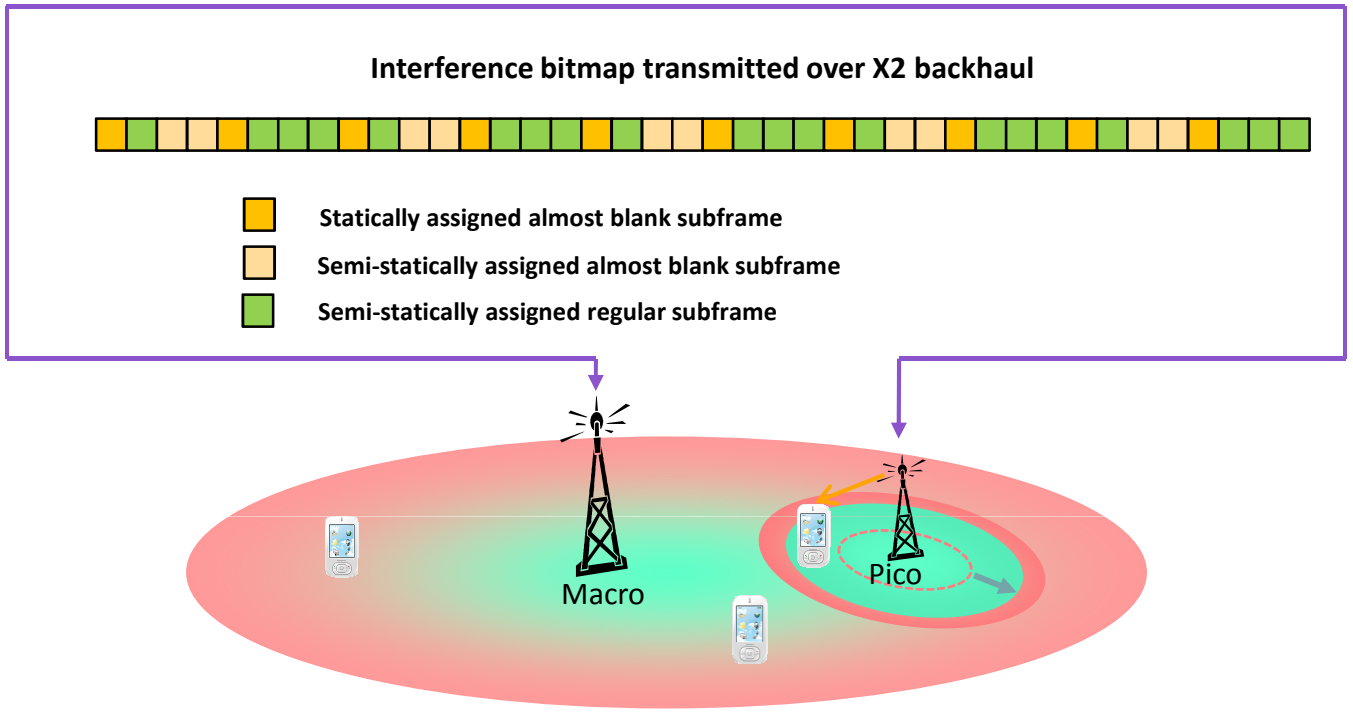
RS antenna port 2 resource element

Empty PDSCH resource element

Empty PDCCH/PHICH/PCFICH resource element

- In Rel-10, almost blank subframes (ABS) have been introduced
- In a ABS, no unicast PDSCH and PDCCH is transmitted
- To ensure backward compatibility, following signals are transmitted
  - CRS (pilot signal)
  - PSS/SSS (synchronization signals)
  - SIB1/MIB (broadcast information)
- CRS/PSS/SSS/SIB1/MIB can still cause strong interference in certain PRBs/REs

Interference Coordination in eICIC (Rel-10)



- Interference coordination between aggressor cell and victim cell is done by means of a bitmap sent over X2 interface
  - Each bit is mapped to a single subframe and indicates an ABS subframe
  - Based on the data traffic demand, the pattern can change each 40ms
  - Cell creating strong interference controls which resources can be used by the victim cell to serve terminals in harsh interference conditions

Updates of the X2AP to support eICIC in Rel10

- Information of ABS pattern is added to the ‘Load Indication’ procedure
  - The ABS pattern (40ms period for FDD) is sent from the aggressor to the victim
  - The ABS patterns are semi-statically updated
- The ‘Load indication’ also contains an invoke indication
  - This indicator is sent from the victim to the aggressor to ask for eICIC activation

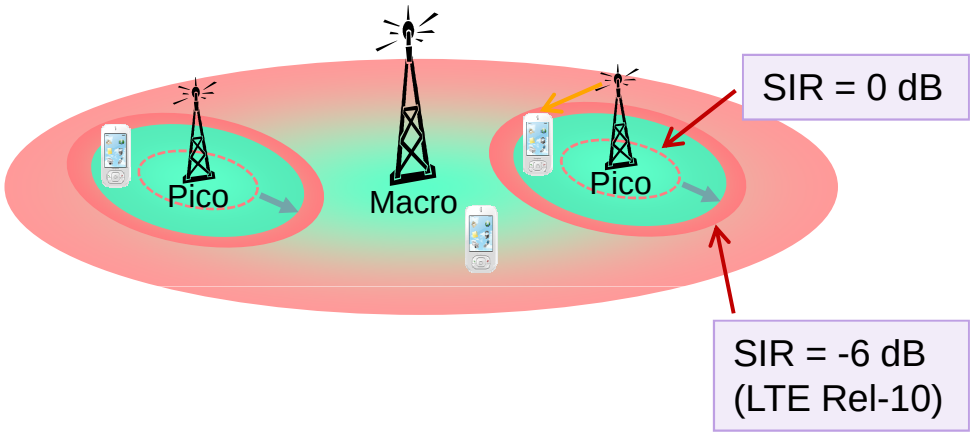
IE/Group Name	Presence	Range	IE type and reference	Semantics description
Invoke Indication	M		ENUMERATED (ABS Information, …)	–

- Information about the status of the ABS is added to the ‘Resource Status Reporting’ procedure
  - Its initialization is enabled in the ‘Resource Status Reporting Initiation’ procedure
  - This information is sent from the victim to the aggressor

IE/Group Name	Presence	Range	IE type and reference	Semantics description
DL ABS status	M		INTEGER (0..100)	Percentage of ABS resource allocated for UEs protected by ABS from strong inter-cell interference.

- References:
  - R3-103667, “Introduction of X2 signaling support for eICIC”, TSG-RAN WG3 Meeting #70, November 2010
  - R3-103776, “Enabling reporting of ABS resource status for eICIC purposes”, TSG-RAN WG3 Meeting #70, November 2010

Performance without IC Receivers (Rel-10)



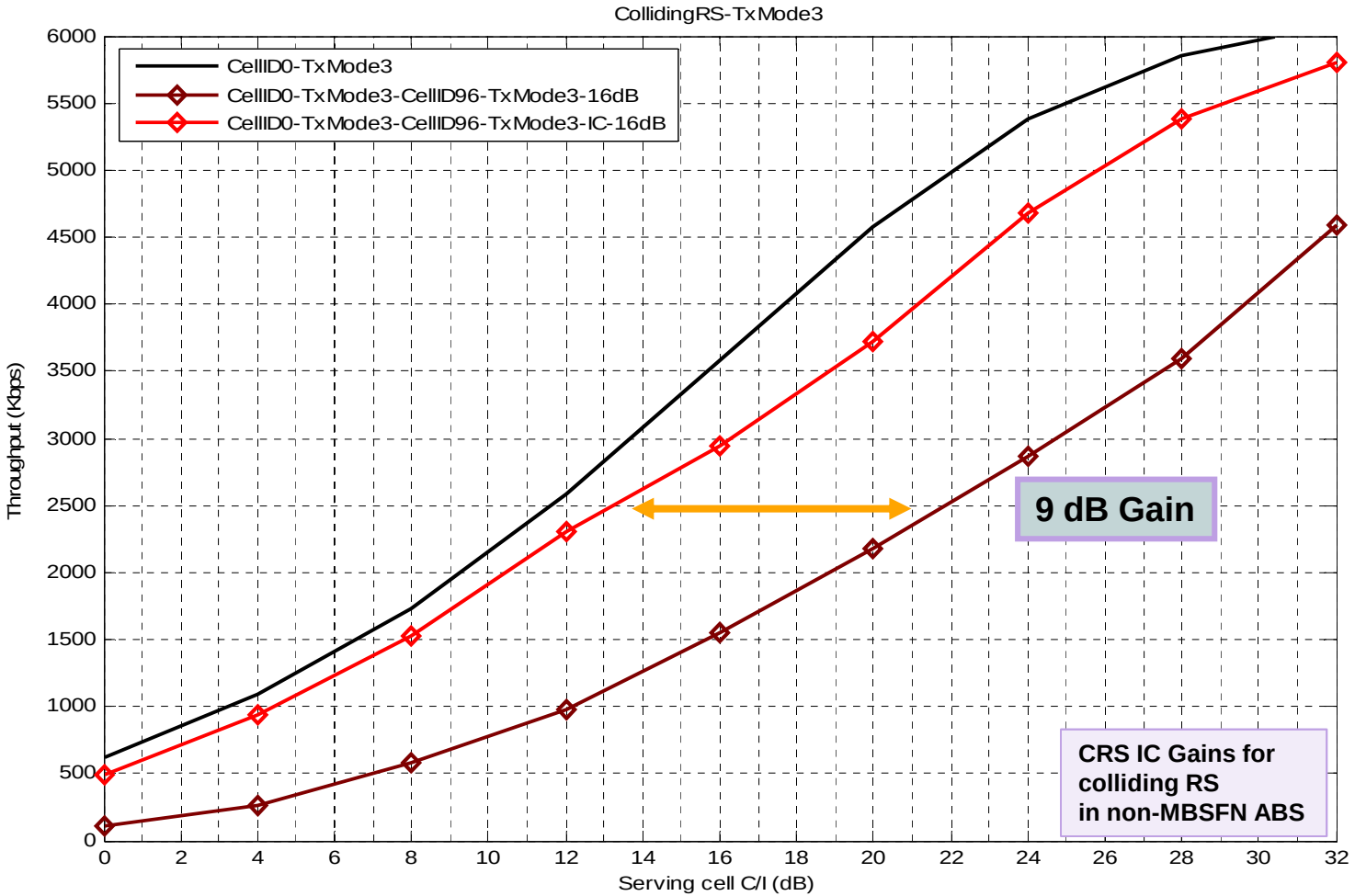
We <u>want</u> much lower SIR → -18 dB!!

- Capacity gains in HetNets are achieved by traffic offloading from macro to pico cells
- Offloading is increased by cell range expansion
  - Cell range expansion increases footprint
  - SIR in expanded cell range < 0 dB
  - ABS subframes allow serving UEs in expanded cell range
- However, interference from pilots and other control signals within ABS limits cell range expansion
- LTE Rel-10 supports cell range expansion of SIR ≈ -6dB
- Why only -6dB?
  - LTE Rel-10 assumes MRC & MMSE receivers, but no inter cell interference cancellation

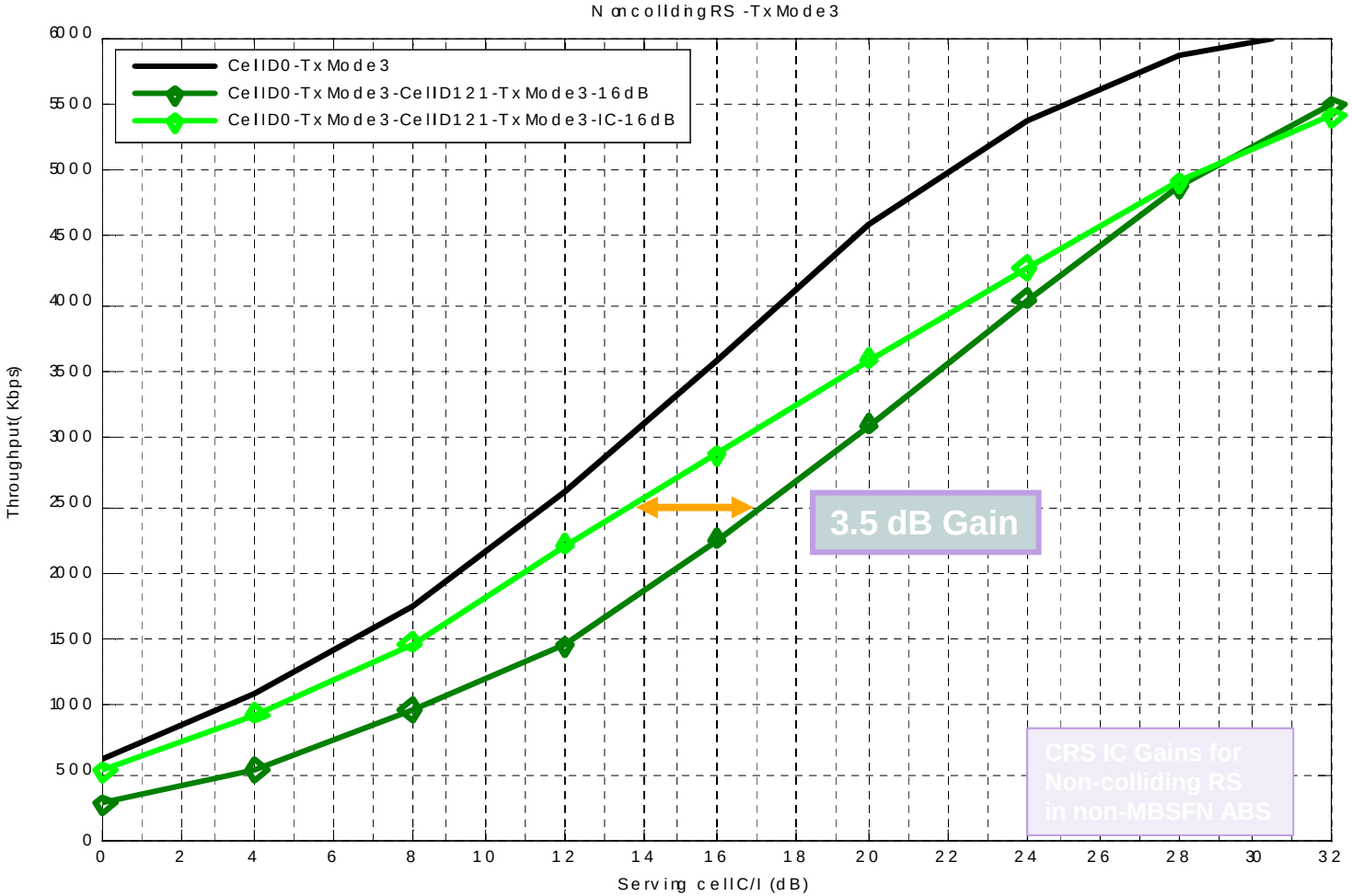
Why IC Receivers are needed

- Even in case of almost blank subframes at the aggressor nodes, the CRS/PSS/SSS/SIB1/MIB are still transmitted
  - PSS/SSS/MIB are always transmitted at the six middle PRBs in subframes #0 and #5 (FDD) → IC for PSS/SSS and PBCH
  - CRS are transmitted in each PRB in OFDM symbols #0, #4, #7, #11 → IC for CRS
- This interference from aggressor node causes significant performance degradation to data and control channels of serving cell
  - Therefore cancelling interference of CRS, PSS/SSS and PBCH is needed to enlarge cell range expansion
- Interference cancelation algorithms for those signals/channels can be designed that achieve SIR = -18 dB

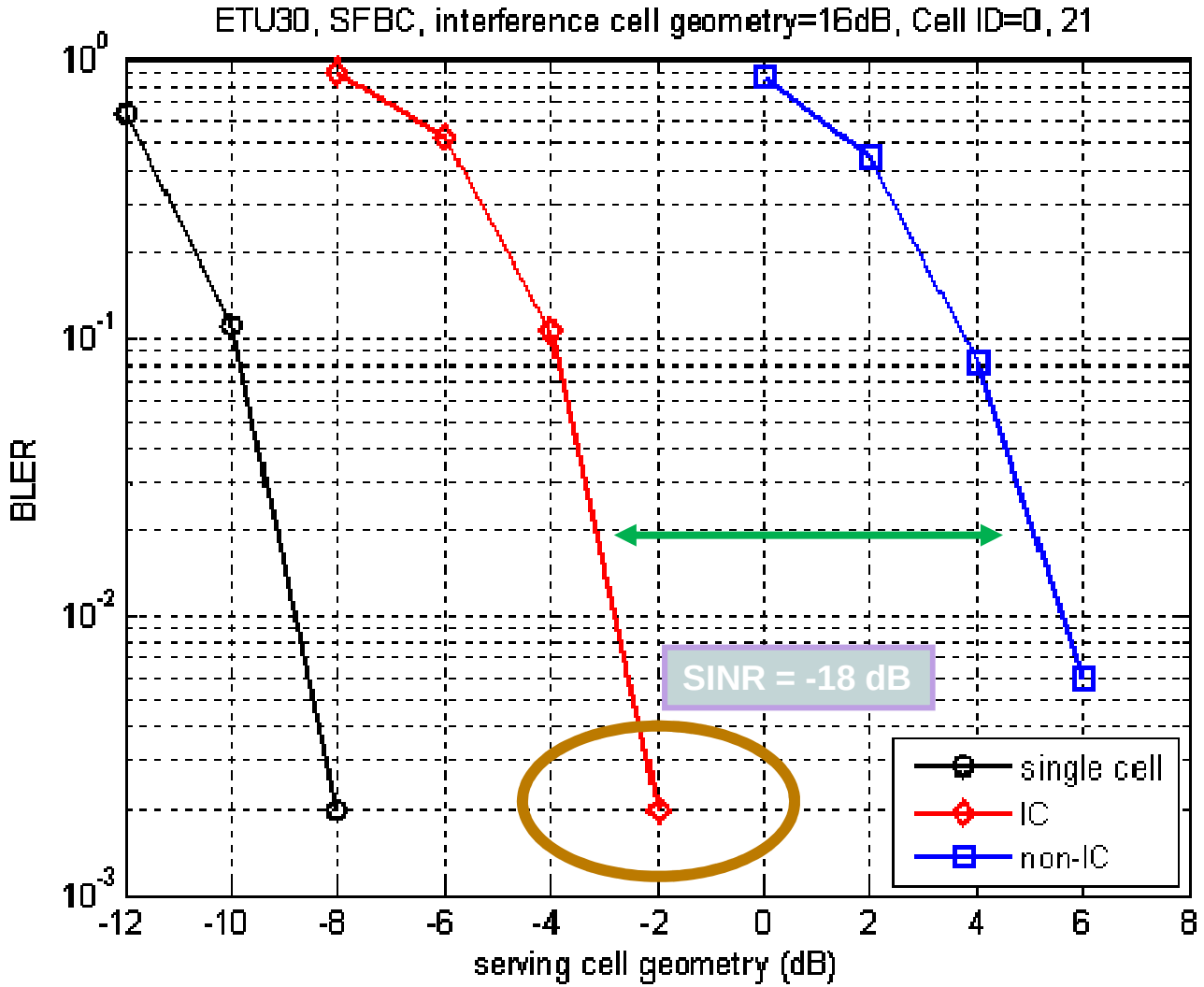
Throughput Gains by CRS IC – Colliding RS



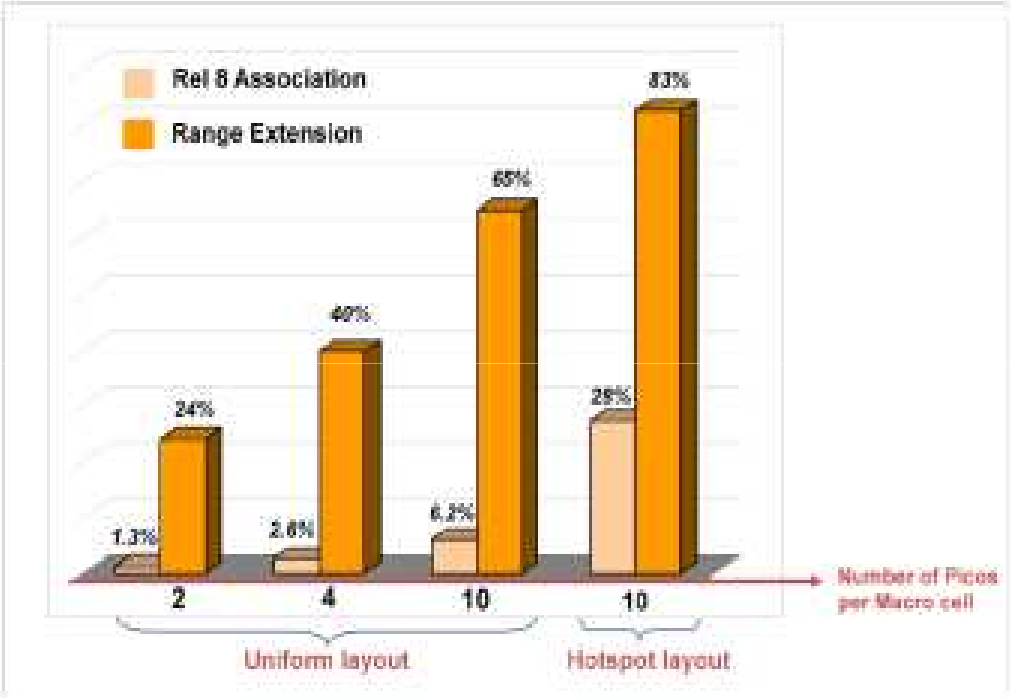
Throughput Gains by CRS IC – Non-colliding RS



Reliability of PBCH with PBCH IC (Rel-11)

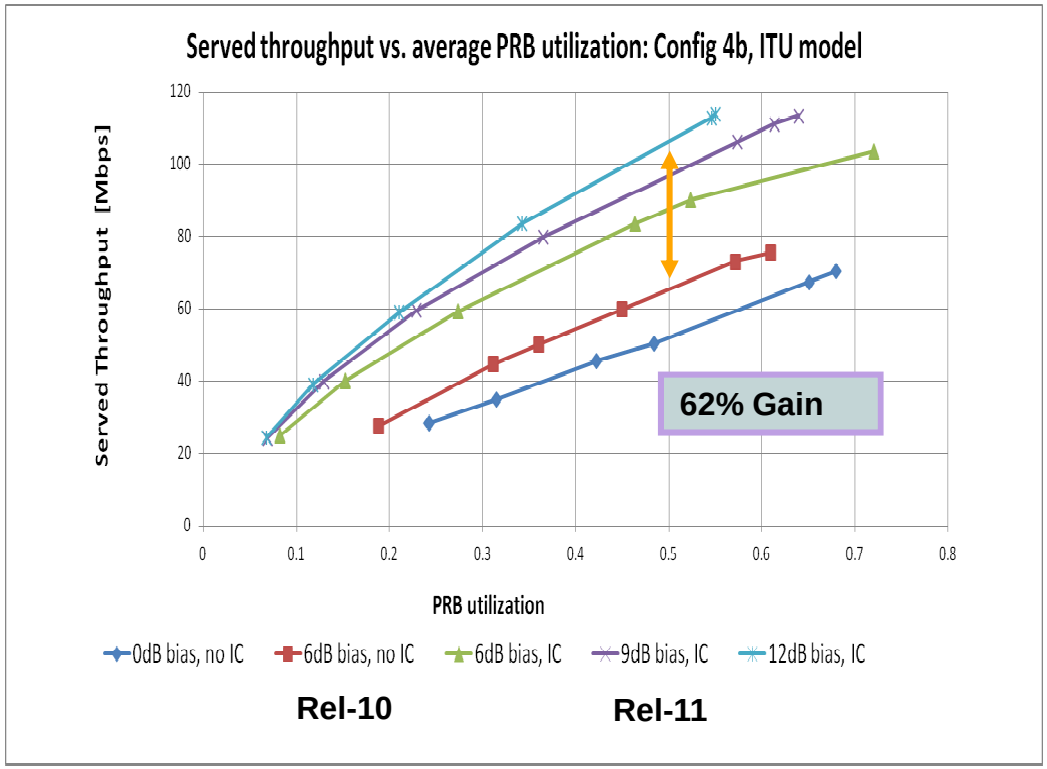


User Association w/ and w/o Cell Range Expansion



- The figure shows the percentage of UEs connected to the pico cells
- **Uniform Layout:** UEs uniformly distributed across the macro cell
- **Hotspot Layout:** 2/3 of the UEs located within 40m radius of the pico cells
- **Rel-8 Association:** UEs connected to the strongest cell
  - Tx power difference between macro and pico impacts association
- **Range Expansion:** UEs connected to the cell with minimal path loss
  - Tx power difference between macro and pico does not impact association

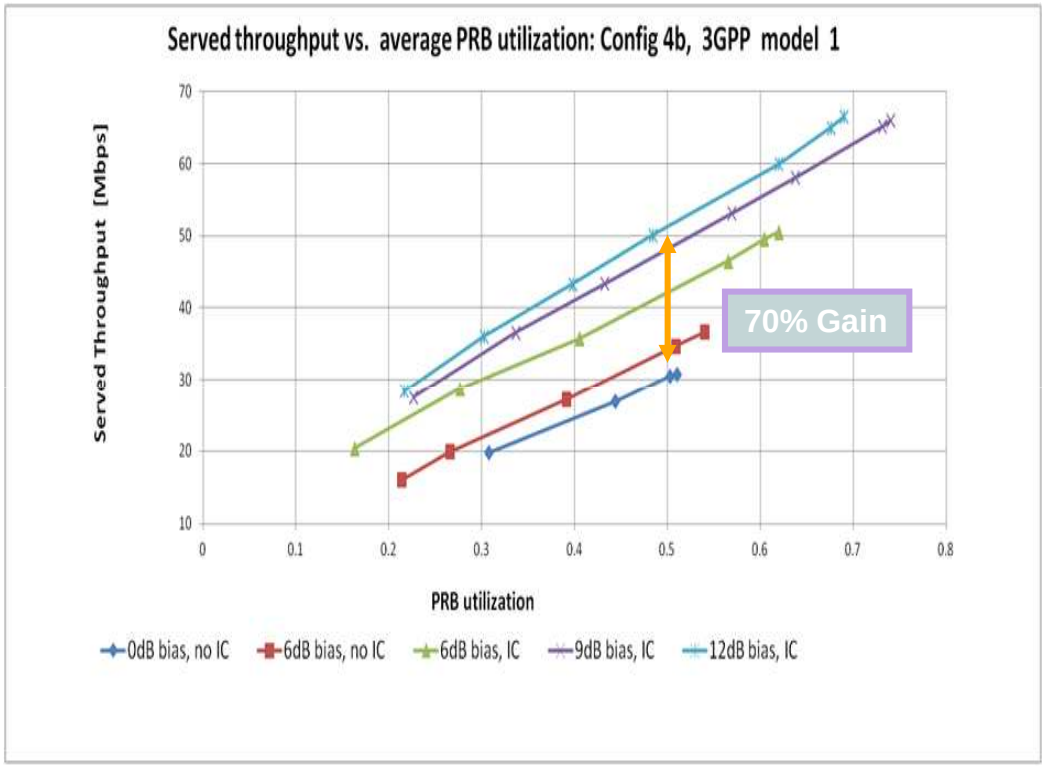
eICIC Performance with IC Receivers – I/II



- Simulation Assumptions
  - ITU UMa for macro, ITU UMi for pico
  - 2x2 antenna configuration (TM4)
  - Hotspot scenario with four pico cells per macro cell randomly placed
  - 2/3 of the UEs located within 40m radius of the two pico cells
  - User arrivals follow Poisson process
  - 1 Mbytes download file size
  - **Cell range expansion of SIR = -12 dB by CRS/PSS/SSS/PBCH IC**
  - Served throughput = total amount of data for all users / total amount of observation time / number of cells

- **Gains up to 62% at 50% load** achievable by aggressive cell range expansion and advanced receivers on top of Rel-10 HetNets

eICIC Performance with IC Receivers – II/II



- Simulation Assumptions
  - Hotspot scenario with four pico cells per macro cell randomly placed
  - 2/3 of the UEs located within 40m radius of the two pico cells
  - User arrivals follow Poisson process
  - 1 Mbytes download file size
  - **Cell range expansion of SIR = -12 dB by CRS/PSS/SSS/PBCH IC**
  - Served throughput = total amount of data for all users / total amount of observation time / number of cells

- **Gains up to 70% at 50% load** achievable by aggressive cell range expansion and advanced receivers

Summary and Outlook

- Heterogeneous Networks are a cost effective approach to significantly enhance capacity of LTE cellular networks
  - Macro cells ensure broad coverage and low power nodes in hotspots provide additional capacity
- Three design features are crucial for Heterogeneous Networks
  - **Interference management** as severe interference limits the coverage area of low power nodes
  - **Cell range expansion** through adaptive resource partitioning as it enables traffic load balancing between high and low power cells (traffic offloading)
  - **Interference cancellation receiver** in the terminal as it ensures that weak cells can be detected and remaining power can be removed
- All three components together are needed to exploit the full potential of heterogeneous networks
  - Improving eICIC further is one of the big topics in Rel-11 in RAN1 and RAN4
  - The target is a cell range expansion of 9 dB with IC receivers in Rel-11 (FeICIC)