Heterogeneous Networks 3G and 4G

Durga Malladi
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Agenda

- Introduction
- Heterogeneous Networks
- Performance
- What’s next

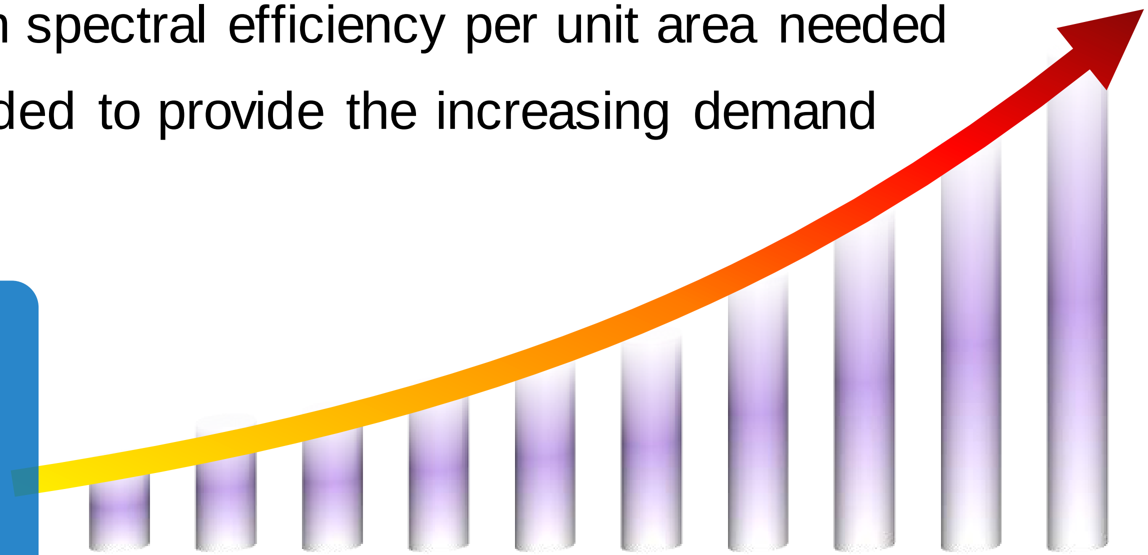
Introduction

Mobile Data Demand Growth

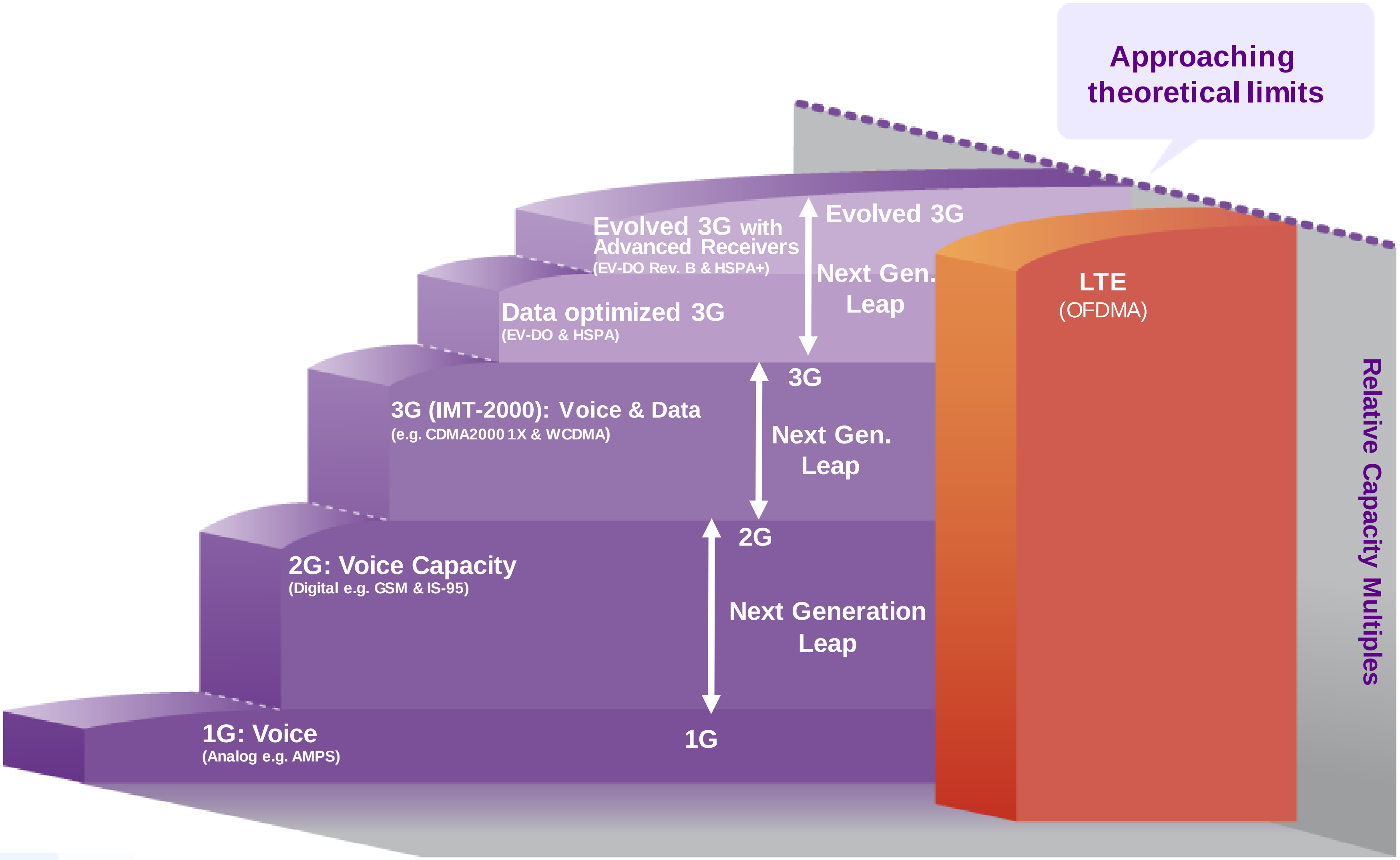
- Operators face increasing demand for mobile network data capacity
  - Adoption of smart phones and plethora of devices continue to drive traffic growth
    - Users increasingly spending more time on the network
- Spectrum is often limited in many markets
  - Dramatic increase in spectral efficiency per unit area needed
  - New topologies needed to provide the increasing demand

By 2014, monthly worldwide mobile data traffic will exceed the total for all of 2008

–ABI Research, August 2009



Radio Link Improvement



Multiple Dimensions for Growth

Higher
bps

Spectrum

Higher Capacity
Higher Peak Rates

Carrier Aggregation
Multiple Bands

Higher
bps/Hz

Antennas

Higher Peak Rates

8x8 DL MIMO
4x4 UL MIMO

MU-MIMO

Higher
bps/Hz/km^2

Network Topology

Higher Capacity

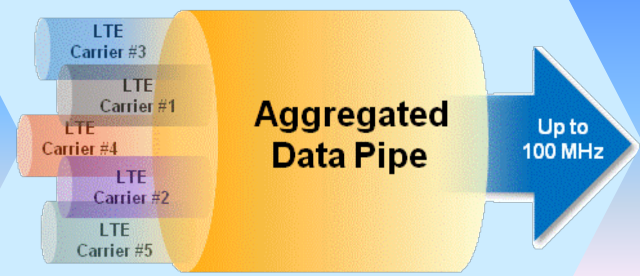
Pico cells
Femto cells
Remote Radio Heads
Relays

Optimized utilization of resources

Another View

More Bandwidth

Carrier aggregation across multiple carriers and multiple bands

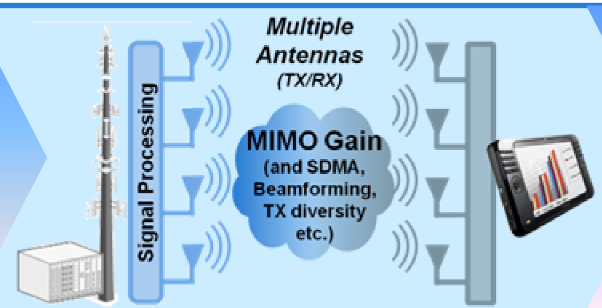


Primarily higher data rates

(bps)

More Antennas

Downlink MIMO up to 8x8, enhanced MU-MIMO and uplink MIMO up to 4x4

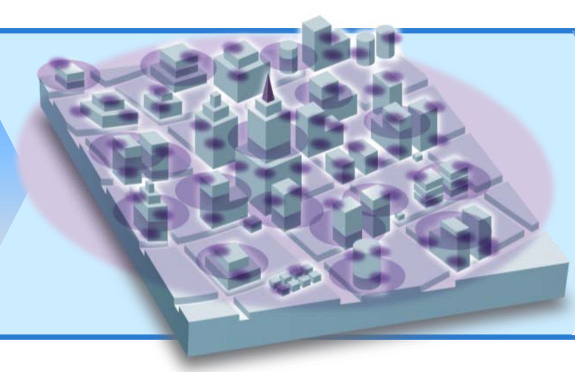


Higher spectral efficiency

(bps/Hz)

Dense Network

Coexistence of high power (macro) and low power (pico, femto, relay, remote radio head) nodes



Higher spectral efficiency per coverage area

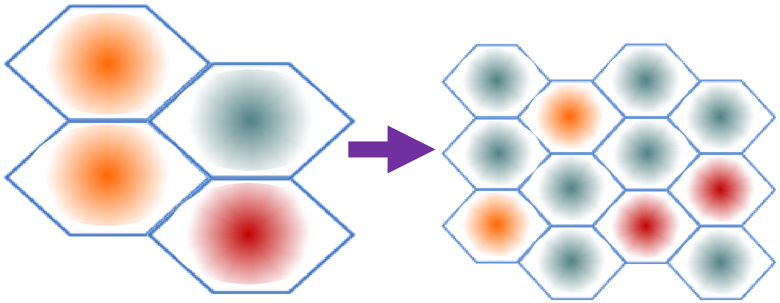
(bps/Hz/km^2)

Heterogeneous Networks 4G Overview

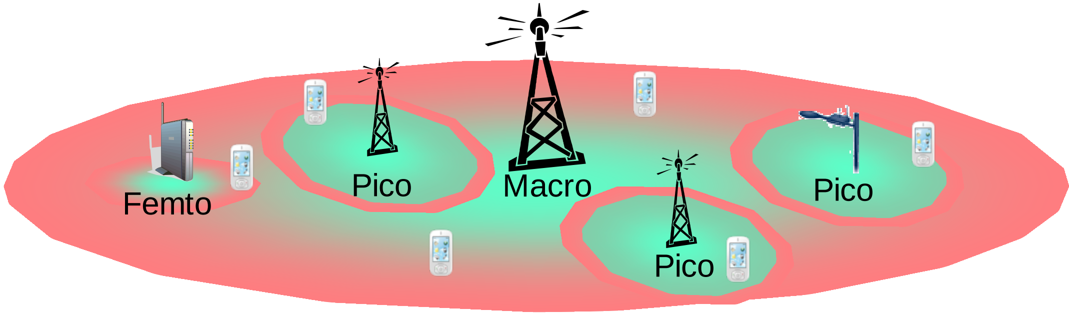
Conventional Cell Splitting

- Macro cell splitting
  - Site acquisition constraints
- Small cells
  - Flexible ad-hoc deployment
  - Co-channel deployment with macro cells

Cell Splitting



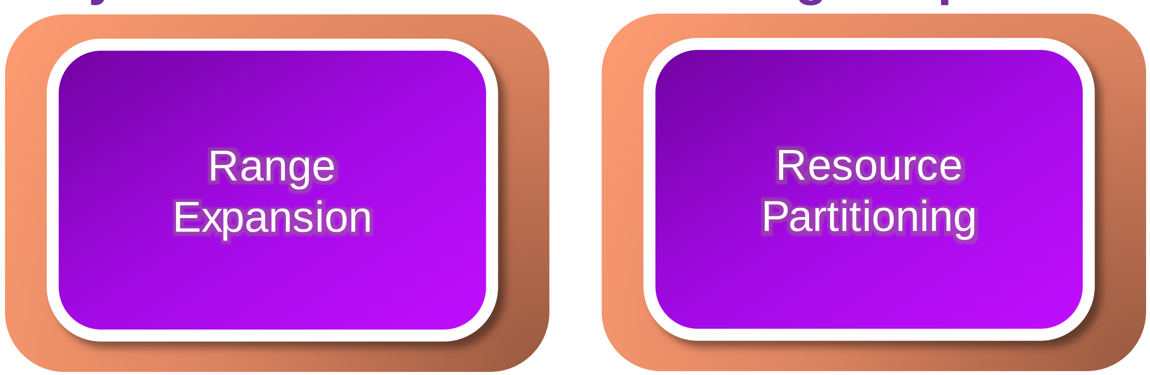
Heterogeneous Network



UE Association Metric

- Typically a UE is served by the cell with strongest SINR
  - With co-channel small cells, strongest SINR metric is not efficient
  - Large disparity in transmit power between macro and pico cells
    - Macro cell (46 dBm), Pico cell (30 dBm)
    - Results in shrunken coverage/range of small cells
    - Equal pathloss ⇔ Pico cell C/I = -16 dB
- Need techniques to enable cell range expansion

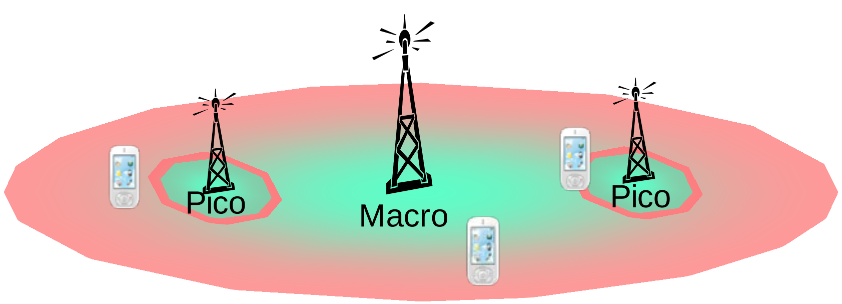
Key Features for Pico Cell Range Expansion



Pico Cell Range Expansion (CRE)

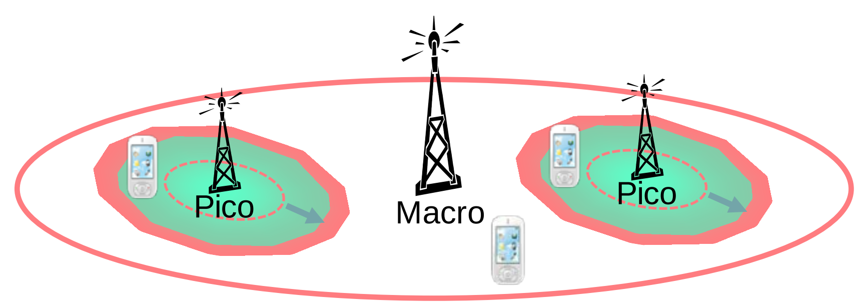
- Large Bias Operation
  - Intentionally allow UEs to camp on weak (DL) pico cells
    - RSRP = Reference signal received power (dBm)
    - Pico (serving) cell RSRP + Bias = Macro (interfering) cell RSRP
- TDM subframe partitioning between macro/pico cells
  - In reserved subframes, macro cell does not transmit any data
  - Reserved subframes ⬄ Almost Blank Subframes (ABS)

In subframes reserved for Macro Cells



Limited footprint of Pico due to Macro signal

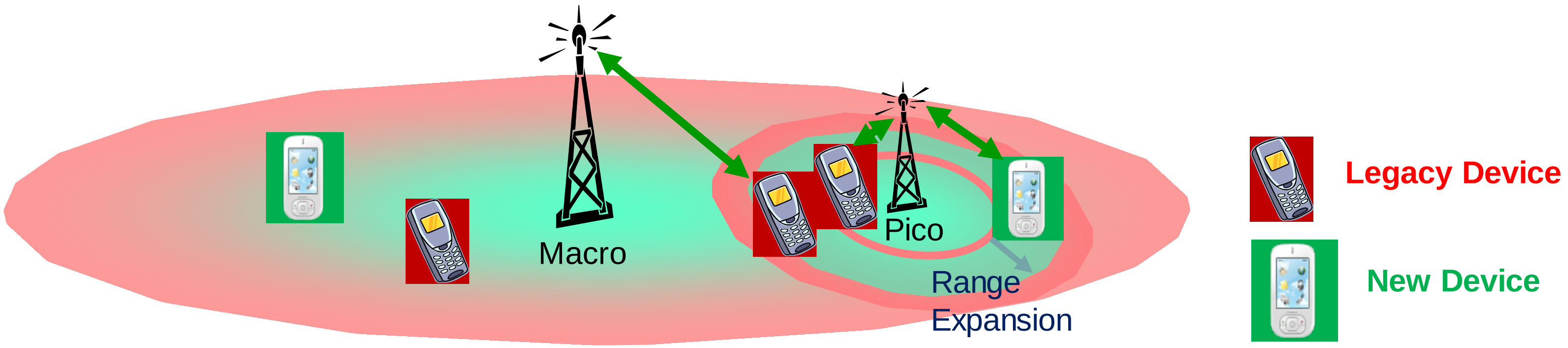
In subframes reserved for Pico Cells



Increased footprint of Pico when Macro frees up resource

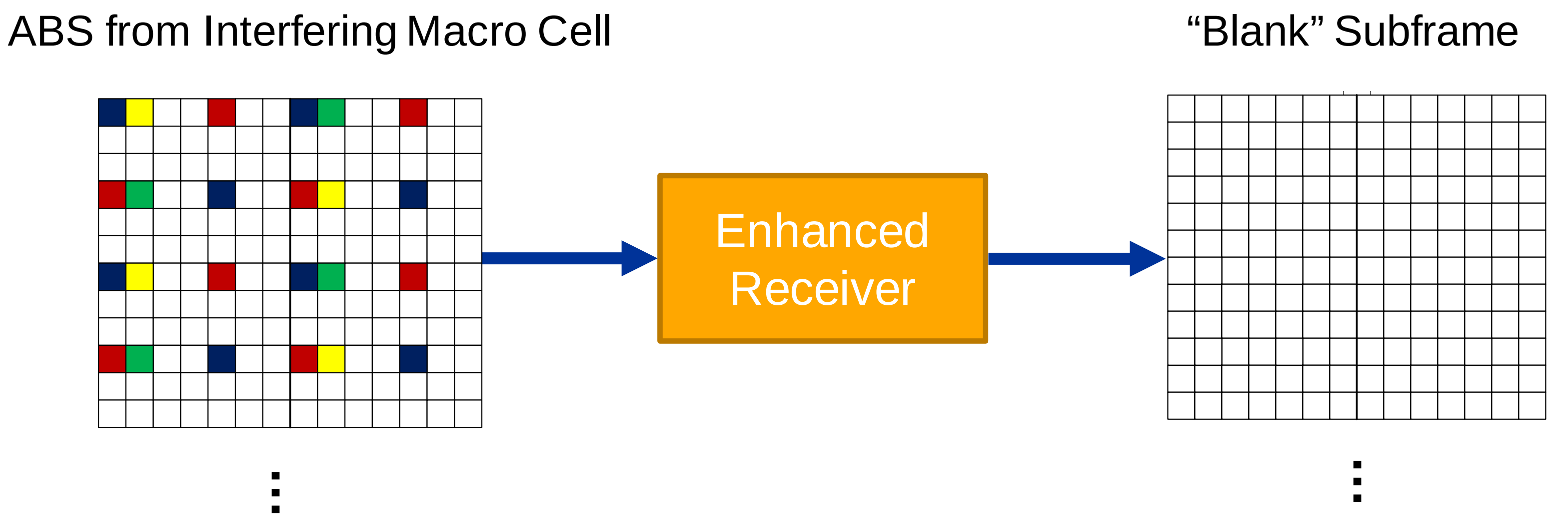
Almost Blank Subframes (ABS)

- Macro cell behavior in ABS
  - Signals transmitted
    - Common reference, sync and primary broadcast
  - Signals not transmitted
    - User specific traffic (data and control)
- Co-existence of legacy and new devices in pico CRE zone
  - Legacy devices served by macro cells
  - New devices served by pico cells



Residual Interference in Macro ABS

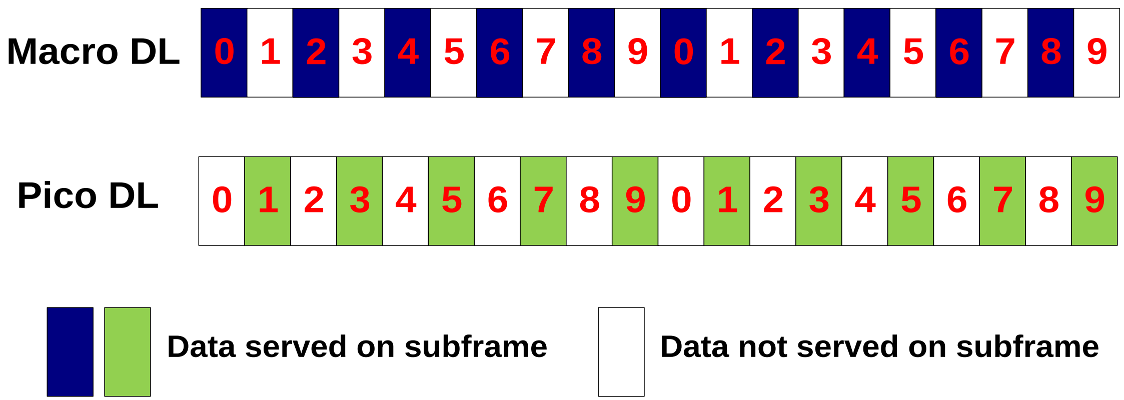
- Enhanced receivers perform interference suppression of residual signals transmitted by macro cells
  - Incl. common reference signals and sync signals



Inter-Cell Load Balancing

- Time-Domain partitioning
  - Negotiated between macro and pico cells via backhaul (X2)
  - Macro cell frees up certain subframes (ABS) to minimize interference to a fraction of UEs served by pico cells
    - TDM partitioning granularity = 2.5%
- Reserved subframes used by multiple small cells
  - Increases spatial reuse

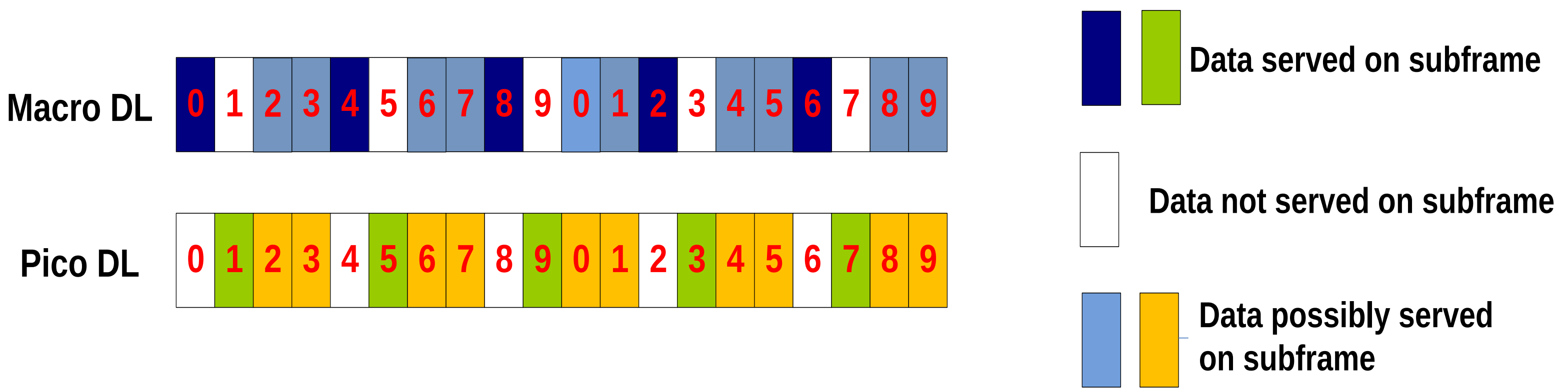
Example:
Semi-static allocation
50% Macro and
50% Picos



Adaptive Time-Domain Partitioning

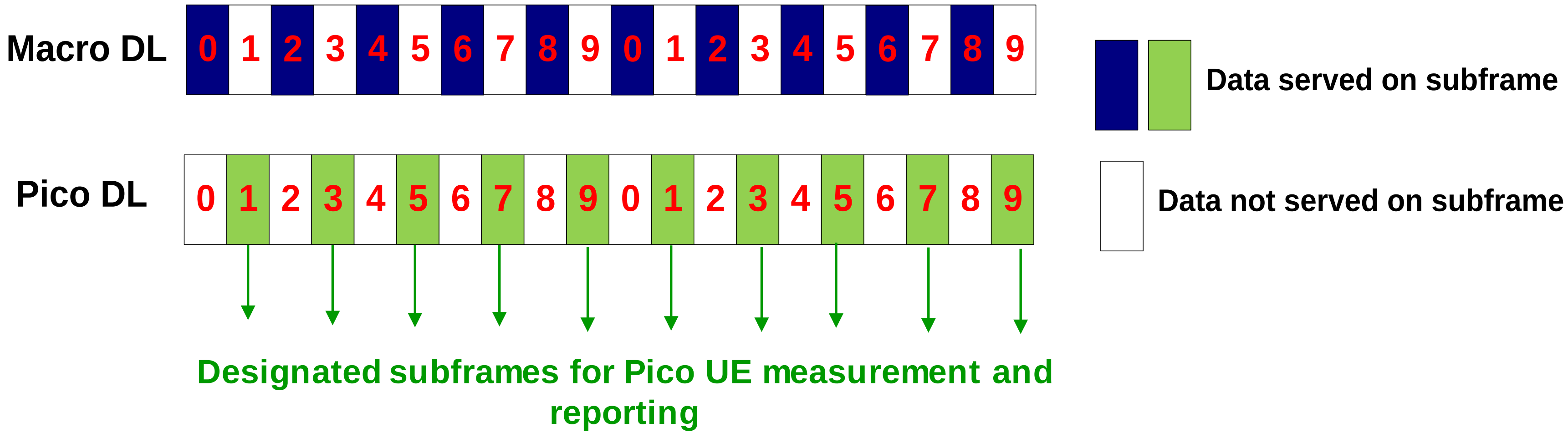
- Load balancing is constantly performed in the network
  - Macro and pico cells negotiate partitioning based on spatial/temporal traffic distribution

Example: 25% each to Macro and Pico Cells; 50% adaptive



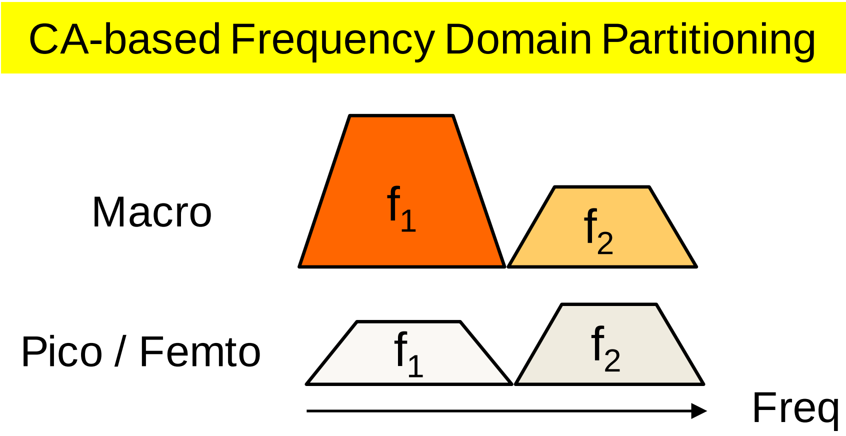
Radio Link Monitoring and CSI Reporting

- RLM
  - Measurements performed on restricted subframes
- CSI reports
  - Devices report multiple CSIs on “clean” and “unclean” subframes



Frequency Domain Partitioning

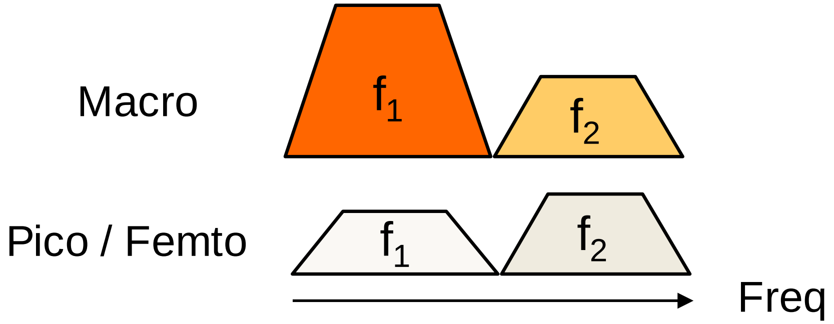
- Macro and Pico cells can use separate carriers to avoid strong interference
- Carrier aggregation (CA) allows additional flexibility to manage interference
  - Macro cells transmit at full power on anchor carrier (f1) and lower power on second carrier (f2)
  - Pico cells use second carrier (f2) as anchor carrier



Frequency Domain Partitioning

- Frequency partitioning
  - Offers less granular resource allocation and lower flexibility
    - Does not scale with pico cell density variation within a macro cell
    - Partitioning ratio limited by number of carriers
  - Does not require network synchronization

CA-based Frequency Domain Partitioning

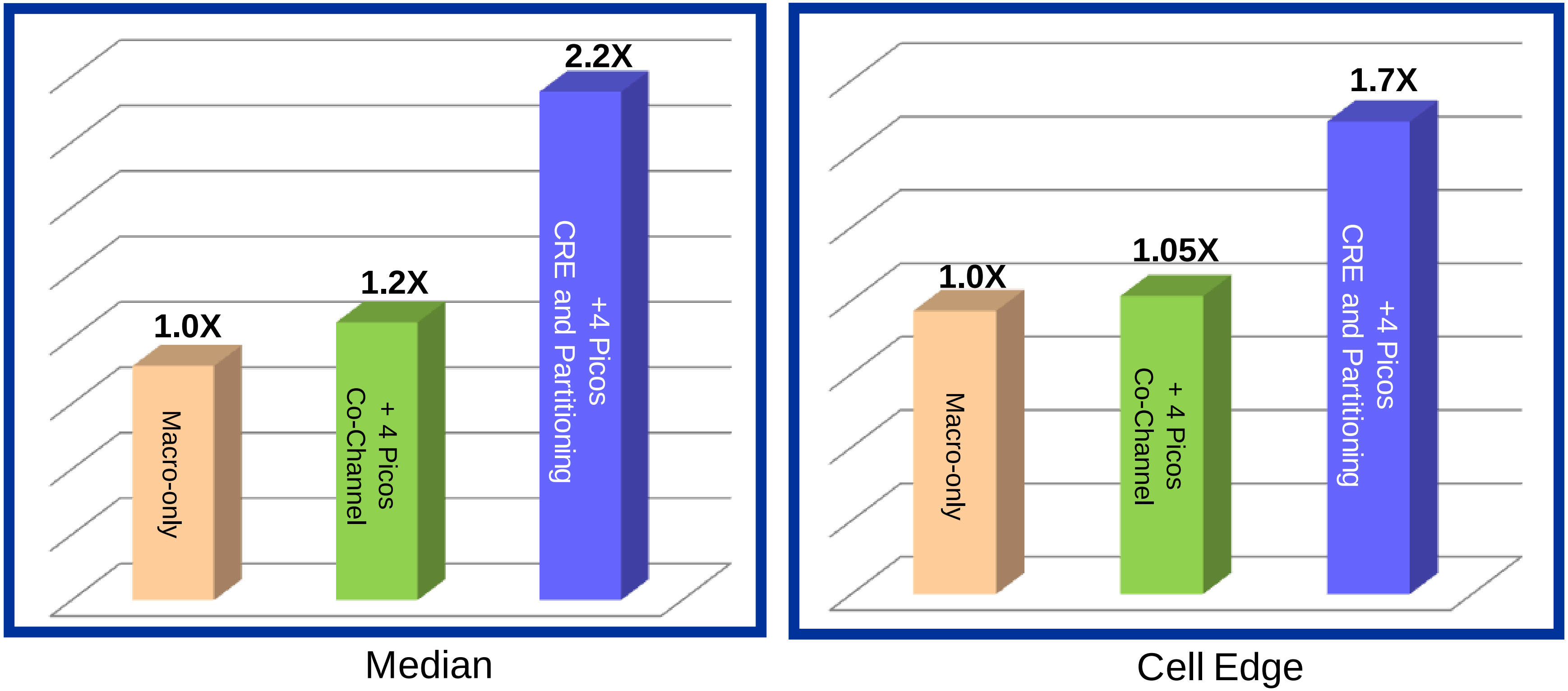


Heterogeneous Networks 4G Performance

Downlink – Uniform UE Distribution

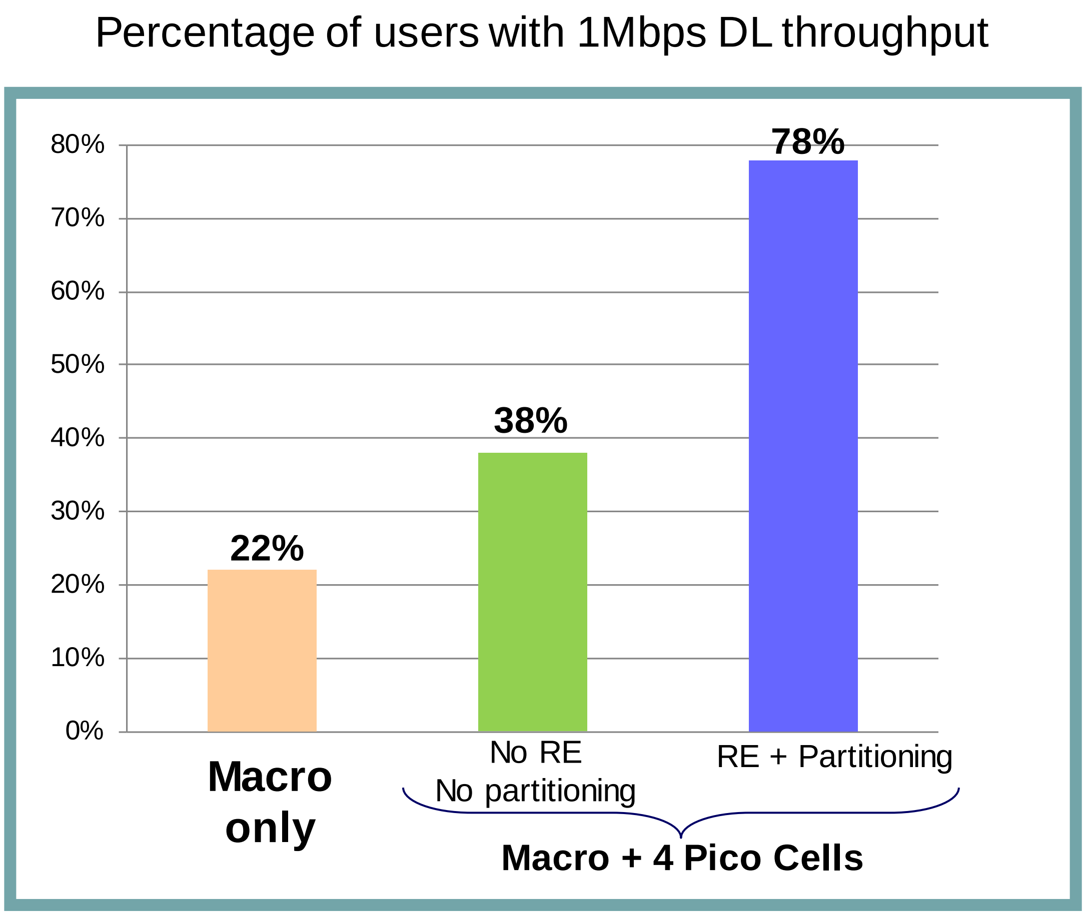
500m ISD

DL User Throughput Improvement



Simulation results based on Qualcomm prototype implementation and 3GPP evaluation methodology TR 36.814
Macro ISD = 500m, 2GHz carrier frequency, full-buffer traffic, 10 degree antenna downtilt, cell edge user is defined as 5 percentile rate user
4 Picos and 25 UEs per Macro cell, uniform random layout, PF scheduler, 10 MHz FDD, 2x2 MIMO, TU3 channel, NLOS, local partitioning algorithm

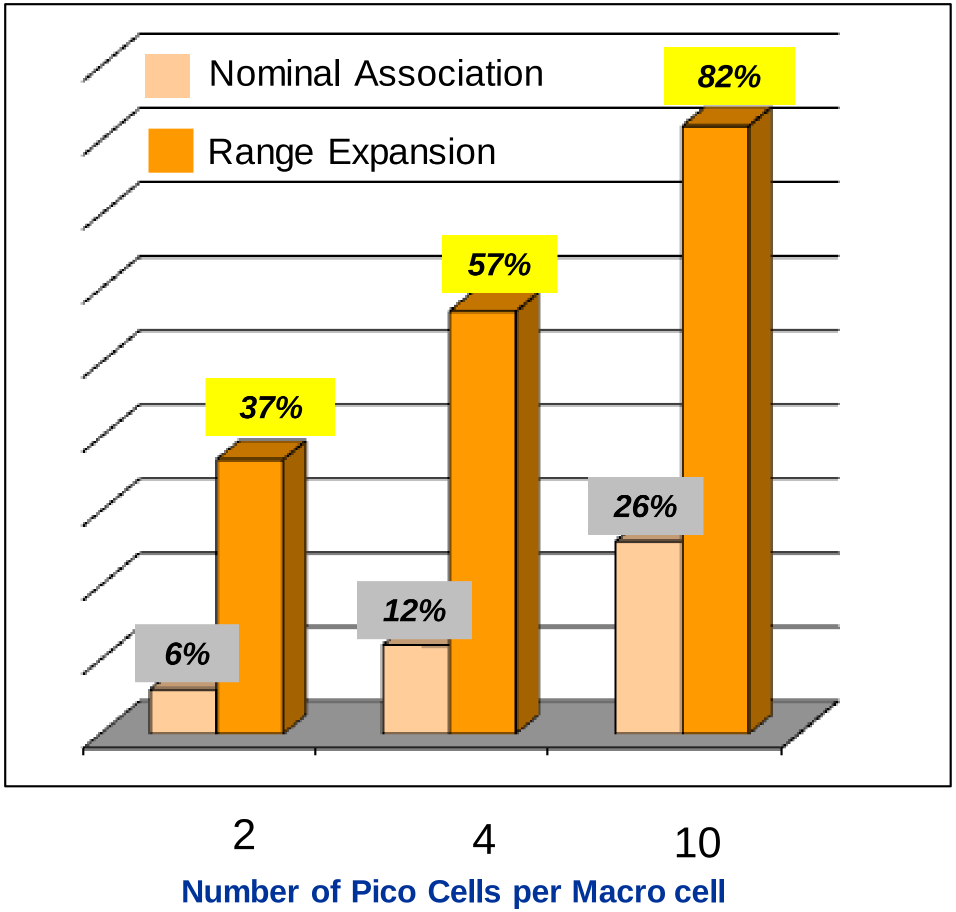
Downlink – Uniform Distribution



Results from 3GPP R1-101509, evaluation methodology TR 36.814, Macro ISD=500m, 10 degree Macro antenna downtilt
4 Picos and 25 UEs per Macro cell, uniform random layout, PF scheduler, cell,10 MHz FDD, 2x2 MIMO, NLOS

Pico Cell Association Statistics

Percentage of UEs offloaded to Pico Cells



Evaluation methodology
TR 36.814

Macro ISD=500m
10 degree Macro antenna downtilt

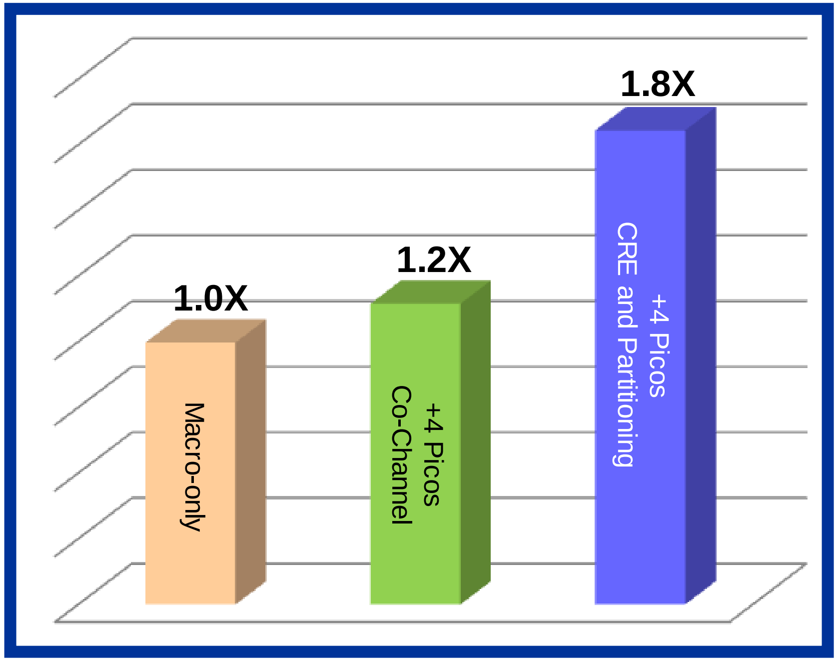
25 UEs per Macro cell, uniform random layout,

10 MHz FDD, 2x2 MIMO

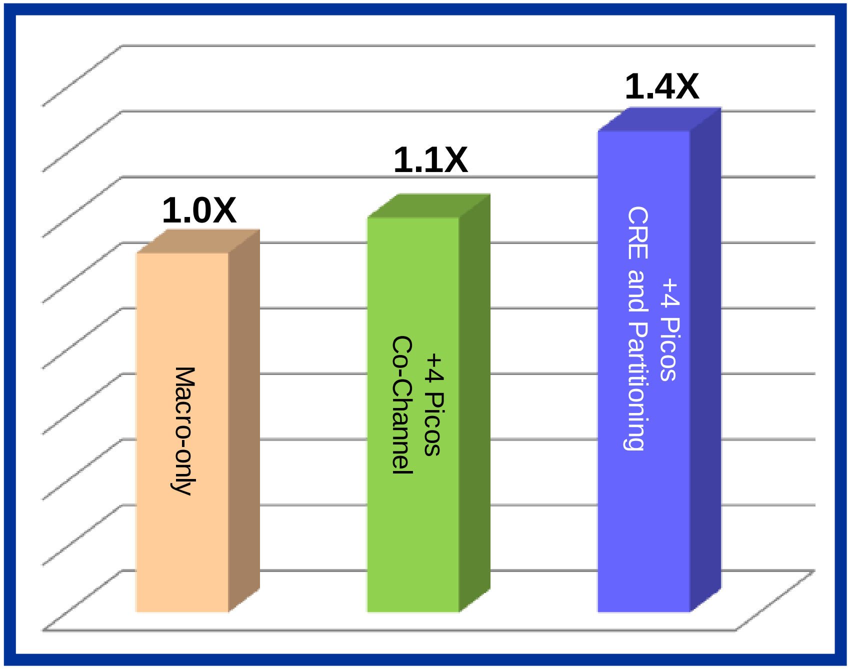
Uplink – Uniform UE Distribution

500m ISD

UL User Throughput Improvement



Median



Cell Edge

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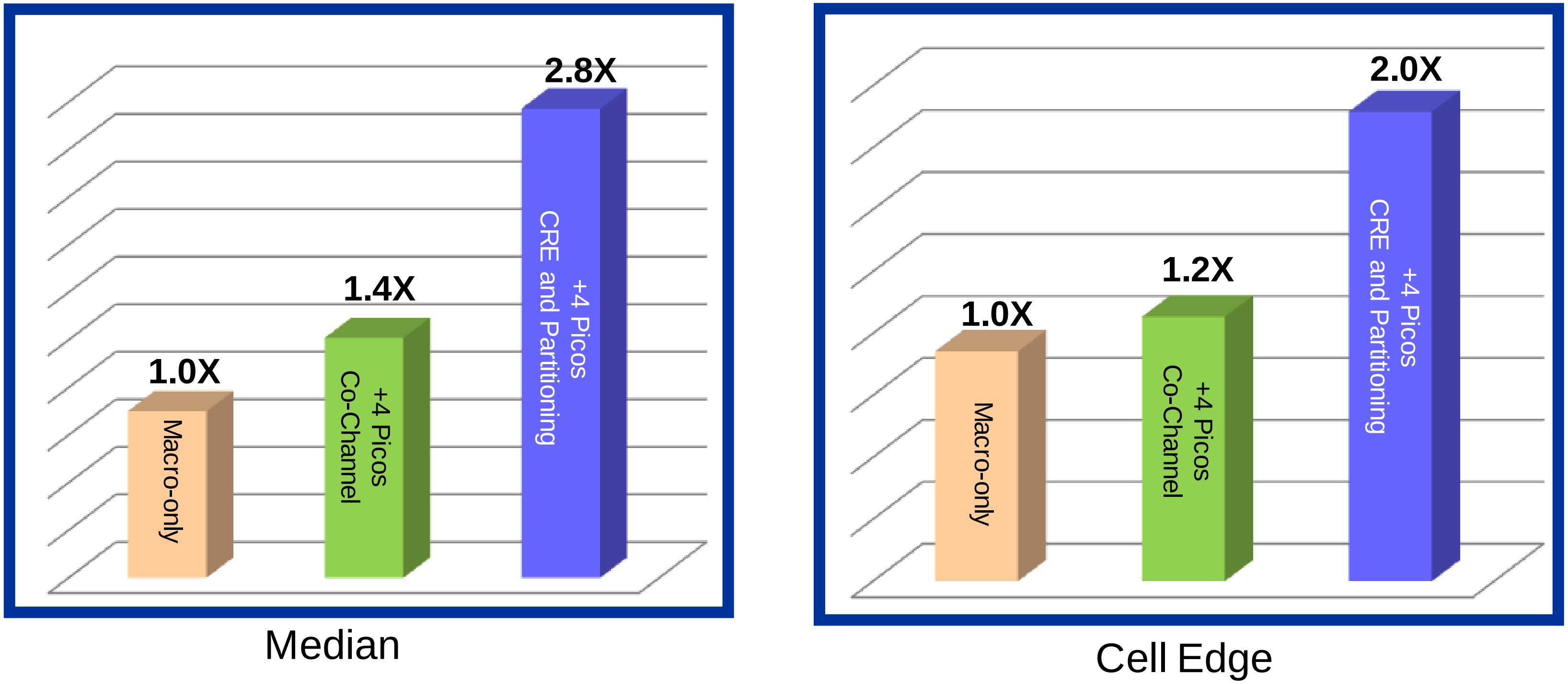
Downlink – Hotspot Distribution

500m ISD

DL User Throughput Improvement



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Clustered configuration (4a): 4 Picos / Macro cell, 8 out of 25 UEs are dropped near Picos. PF scheduler, 10 MHz FDD, 2x2 MIMO, TU3 channel, NLOS

Uplink – Hotspot Distribution

500m ISD

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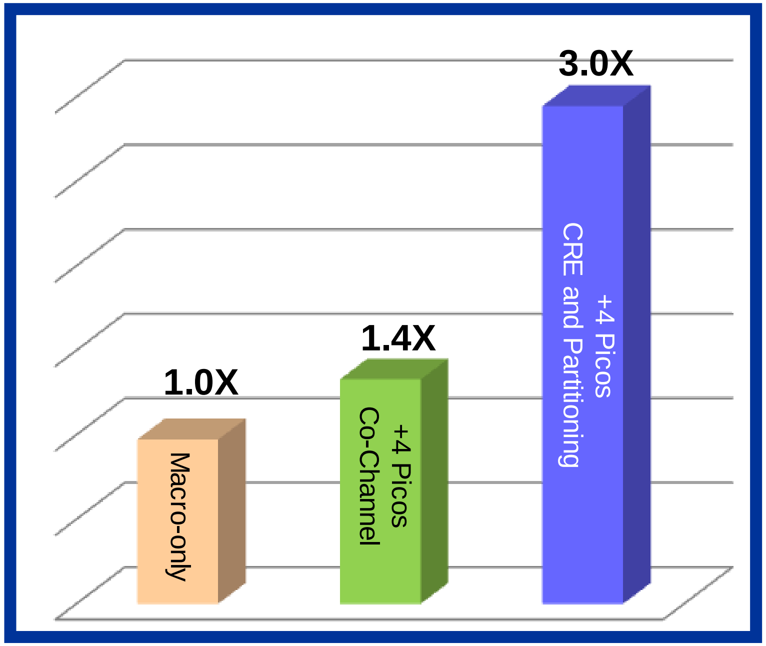

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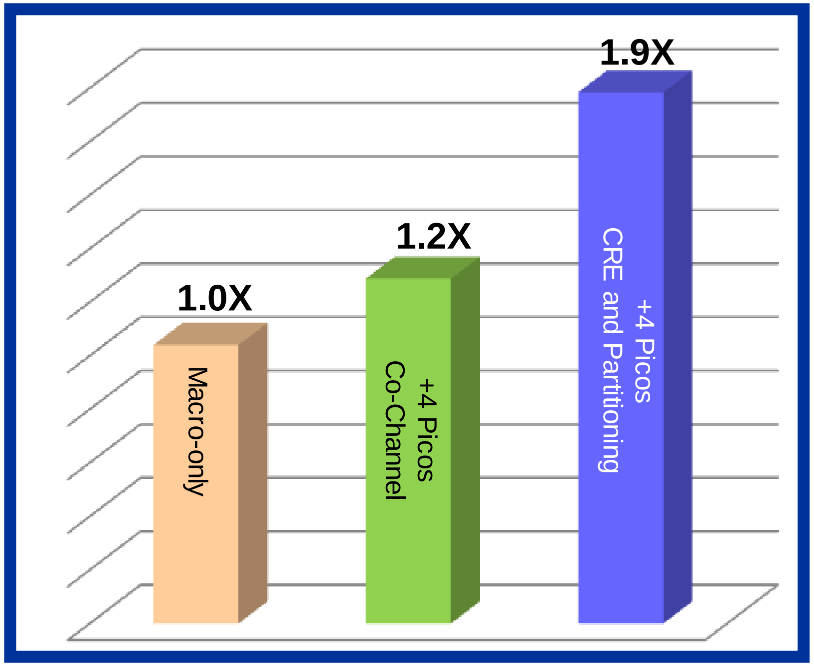

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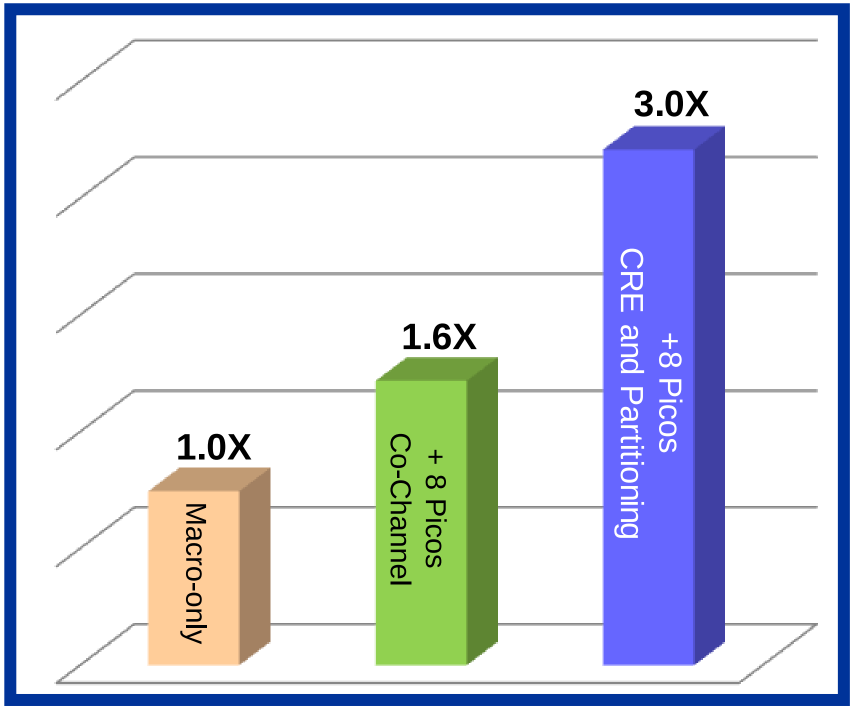
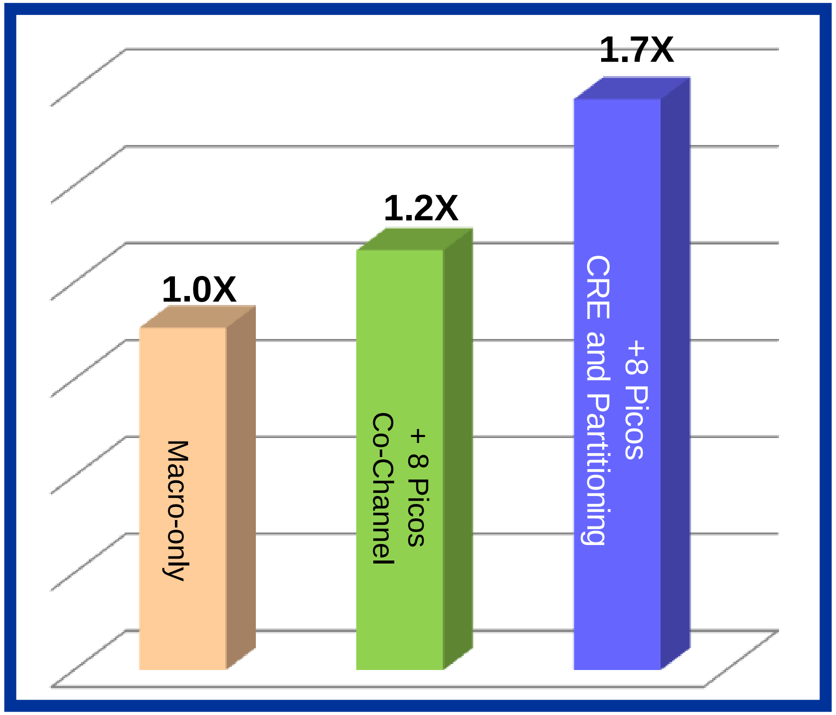
Downlink – Uniform Distribution

1732m ISD

DL User Throughput Improvement



Median



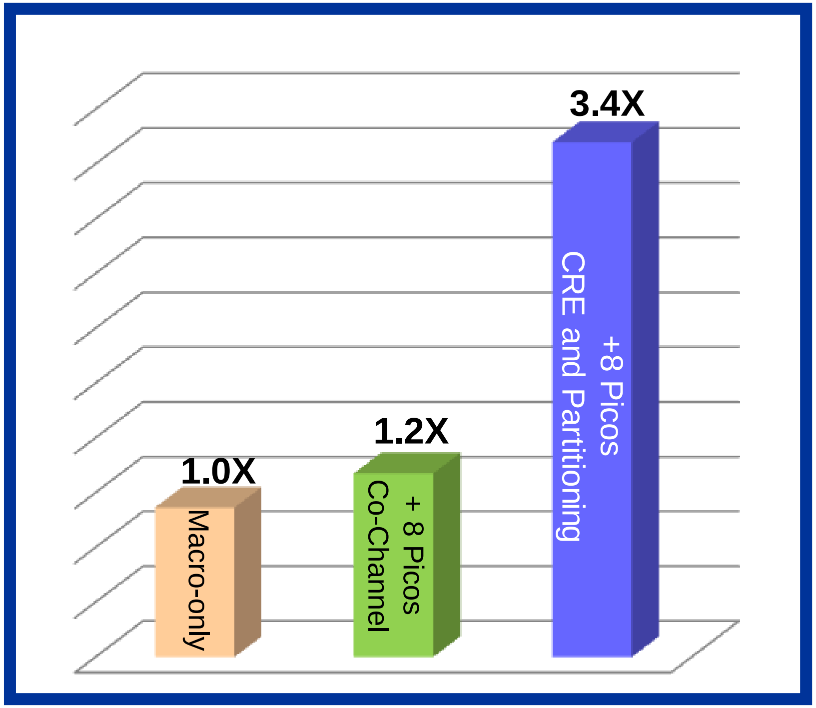
Cell Edge

Simulation results based on Qualcomm prototype implementation and 3GPP evaluation methodology TR 36.814
Macro ISD = 1.7km, 700MHz carrier frequency, full-buffer traffic, 6 degree antenna downtilt, cell edge user is defined as 5 percentile rate user
8 Picos and 25 UEs per Macro cell, uniform random layout, PF scheduler, 10 MHz FDD, 2x2 MIMO, TU3 channel, NLOS, local partitioning algorithm

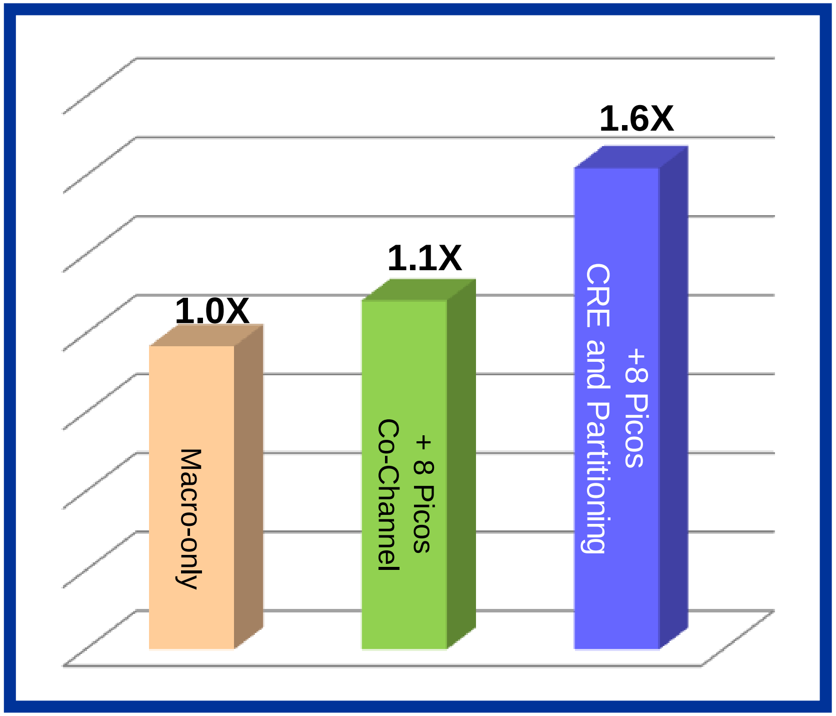
Uplink – Uniform Distribution

1732m ISD

UL User Throughput Improvement



Median



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LTE HetNet OTA Testbed

- Co-channel deployment of macro and pico cells

- Advanced Features
  - X2 based interference management
  - TDM resource partitioning
  - Advanced receivers

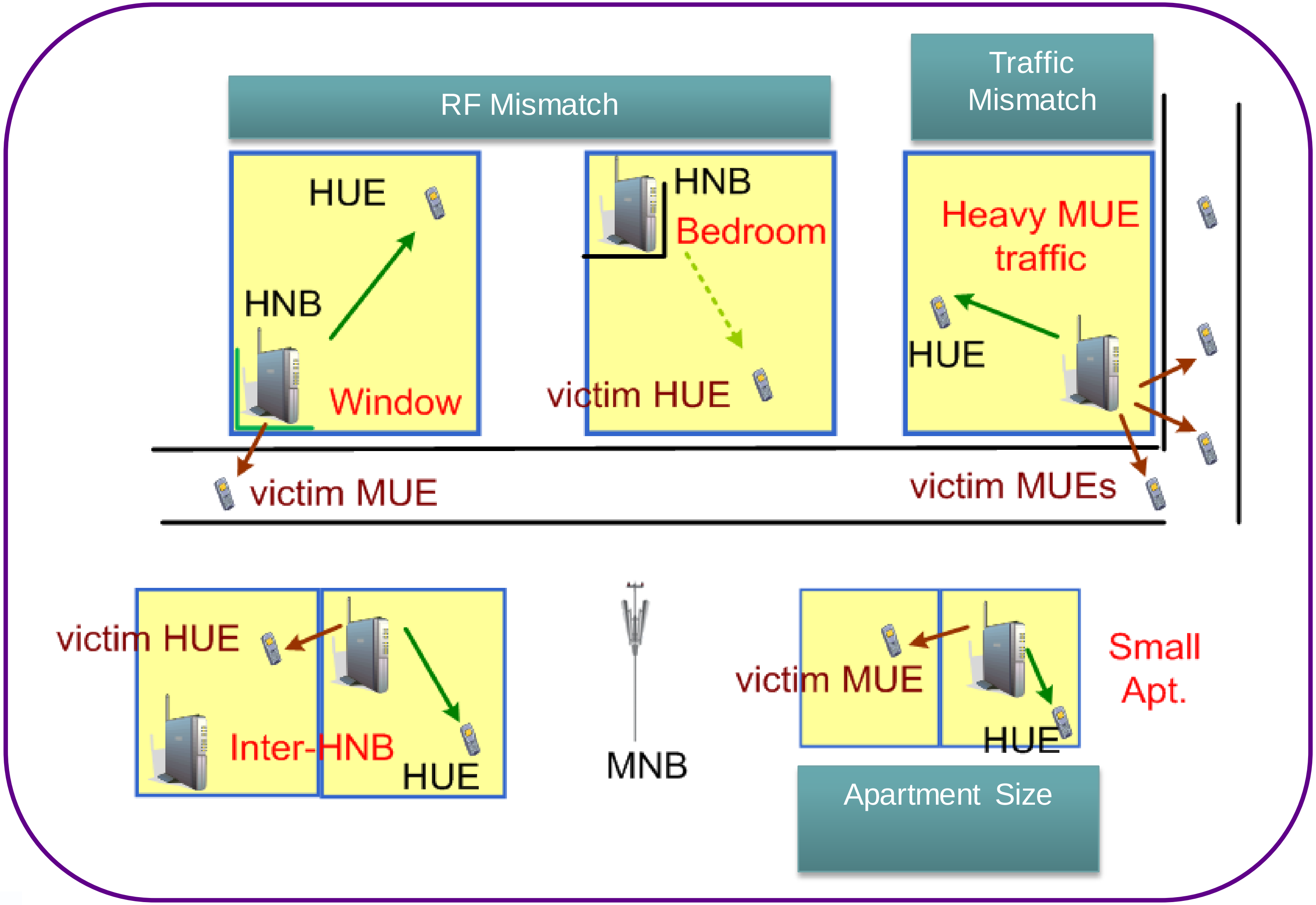
Heterogeneous Networks
3G Closed Access Cells

Overview

- Co-channel closed access femtocell deployment in residential scenarios requires effective interference and mobility management
  - Unplanned closed subscriber group (CSG) usage by residential users cause complex interference problems that requires effective SON features in femtocells
  - Legacy devices

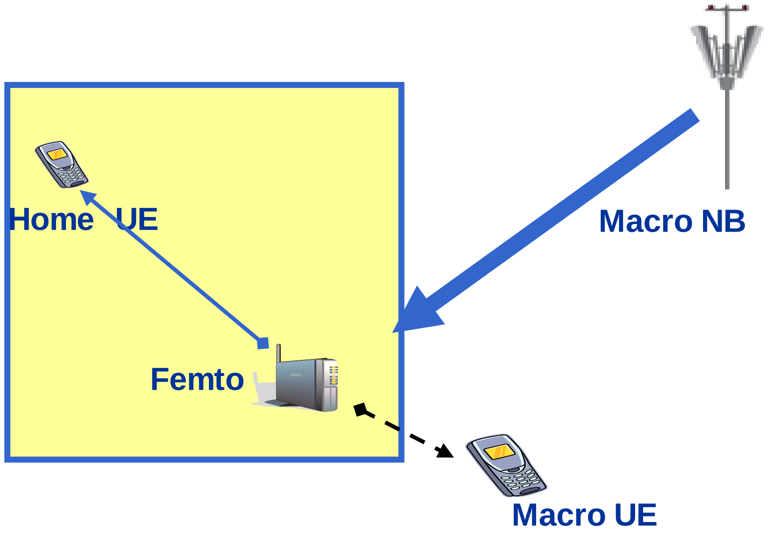
- Need to address interference and mobility management challenges in residential CSG femto deployments
  - Femto ⇔ Macro interference
  - Femto ⇔ Femto interference

Scenarios in Downlink

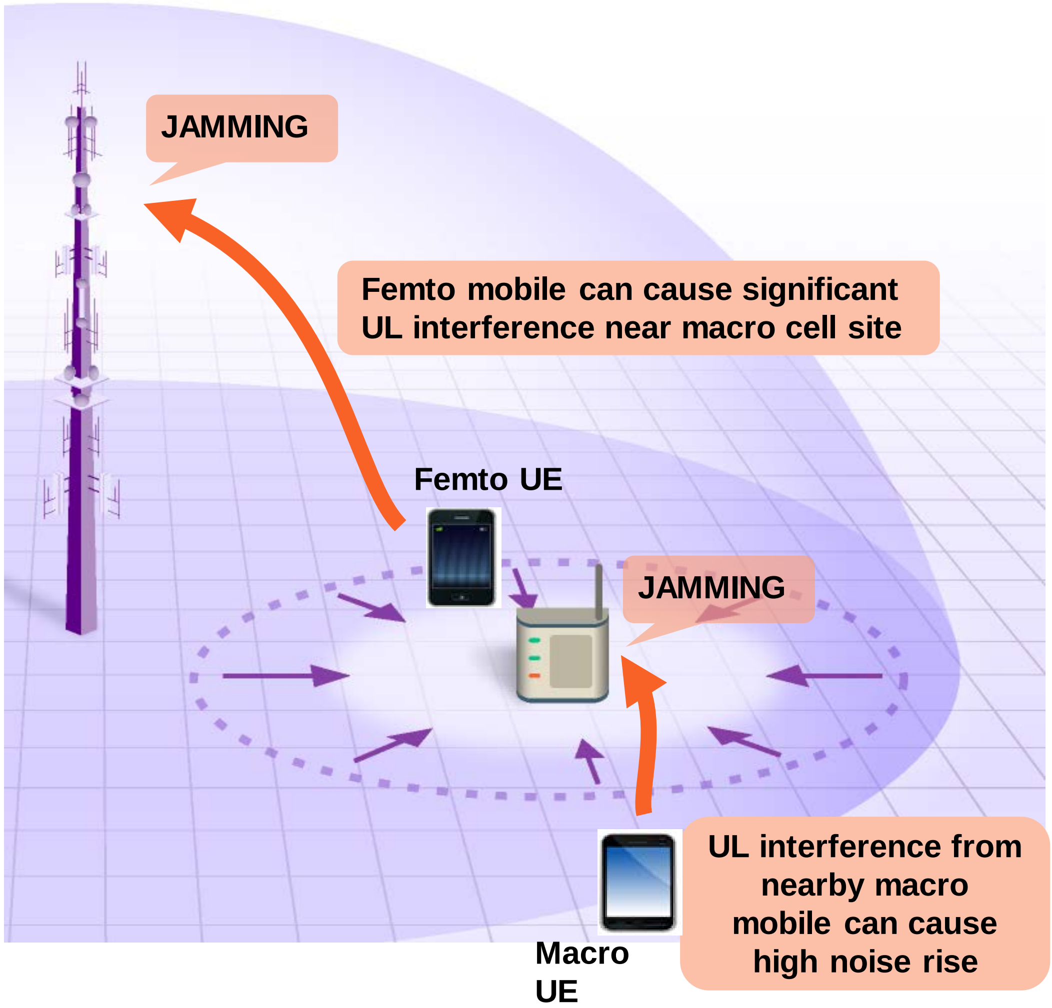


Transmit Power Setting

- Objective
  - Provide good CSG coverage for the home UEs while protecting macro UEs
- Solutions
  - Set CSG transmit power as a function of RSSI from all neighbor NBs and pilot strength of dominant macro NB
  - Fine tune Tx power based on detection of macro UEs using uplink RSSI

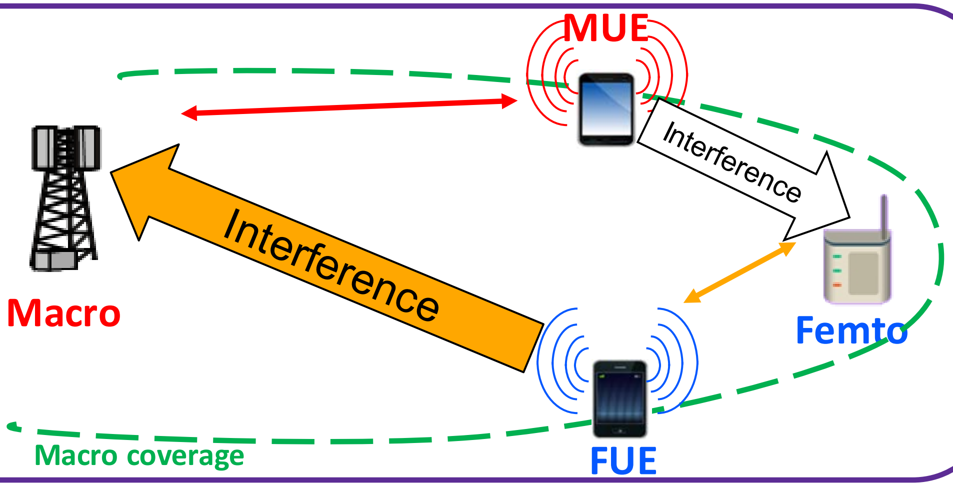


Scenarios in Uplink

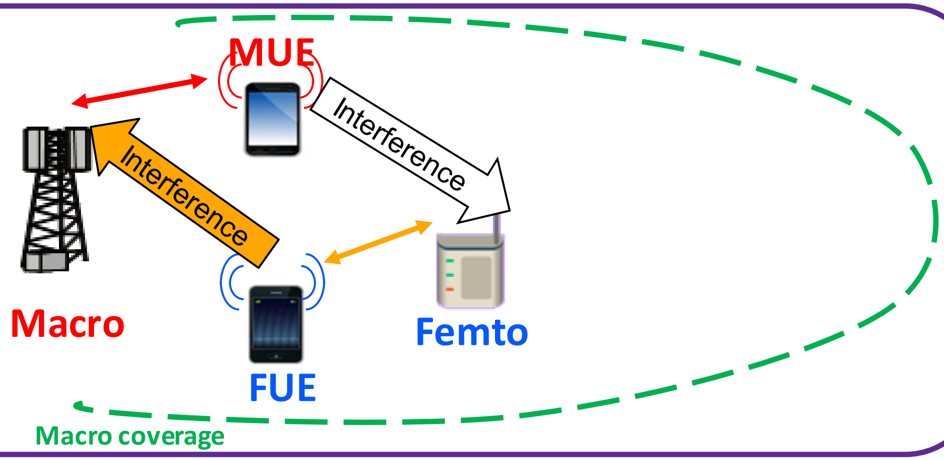


Uplink Rise Setting

- **Macrocell edge ⇒ High femto noise rise threshold**
  - Provides enough tolerance for FUE UL against nearby MUEs transmitting at high power
  - Less likely to cause interference at the macrocell site since FUEs also away from macrocell site



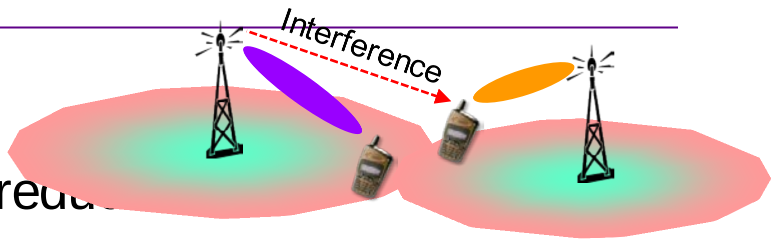
- **Macrocell site ⇒ Low femto noise rise threshold**
  - Less femto UL tolerance is needed since MUEs at cell site transmit at lower power
  - Protects macro from nearby FUEs



CoMP

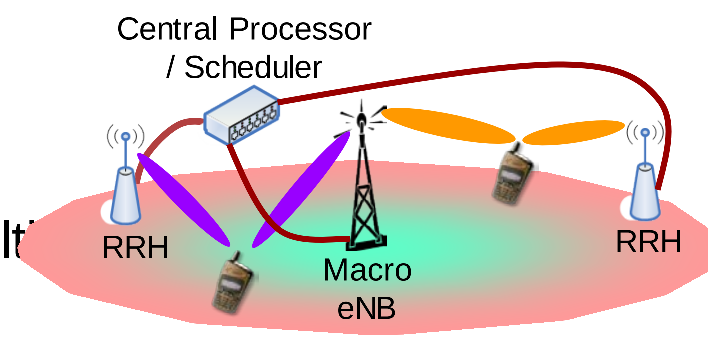
CoMP Techniques

- Coordinated Beamforming (CBF)
  - Beamforming with spatial interference redu
    to a UE served by adjacent cells
  - Inter-cell scheduling and beam coordination to maximize the aggregated utility metric
  - Need UE feedback of CSI from serving and interfering cells



Coordinated Beamforming

- Joint Processing (JP)
  - Multi-cell beam transmission to serve mult
    UEs together at the same time
    - Balance between energy combining and transmit interference nulling to UEs scheduled by other cells
  - Requires backhauls with large bandwidth and small delays (e.g. fiber-connected RRH)



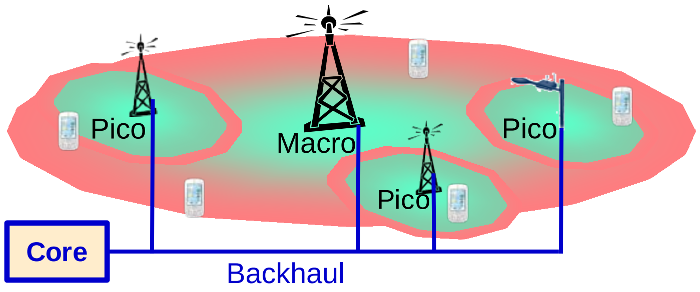
Joint Processing

CSI: Channel State Information
RRH: Remote Radio Head

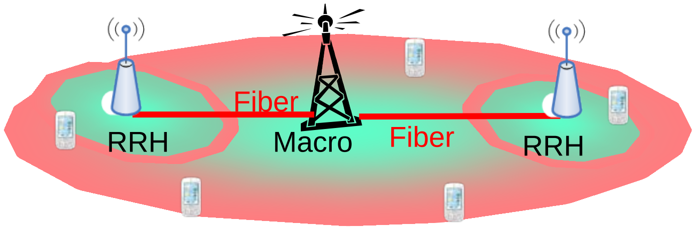
Deployment

- Standalone low power pico cells
  - Relaxed backhaul requirements
  - X2 interface to macro cells
  - Diverse vendor selection
- RRHs as extensions of macro cells
  - High speed backhaul
  - No inter-vendor operability
  - Natural support for eICIC coordination and centralized processing

Macro + Pico

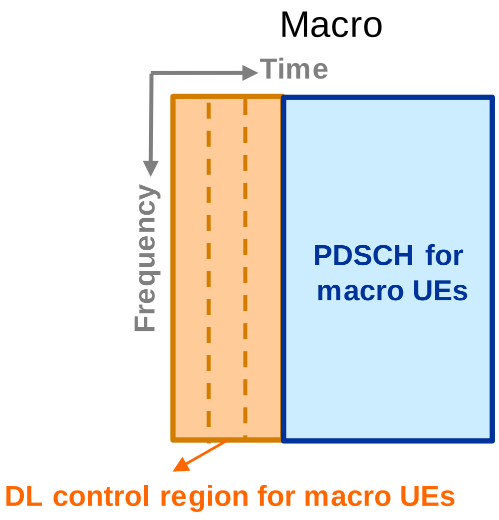


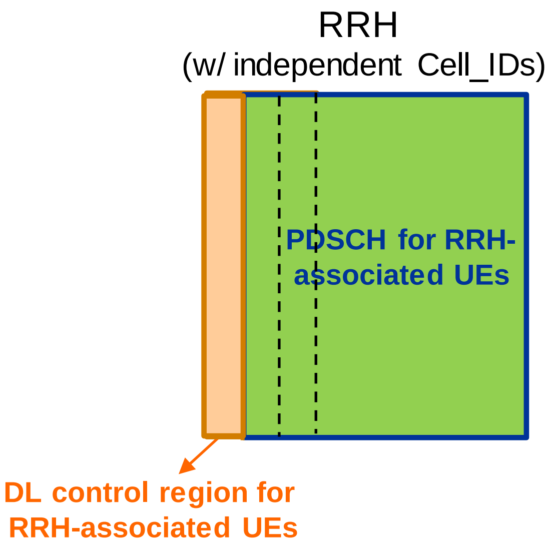
Macro + RRH



Control Region

- Common control across macro/RRHs limit capacity
  - Control bottleneck ⇔ Scheduling loss
  - SNR combining gain
- Independent cell IDs expand control dimensions

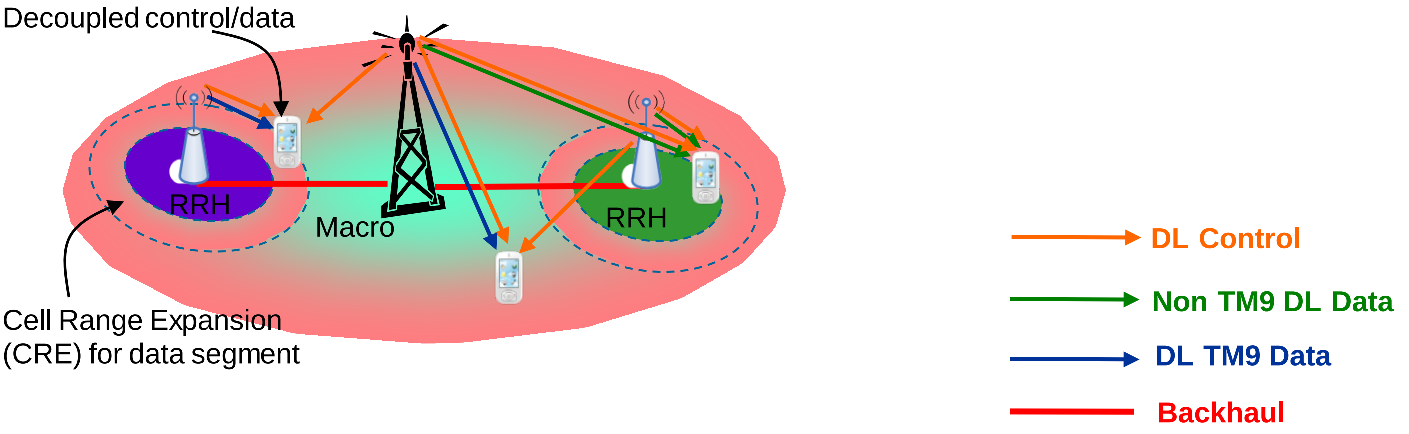




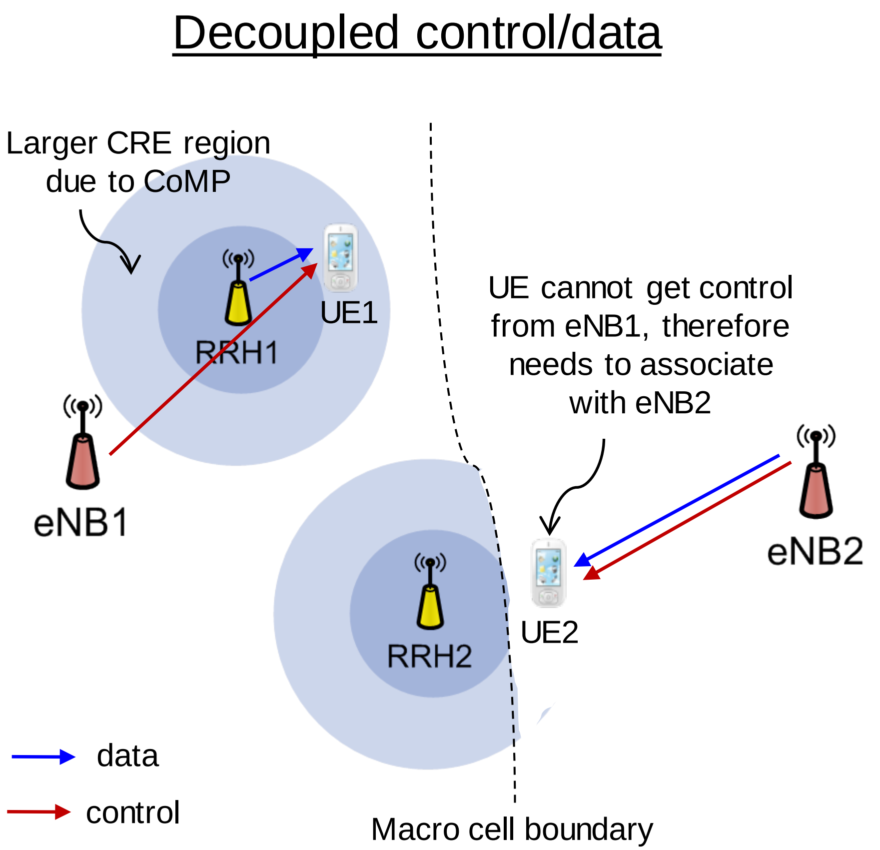
Demodulation Reference Signals

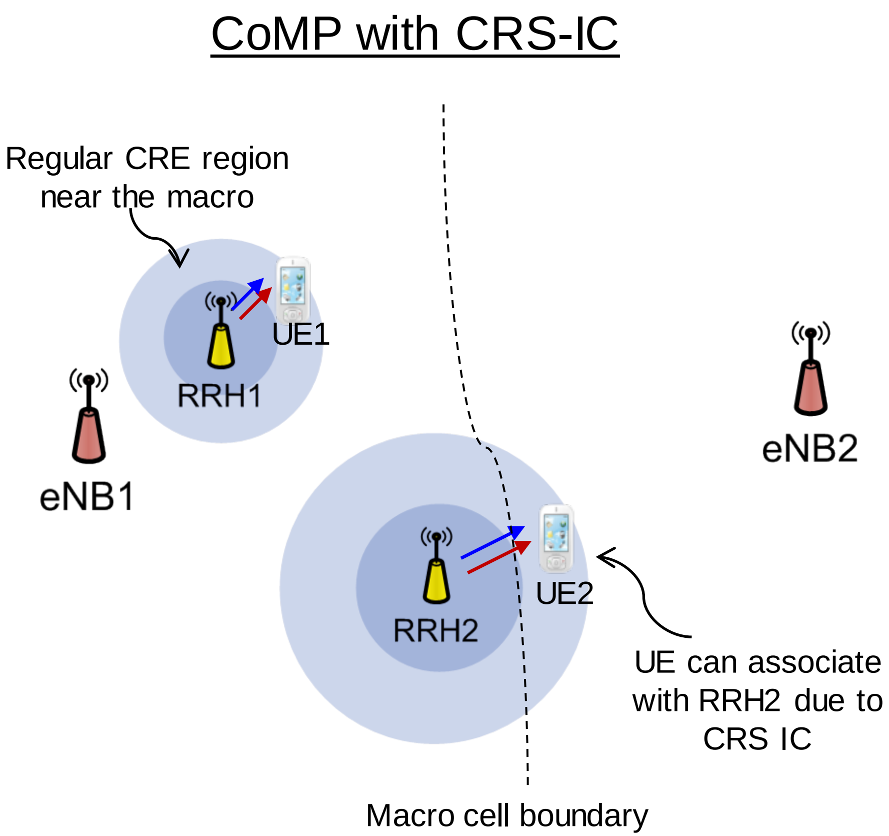
- Same cell ID
  - Decoupled data and control transmissions
  - Additional demodulation reference signals used
  - Overhead = 9%

Same cell ID for macro/RRHs



Boundary Artifacts

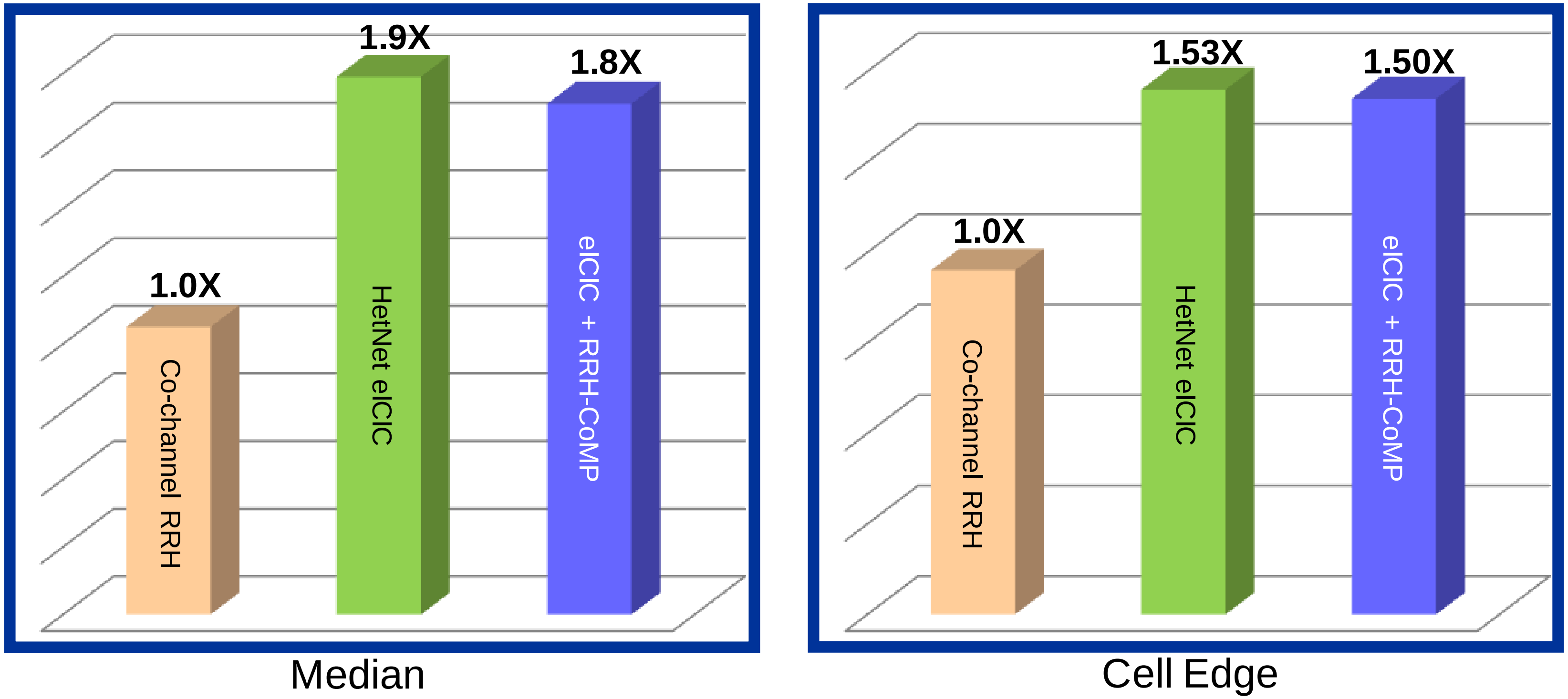




Downlink – Uniform Distribution

500m ISD

DL User Throughput Improvement

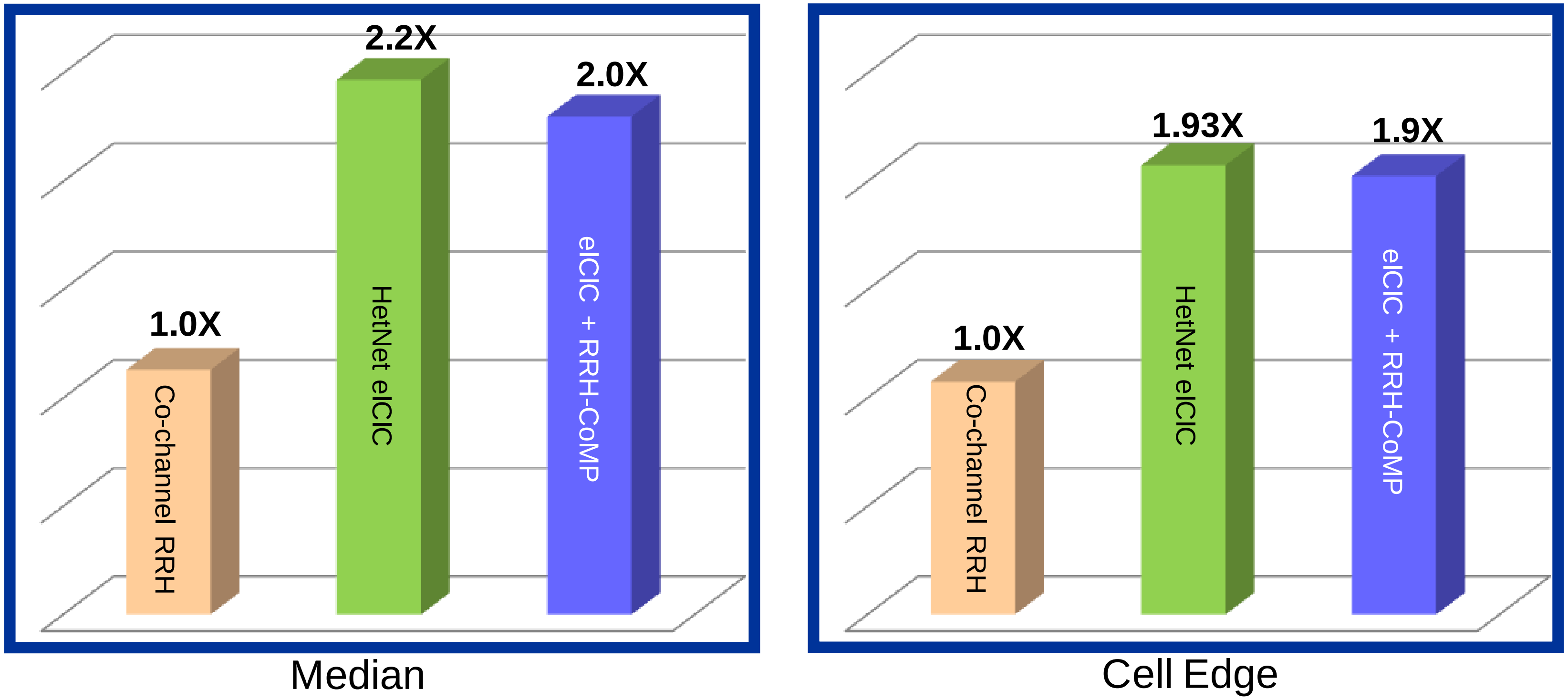


Results from R1-xxxxxx, simulation based on 3GPP 36.819. Macro ISD = 500m, 2GHz carrier, 10 degree antenna downtilt, 10 MHz FDD, 2x2 MIMO
Configuration 1: 4 RRHs per Macro cell, cell, 25 UEs are uniform-randomly dropped, TU3 channel, NLOS, full-buffer traffic, PF scheduling
Realistic CSI feedback. eICIC uses TM4, RRH-CoMP uses TM9 with centralized scheduler and multi-hypothesis CSI(3-bit codebook) with DM-RS overhead

Downlink – Hotspot Distribution

500m ISD

DL User Throughput Improvement



Results from R1-xxxxxx, simulation based on 3GPP 36.819**.** Macro ISD = 500m, 2GHz carrier, 10 degree antenna downtilt, 10 MHz FDD, 2x2 MIMO
Clustered configuration 4b: 4 RRHs per Macro cell, 20 out of 30 UEs are dropped near RRHs, TU3 channel, NLOS, full-buffer traffic, PF scheduling
Realistic CSI feedback. eICIC uses TM4, RRH-CoMP uses TM9 with centralized scheduler and multi-hypothesis CSI(3-bit codebook) with DM-RS overhead

Summary

- HetNet CoMP provides limited capacity gain with the current framework
  - DL overhead
  - Imperfect feedback
  - Control bottleneck when one steps away from cell splitting

What’s Next?

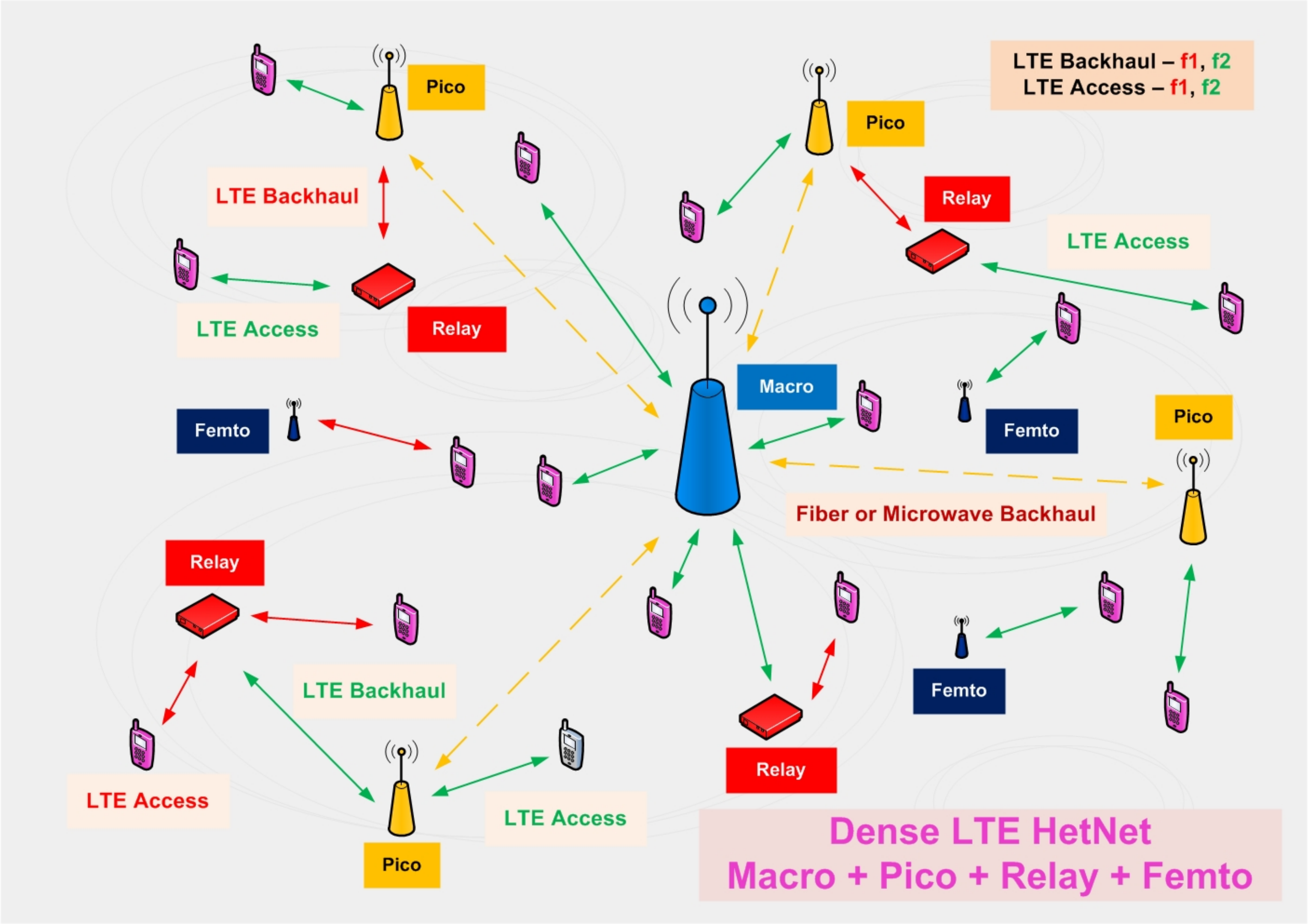
Goal

- Meet 1000x data demand in 10 years
  - 2x growth per year
  - Significant improvement in capacity
- How do we get there?
- More spectrum
  - Today's LTE FDD deployments are typically 10 MHz
  - We need ~100 MHz
  - Assuming we get there, that should yield 10x capacity increase
- Where do we get the remaining 100x?

Hyperdense LTE Network

- Viral deployment of small cells
  - 200-300 small cells per typical macro cell coverage
  - Approach 1:1 ratio with number of devices
- Very small form factor for a flexible deployment
  - Light poles, wall sockets, indoor malls
- Innovative backhaul
  - Relays or inside-out coverage with open access femto cells
- Opportunistic usage
  - Small cells adapt to spatial/temporal traffic pattern and light up/down accordingly

LTE HetNet 2.0



Thank You!