Heterogeneous Networks
A new paradigm for increasing cellular capacity

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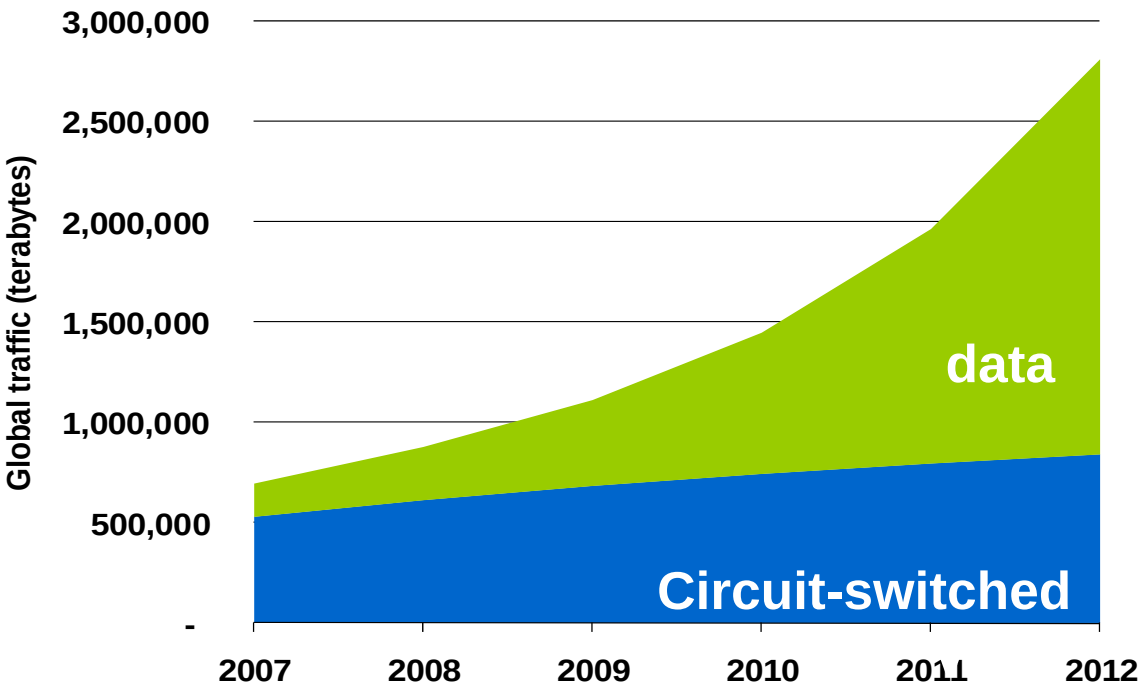
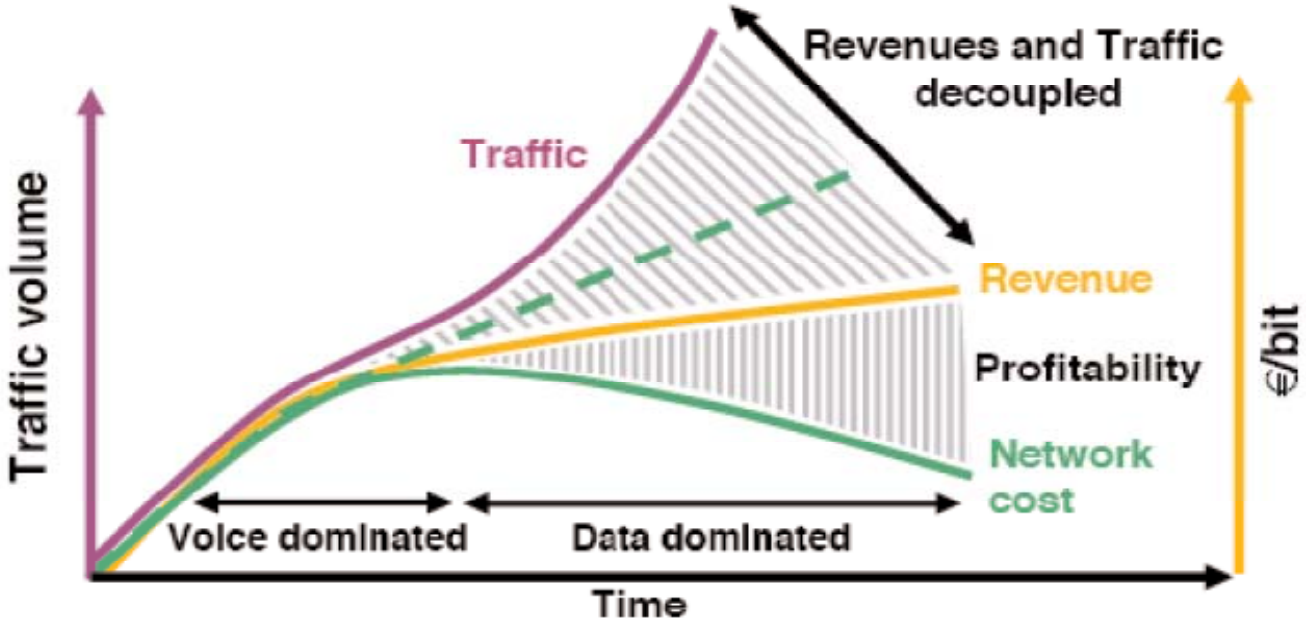
Wireless data traffic is increasing exponentially



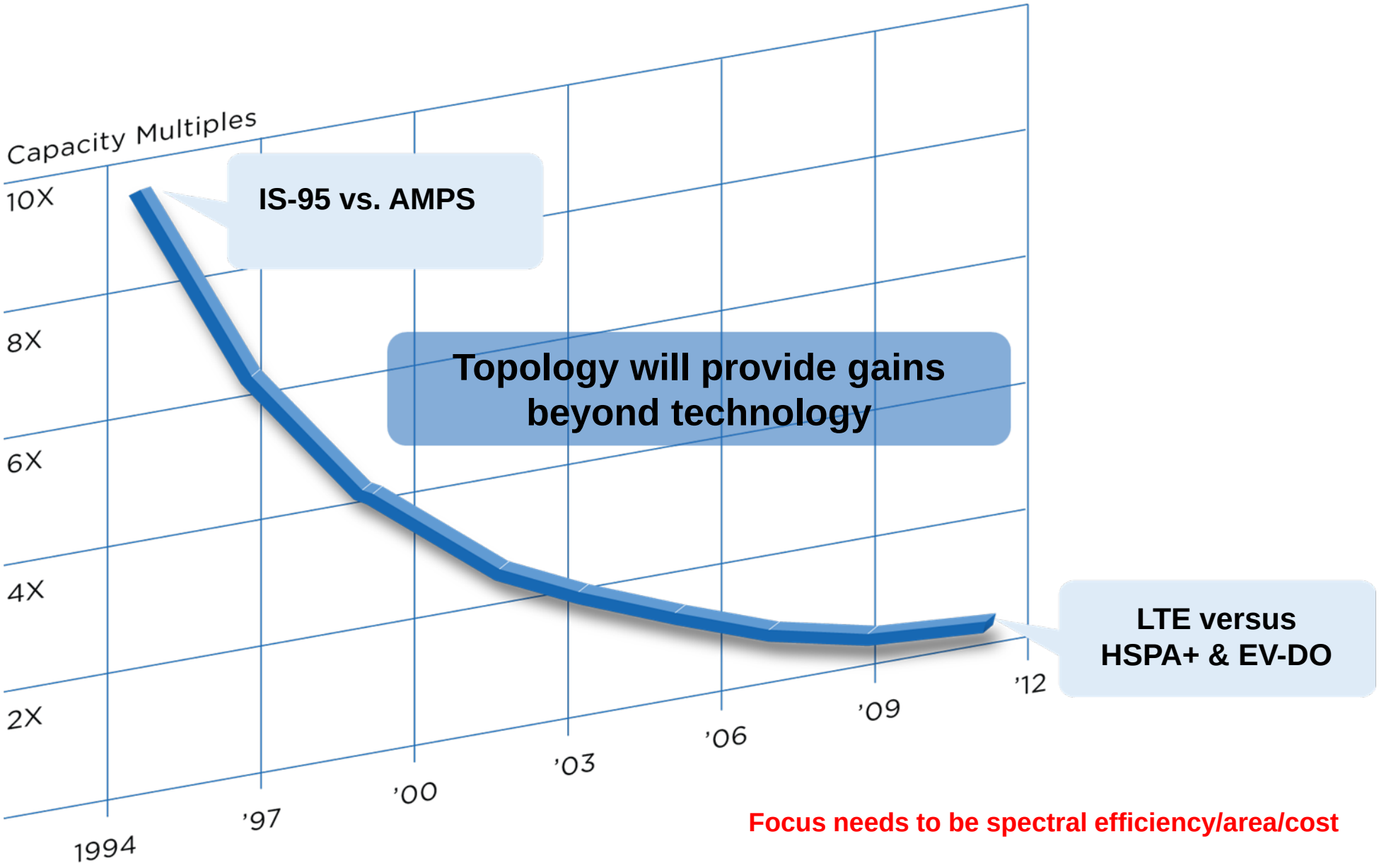
Source: Informa Telecoms & Media

Revenue growth is slowing.



Source: T-Mobile

Radio Link Improvement is Slowing, What is Next?



Focus needs to be spectral efficiency/area/cost

Terminology

- *Macro – conventional base stations that use dedicated backhaul and open to public access. Typical transmit power ~43 dBm; antenna gain ~12-15 dBi.*

- **Pico – low power base stations that use dedicated backhaul connections and open to public access. Typical transmit power range from ~ 23 dBm-30 dBm, 0-5 dBi antenna gain;**

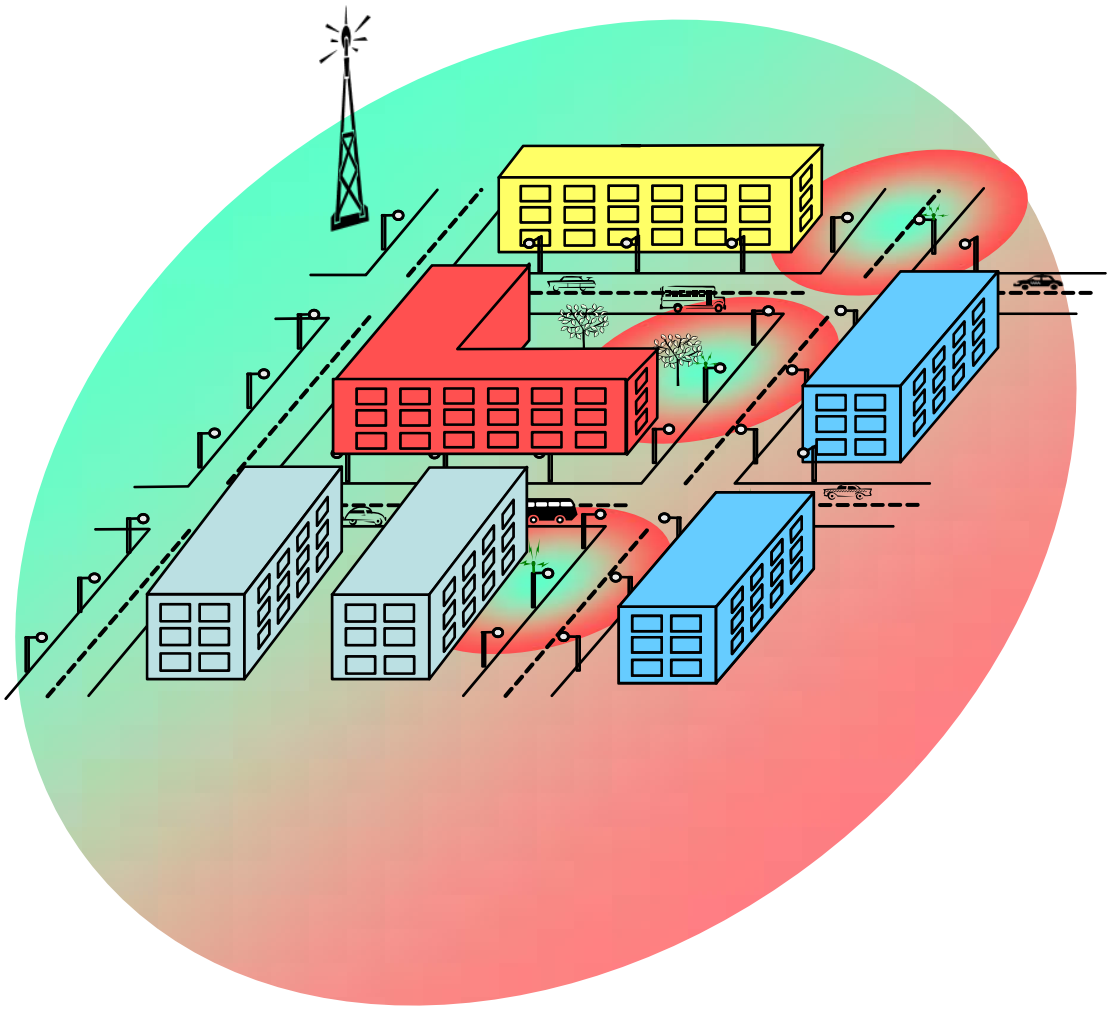
- *Femto – consumer-deployable base stations that utilize consumer's broadband connection as backhaul; femto base stations may have restricted association. Typical transmit power < 23dBm.*

- *Relays– base stations using the same spectrum as backhaul and access. Similar power as Pico's.*

- *Heterogeneous Network: A deployment that supports macros, picos, femtos and relays in the same spectrum.*

- *UE = User Equipment*

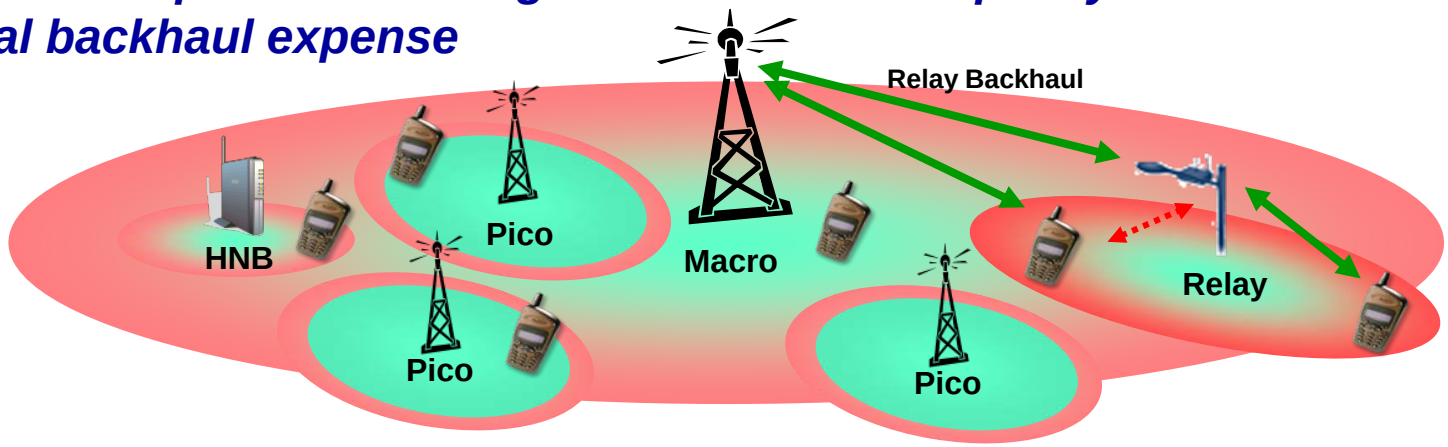
Macro-centric Planned Network Expansions Are Complex And Iterative



- ***Network topologies change with time***
  - Varying traffic demand and RF environment
- ***Cell splitting needed to maintain uniform user experience by overcoming capacity and link budget limitations.***
- ***Indoor coverage very challenging***
- ***Site acquisition is difficult***

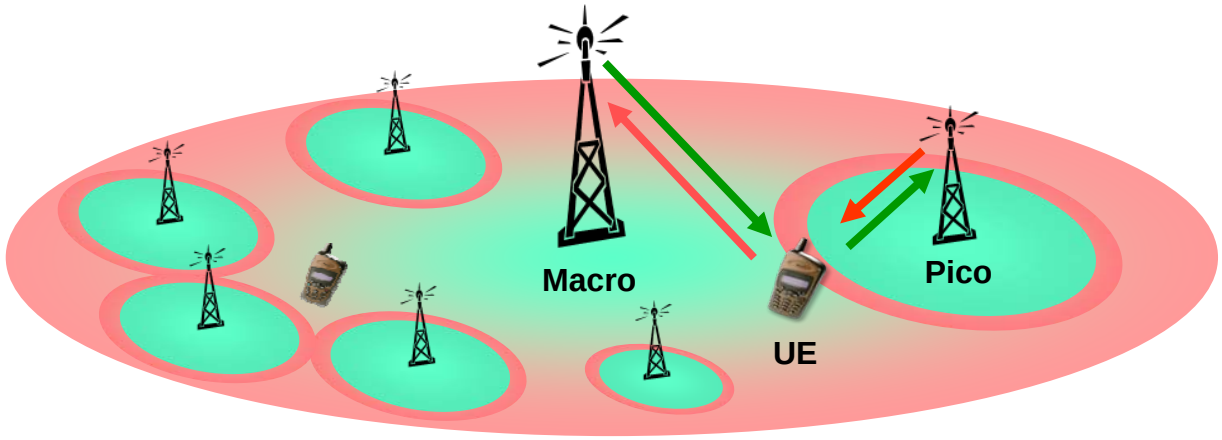
Deployment Model Vision: Heterogeneous Networks

- *Target coverage with Macro base stations for initial deployments*
- *Pico/Femto and Relay stations added for incremental capacity growth, richer user experience and in-building coverage*
- *Pico, Femto and Relay base stations can offer flexible site acquisition with low power base stations*
- *Relays & Femtos provide coverage extension and capacity with little to no incremental backhaul expense*



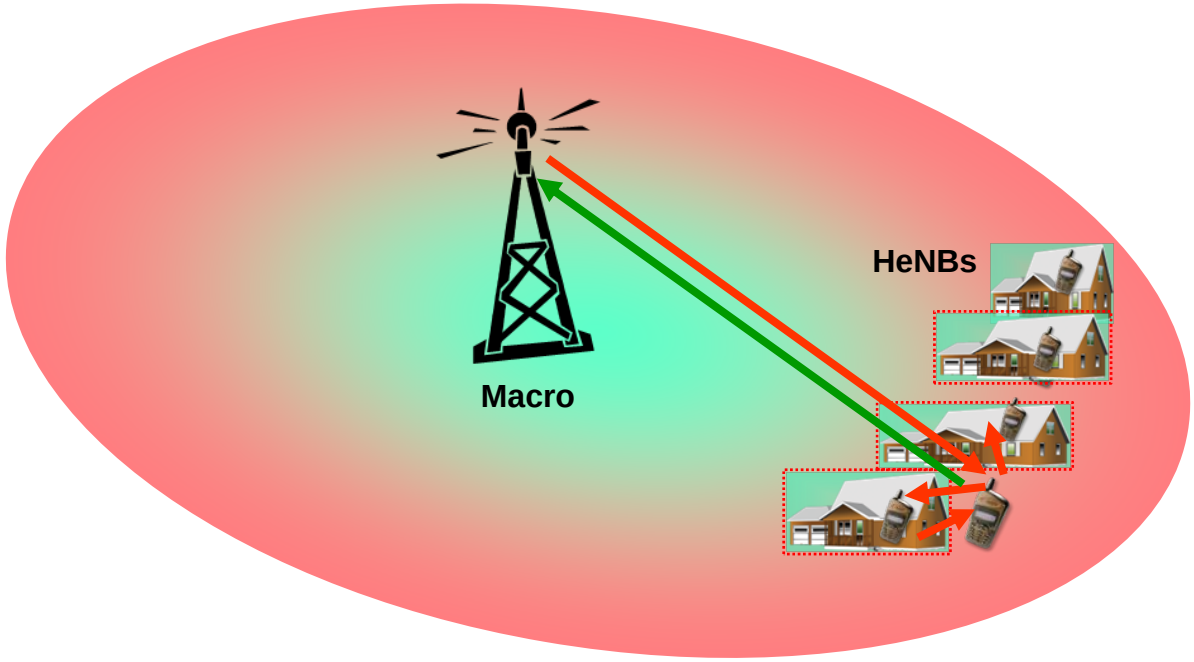
Heterogeneous networks create significant challenges in interference management. Overcoming these challenges is the focus of this talk.

Macro-Pico base station Coexistence Creates Challenging RF Environment



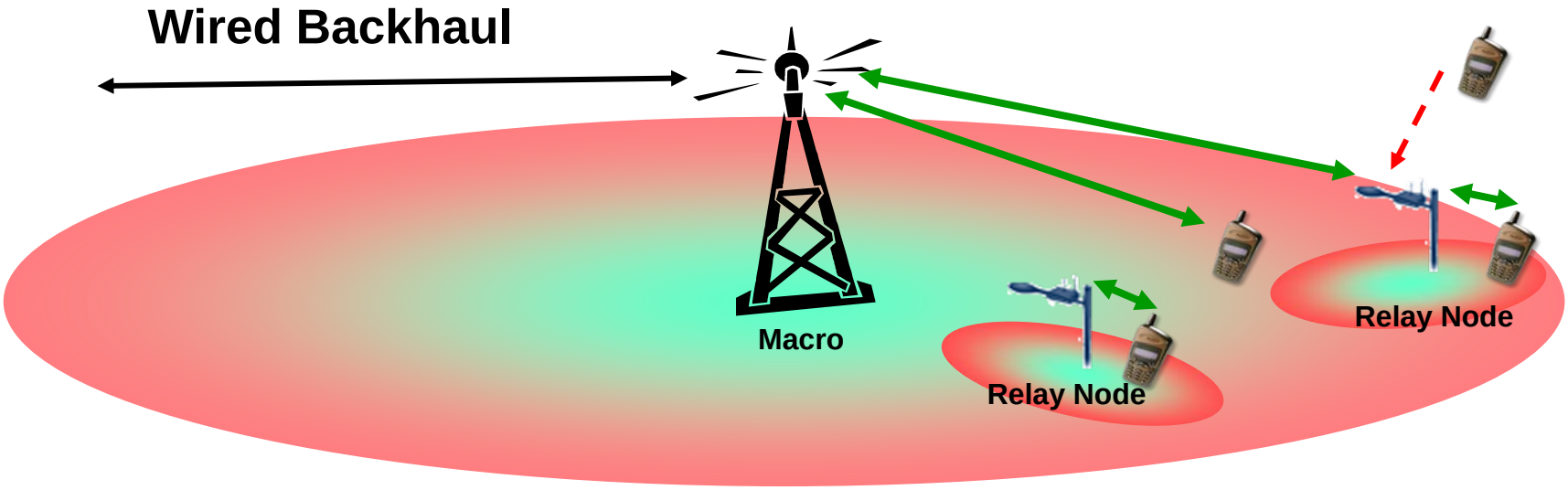
- ***More "cell-edge" created by Pico base stations within macro coverage***
- ***In conventional cellular systems (e.g: 3G, LTE) UE associates with a base station with best DL SINR***
  - UE with larger Macro SINR may have lower path loss to pico base stations thus causing significant UL interference at the lower power base stations.
  - Pico/femto cell coverage is limited (significantly) in the presence of macro coverage.

Home Femtos with Restricted Association Leads To Complex Co-channel Deployments



- ***Unplanned deployments of home femtos with restricted association creates significant interference scenarios***
  - DL of macro UE can be jammed due to close proximity to femto
  - UL transmissions from macro UE can severely impede femto
  - Severe interference may exist between femto's and their UEs

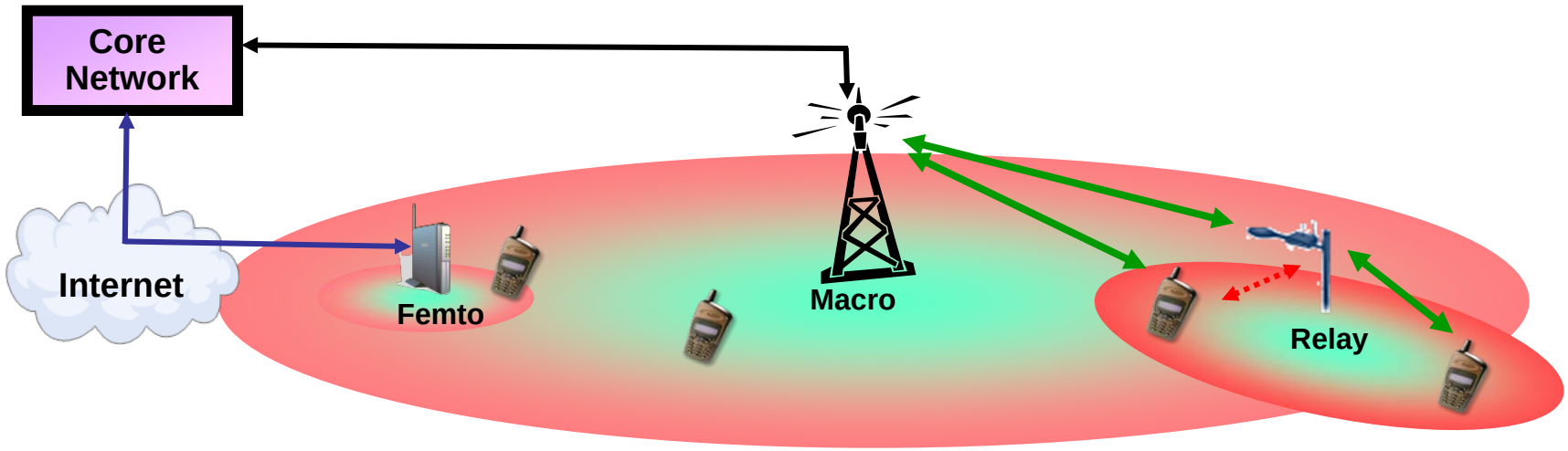
Relays Create Additional Interference Challenges



- ***Relays create extra "cell-edge" similar to a Pico base station***
- ***Multiple relay nodes can have different duplexing schedules which create interference.***

Relay and Femto's Support Non-traditional Backhaul Connections

- ***Handoff decisions need to take backhaul availability into consideration***
- ***Relays use over-the-air (OTA) link to Macro base stations as backhaul connection***
  - Need to take OTA backhaul into considerations when choosing between relay access and direct access
  - Direct access to macro by UEs in relay coverage may cause significant interference with relay base station
- ***Femto uses customer's broadband connections for backhaul***
  - Femto's need to support non-carrier-grade backhaul in terms of outage and bandwidth



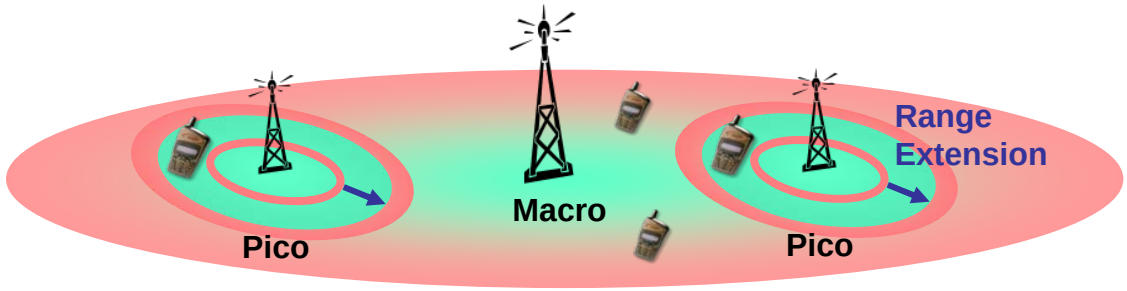
Some techniques for enhancing performance with heterogeneous networks

- ***Range Extension using Intelligent Association Algorithms***

- ***Dynamic resource reservation/load balancing across base stations.***

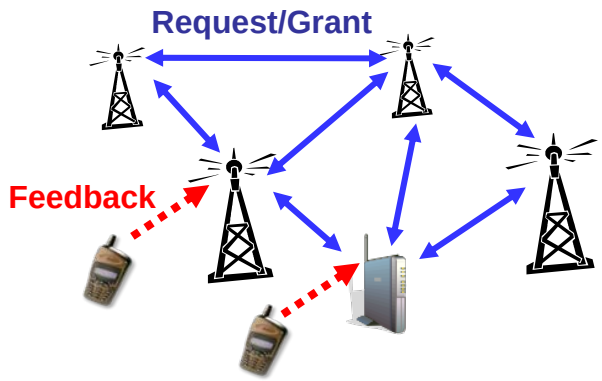
Range Extension using Intelligent Association

- ***Range extension can be used to expand coverage area for low-power base station***
  - UE association is determined by minimal path loss
- ***Intelligent association achieves better spectrum efficiency and network capacity***
  - Lower interference per bit to the network on both DL and UL
  - Achieve better spatial reuse efficiency similar to cell splitting
    - Multiple Pico/Femto nodes can simultaneously use the resource vacated by the macro base station
  - Lower traffic load on macro base station
- ***Enabling techniques***
  - Deep penetration synchronization signals
  - Deep penetration control channels
  - Adaptive Resource Reservation

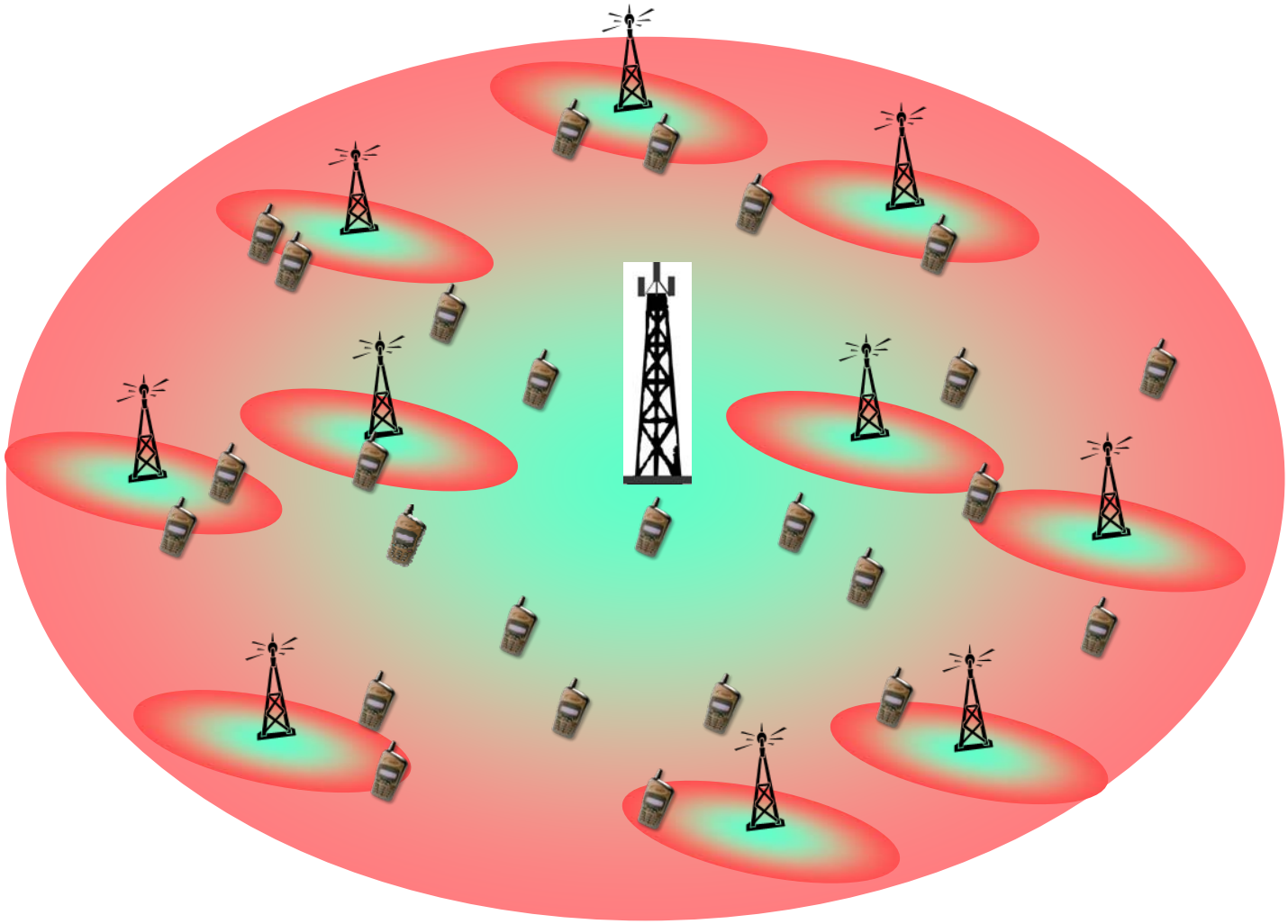


Distributed Adaptive Resource Partitioning Algorithm

- ***Resource partitioning should adapt to network loading, backhaul availability, topology, SINR conditions at UE/base station, mobility, QoS, traffic patterns, etc.***
- ***Distributed, adaptive resource partitioning schemes are essential to manage interference and optimize throughput performance in heterogeneous networks***
  - The nodes in the network negotiates their resource reservation by sending messages to each other
  - The resource request/grant messages can be sent over backhaul connections or OTA
- ***Slowly adaptive resource negotiation algorithm***
  - Based on node load status and feedback from active UEs
  - Works in a longer time scale (hundreds of msec)
  - Partitioning can be applied to both control resources and traffic resources
- ***Dynamically adaptive resource negotiation algorithm***
  - Further improves the user experience with bursty traffic
  - Resources can be temporarily loaned between nodes
  - Requires OTA signaling



Simulation Scenario: Hierarchical cells, Macro-Pico co-existence



Picos are randomly dropped within macro coverage.

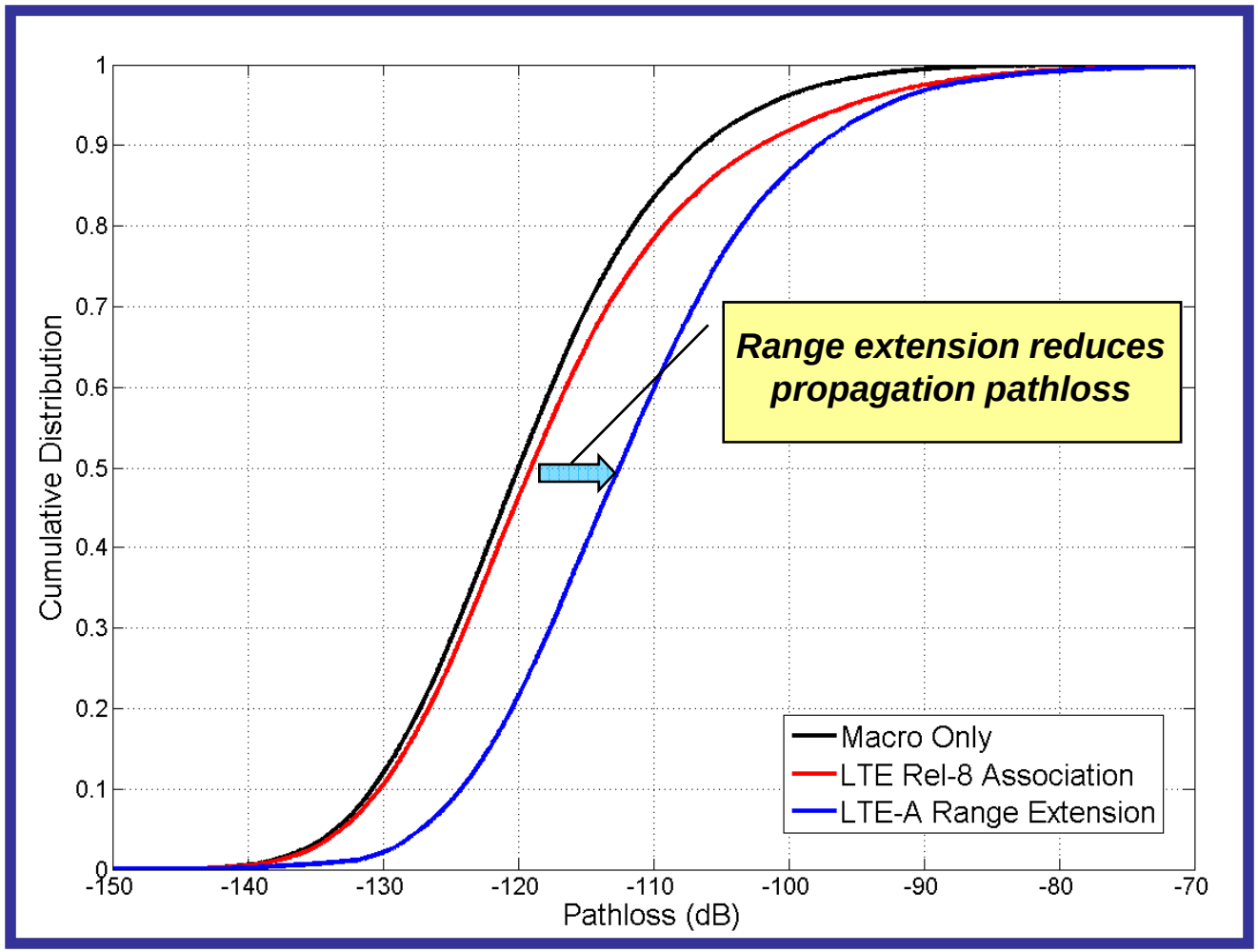
Mixed Macro and Pico/Relay Deployment

- *Evaluation methodology proposed for LTE-A in R1-084026*
- *10 MHz FDD spectrum*
- *2x2 MIMO*
- *19 cell wrap around, 500m site-to-site distance*
- *1 macro base station per cell*
- *UE density: 25 UEs in each macro cell*
- *10 Pico/Relay per macro cell unless specified otherwise*
  - *Uniform layout: UEs and Pico/Relays randomly dropped within macro cell*
  - *Hotspot layout: 80% UEs are placed within 28.9 meters from corresponding Pico/Relay nodes*
- *Pathloss model*
  - *Macro to UE: 128 + 37.6*logD*
  - *Macro to Relay: 124.5 + 37.6*logD*
  - *Relay to UE: 140.7 + 36.7*logD*
- *Building penetration loss 20 dB*
- *Log-normal shadowing and TU3 fading channel modelled*
- *Noise figure at UE: 10 dB*
- *Noise figure at base station: 5 dB*
- *Full Buffer Traffic Model with EGOS scheduler*
- *Throughput shown reflects respective overhead*

	Macro eNB	*Pico / Relay*	*UE*
Maximum PA Power (dBm)	*46*	*30*	*23*
Antenna Gain (dB)	*16*	*5*	*-1*
Connector Loss (dB)	*2*	*0*	*0*

Range Extension Brings the Network Closer to UEs

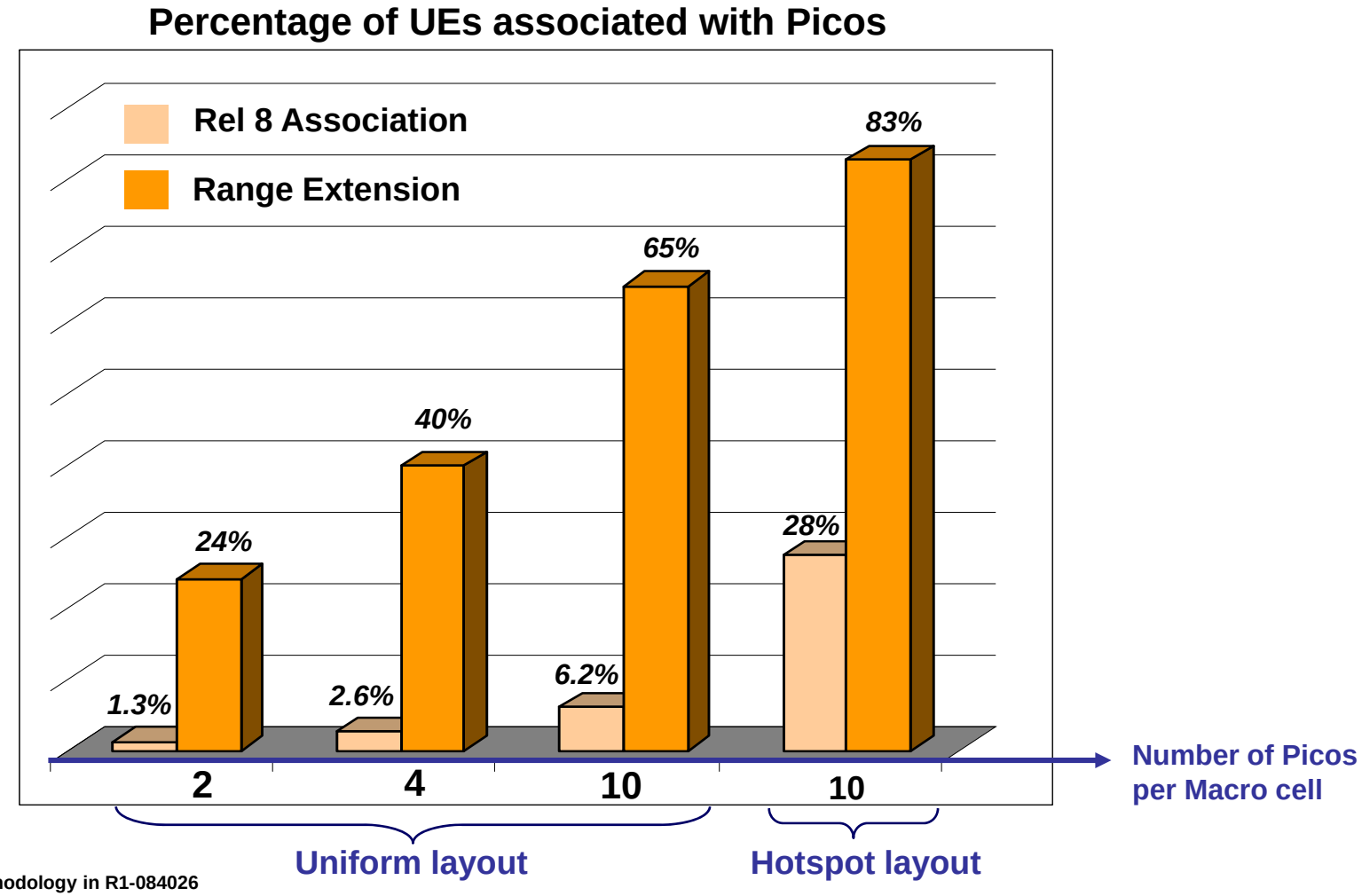
- ***Compared to LTE Rel-8 association, range extension reduces the propagation pathloss from base station to UEs***
- ***Smaller pathloss lowers interference per bit to the network***



Pathloss excluding eNB transmission antenna gains
10 picos, 25 UEs, uniform random layout
Based on proposed LTE-A evaluation methodology in R1-084026

Range Extension Allows More UEs to Benefit Directly from Low-power base stations

- ***With default association method in LTE Rel 8, only a small fraction of UEs are served by Pico nodes***
- ***Range extension enables more equitable distribution of air resource to each UE***

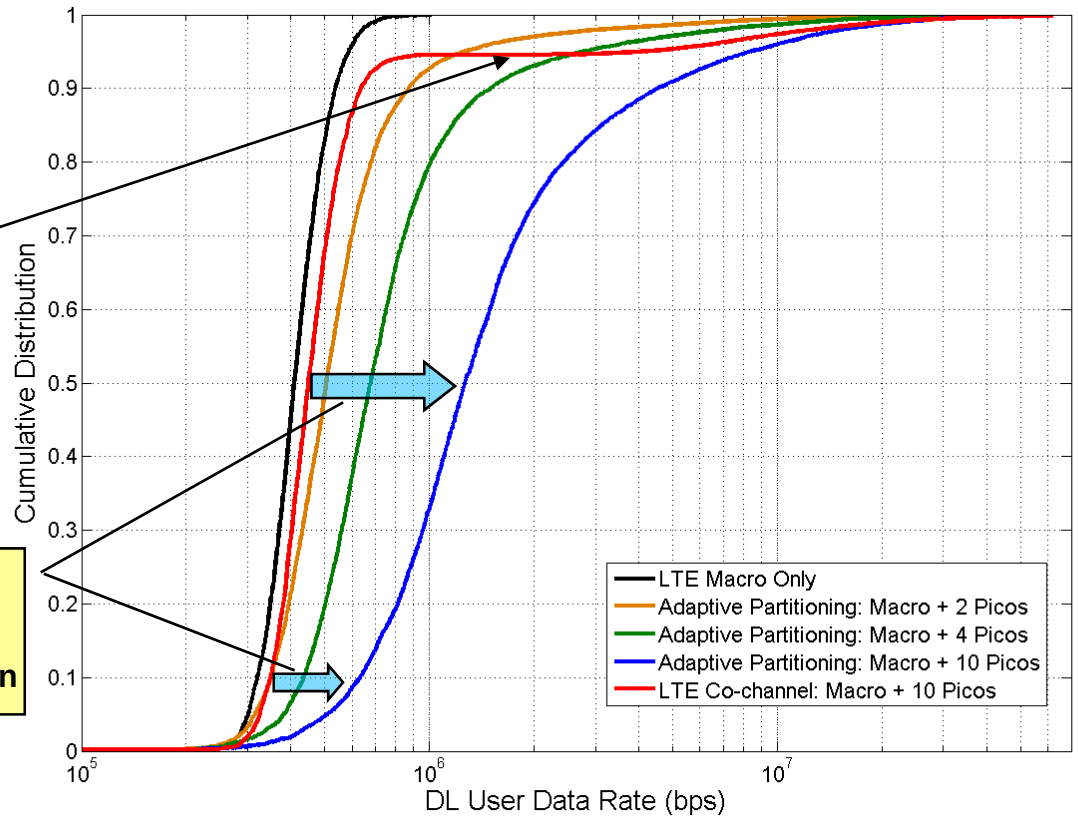


Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, 2x2 MIMO, 25 UEs, uniform random or hotspot layout

DL Performance

Improvement by co-channel heterogeneous deployment using LTE Rel-8 is concentrated to a small fraction of users

Smaller numbers of Picos with proposed techniques outperform Rel-8 co-channel deployment using 10 Picos/Macro at cell edge to median



DL user data rates using proposed adaptive interlace partitioning compared to LTE Rel-8 co-channel deployment of Macro + 10 Pico

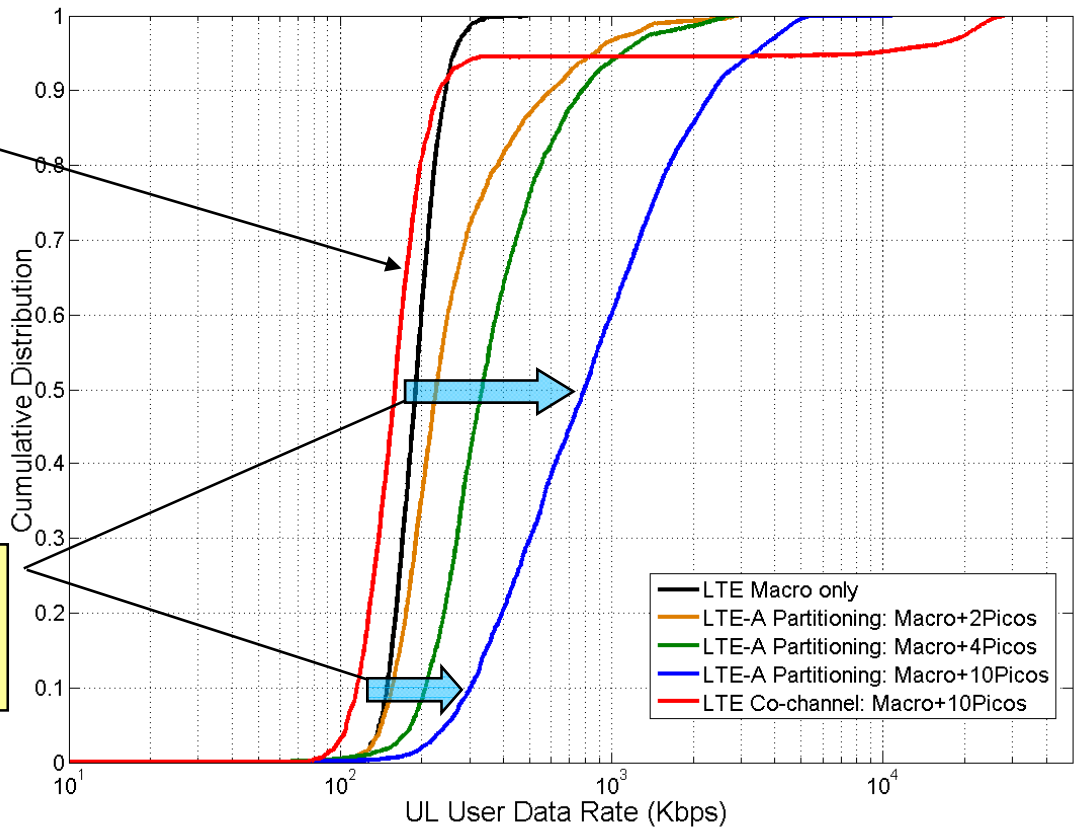
Pico density	*Gain of cell edge data rates*	*Gain of median users rates*
10 Picos / Macro	*82 %*	*183 %*

Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, 2x2 MIMO UE, uniform random layout
Picos and UEs randomly dropped in Macro cell

UL Performance

A small fraction of users benefit from co-channel heterogeneous deployment using LTE Rel-8 at expense of other users

Smaller numbers of Picos with proposed techniques outperform Rel-8 co-channel deployment using 10 Picos/Macro at 10% to median



UL user data rates with resource partitioning compared to LTE Rel-8 co-channel deployment of Macro + 10 Picos

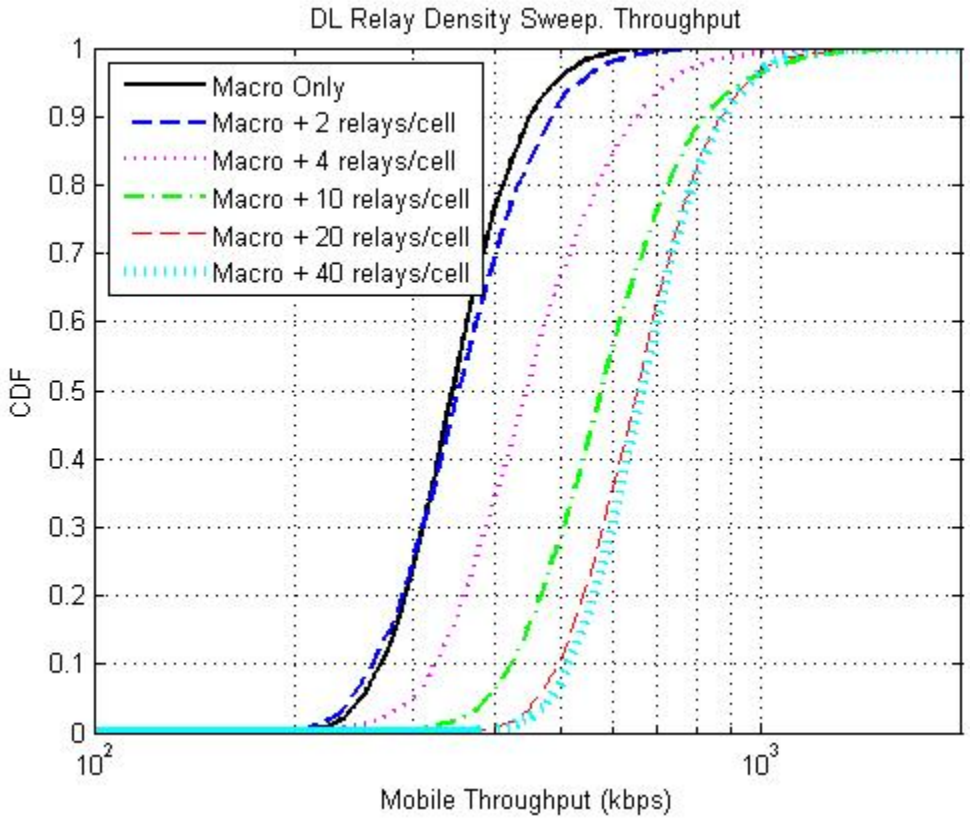
Pico density	*Gain of cell edge data rates*	*Gain of median users rates*
10 Picos / Macro	*160 %*	*406 %*

Resource partitioning for this simulation is fixed throughout the network.

Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, uniform random layout, single TX antenna UE
Picos and UEs randomly dropped in Macro cell

Macro + Relay Deployment

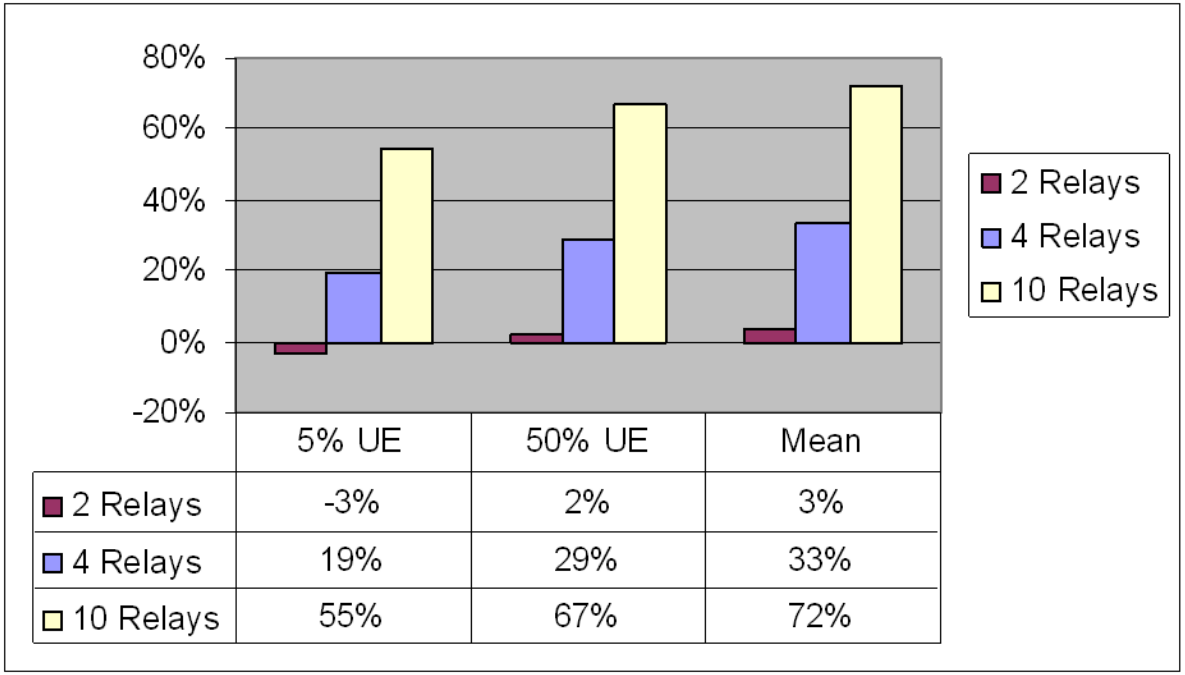
- ***Decode and Forward Relay***
  - Behaves like a MS on the backhaul link with directional patch antenna (Shown below)
  - Behaves like an BS on the access link with backhaul limitation



Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, 2x2 MIMO UE, Relays using 2 Rx donor antennas, uniform layout
DL partitioning between access/direct link and relay backhaul is 8:2

Relay Performance

Gains in DL User Data Rate Compared to Macro-only LTE



	5% UE	50% UE	Mean
2 Relays	-3%	2%	3%
4 Relays	19%	29%	33%
10 Relays	55%	67%	72%

Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, 2x2 MIMO UE, Relays using 2 Rx donor antennas, uniform layout
DL partitioning between access/direct link and relay backhaul is 8:2

Conclusion

- ***There is a need for substantial increase in cellular capacity.***
- ***Radio link improvements alone cannot meet the traffic requirements.***
- ***Focus should be on increasing cell density cost effectively using heterogenous networks.***
- ***Optimizing heterogeneous network performance requires a rethinking of the cellular design paradigm.***
- ***Techniques such as range extension and adaptive resource partitioning promise substantial gains in capacity.***

- ***Interference management for heterogeneous networks is a promising area for wireless research.***

Thank You