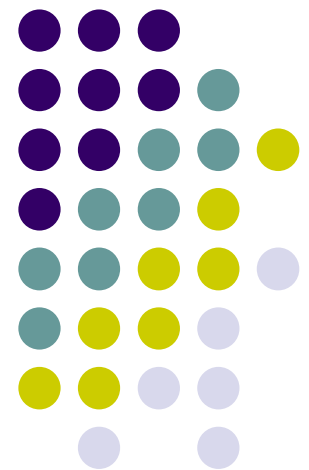


Cooperative, Green and Mobile Heterogeneous Wireless Networks

Rose Qingyang Hu
Utah State University

Shilpa Talwar
Intel Corporation

Pingping Zong
Verizon Wireless

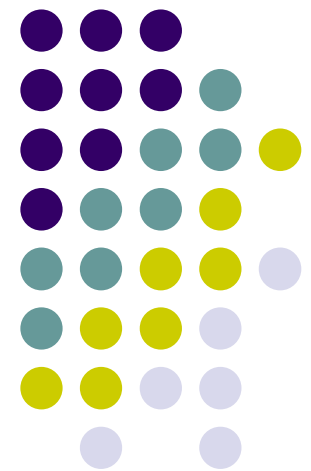




Outline

- Future Networks and why Hetnet
- What is HetNet
- Green HetNet
- Cooperative HetNet
 - ICIC
 - CoMP
 - Relay
- Other Enablers of HetNet
 - HetNet Mobility
 - SON in HetNet
- Advanced Services
- Conclusions

Future Networks and Why Hetnet



The Big Picture

Market Trends & Usages



Convergence of information & communications

Proliferation of applications and services

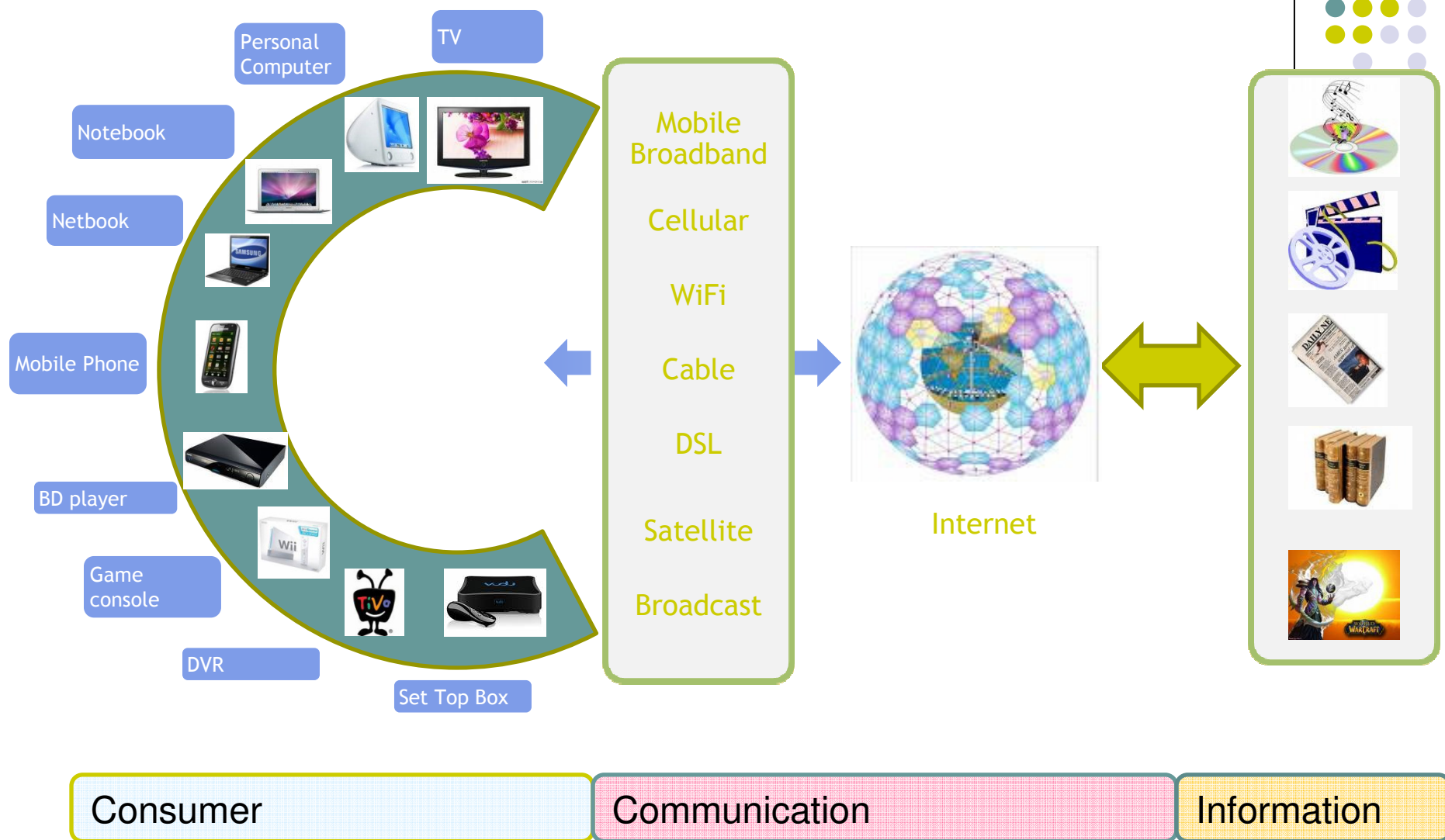
Diversification of connected devices

Interworking of communication technologies

Environment friendly 'Green' radios

**Explosion of wireless
traffic**

Convergence of Information & Communications



Proliferation of Mobile Internet Apps & Services



PANDORA

Rhapsody

Spotify

amazonmp3
Play Anywhere, 0.99¢ Free Music Downloads

last.fm

flickr

30.4M Photos viewed / day
152 TB/day

skype

twitter



Picasa

shutterfly
where your pictures go

NETFLIX



hulu

facebook

myspace
a place for freedom

facebook

8.6B Pages viewed / day
1.7 PB/day



App Store

ovi



Google

YAHOO!

bing

Baidu 百度

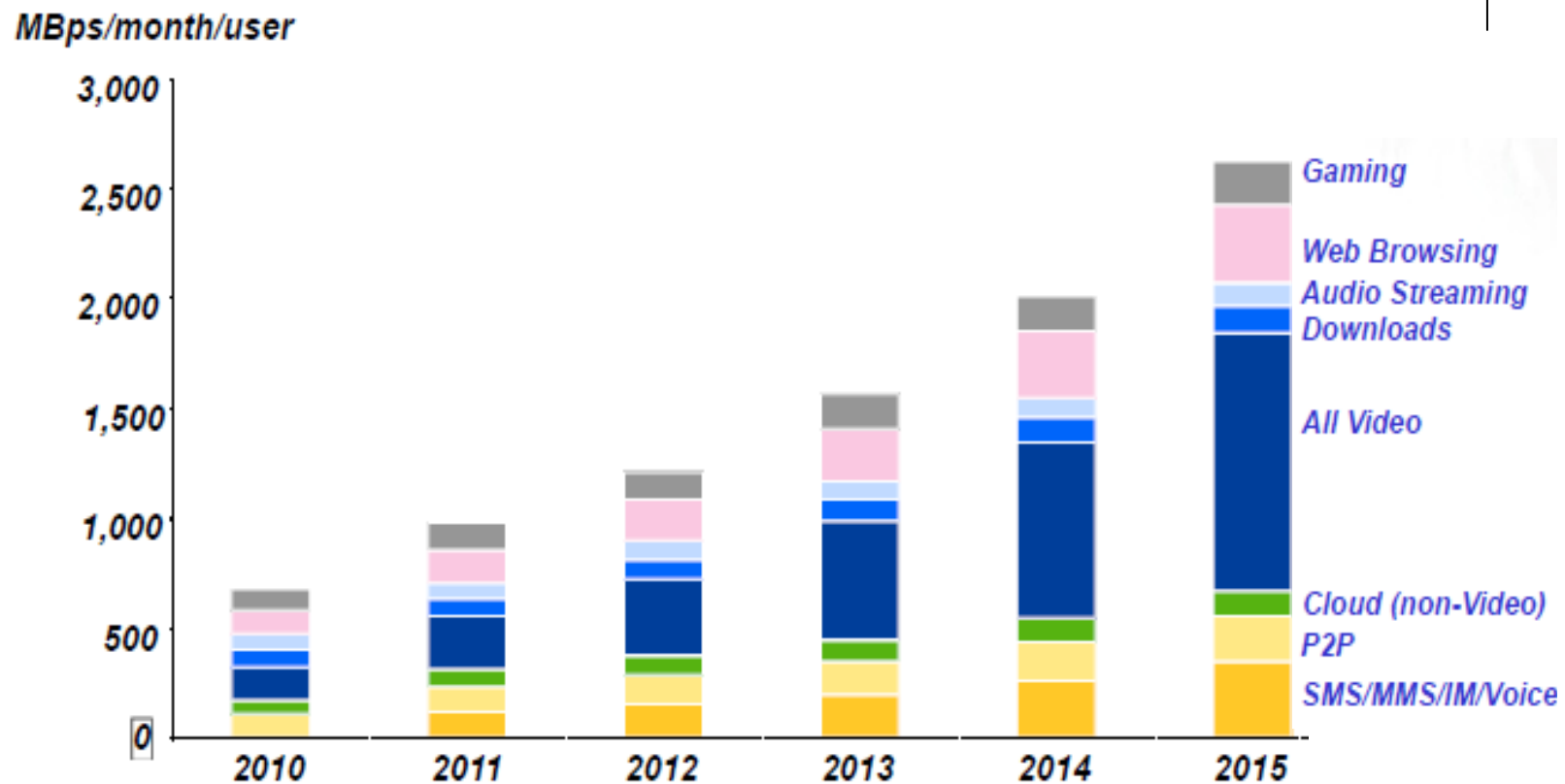


WIKIPEDIA
The Free Encyclopedia

You Tube

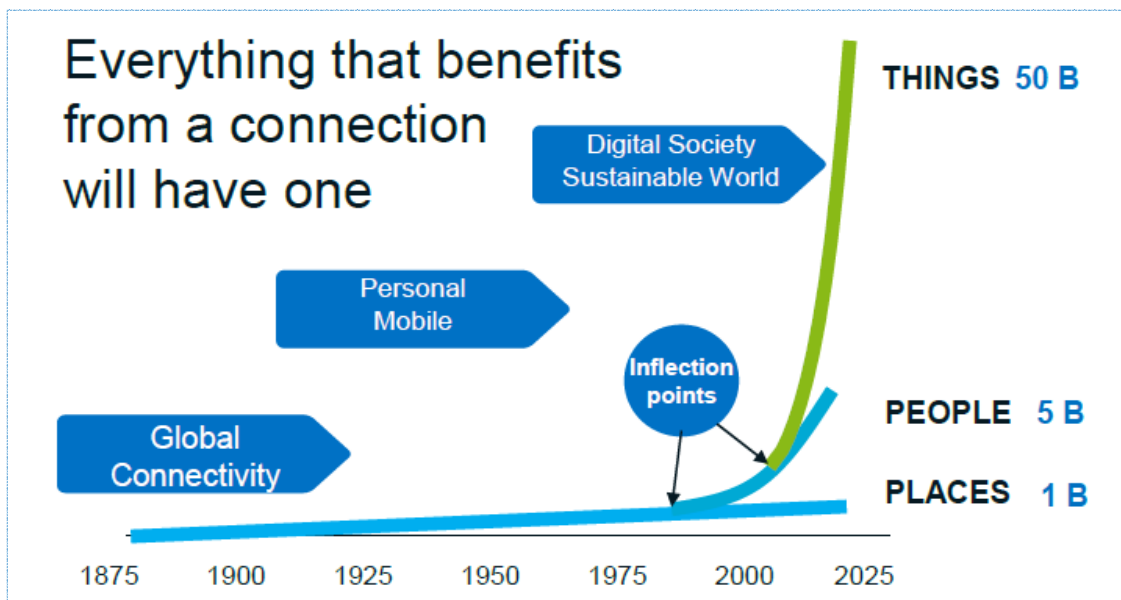
2 B Videos viewed / day
25 PB/day

Per user Mobile internet traffic



Web browsing, video applications are dominant

Diversification of connected devices



+Logos and trademarks belong to the other entities
++ These are examples of devices

More traffic with large screen devices



Explosion of Wireless Data Traffic



Capacity Challenge: 500x in 10 Years

Billions of new users
& connections



7.5 Billion
users



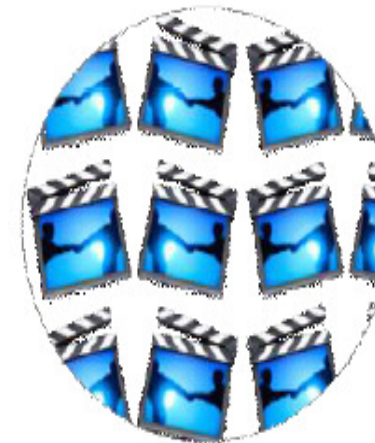
60 Billion
connections

Booming
smart devices



50%+ YoY growth of traffic
per user

Bandwidth
hogs

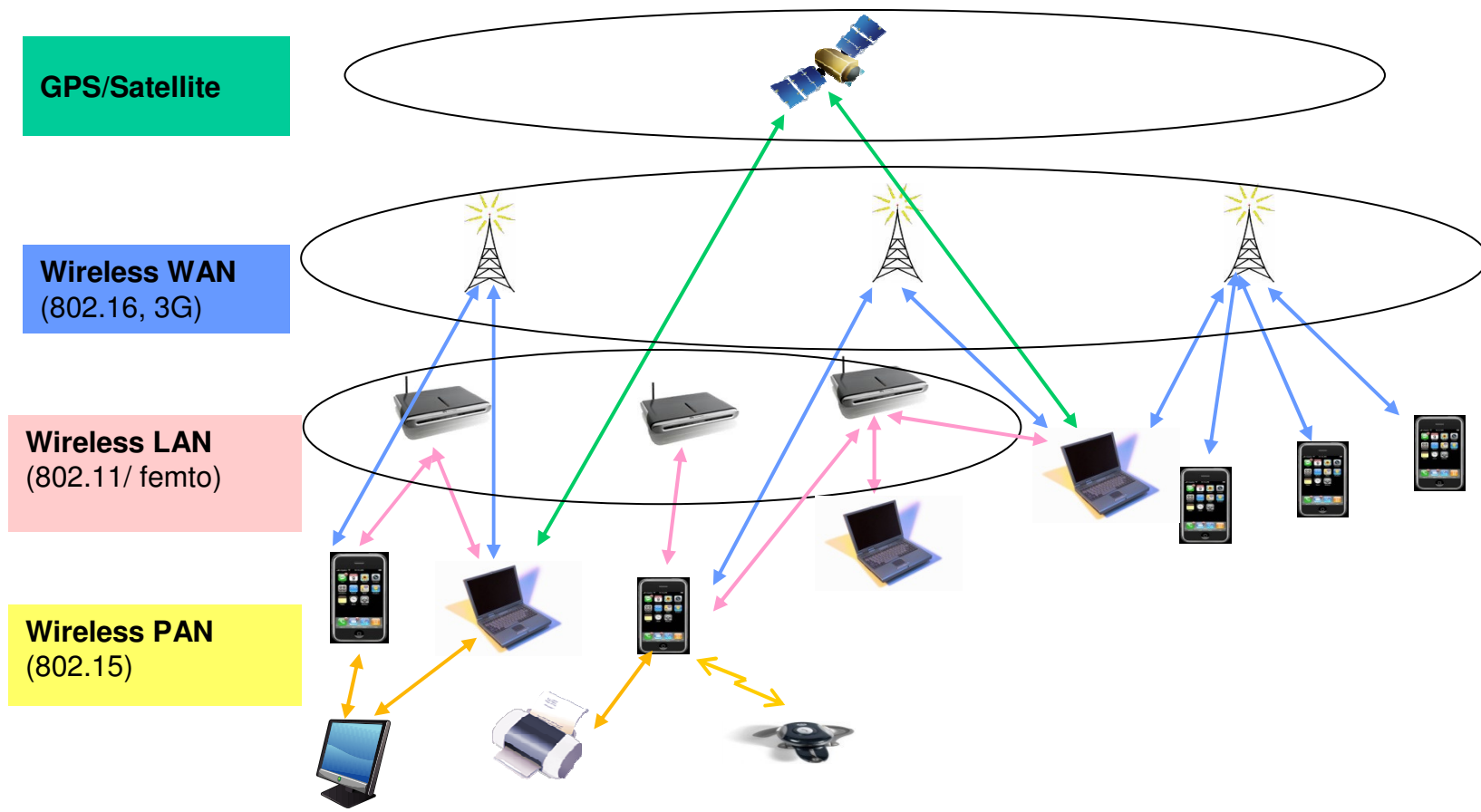


Video @ 130% CAGR

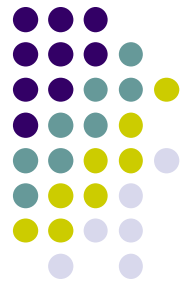
Interworking of communication technologies



- Multiple radios will operate simultaneously to offer new usages
- Ex: Mobile Hotspots, WiFi-Offload technologies



Environment-friendly Green radios

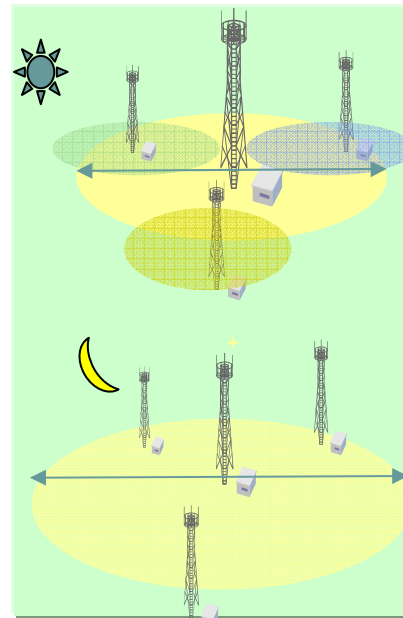


Consumer



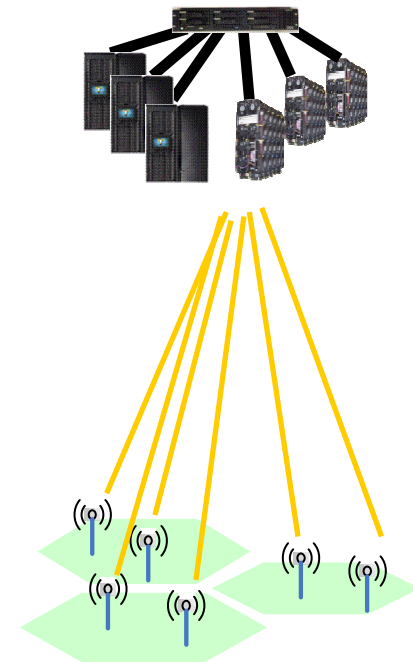
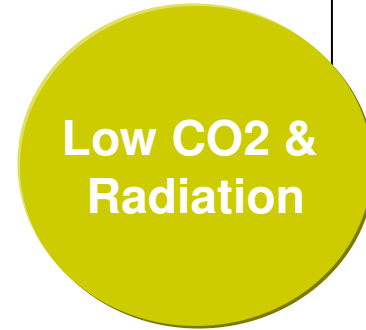
Energy Saving Products

Network



Protocols

Environmental



Architectures

Market trends present new requirements for Future Networks



- Future networks should support explosive mobile data traffic growth driven by
 - Large screen devices
 - Multimedia applications
 - More connected users & devices
- Future networks should be optimized for mobile broadband traffic
 - Efficiently support low-mobility traffic, mobile video, internet applications
- Future networks should be low power, and environmentally friendly
- Future networks should interwork efficiently with other radio technologies
 - Converged multi-access networks and terminals

HetNets offer Promising Solution

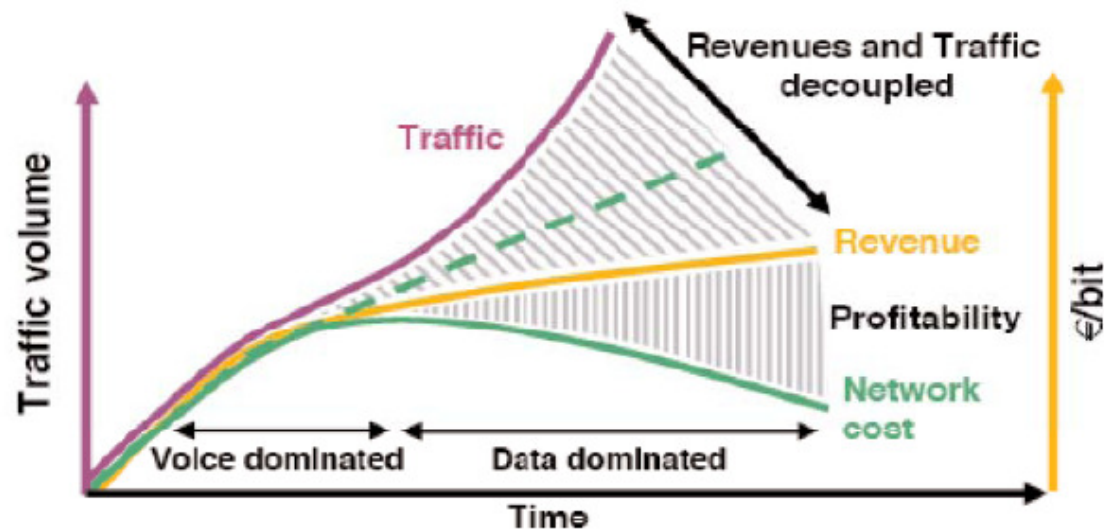


- Future networks should support explosive mobile data traffic growth
 - HetNets offer linear capacity scaling with number of BS nodes
- Future networks should be optimized for mobile broadband traffic
 - HetNets bring serving BS closer to user, efficiently supporting low mobility and high rate traffic
- Future networks should be low power, and environmentally friendly
 - HetNets offer opportunity to lower transmission power, saving energy at BS and battery life at clients
- Future networks should interwork efficiently with other radio technologies
 - HetNets enable seamless integration of unlicensed LAN/PAN technologies into cellular networks



Service Providers also facing Flat Revenues

- Cost of Network deployments to meet demand is increasing faster than revenue



Source: T-Mobile

- Service providers are facing challenges at two ends
 - Invest in network capacity to meet demand
 - Increase revenue with new applications and services



Service provider options

Ration Network Usage

- Tiered service levels
- Traffic shaping

Invest in Advanced Networks (HetNets)

- High capacity
- Low cost
- Multi-radio access
- Green Radio

Create Revenue through New Services

- Enterprise Services
- Home broadband
- Enhanced QOE
- M2M – new business

HetNets offer solution to lower Cost per Bit, as well as help improve Revenue per Bit



Why HetNets: Capacity

- Explosion of mobile data traffic
 - Adoption of new devices (ex. smartphone, tablet, etc);
 - Introduction of rich applications (social networking, video streaming, etc);

ABI Research, August 2009:

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

Cisco, October 2009:

“Mobile traffic data is expected to grow by **66x** between 2008 and 2013”

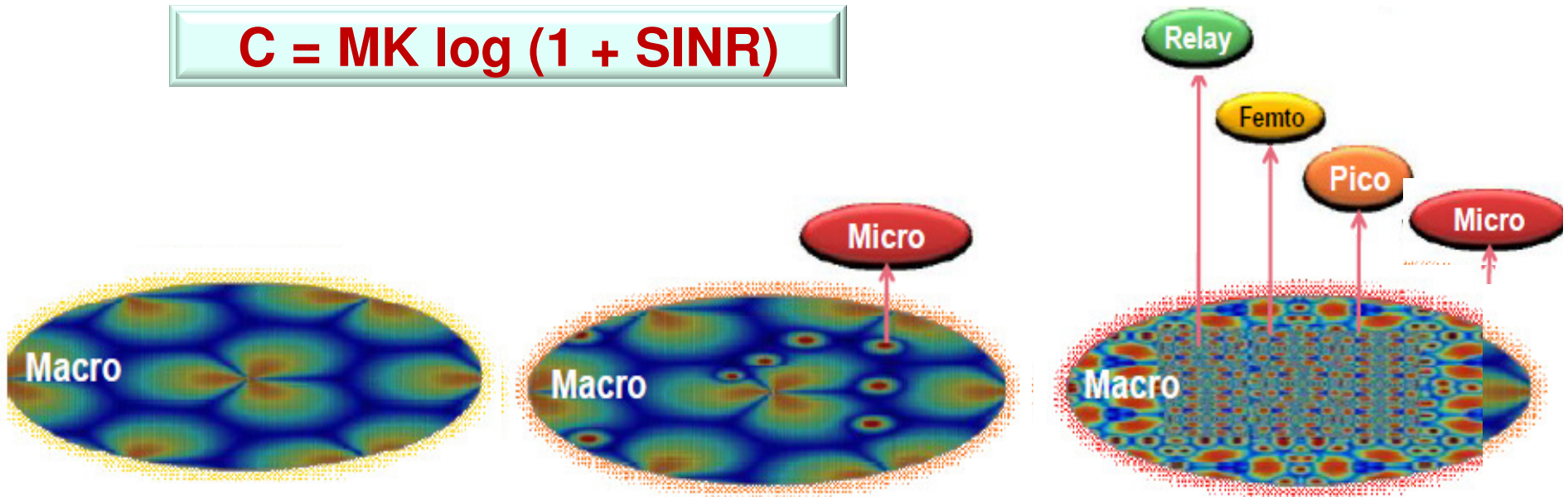
- Concentration of mobile data traffic in hot spots
 - Traditionally the wireless network sees un-evenly distributed traffic
 - 10% of network carries 35% of data traffic
- Ways to increase the capacity
 - Spectrum efficiency, MIMO, Spectrum, Cell splitting, HetNet



Why HetNets: Capacity

- **Heterogeneous Networks Capacity:** scales with number of lower tier cells

$$C = MK \log (1 + \text{SINR})$$



- M = number of antennae, ~ 4 to 8 maximum
- K = number of small cells, can be $\gg 100$
- Capacity is limited by interference



Why HetNets: Capacity

Scenarios/interference mitigation scheme		SINR degradation of 50% outdoor user (dB)	Outage ^a (%)		50% user rate (Mb/s)		Center cell throughput (Mb/s)
			Outdoor	Indoor	Outdoor	Indoor	
Macro-only (no FAP)			25.79	42.15	0.062	0.031	258.19
Fixed power level		4.77	53.63	0.29	0	24.99	45119.81 (~175x)
Power control	Femto-user QoS	0.39	28.57	0.06	0.076	3.57	7058.54 (~27x)
	Macro-user QoS	0.96	31.52	3.83	0.063	14.28	32168.10 (~125x)
Frequency planning	Separate channels for MBS & FAP (50% each)		25.79	0.06	0.046	21.42	26399.97 (~102x)
	Femto-free zone. (FFZ ratio = 27.25%)		25.79	0.12	0.064	18.18	32928.61 (~128x)

^a For data, outage is defined as SINR < -0.8 dB (SE = 0.5)

^b Results are derived from the same simulation methodology described in [7].

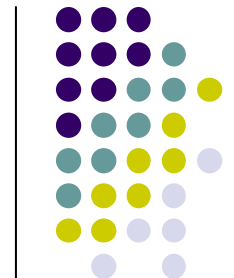
Table 1. Performance of femtocell overlay networks (max FAP Tx power: 10 dBm, 50 FAPs/sector ~231 FAPs/km²).

Source: S. Yeh et al, "Capacity and Coverage Enhancement in Heterogeneous Networks", IEEE Comm Magazine, June 2011

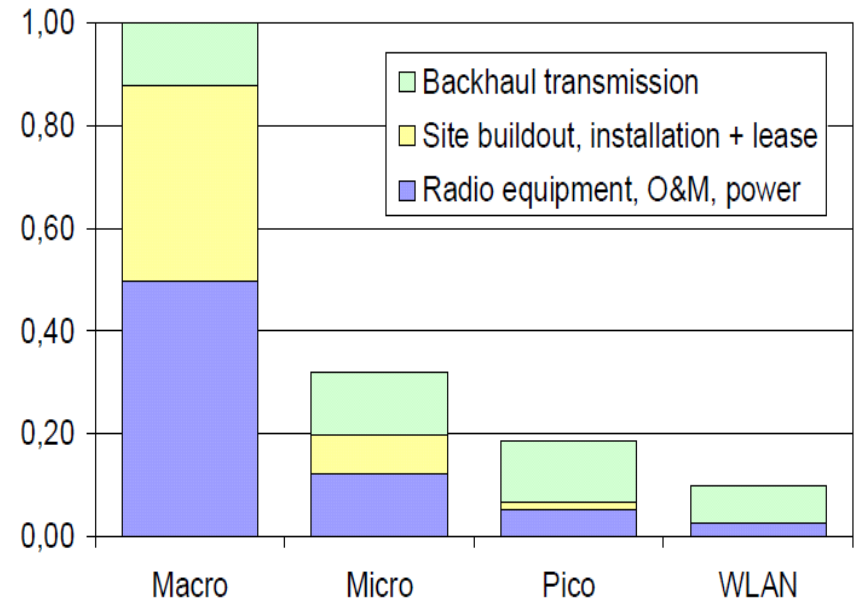
Why HetNets: Cost

Cost structure of smaller cells (pico and femto) is more favorable

- Small range: lower power consumption at infrastructure, longer battery life for user, lower cost
- Limited functionality: support few users
- Can take advantage of unlicensed (free) spectrum
- Can be deployed easily by user (no site acquisition cost)
- Backhaul cost can be passed to user (in-home)



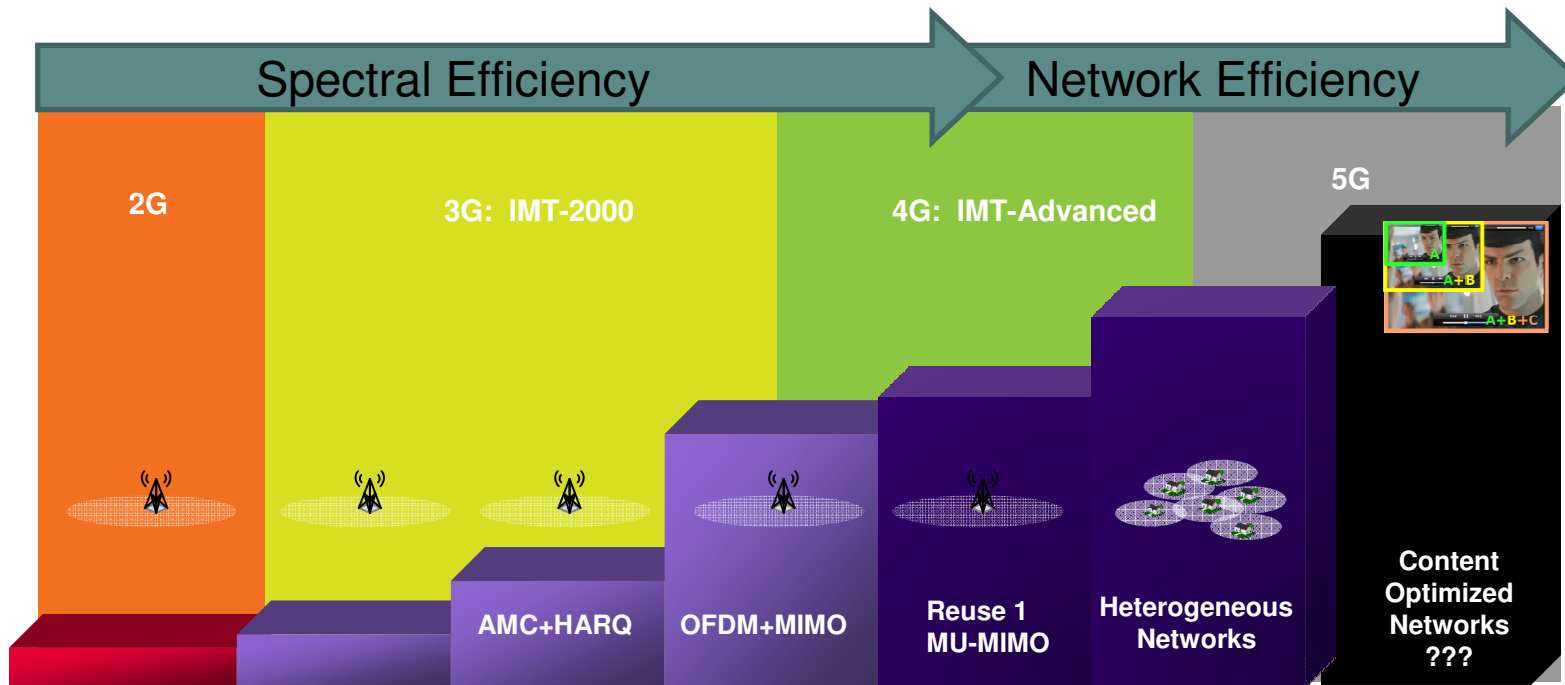
Cost structure CAPEX+OPEX (new sites)



Source: Johansson et al, 'A Methodology for Estimating Cost and Performance of Heterogeneous Wireless Access Networks', PIMRC'07.

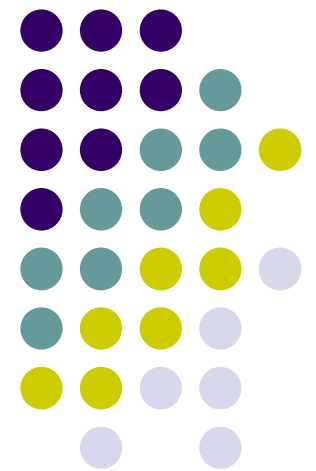
Significant potential savings in **cost per bit** with HetNets

Shift from Spectral Efficiency to Network Efficiency

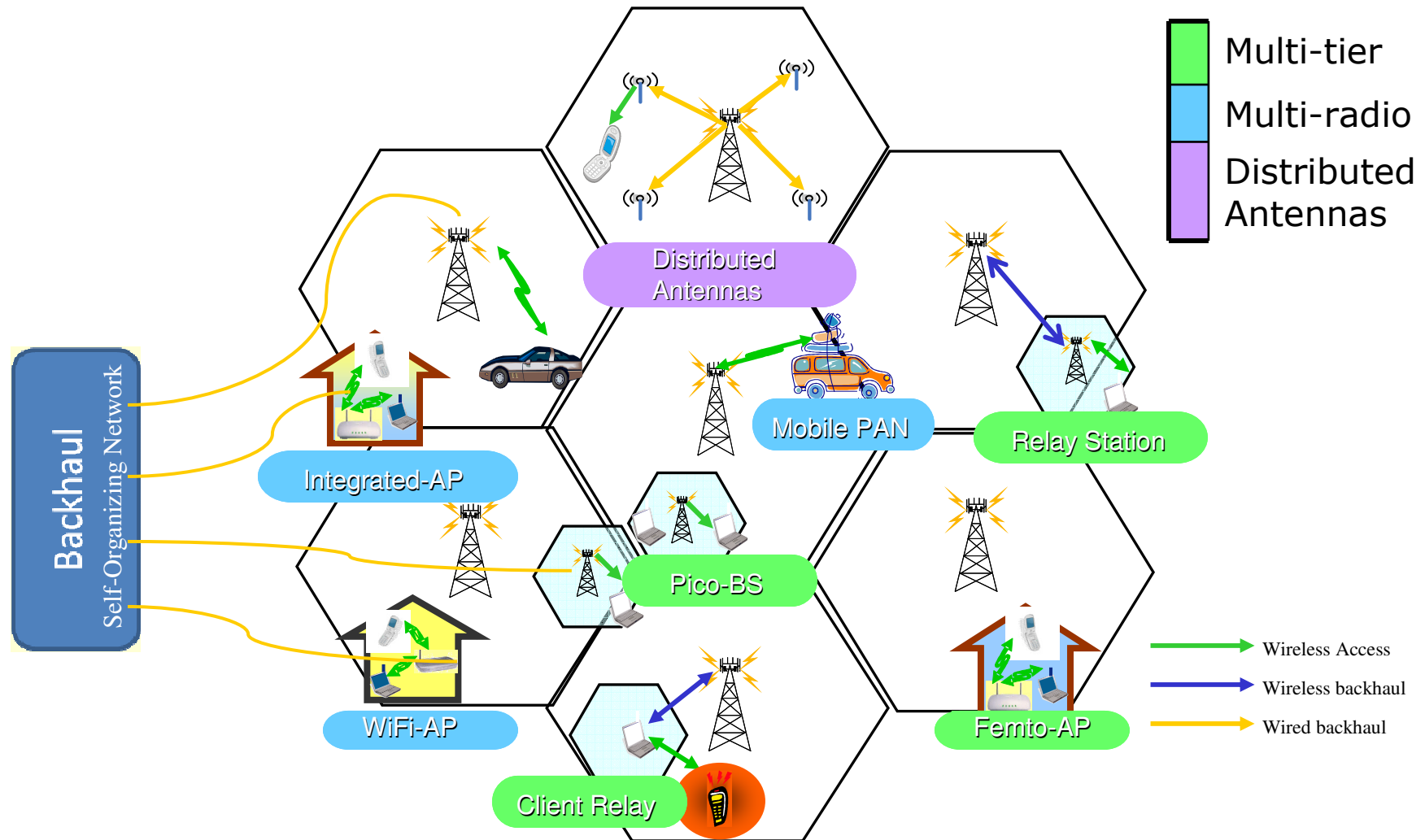


- 4G networks have nearly achieved system capacity limits (MIMO, universal frequency reuse, multi-user scheduling)
- Focus of wireless industry shifting to network efficiency (areal capacity)
- Future networks will improve network efficiency in two ways:
 - Continue to Improve efficiency of access network (interference management , co-operative RAN's)
 - Improve efficiency of transmitted information (content aware networks, QOE)

What is HetNet?



What is HetNet?

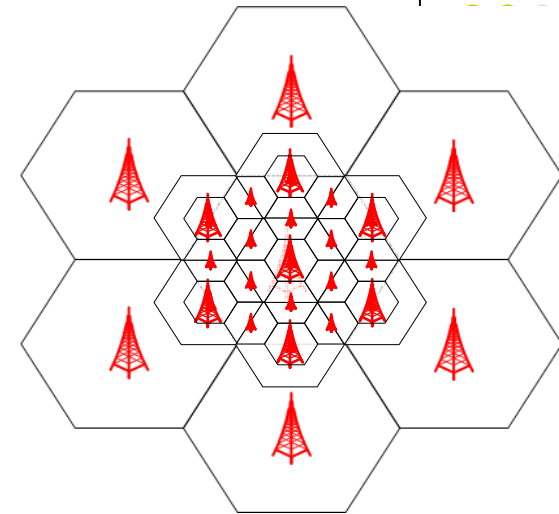


Heterogeneous Network (HetNet): A network that consists of a mix of macro cells and low-power nodes, e.g. Pico, Femto, Relay Node (RN) and Remote Radio Head (RRH)

Topology Elements/Nodes



- Overlay low power low cost network devices in same coverage area as macro-cell
 - Single radio (shared spectrum, aggregation)
 - Multi-Radio (leverage unlicensed spectrum)
- Large macro-cells provide mobility, while small cells boost coverage and capacity
- Devices are deployed opportunistically, where needed
 - Coverage holes, range extension
 - Capacity demanding hotspots
 - Indoor coverage
- Capacity gain from spatial reuse and improved link reliability as serving device is brought closer
- Heterogeneous nodes interface to a self-organizing network, that manages communication between small cells, and macro



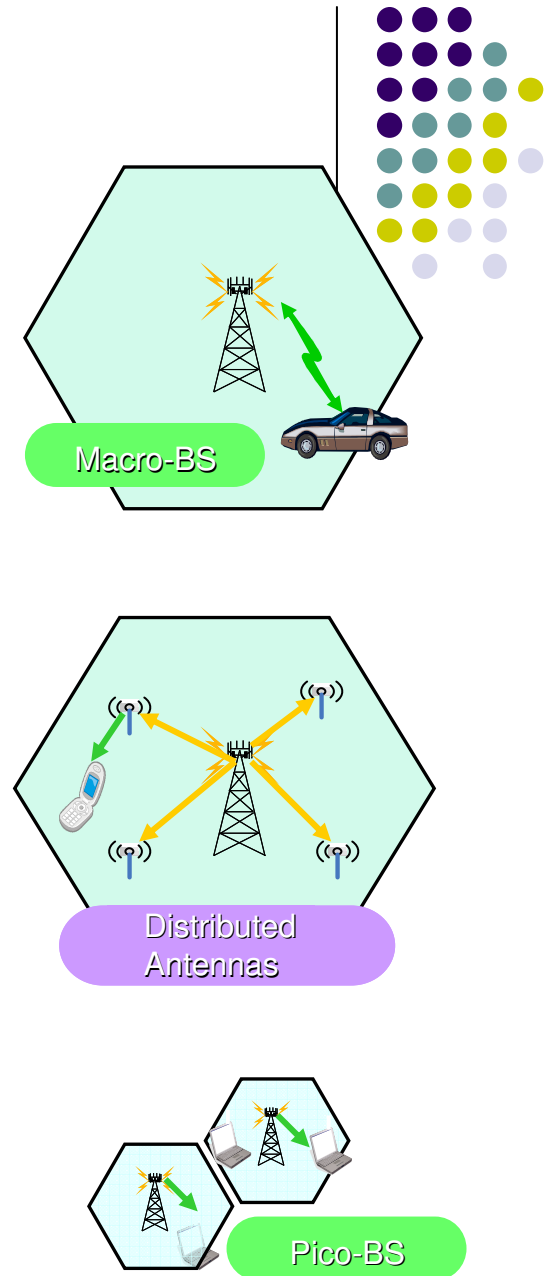
Hierarchical Cells



New Network Elements

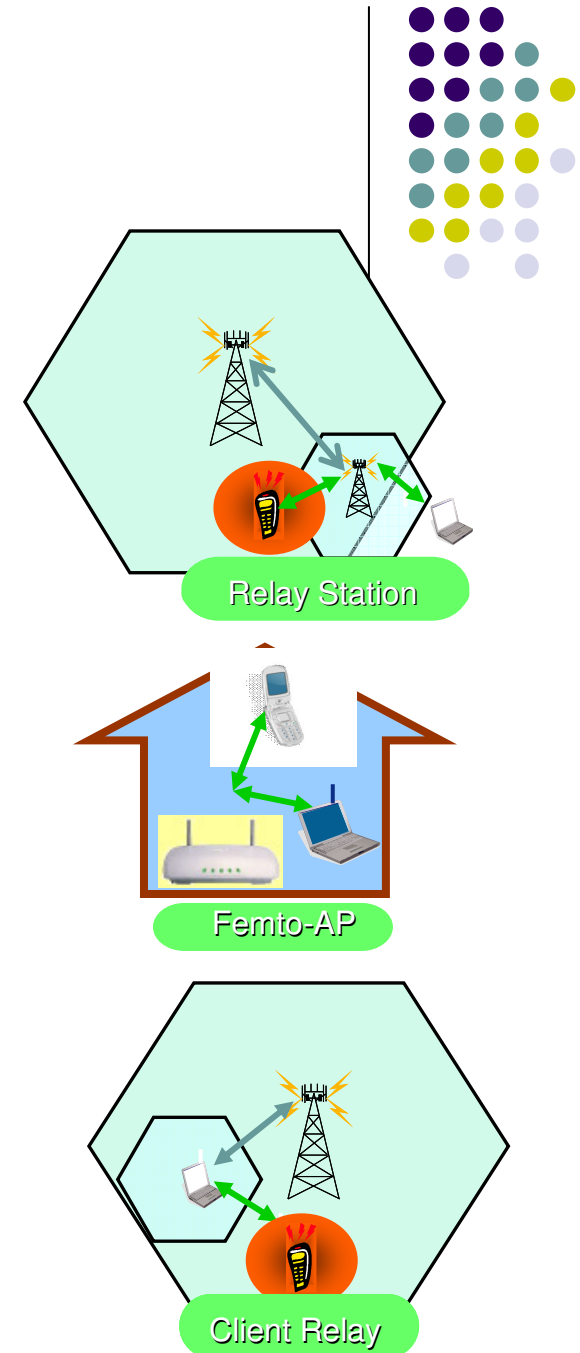
Tiers - by footprint

- Macro/micro cells
 - Provide wide-area cellular coverage
 - Typically > 500m inter-site distance
 - Support high mobility users, minimizing handover frequency
- Distributed Antennas
 - Create small virtual cells by distributing antennas of macro BS across entire cell
 - Each antenna typically has LOS to user, hence improved coverage & link reliability
 - Antennas are connected to a common processing unit via fiber
- Pico cells
 - Provide hotspot coverage in malls, airports, stadiums, high user rates
 - Typically, 100 - 300m inter-site distance
 - Access is open to all cellular users
 - Operator deployed and managed (small BS)



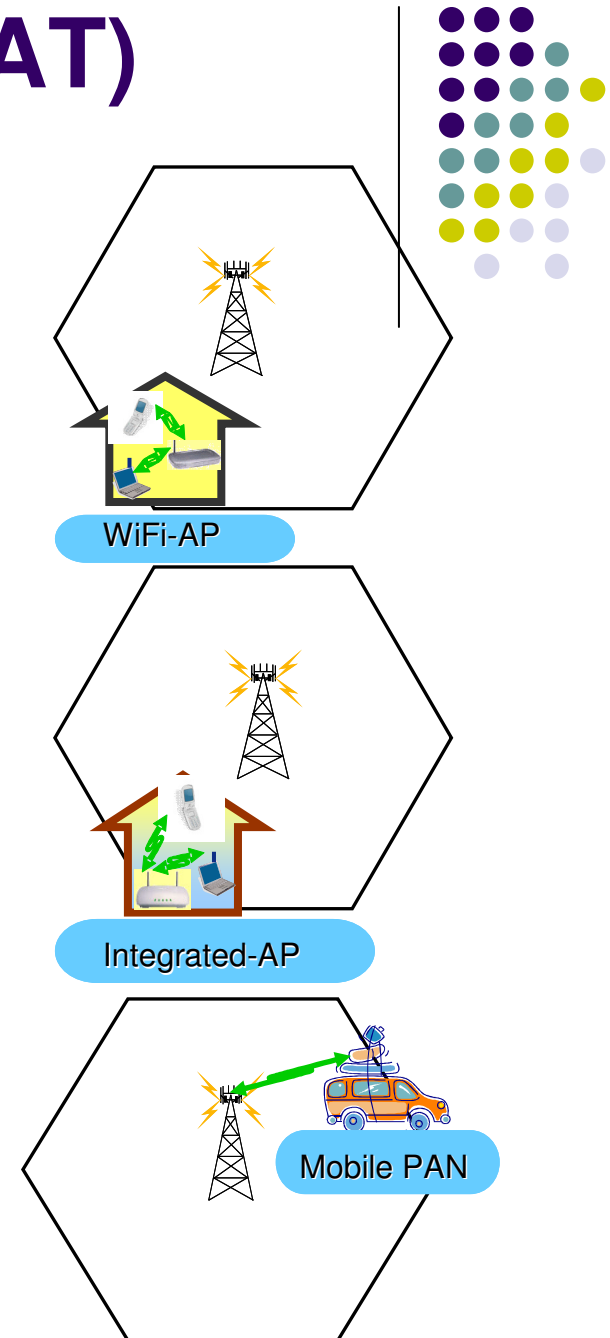
Tiers - by footprint (2)

- Relays
 - Provide coverage enhancement, range extension
 - Similar footprint as Pico cells
 - Backhaul is wireless, using operator's spectrum
 - Better flexibility in deployment, but lowers access bandwidth
- Femtocells
 - Provide in-building coverage
 - Typically serve < 100m radius, similar to WiFi
 - Access can be closed for residential users
 - Utilize subscriber backhaul, install
- Client Relays
 - Improve coverage & short-range link quality
 - Smallest tier, typically < 30m
 - Better flexibility in deployment, but lowers access bandwidth

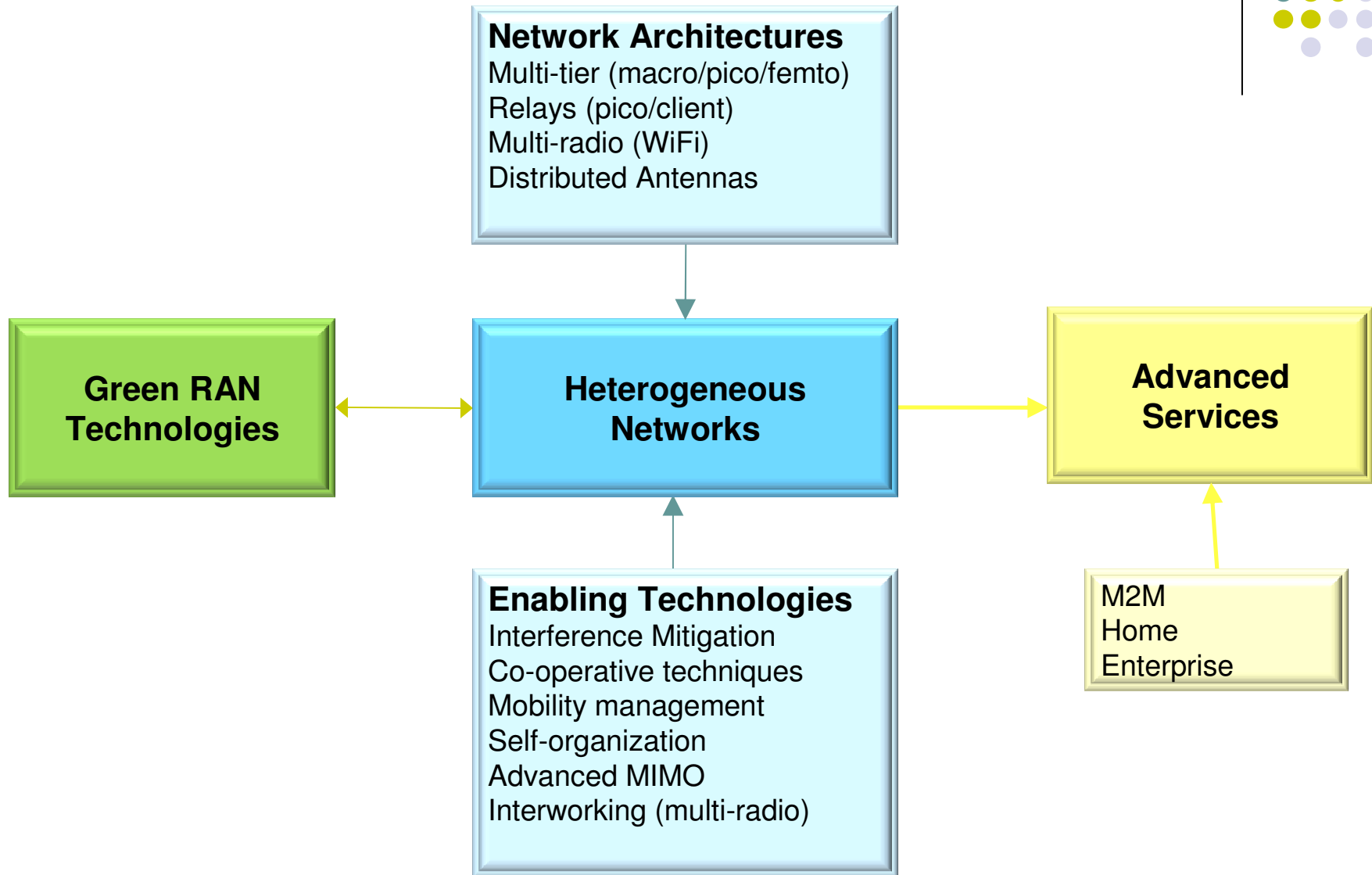


Tiers - by footprint (Multi-RAT)

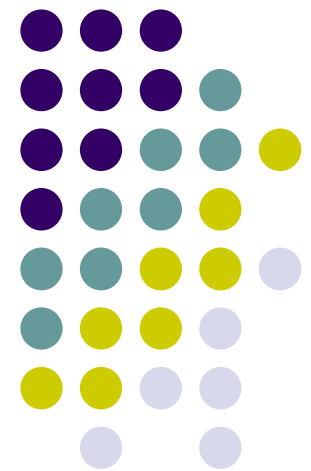
- WiFi Access Points
 - Offload traffic from macro-cells in fixed, hotspot settings
 - Similar footprint as femtocells, unlicensed bands
 - Operator controls WiFi network
- Integrated Access Points
 - Synergistic use of licensed and unlicensed spectrum in single device
 - Improve network capacity by carrier aggregation (WiFi is virtual carrier)
 - Improve user QoS by dynamic switching between RAT's
- Mobile Hotspots
 - Connect non-cellular devices within short range to the cellular network
 - Create a virtual WiFi hotspot
 - Devices have WAN and LAN/PAN capability



HetNets - in Perspective



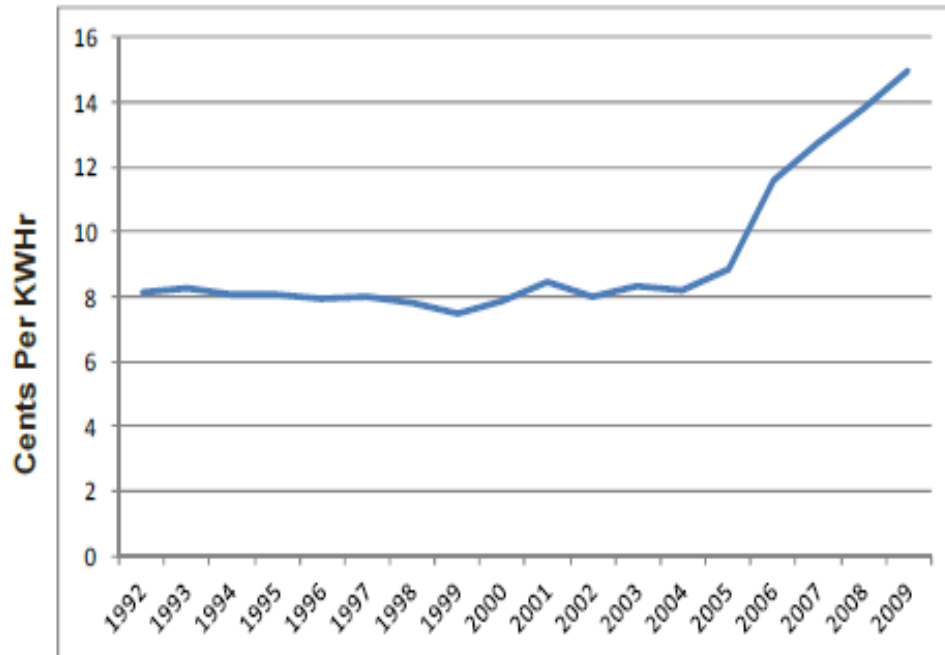
Green Hetnet





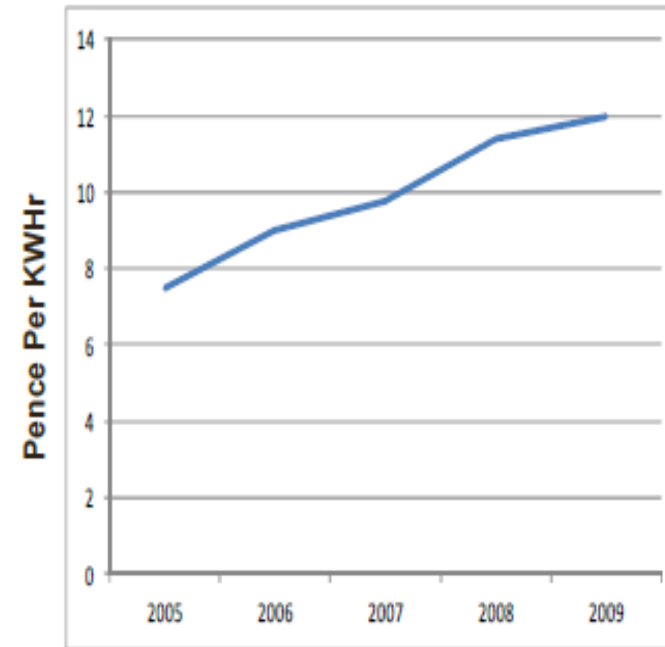
KWHR Cost of Electricity

New England Electricity Cost



Source: US Energy Information Administration

UK Electricity Cost



Source: UK House of Commons

The Last Five Years has Experienced Growth in Energy Cost Worldwide



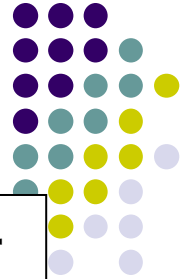
Why Green Radio?

Operator & Manufacturer Perspective

- Increasing energy costs with higher base station site density and energy price trends
 - A typical UK mobile network consumes 40MW
 - Overall this is a small % of total UK energy consumption, but with huge potential to save energy in other industries
 - Energy cost and grid availability limit growth in emerging markets (high costs for diesel generators)
- Corporate Responsibility targets set to reduce carbon emissions and environmental impacts of networks
 - Vodafone¹ - “Group target to reduce CO₂ emissions by 50% by 2020, from 2006/07 levels”
 - Orange²: “Reduce our greenhouse emissions per customer by 20% between 2006 and 2020”

1. http://www.vodafone.com/etc/medialib/attachments/cr_downloads.Par.25114.File.tmp/CR%20REPORT_UKFINAL%20ONLINE_180908_V6.pdf

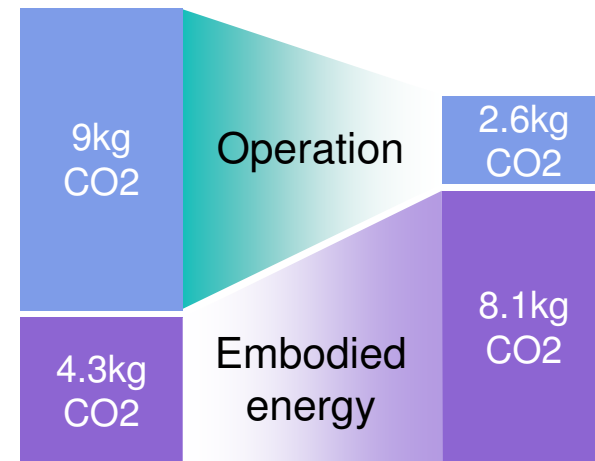
2. http://www.orange.com/en_EN/tools/boxes/documents/att00005072/CSR_report_2007.pdf



Where is the Energy Used?

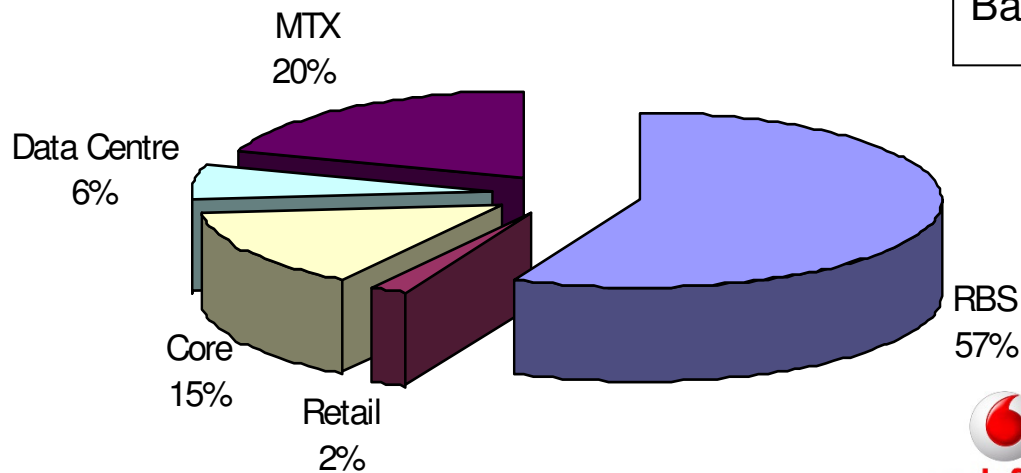
- For the operator, 57% of electricity use is in radio access
- Operating electricity is the dominant energy requirement at base stations
- For user devices, most of the energy used is due to manufacturing

CO2 emissions per subscriber per year³



Base station

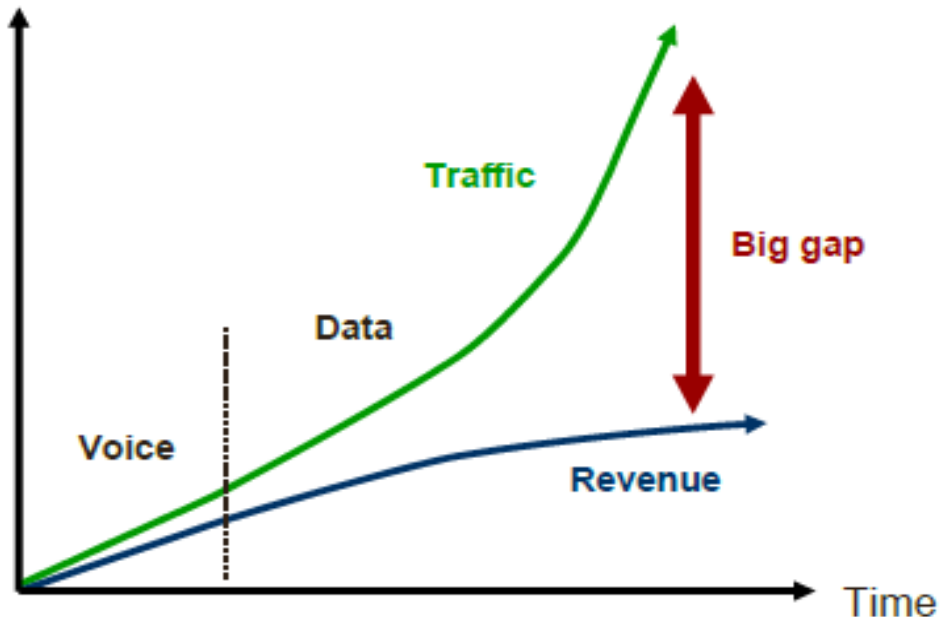
Mobile



3. Tomas Edler, Green Base Stations – How to Minimize CO2 Emission in Operator Networks, Ericsson, Bath Base Station Conference 2008



Green Radio – A Key Enabler



Trend

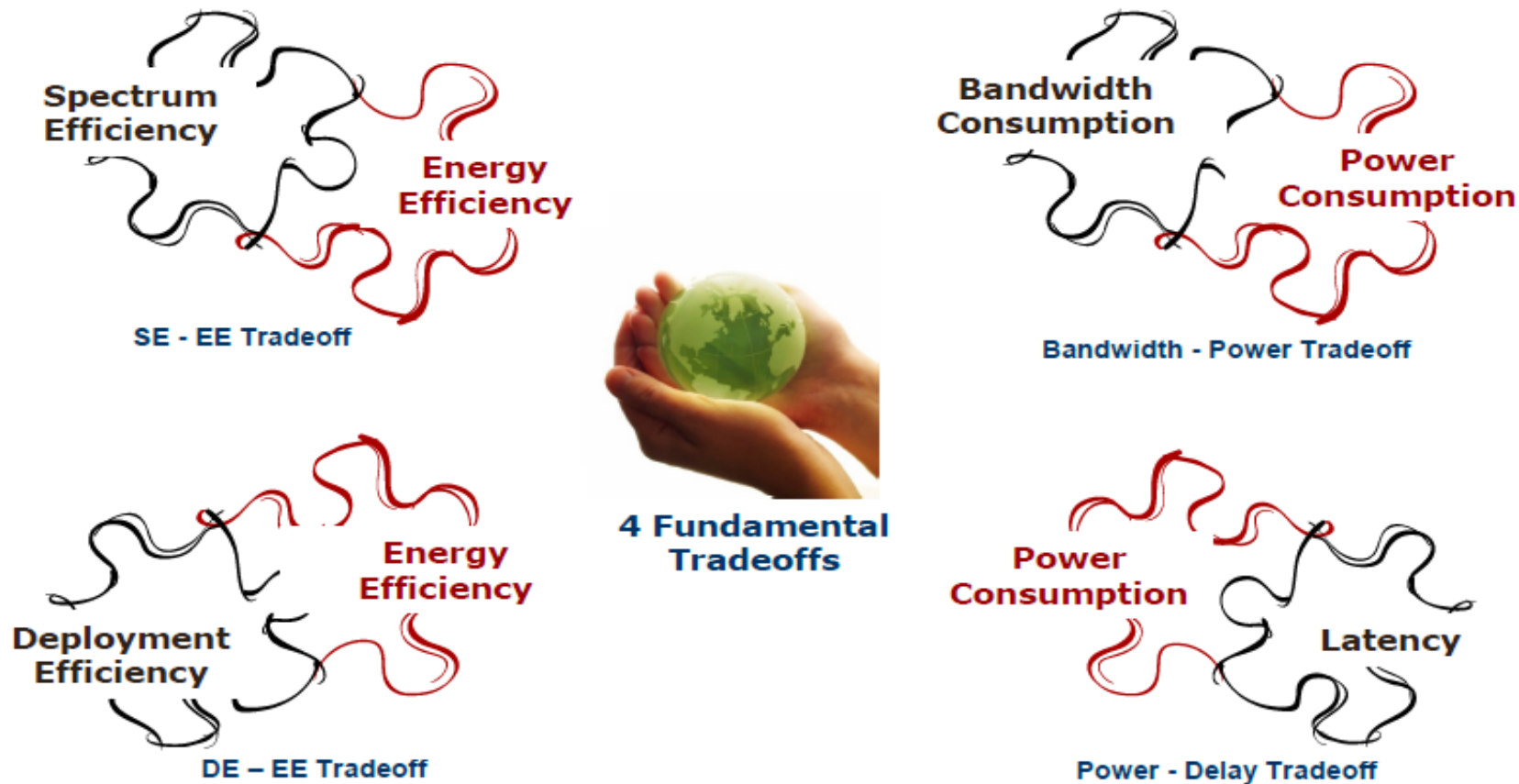
- Exponential growth in data traffic
- Number of base stations/area increasing for higher capacity
- Revenue growth constrained and dependent on new services
- Carriers under pressure to dramatically reduce TCO and energy bill

- Consequences
 - Energy use cannot follow traffic growth without significant increase in energy consumption -> must reduce Energy Per Bit
 - Number of base stations increasing -> must reduce Operating Power cell to save TCO



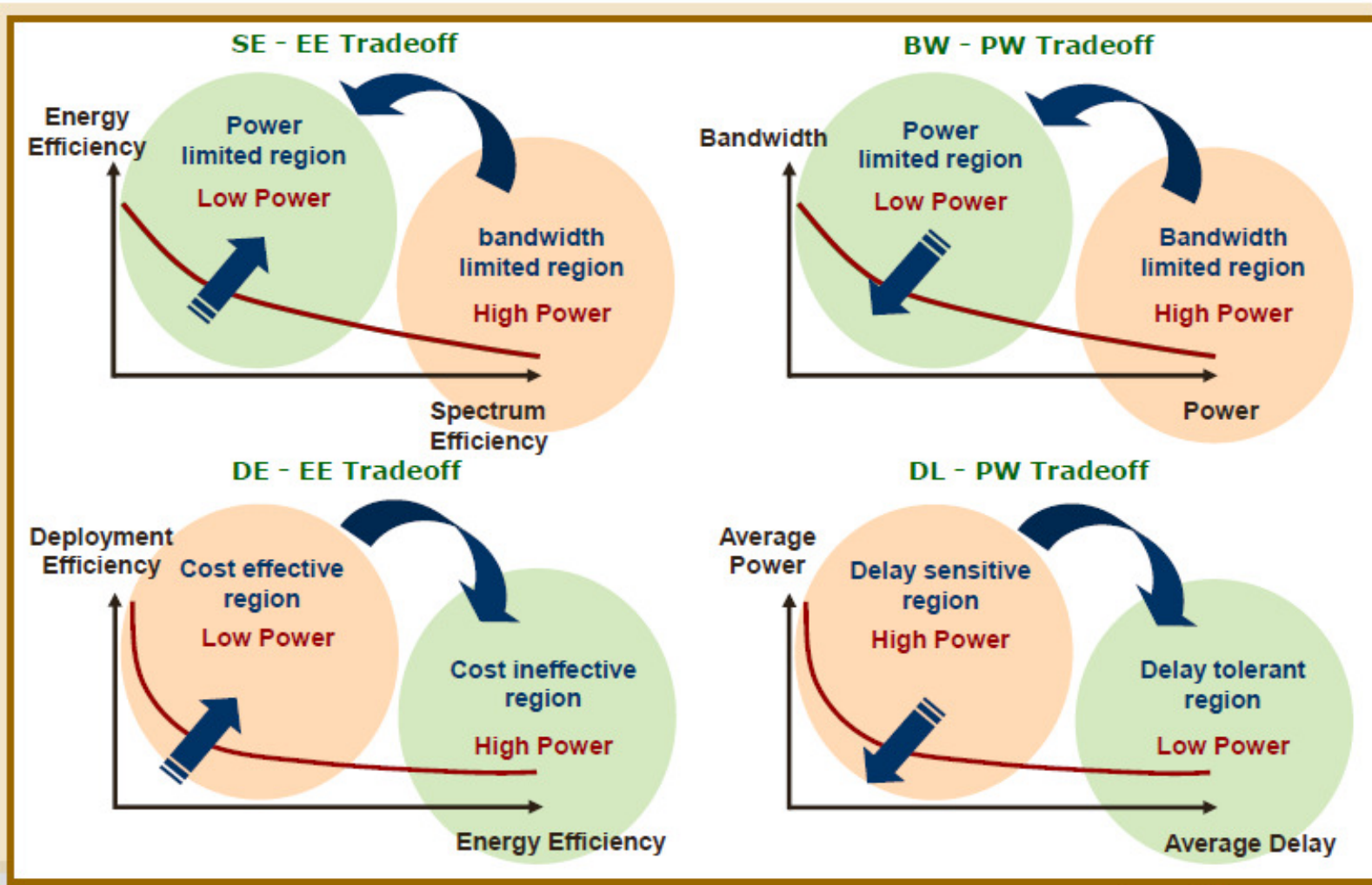


Fundamental tradeoffs in green radio



G. Y. Li, Z.-K. Xu, C. Xiong, C.-Y. Yang, S.-Q. Zhang, Y. Chen, and S.-G. Xu, "Energy-efficient wireless communications: tutorial, survey, and open issues," to appear in *IEEE Wireless Communications Magazine*

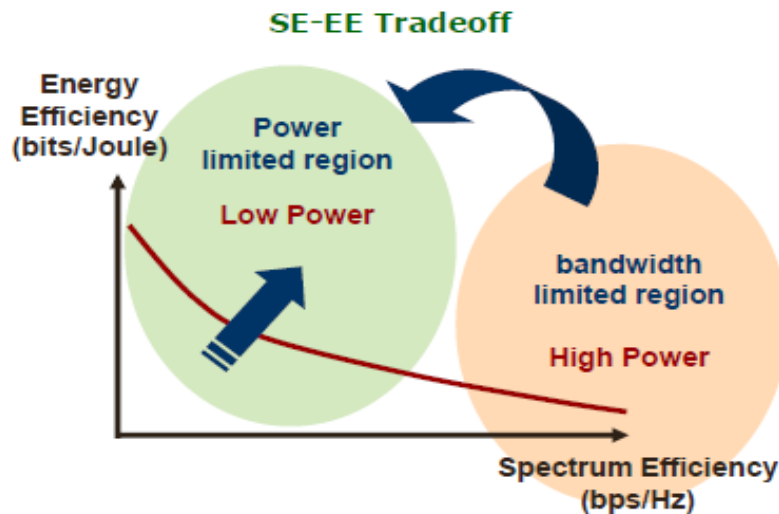
Insight from information theory



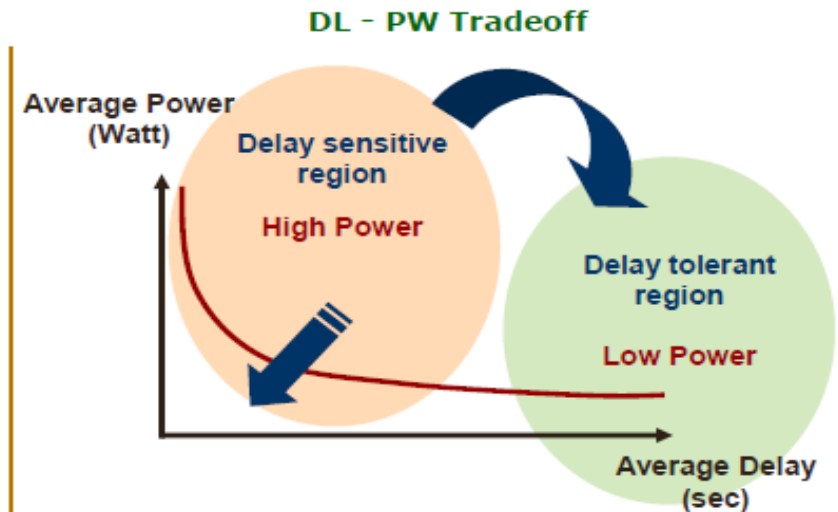
G. Y. Li, Z.-K. Xu, C. Xiong, C.-Y. Yang, S.-Q. Zhang, Y. Chen, and S.-G. Xu, "Energy-efficient wireless communications: tutorial, survey, and open issues," *to appear in IEEE Wireless Communications Magazine*



Fundamental Tradeoffs



- **Expanding** the channel bandwidth at given rate requirement (i.e., trading bandwidth for power) ;
- **Reducing** the transmission rate at given bandwidth (i.e. trading rate for power)
- **Developing** novel radio transmission technologies and architectures to push the tradeoff curve outwards (i.e. improving spectrum efficiency and energy efficiency simultaneously).



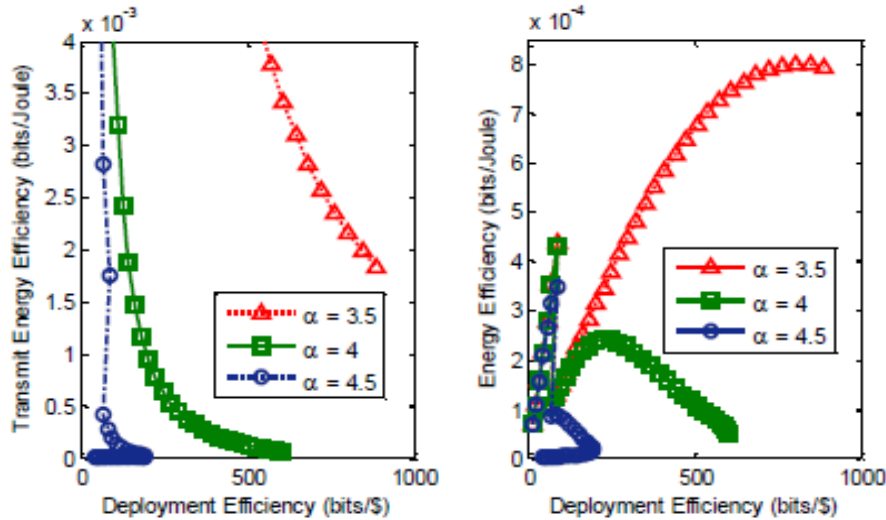
- **Prolonging** the service/transmission time but without deviating the user's QoS requirement by developing novel resource management and scheduling algorithms (i.e., trading delay for power) ;
- **Developing** novel radio transmission technologies and architectures to make the service more efficient (i.e. reducing energy consumption and reducing delay simultaneously).

G. Y. Li, Z.-K. Xu, C. Xiong, C.-Y. Yang, S.-Q. Zhang, Y. Chen, and S.-G. Xu, "Energy-efficient wireless communications: tutorial, survey, and open issues," to appear in *IEEE Wireless Communications Magazine*



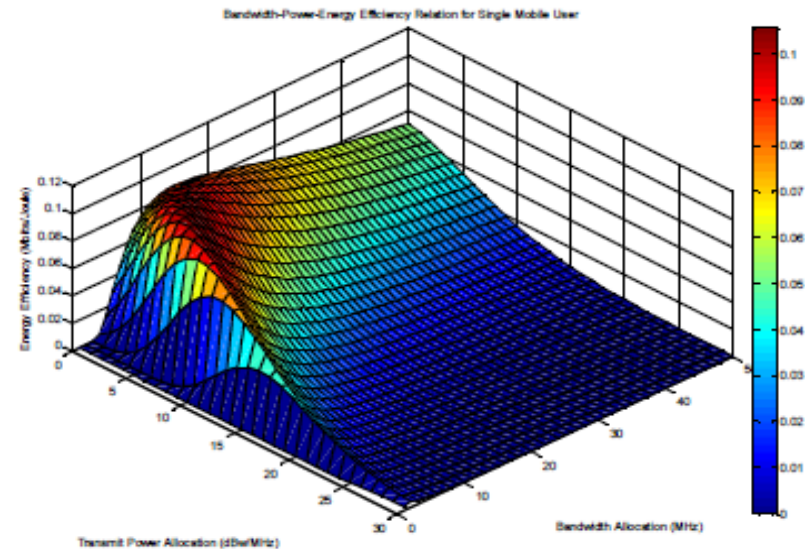
In Practice

Example of DE-EE Curves under practical constraints



- ◆ Only Tx power considered, the tradeoff curve matches our intuition
- ◆ Static power and circuit power also considered, the tradeoff curve deviates our intuition
- ◆ Be careful when embracing smaller cells

Example of BW-PW-EE Curves under practical constraints



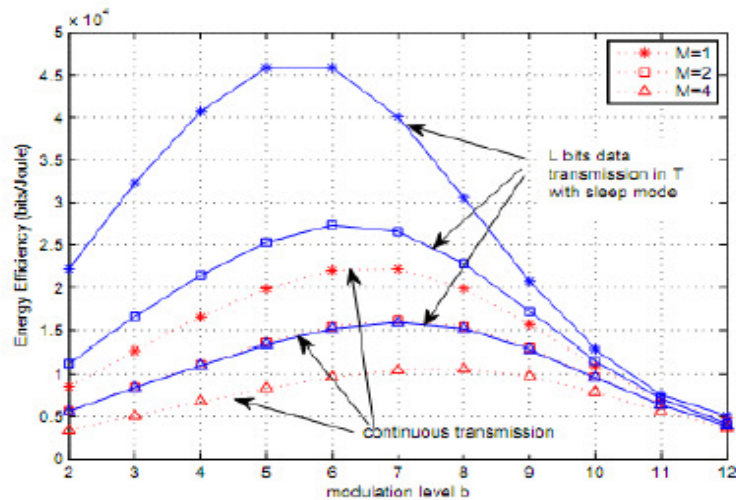
- ◆ Full utilization of bandwidth-power resource may not be most energy efficient
- ◆ Given target EE, the BW-PW tradeoff relation is not monotonic

G. Y. Li, Z.-K. Xu, C. Xiong, C.-Y. Yang, S.-Q. Zhang, Y. Chen, and S.-G. Xu, "Energy-efficient wireless communications: tutorial, survey, and open issues," to appear in *IEEE Wireless Communications Magazine*



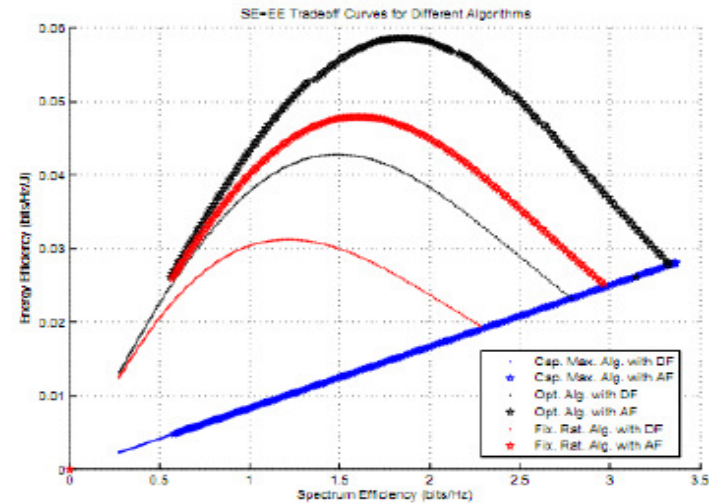
In Practice

Example of DE-EE Curves under practical constraints



- ◆ The SE-EE curve under practical power model is no longer monotonic
- ◆ Sleep mode helps reduce circuit power
- ◆ Given the traditional way of RF architecture, increasing antenna does not always help increase EE

Example of SE-EE Tradeoff in single relay system under practice constraints

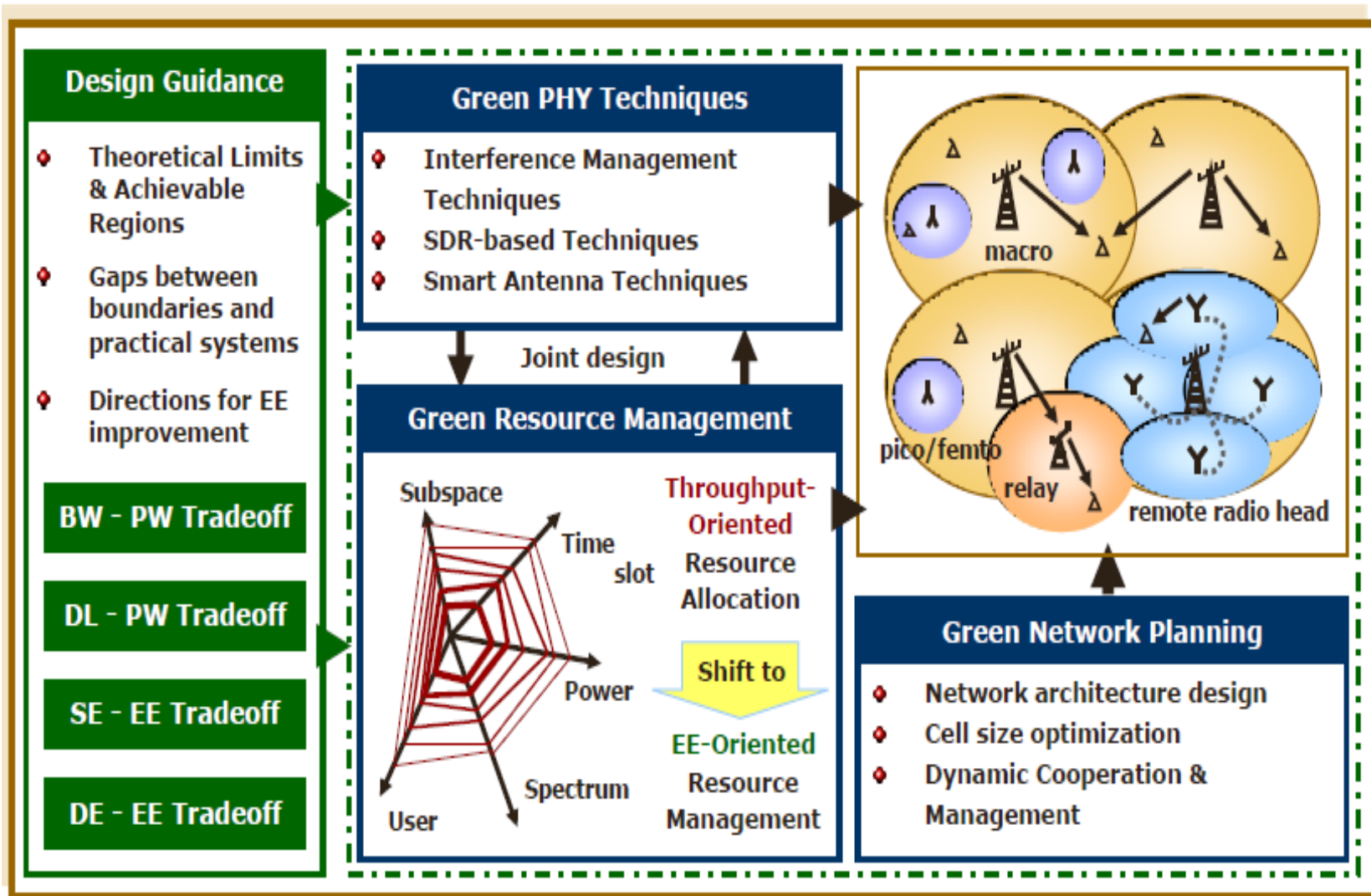


- ◆ When circuit power for both source and relay are considered, the SE-EE curve is no longer monotonic
- ◆ Optimized resource allocation between source and relay always helps increase EE

G. Y. Li, Z.-K. Xu, C. Xiong, C.-Y. Yang, S.-Q. Zhang, Y. Chen, and S.-G. Xu, "Energy-efficient wireless communications: tutorial, survey, and open issues," *to appear in IEEE Wireless Communications Magazine*



Fundamental framework



Distributed Antenna System



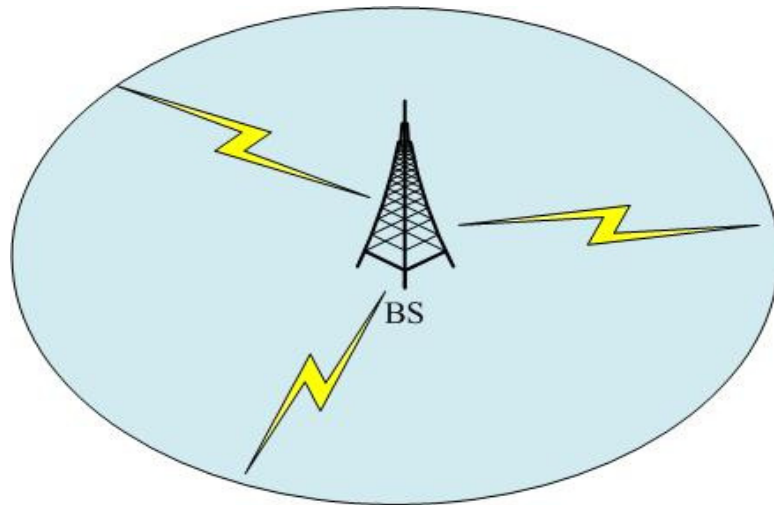
❖ Definition

- A network of spatially separated antennas called “nodes” connected to a common source via a transport medium that provides wireless service within a geographic area or structure [wikipedia.com]

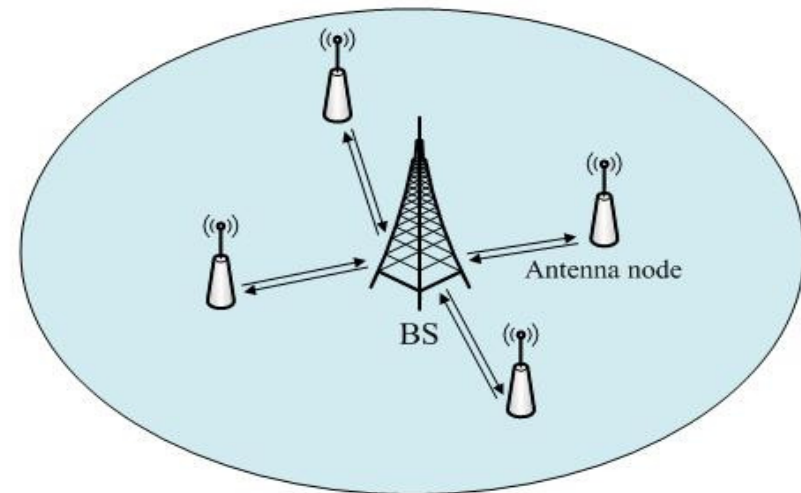
❖ Once deployed, multiple-airlink/frequency/WSP* can be supported

- Remote Radio Head (RRH) supporting single airlink/frequency/WSP* has evolved into antenna node in DAS.

*WSP: Wireless Service Provider



Centralized Antenna System (CAS)

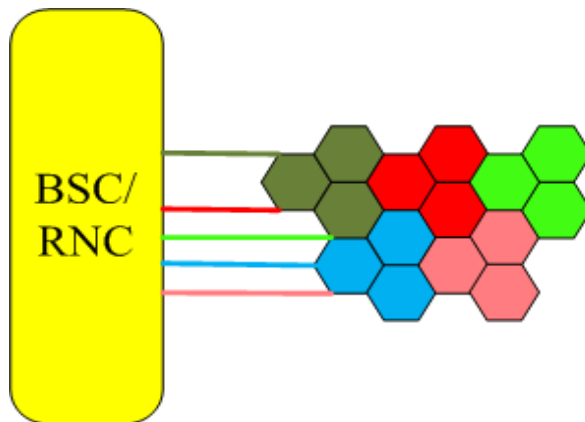


Distributed Antenna System (DAS)

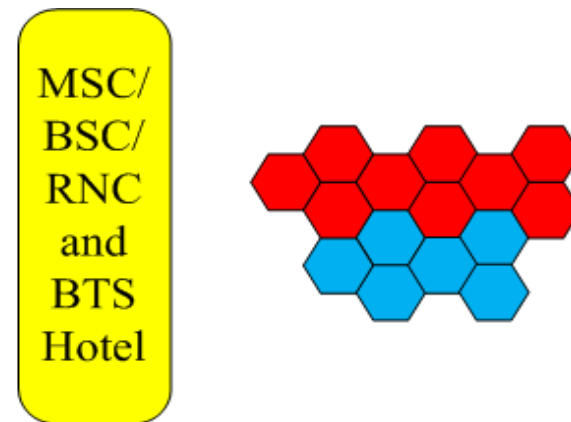


Benefits of DAS

- ❖ In DAS, the RF is taken from a base station and moved to distributed locations.
 - Radio resources can be placed in a single location.
 - Minimizing real estate
 - Simplifying management & maintenance
 - Smart solution overcoming the lack of backhaul capacity between cell cities and mobile switching center (MSC) for the growing traffic
 - Thanks to the increased backhaul capacity, DAS can facilitate advanced multi-BS cooperation techniques such as network MIMO techniques.



Traditional RAN Architecture
(Three Sector Cell Sites)

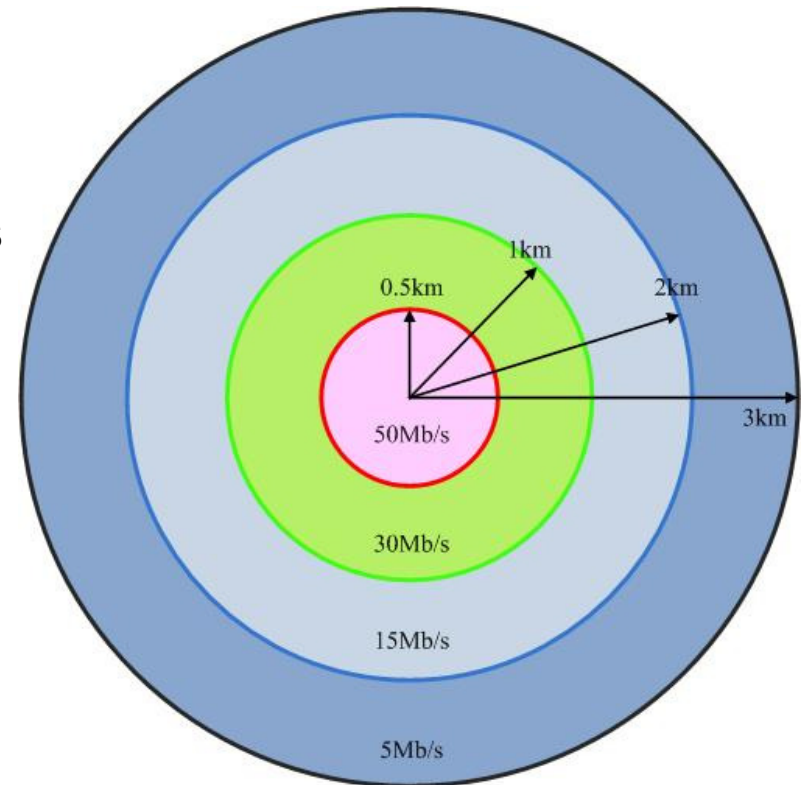


Small Cell RAN Architecture with BTS
Hotel and DAS
(Each Hexagon is a Cell Site)



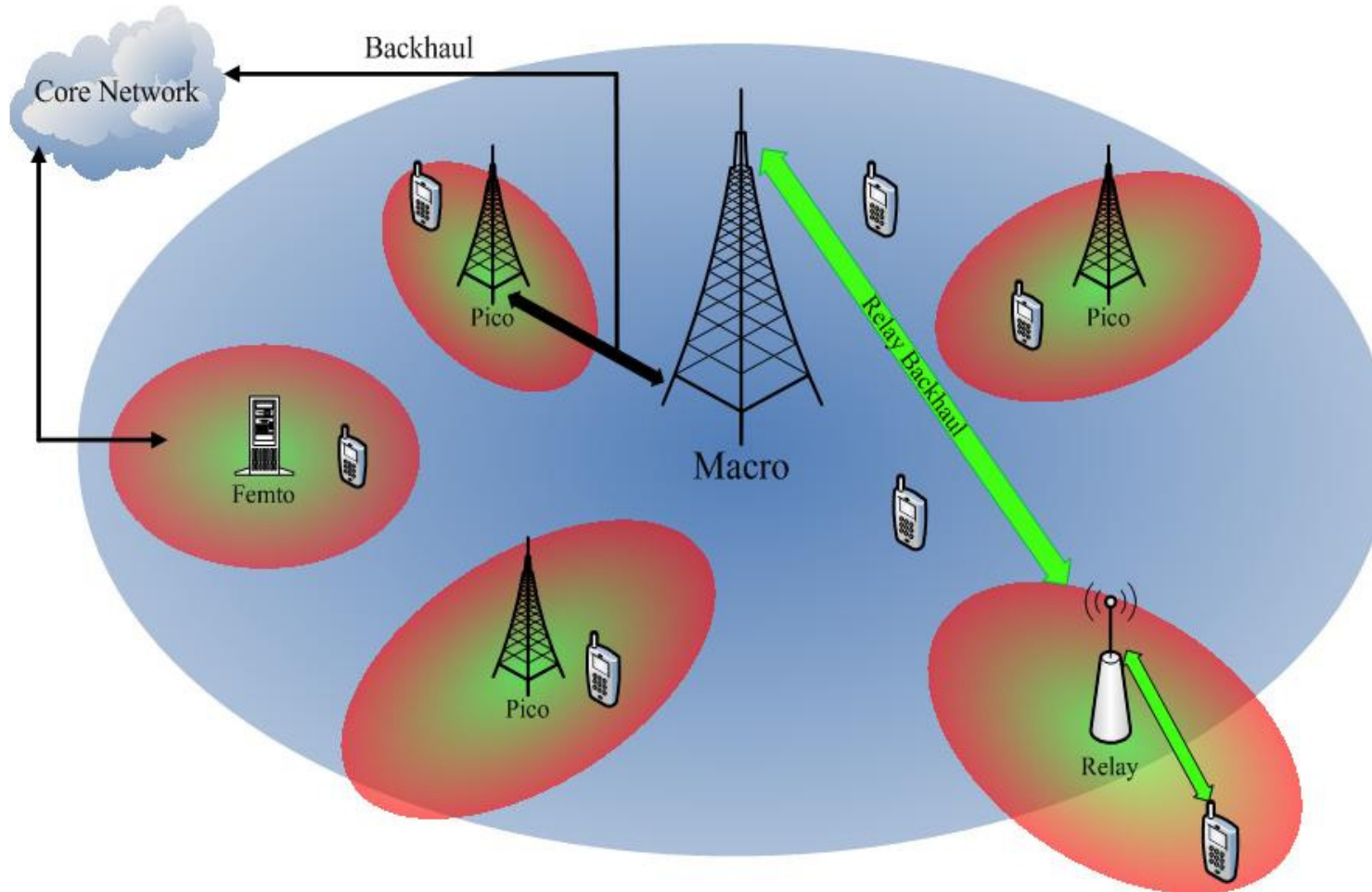
Macrocell Deployment Issues

- Data rates drop as cell size increases
 - LTE is path-loss adaptive
 - Propagation distance and shadowing
 - Building walls (15 dB loss)
 - LTE leverages high frequency bands
 - More spectrum available
 - High Throughput requires small cells
- Macrocell Site
 - Per site can cost \$250K
 - Maybe difficult to get a site (e.g., Gov. regulations)
- Maintenance
 - Tower top electronics
 - Feature upgrades

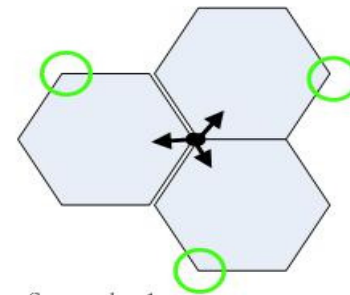
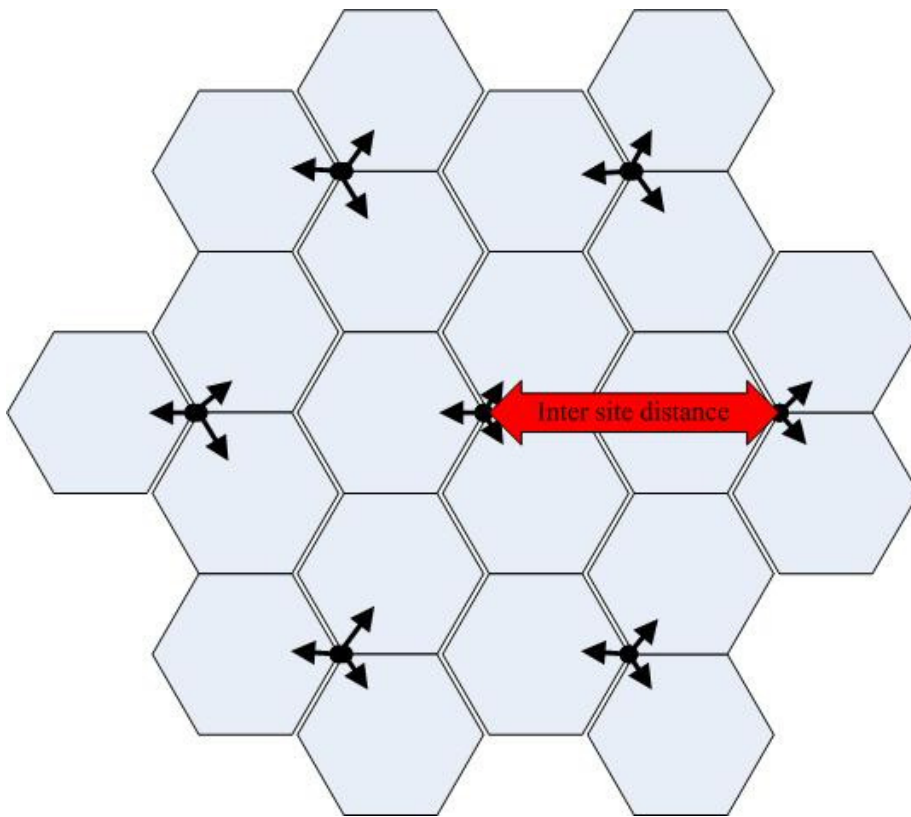




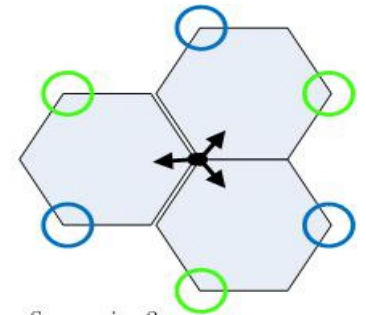
Alternative Deployment Scenarios- Beyond basic Macrocells



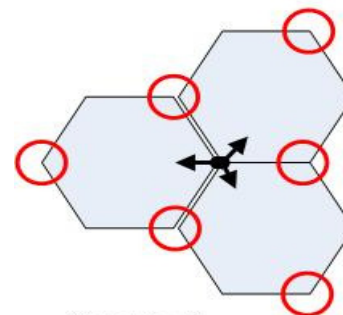
Hetnet deployment scenarios



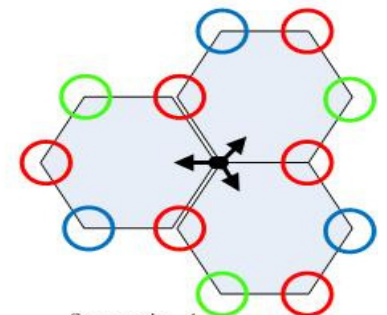
Scenario 1
1 micro cell per macro site



Scenario 2
2 micro cells per macro site



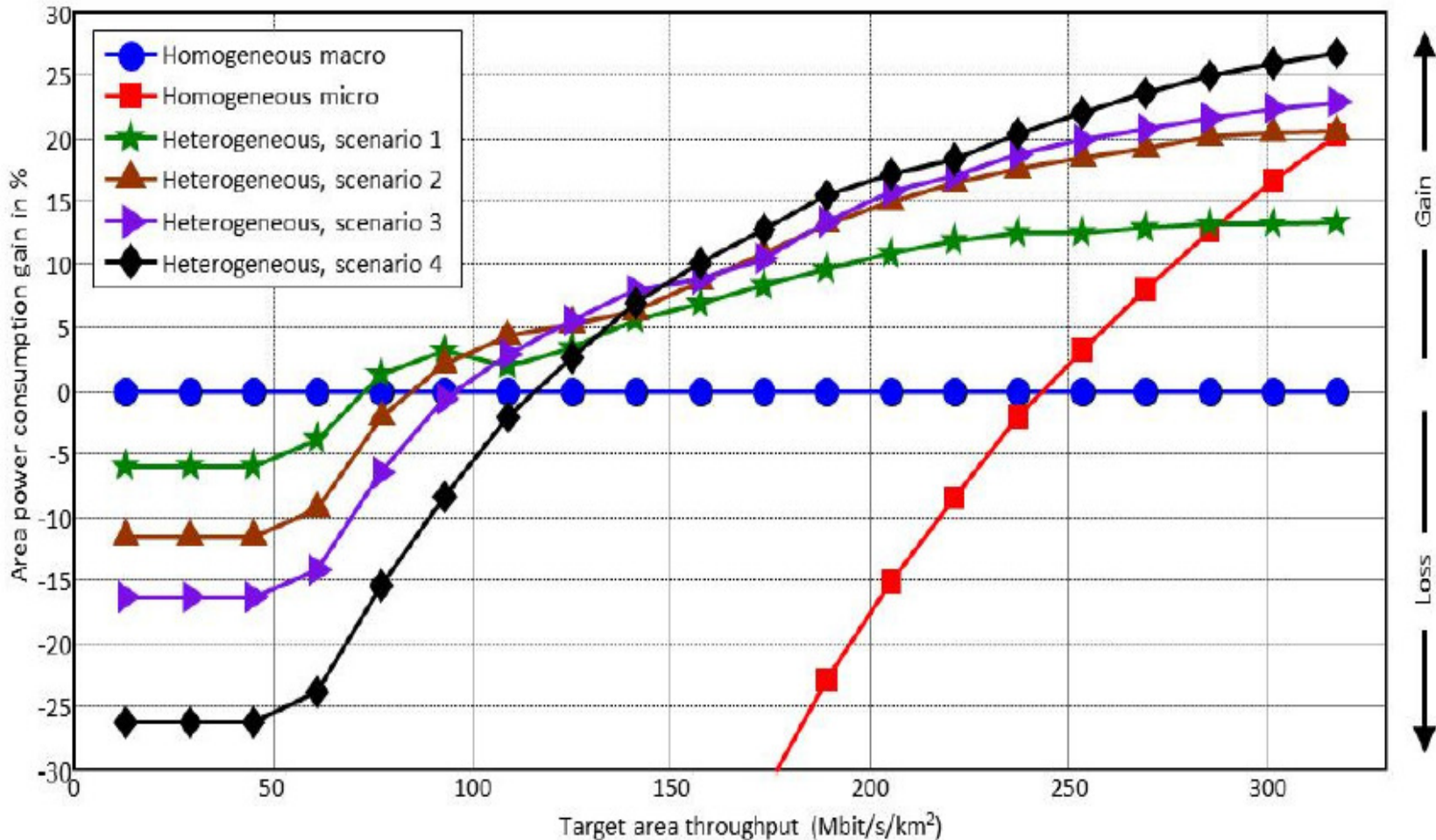
Scenario 3
3 micro cells per macro site



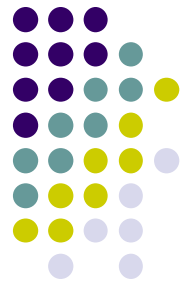
Scenario 4
5 micro cells per macro site

“Green Promising Tracks of Green Network Technologies”, EARTH project delivery by ALUD, EAB, DOCOMO, TI, ETH, CEA, UNIS, TUD, IST-TUL, UOULU, BME, TTI

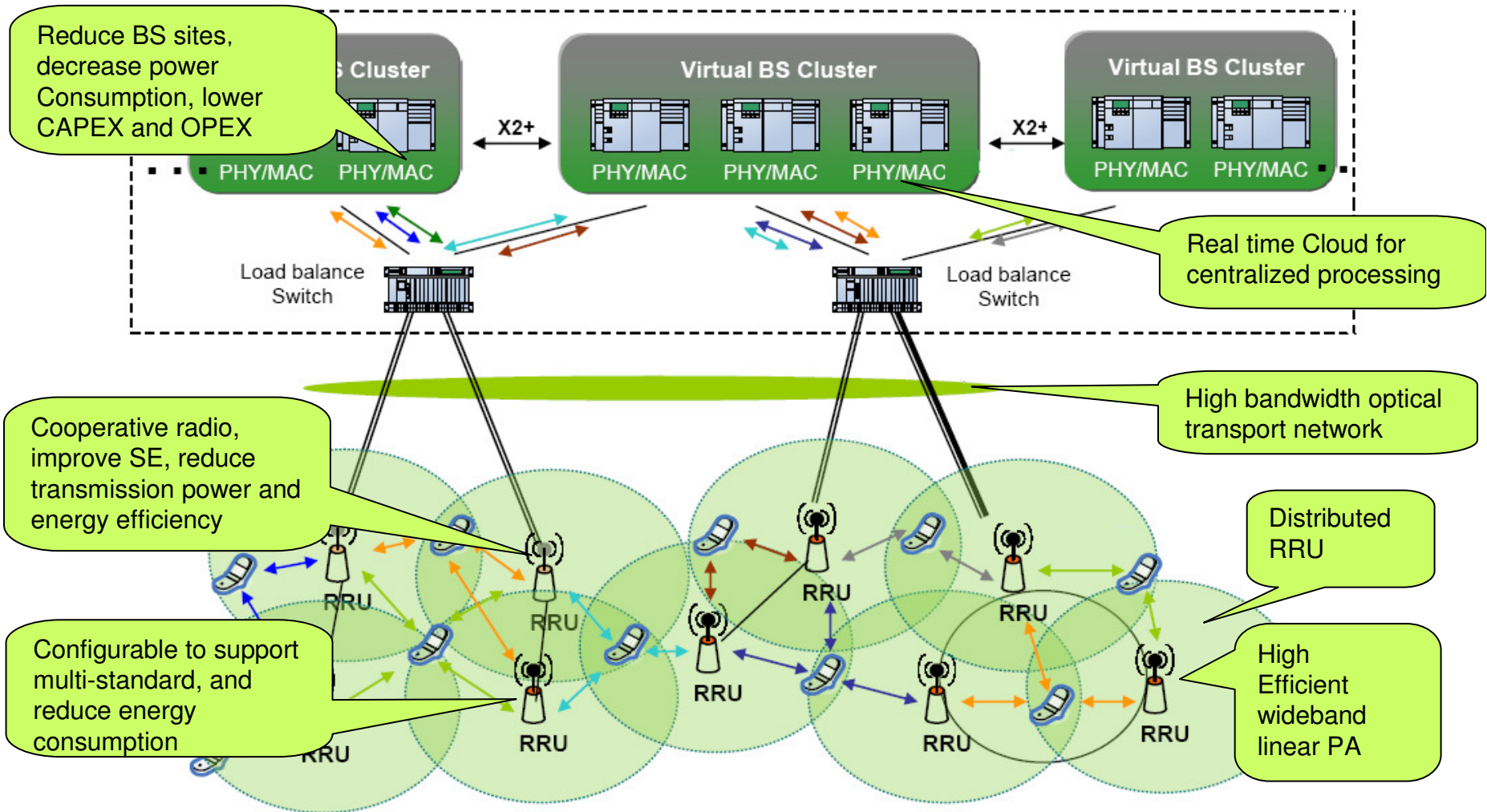
Area power consumption vs. area throughput



“Green Promising Tracks of Green Network Technologies”, EARTH project delivery by ALUD, EAB, DOCOMO, TI, ETH, CEA, UNIS, TUD, IST-TUL, UOULU, BME, TTI

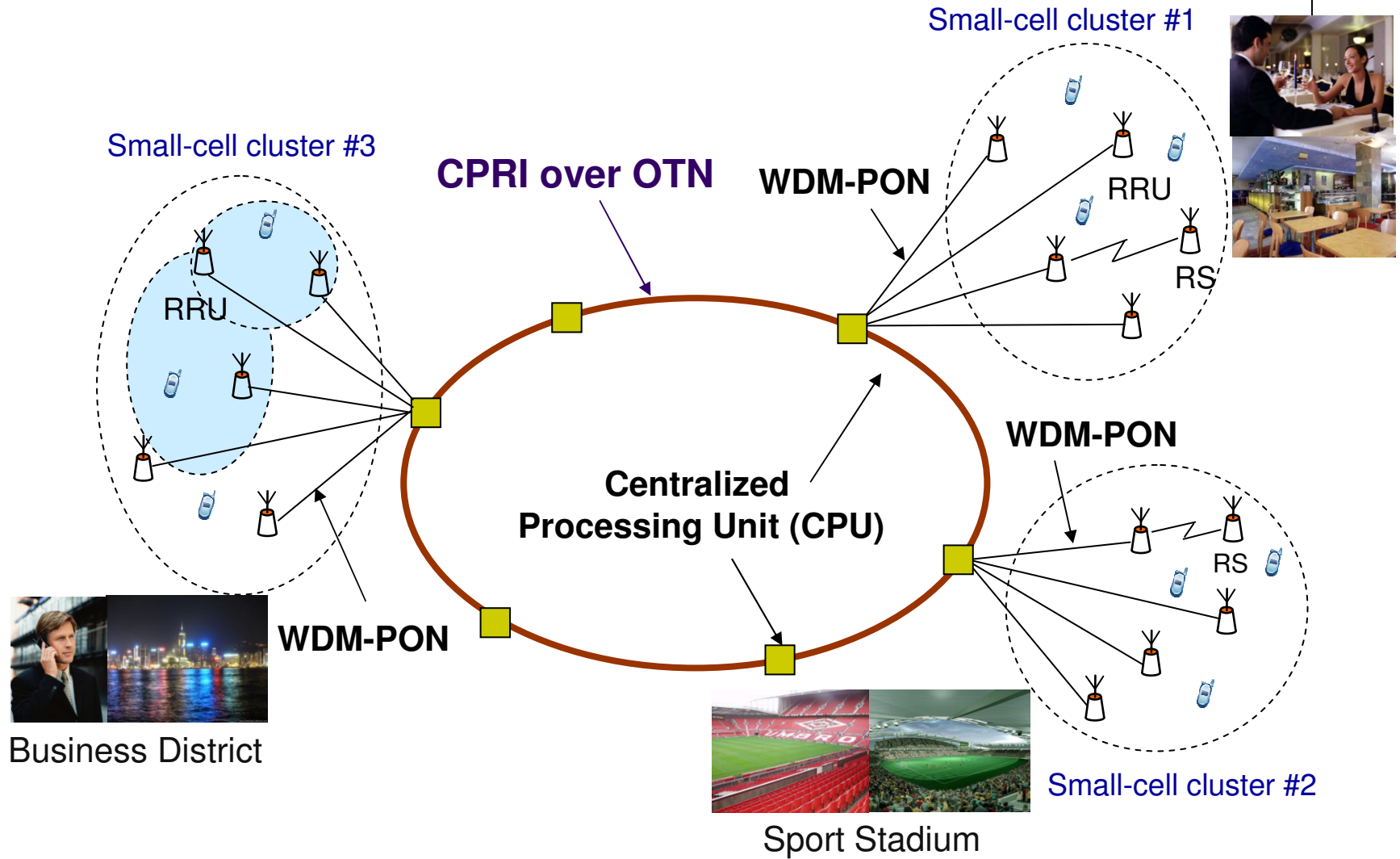


Vision of C-RAN Architecture





Cloud-RAN layout

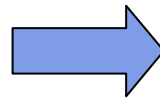
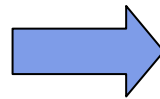
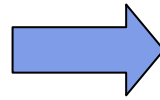
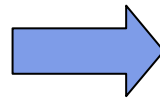




Benefits of Cloud-RAN

Traditional RAN

- Large number of BS
 - High power consumption
 - High CAPEX/OPEX
- Isolated BS
 - Low BS utilization rate
- Interference limited
 - Hard to improve SE
 - Low energy efficiency
- Low efficient PA
 - High power consumption

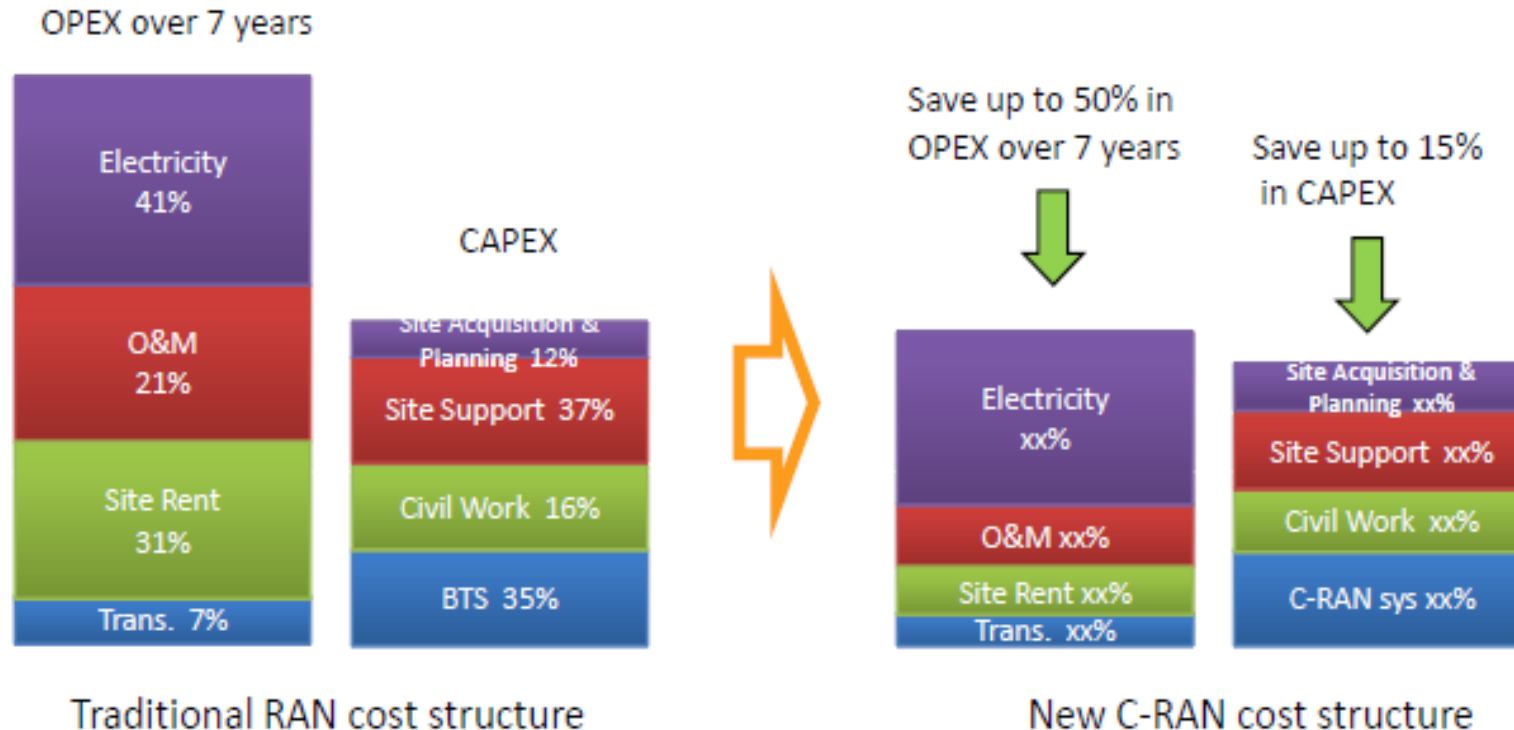


Cloud-RAN

- Centralized BBU pool
 - Low power consumption
 - Low CAPEX/OPEX
- Resource aggregation
 - High utilization rate
- Cooperative multipoint processing
 - Improve SE
 - Improve energy efficiency
- High efficient linear PA
 - Low power consumption



Save Cost of Deployment

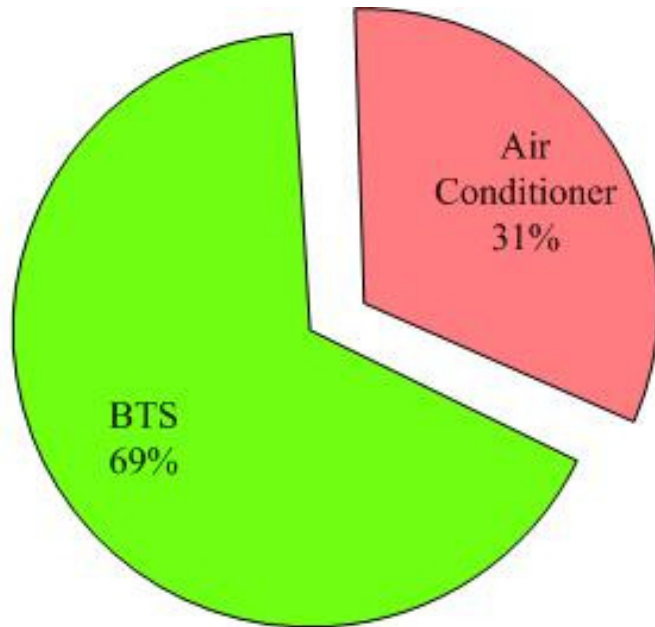


- **C-RAN allows low cost and fast deployment of network**
 - Compared with traditional deployment, may **save up to 50%*** in OPEX
 - Compared with traditional deployment, may **save up to 15%*** in CAPEX

* Notes: data estimated on typical dense city deployment scenario, China Mobile

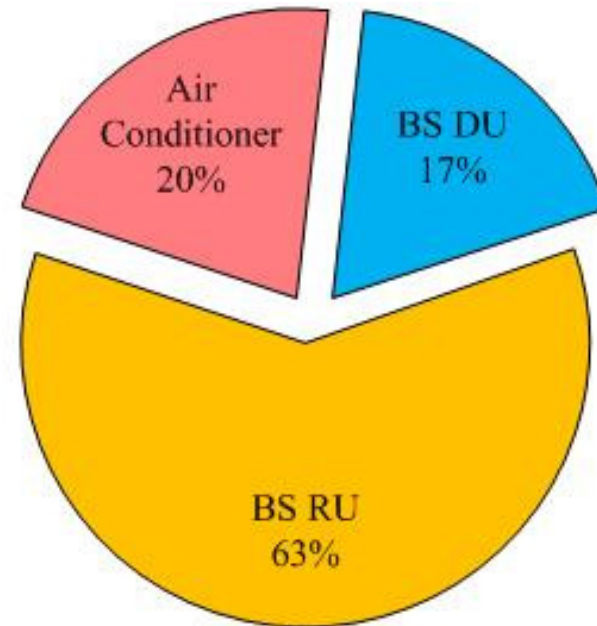


C-RAN Energy Saving



Total : 17,000 kwatt/month

Traditional Power Consumption

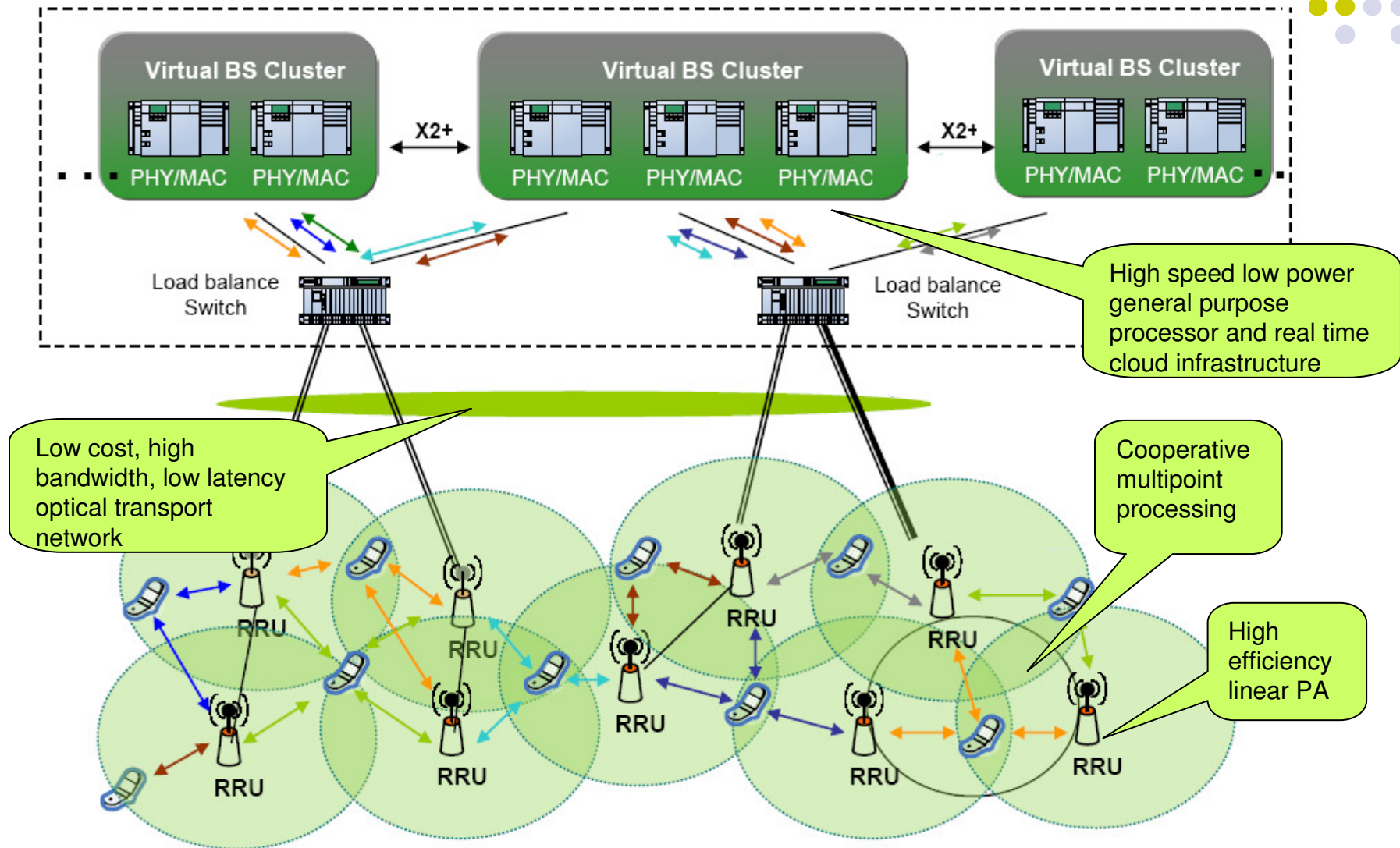


Total : 8,000 kwatt/month

C-RAN Power Consumption

Source: China Mobile

Technical Challenges

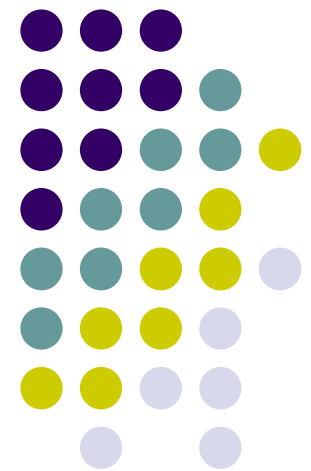




Key techniques of Cloud-RAN

- **Cloud computing architecture**
 - ✓ SDR based multi-protocol baseband processing platform
 - ✓ Virtualization and computing/memory resource scheduling
 - ✓ Load balancing and CPRI signal routing
- **CPRI signal transmission**
 - ✓ CPRI over OTN/DWDM
 - ✓ CPRI over WDM-PON
- **Dynamic cell architecture and multi-cell joint scheduling**
 - ✓ Dynamic cell architecture adapting areal traffic varying
 - ✓ User centric (per-user) dynamic cell architecture
 - ✓ Multi-cell joint radio resource scheduling and interference avoidance
- **Physical layer enhancement**
 - ✓ Network MIMO and interference cancellation
 - ✓ Very high order modulation (128QAM and 256QAM)
 - ✓ CP-less OFDMA, e.g. FMBC

Cooperative Hetnet





Emerging Trend

- The future network architecture is heterogeneous, with macro-, pico- and femto-cells, along with WiFi and (some) ad hoc nodes
- A large part of the capacity increase predicted by Cisco will be drained by increased deployment of WiFi, relays, femto/picocells for stationary or slow moving users
- Macrocell bandwidth is precious and should be used only when there is no alternative (like satellite networks are today)
- Cooperative networking can be used in such emerging environments by using user end devices, femtocells, relays, picocells, and macrocell infrastructure as the devices that constitute the cooperating nodes



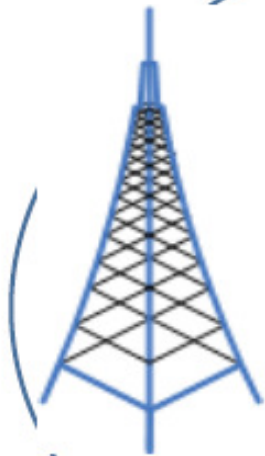
Motivation for Cooperation

- Wireless channel by nature is a broadcast one.
 - The broadcast channel can be fully exploited for broadcast traffic.
 - But it is considered more as a foe than a friend, when it comes to unicast.
- Cooperative communications allow the overheard information be treated as useful signal, instead of interference.
 - Relays process this overheard information and forward to destination.
 - Network performance improved because edge nodes transmit at higher rate thus improving spectral efficiency.
 - Candidate relays?
Mobile user, macro/pico-cell BS, fixed relays, femtocell BS, etc.
 - What are the incentives? Throughput, power, interference.
- A cross-layer design encompassing physical, MAC, network and application layers is required to address this problem.



We live and work in clusters

Most devices have more than one type of connectivity
Most users are nomadic/stationary 🎵



Coffee shops



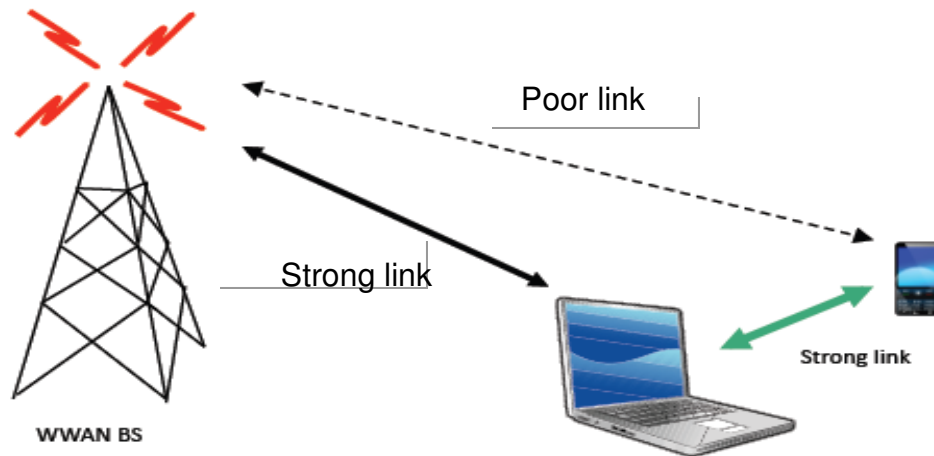
Meetings /
Offices



Class rooms

Can we leverage this clustering to offer better end-user experience?

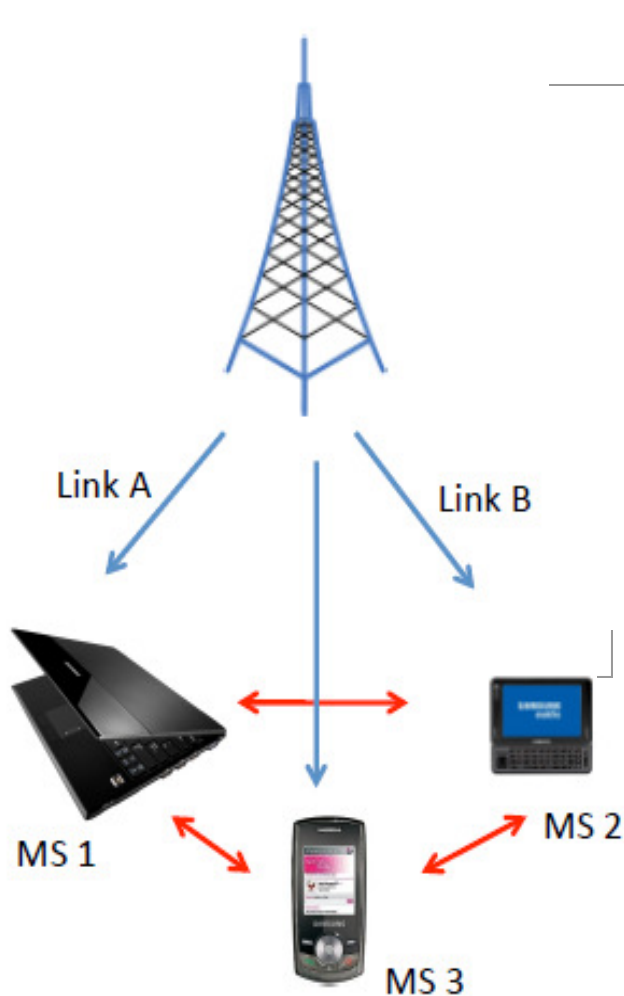
Client Cooperation



- Client cooperation is a technique where clients interact to jointly transmit and/or receive information in wireless environments.
 - Idea: Exploit client clustering and P2P communication to transmit/receive information over multiple paths between BS and client
 - Benefits:
 - Faster over the air = improved “cell-edge” rates without increase in infrastructure cost
 - Less interference => increased system capacity
- Lower power transmission => extended battery of clients with poor channels.



Enabling Client Cooperation



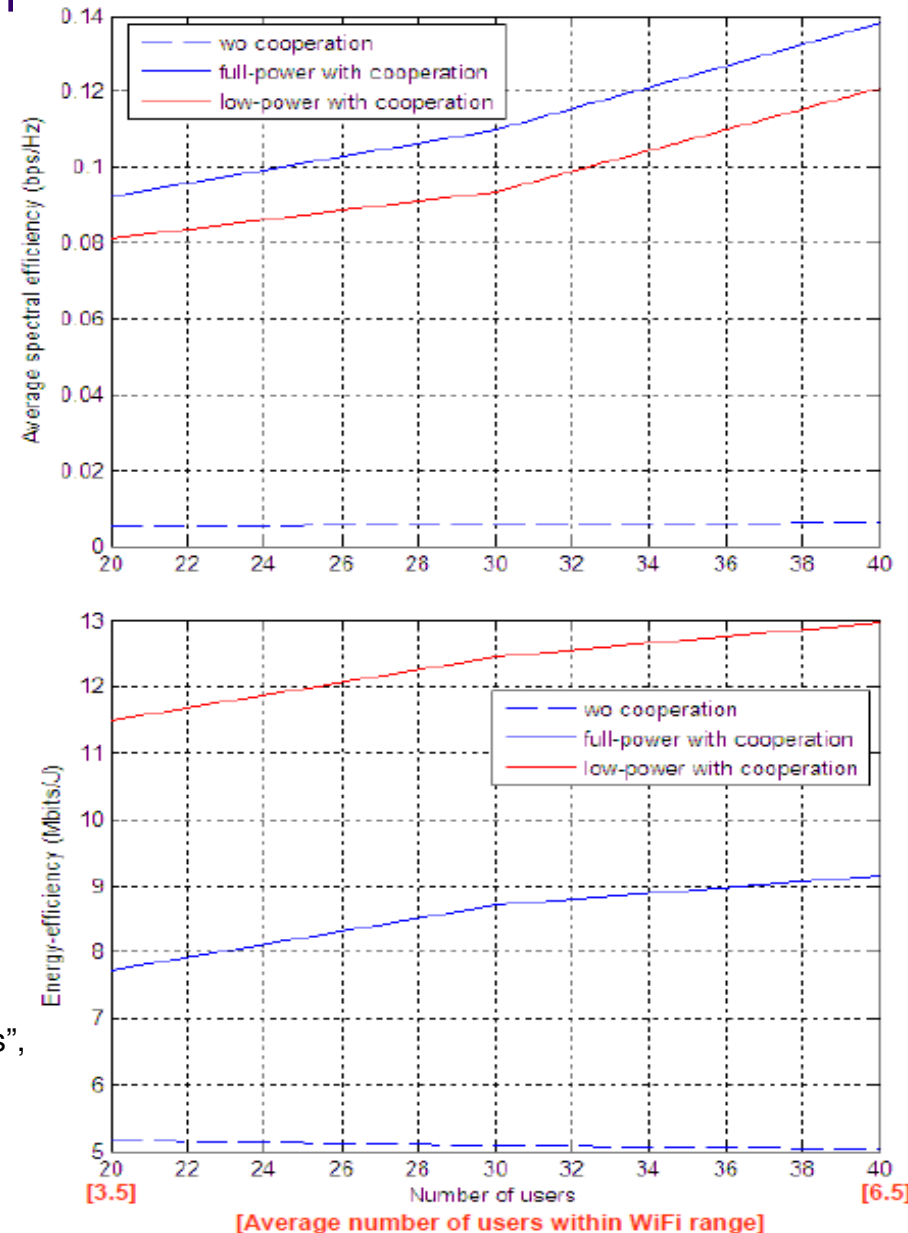
- Enablers needed to take advantage of client clustering
 - How to discover neighbors
 - How is neighbor discovery/cluster information conveyed to the 16x BS
 - Who acts as the leader/coordinator of the cluster?
 - Who talked to the BS
 - How to size the clusters?
 - How does the macro act on this cluster and signal data meant for any member(s) of the cluster?
 - If in-band signaling is used, which relaying scheme to use?
- Efficient signaling support is crucial and necessary.

Client Cooperation

- Performance Gain



- Client cooperation significantly improves cell-edge rates
 - Small clusters of clients (<6) suffice for large gains
 - Full power cooperation outperforms low-power cooperation
 - Gains decrease with increased channel correlation among clients
- Client cooperation decreases total networks energy consumption
 - Originating MS conserves energy by requiring fewer retransmission with higher MCS
 - Cooperator consumes energy, but net result is energy saving
 - Extends battery of clients w/poor channels.

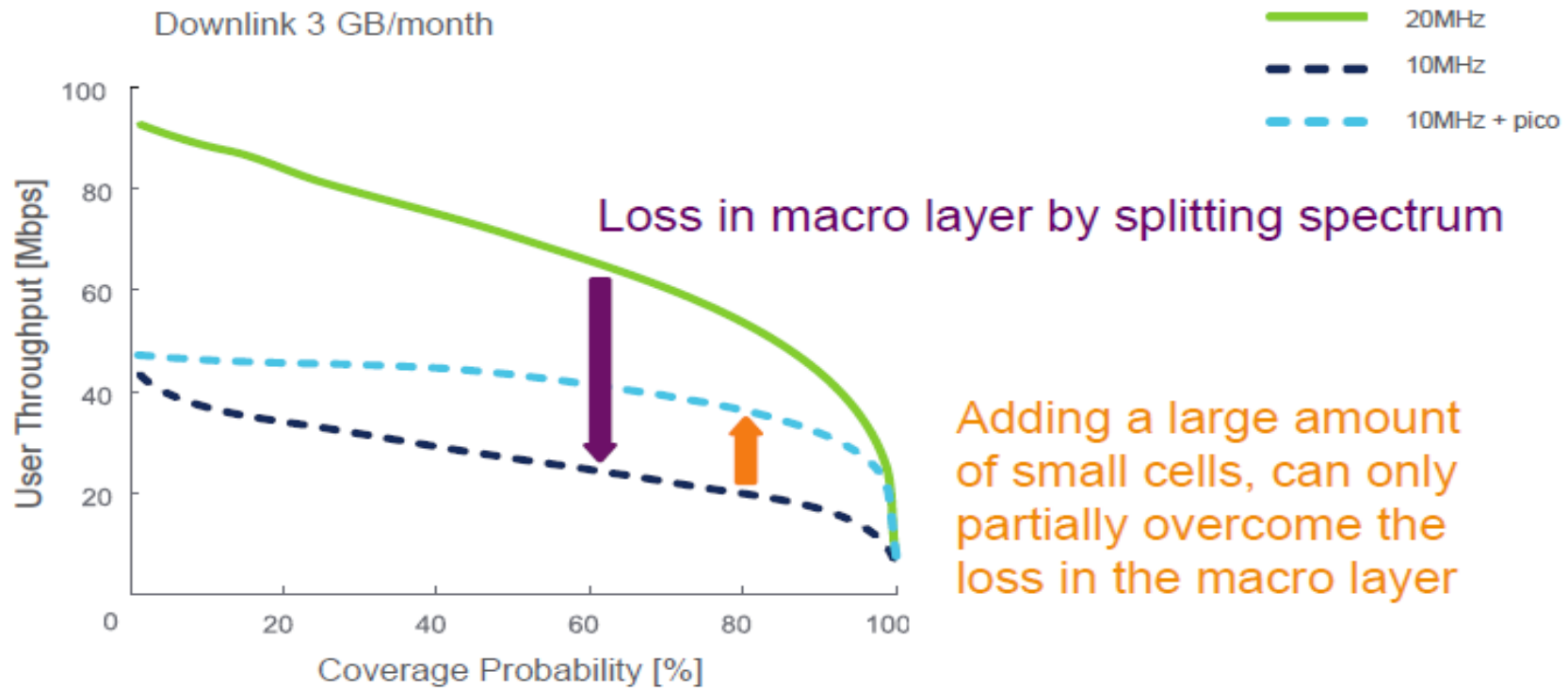


Source: "Future 802.16 Networks: Challenges and Possibilities",
IEEE C802.16-10/0016r1



Node cooperation

--Uncoordinated Hetnet



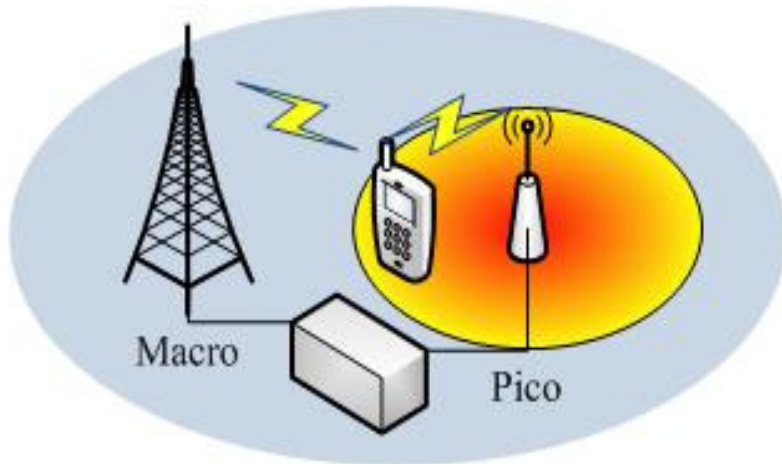
Source: Ericsson Hetnet Telebriefing



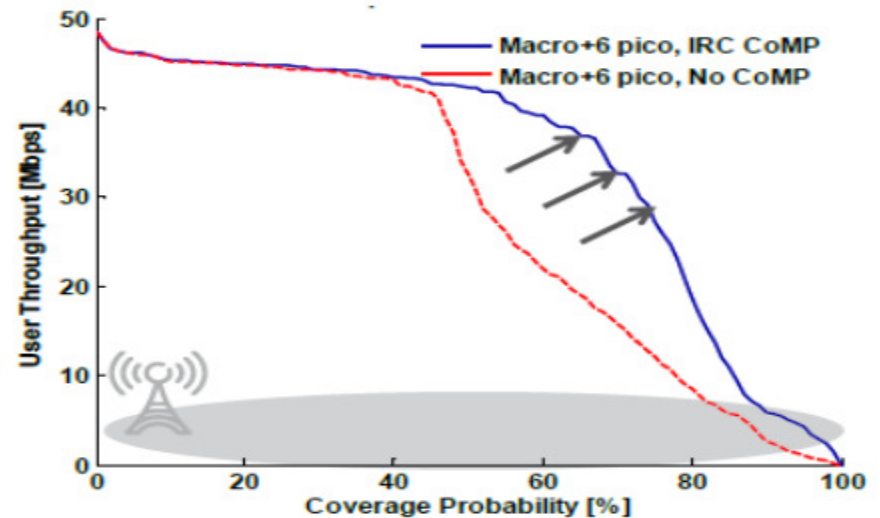
Coordinated Hetnet

Coordinated cells increase data volume and throughput

- Up to 3 times more data per subscriber, no loss of data speed
- Up to 12 times better data speeds on cell edges



Macro and Pico jointly decode uplink signal
with IRC-CoMP

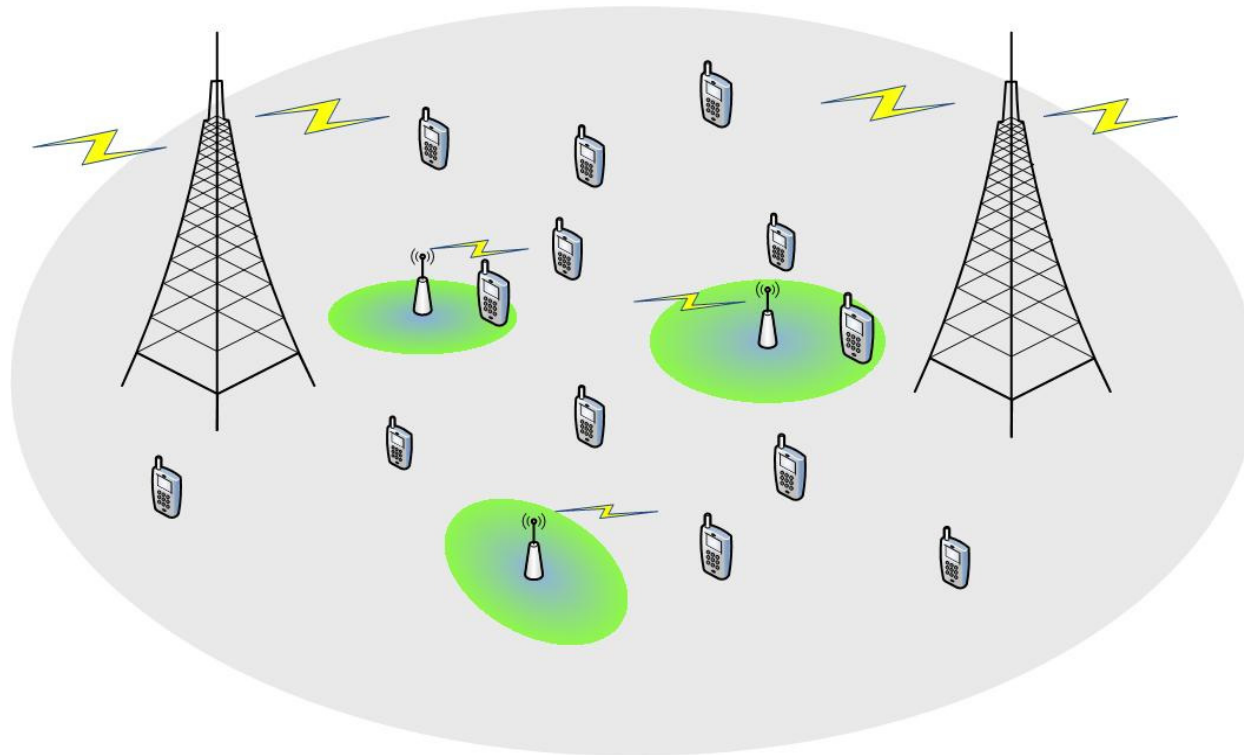


Source: Ericsson Hetnet Telebriefing



Coordinated Hetnet

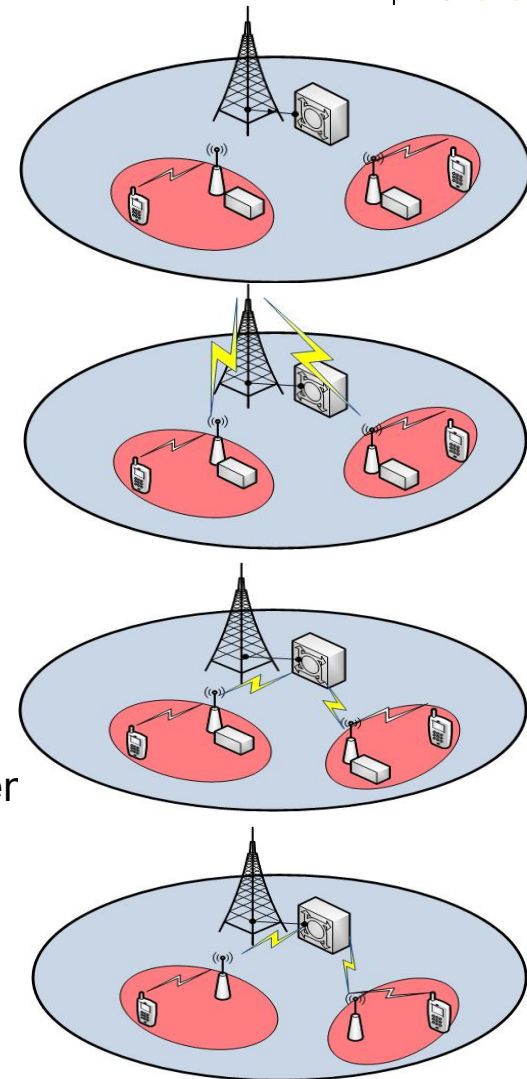
- Improved data throughput with reuse of frequencies
- Reduced interference with small cell interaction
 - Soft handover in WCDMA and Inter-Cell Interference Coordination (ICIC) in LTE
- Capacity off-load of macro network





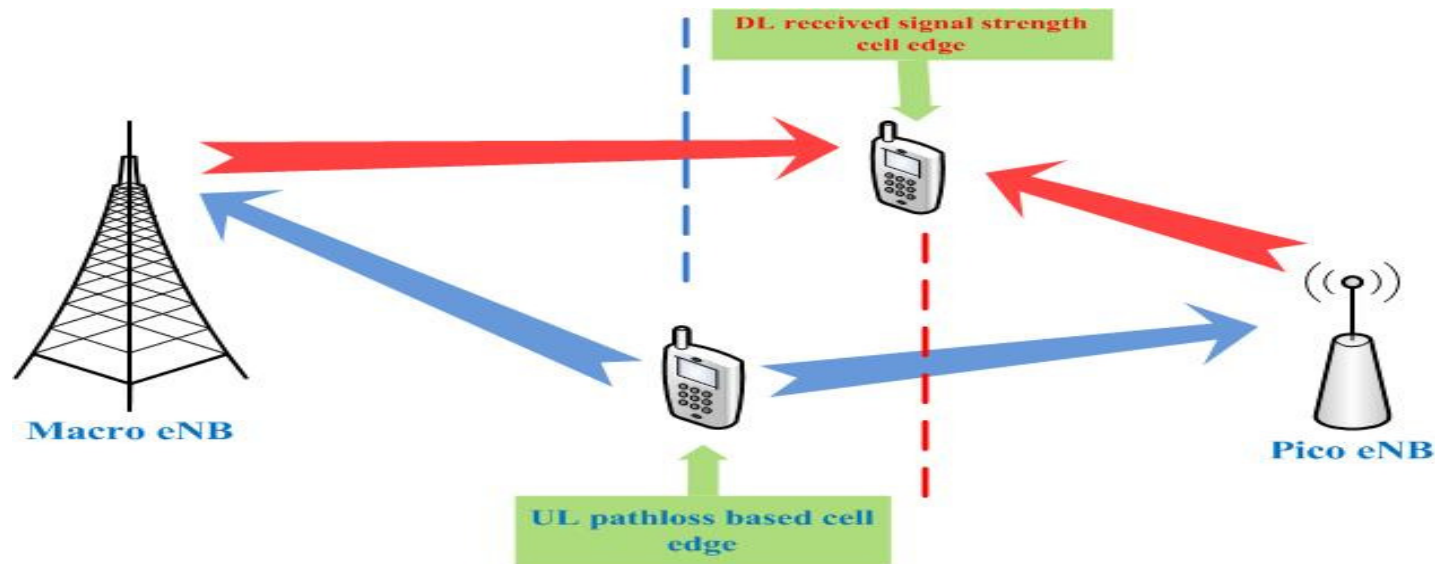
Hetnet examples

- ❖ Conventional loosely coordinated pico or home eNB deployment
 - Individual pico/home eNBs, independent from overlaid macro layer
 - Operator or end-user driven
- ❖ Relay deployment
 - Basic Coordination
- ❖ Tightly coordinated pico deployment
 - Individual pico eNB
 - Operator driven
 - Allows for any type of coordination from semi-static allocation of resources till CoMP, of “SHO-like” scheduler
- ❖ Radio Remote Unit (RRU) deployment (centralized processing)
 - Pico layer tied to overlaid macro layer
 - Allows for tight coordination





Hetnet interference



- ❖ Significant imbalance in the DL Tx powers of macro eNB & low power NBs
- ❖ Scenario: Open Access Picos, No Extended Range, No Interference Management
 - Same interference situation as within homogeneous networks
- ❖ Scenarios with pico cells using extended range or with CSG low power nodes
 - Interference problems on DL Control Channel Region
 - Interference management mechanisms need some new thinking
E.g, CA, Almost Blank Subframes (ABSF)



Interference management

❖ Downlink carrier aggregation

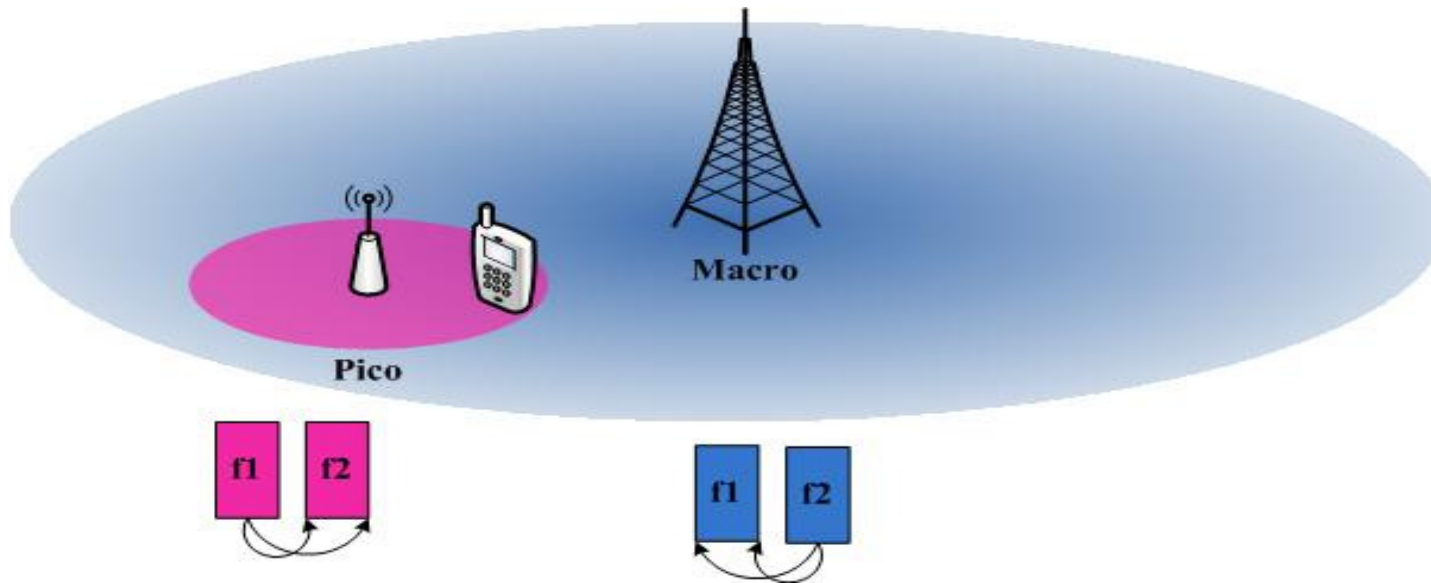
- Rel-10 carrier aggregation used for interference management
 - Macro and pico operate DL control signaling on different primary component carriers
 - Macro and pico operate data on same carrier frequencies
- All building blocks are present in Rel-10

❖ “Same carrier” (“single carrier”, “co-carrier”)

- Macro and pico operate on the same carrier frequency
- Large coordination effort



Downlink Carrier Aggregation



- ❖ Data
 - Can use multiple component carriers as determined by ICIC
- ❖ L1 Control signaling (including broadcast, synchronization channels & reference symbols)
 - Interference management in frequency domain
 - Macro
 - f1: normal operation (primary component carrier)
 - f2: low/zero-power for control (secondary component carrier)
 - Pico
 - f1: low or zero power for control
 - f2: normal operation
 - Macro CRS should preferably collide with pico CRS



Downlink Carrier Aggregation

- ❖ **All major building blocks are present in Rel-10**
 - CA-based heterogeneous network support

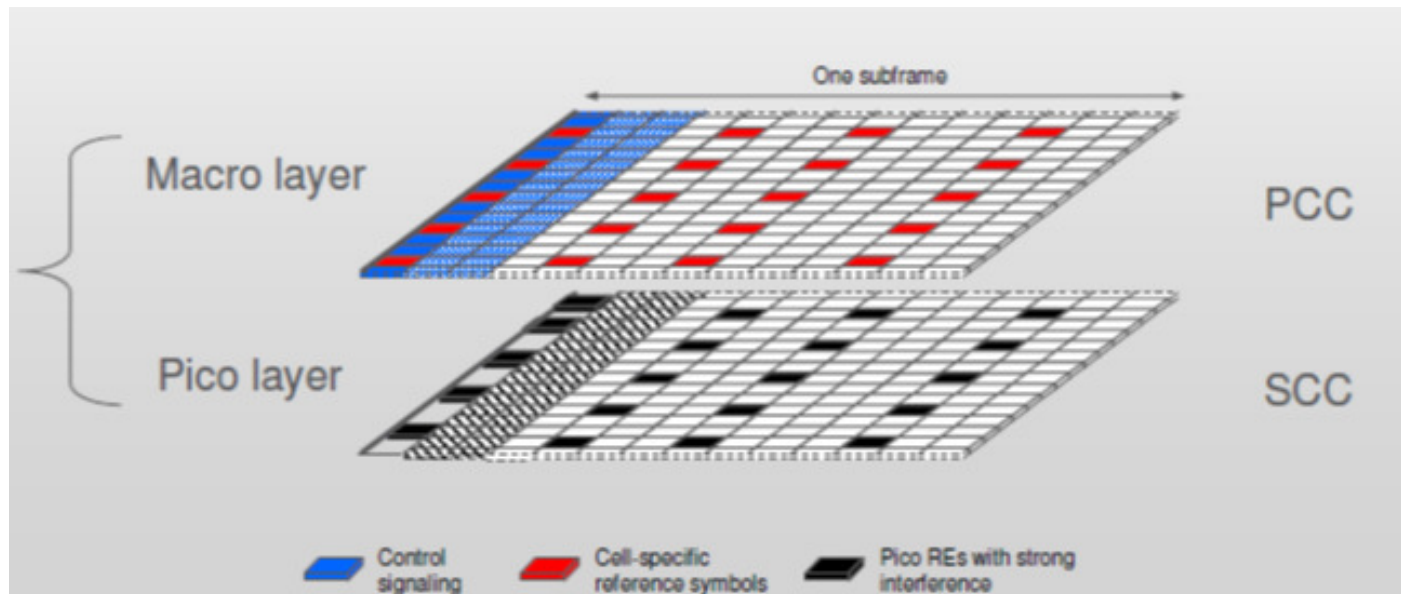
- ❖ **Need to split overall spectrum into multiple carriers**
 - Rel-8/9 Ues can only access one component carrier
 - can access pico but not benefit from all available spectrum

- ❖ **Pico CRS can be severely interfered**
 - Need for mechanisms removing interference originating from neighbor macro cells



Practical issues

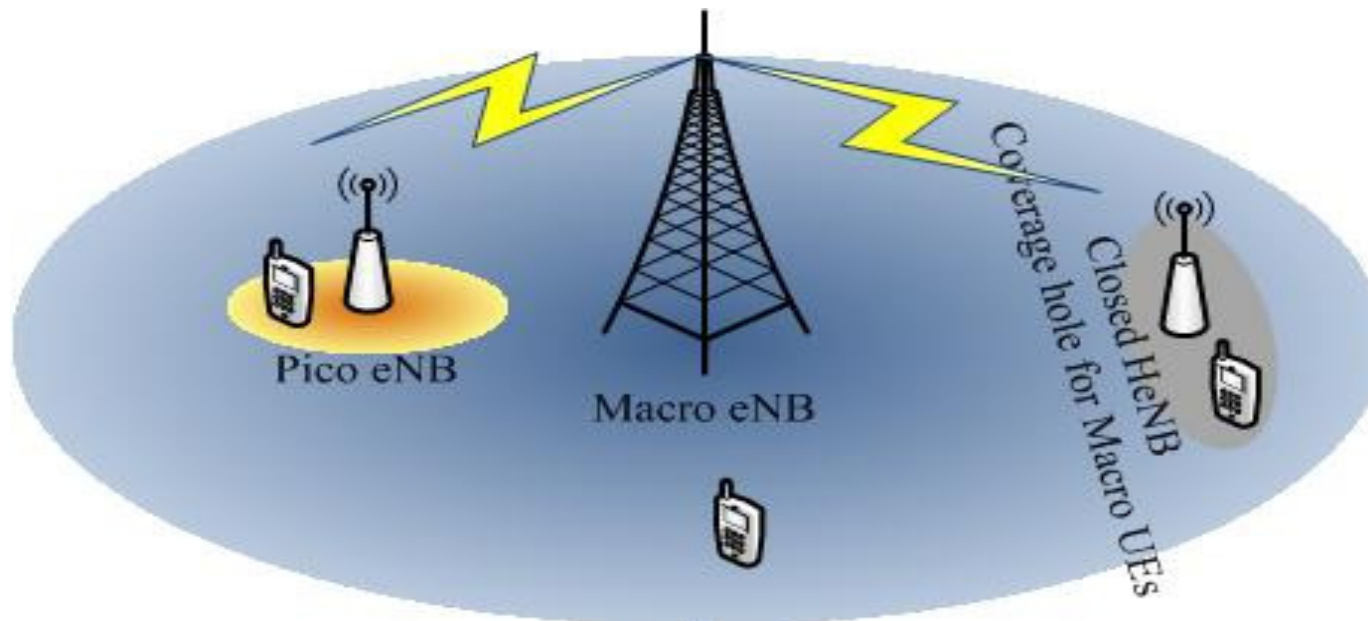
- ❖ Time alignment between cell layers assumed
 - Known which Res in pico that are heavily interfered from macro (control, RS, synchronization & broadcast channels)
 - Can be beneficial to ensure cell-specific RS 'collide' between layers





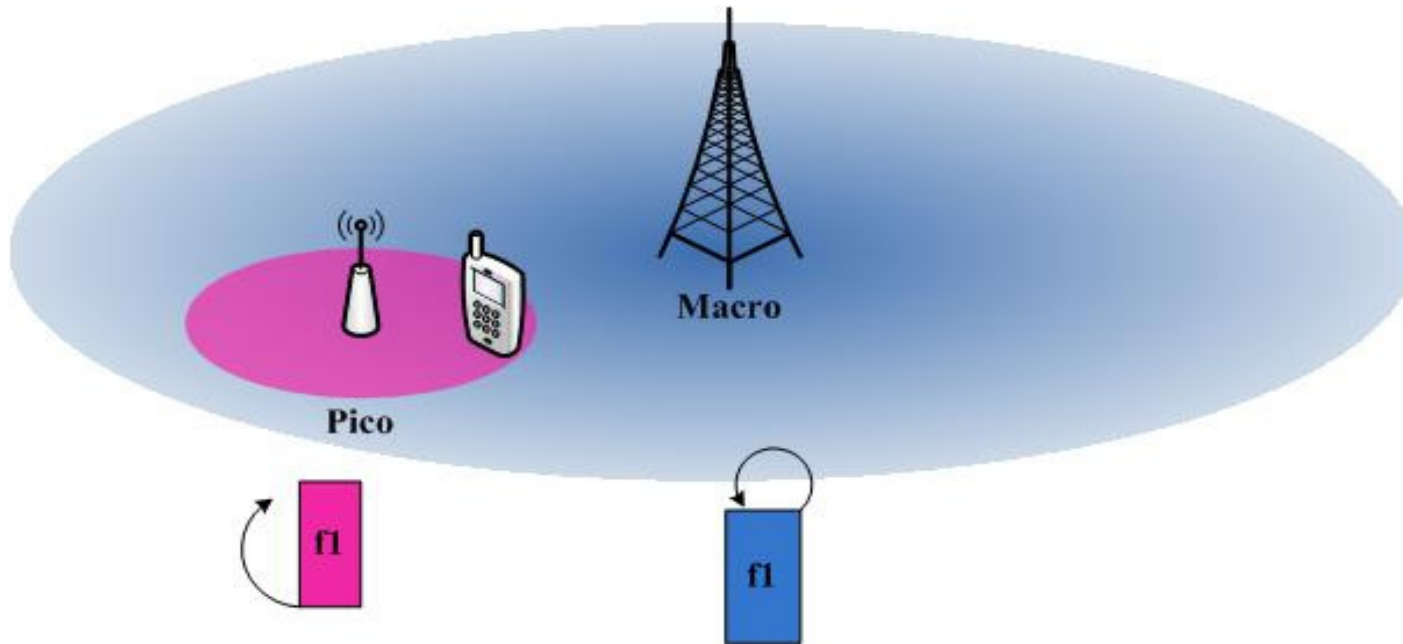
Same Carrier challenges

- ❖ Challenges for co-channel HetNet deployment in Rel 8/9
 - Co-channel Rel 8 deployments have limited inter cell interference coordination (ICIC) and load balancing capacity
 - Rel 8 mechanism does not provide mechanisms for DL control channel ICIC
 - ✓ Cell association generally based on best DL cell or limited bias negotiated over X2
 - Limited number of Ues can be associated with low power eNBs, which limits potential for load balancing and increase in network throughput
 - DL control channel outage is observed when closed HeNBs are deployed in co-channel manner with macro network





“Same Carrier” approach in control plane

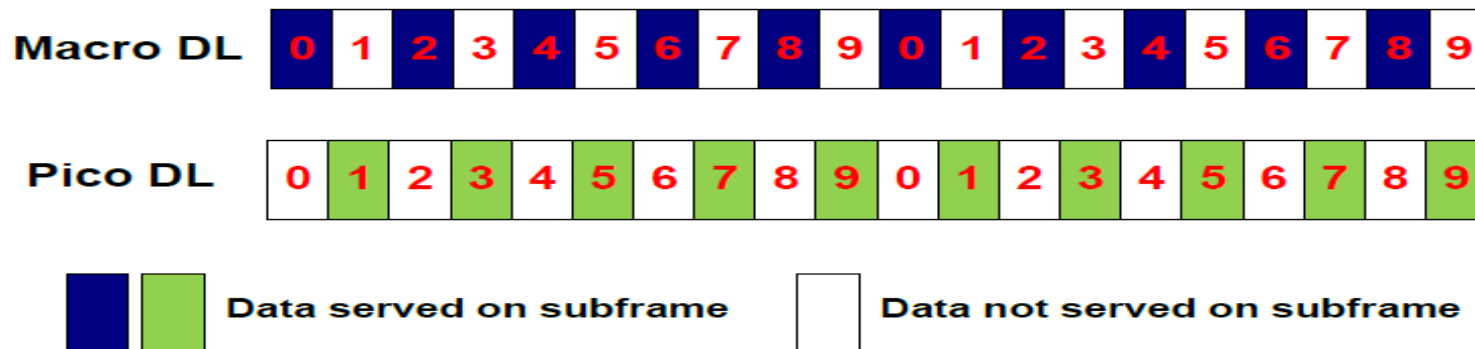


- ❖ L1 Control signaling (PDCCH, PCFICH)
 - Interference avoidance only in time domain
 - Almost blank subframes (ABSF)
One layer does not transmit L1 control signaling within given subframe



Almost Blank Subframes

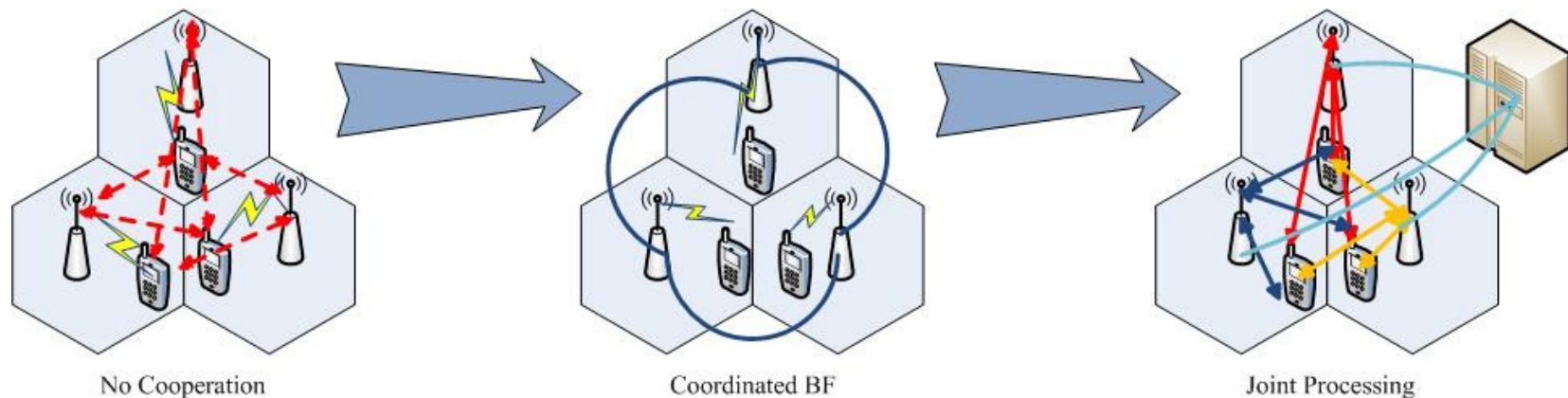
- Backhaul based eICIC for DL control and data channel interference mitigation leads to creation of almost blank subframes
 - Unicast DL data traffic is not scheduled in almost blank subframes
 - Only legacy broadcast signals and channels are transmitted to support legacy UEs
 - PSS/SSS/PBCH and CRS





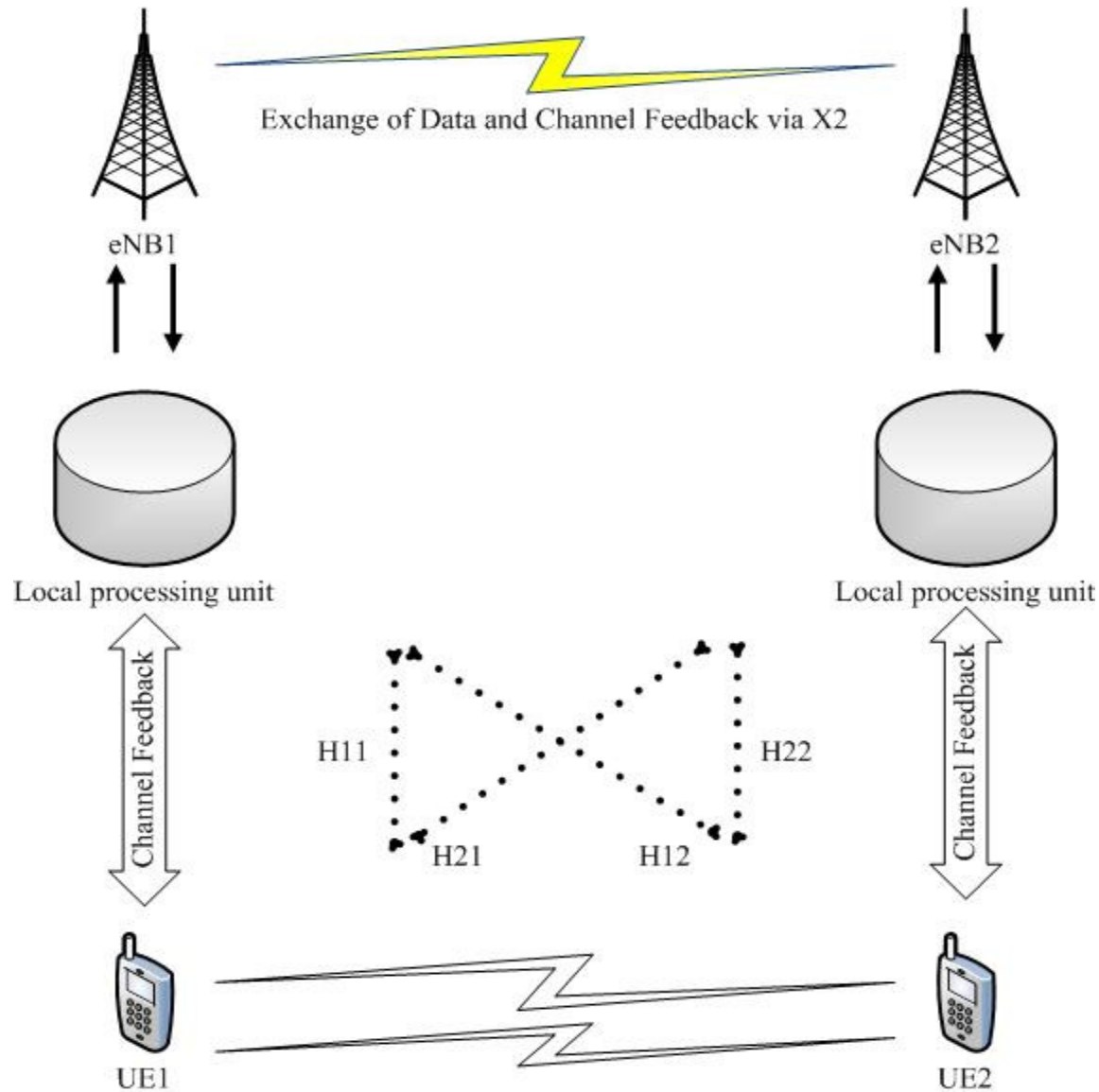
CoMP

- CoMP transmission schemes on downlink
 - Joint Processing (JP)
 - Joint transmission (JT); Downlink physical shared channel (PDSCH) is transmitted from multiple cells with precoding using DM-RS among coordinated cells
 - Dynamic cell selection: PDSCH is transmitted from one cell, which is dynamically selected
 - Coordinated scheduling/beamforming (CS/CB)
 - PDSCH is transmitted only from one cell site, and scheduling/beamforming is coordinated among cells
- CSI feedback (FB)
 - Explicit CSI FB (direct channel FB) is investigated to conduct precise precoding, as well as implicit CSI FB (precoding matrix index FB) based on Rel.8 LTE ->tradeoff between gain and FB signaling overhead





CoMP in the distributed RAN



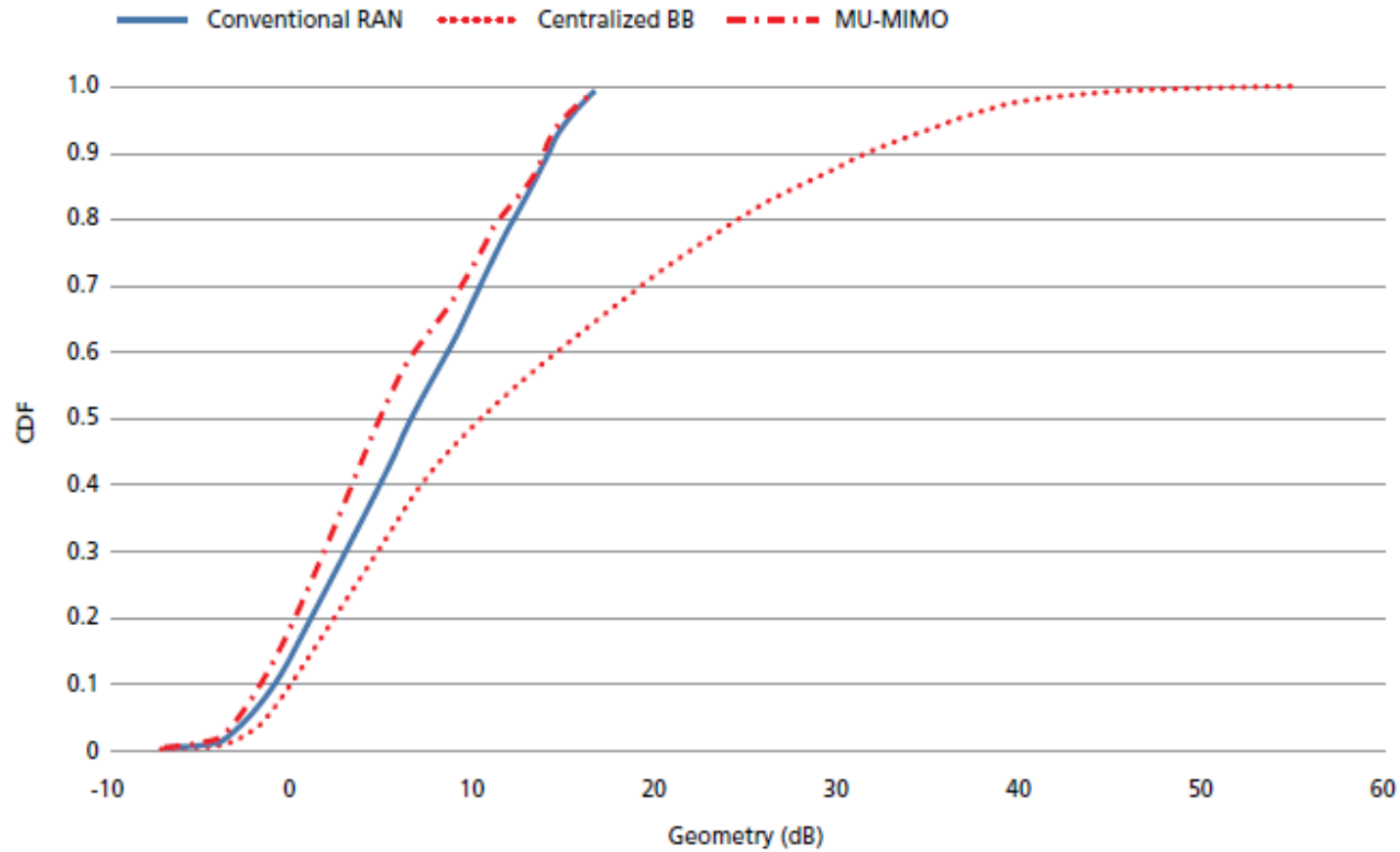


CoMP in C-RAN

- Cloud RAN makes CoMP easier for implementation
 - Centralized traffic data, easier for collaboration
 - Low latency in data exchange
 - Scalable processing power on cloud computing



CoMP gain

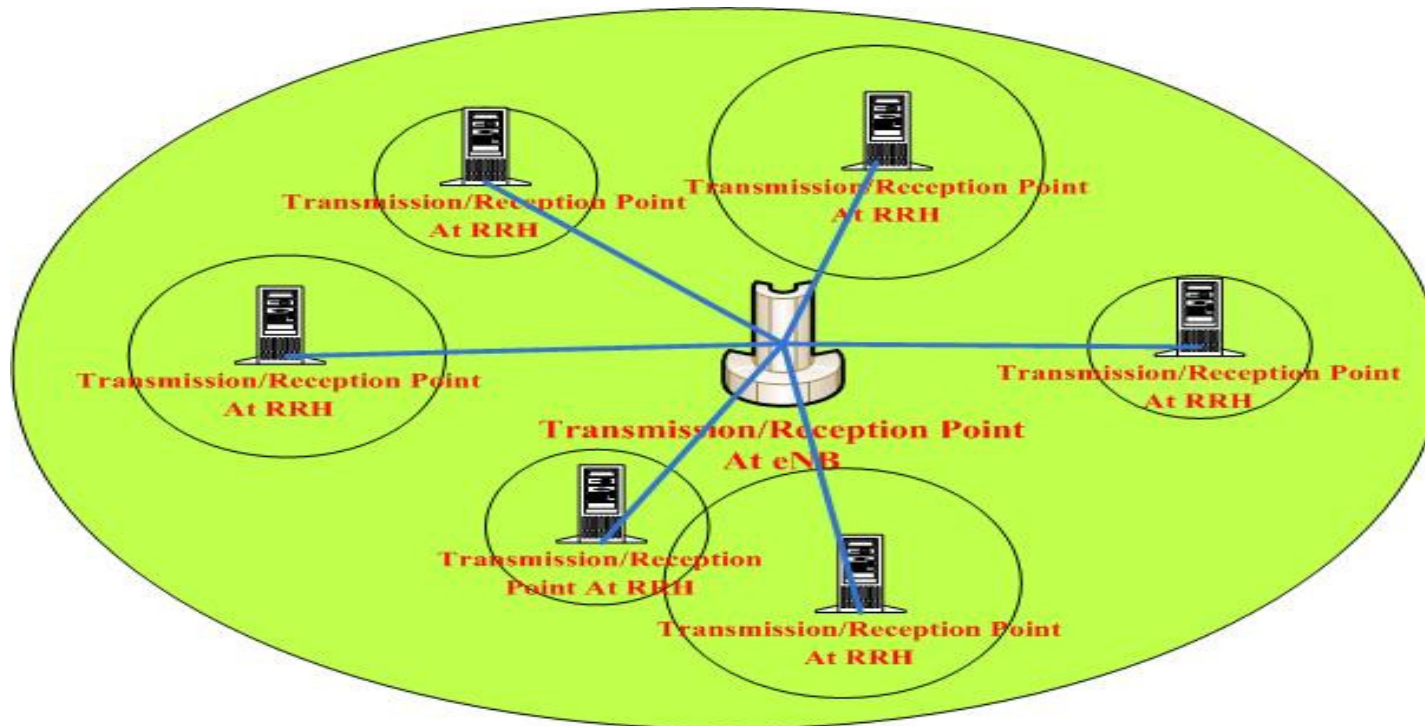


Source: R1-110232



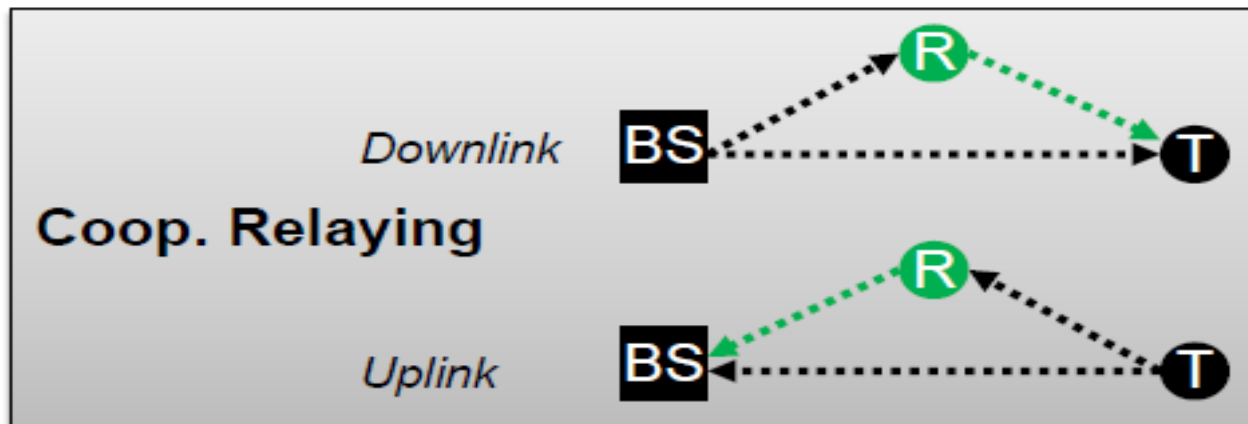
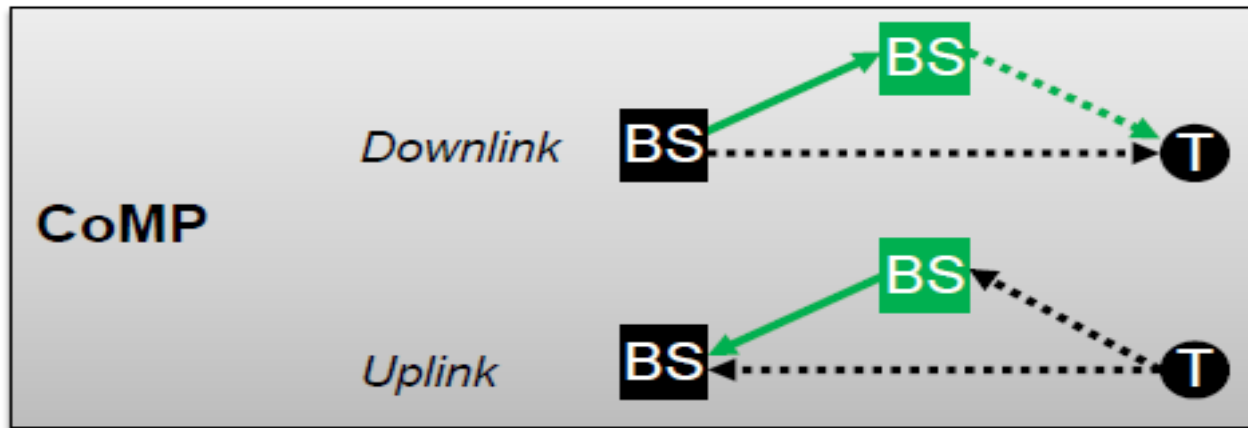
CoMP in hetnet: release 11 in 3GPP

- ❖ New deployment scenarios for CoMP
 - Scenario A: Heterogeneous network with low power RRHs within the macrocell coverage, where transmission/reception points created by the RRHs have different cell IDs as the macro cell
 - Scenario B: Network with low power RRHs within the macrocell coverage where the transmission/reception points created by the RRHs **have the same cell IDs** as the macro cell.





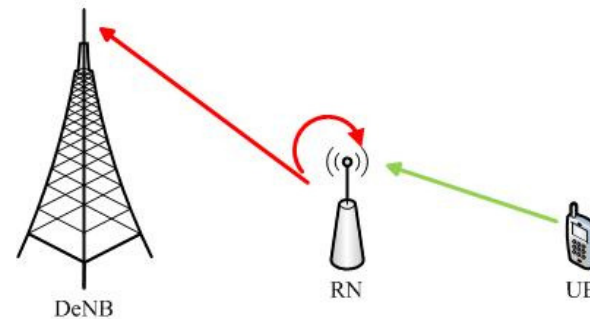
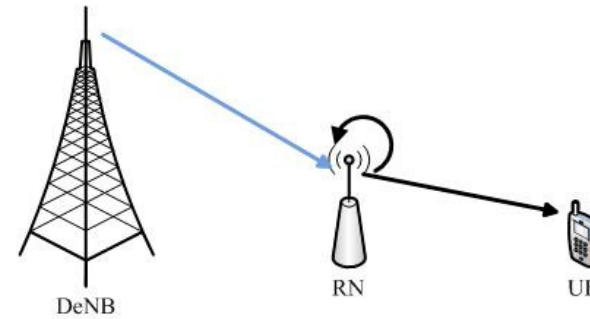
CoMP vs. Cooperative relaying



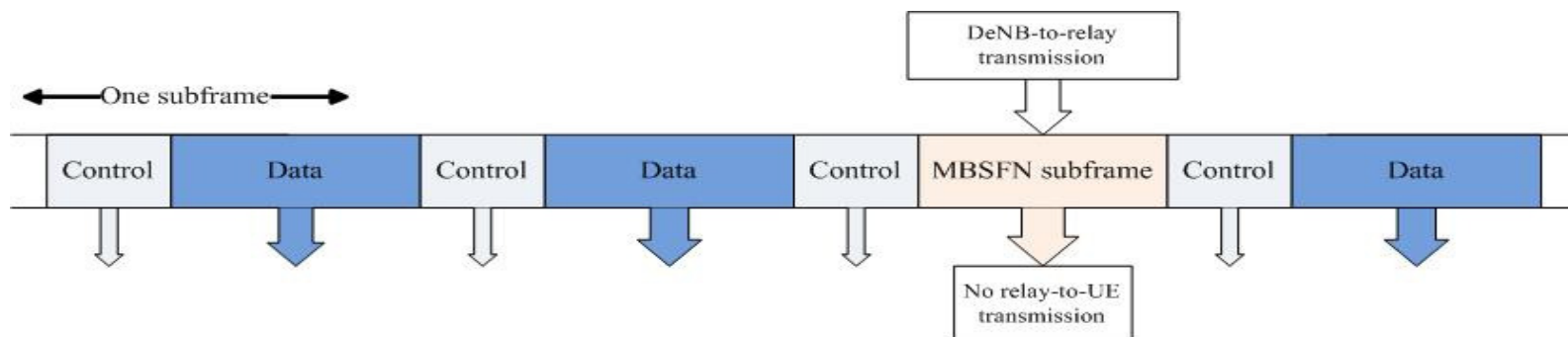


Multi-hop relaying

- ❖ Due to self-interference RNs cannot simultaneously
 - Transmit on access (DL) and receive on backhaul (DL)
 - Receive on access (UL) and transmit on backhaul (UL)

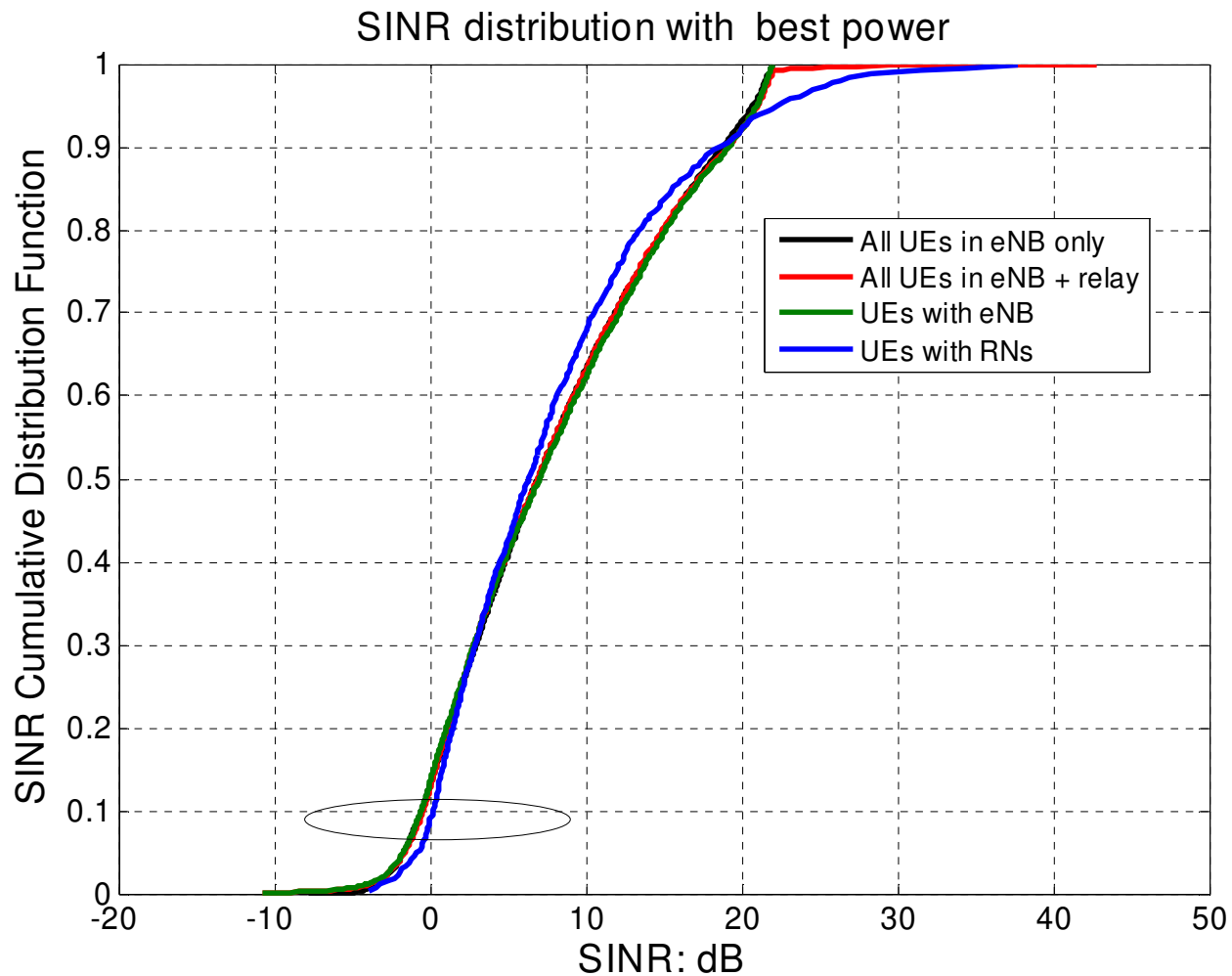


- ❖ RN separates backhaul and access in time
 - Access (backhaul) link operates on access (backhaul) subframes only





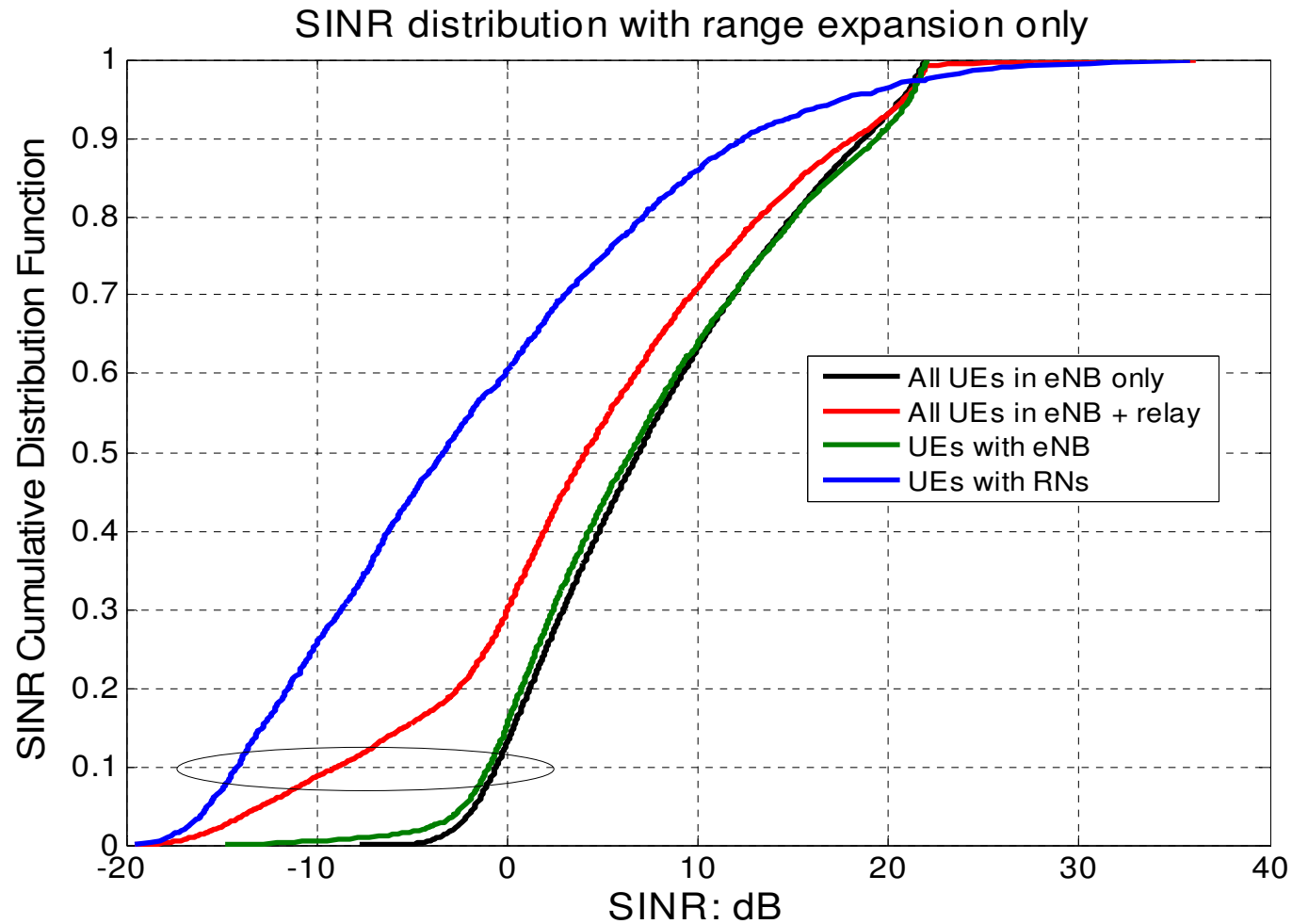
Best power based cell selection



R. Q. Hu *et al.* "On the downlink time, frequency and power coordination in an LTE relay network," to appear in *IEEE GLOBECOM 2011*

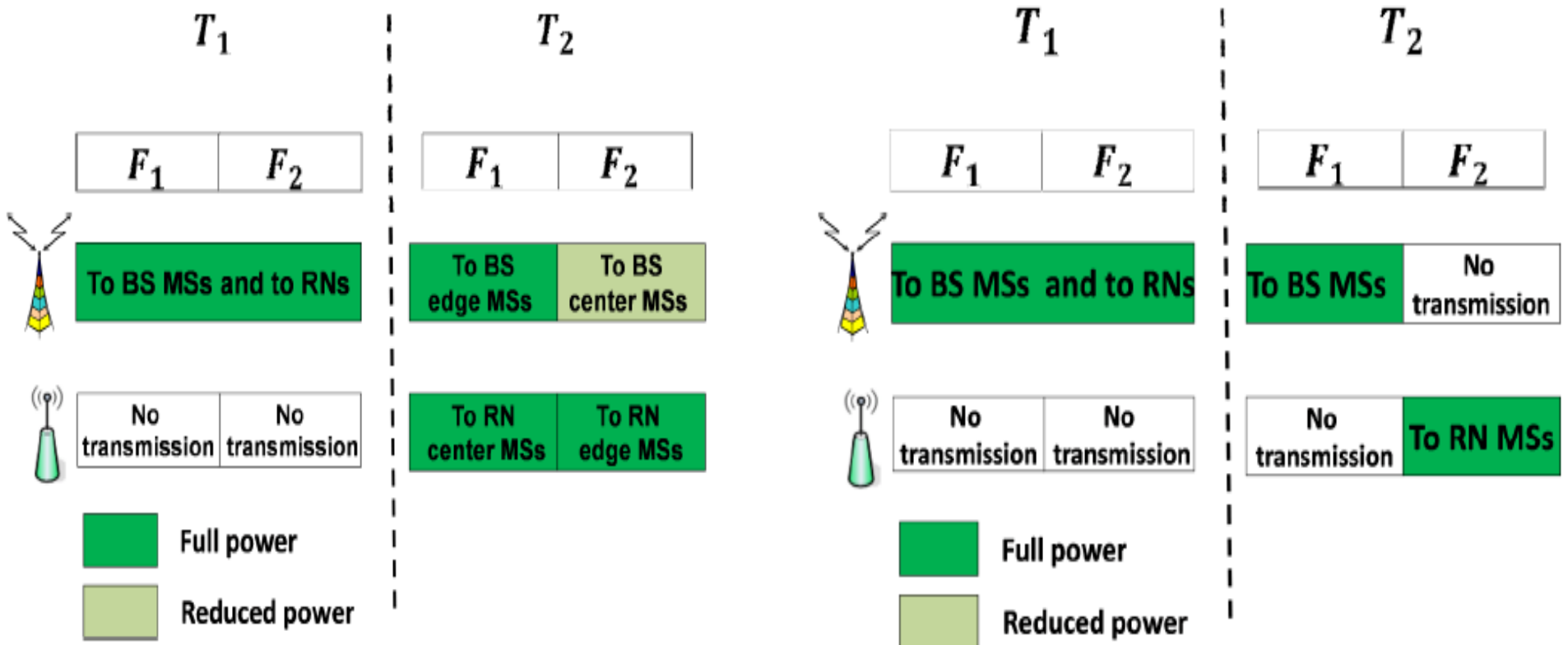


Range expansion based cell selection



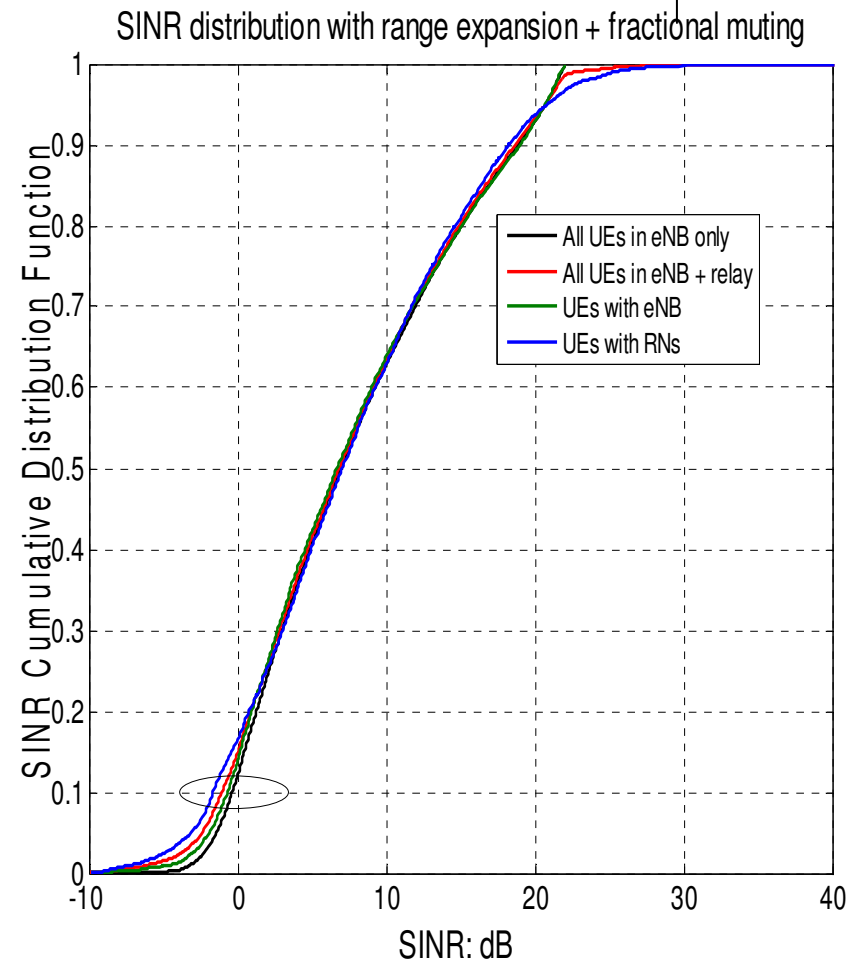
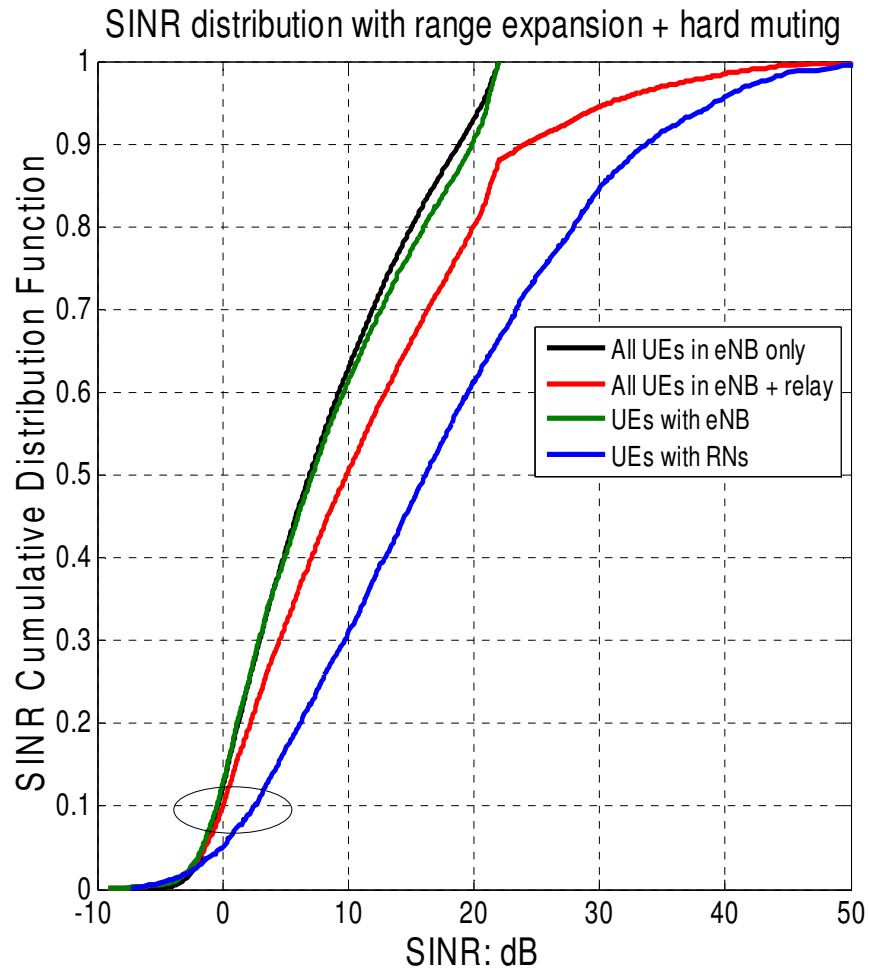


eCIC in relay network



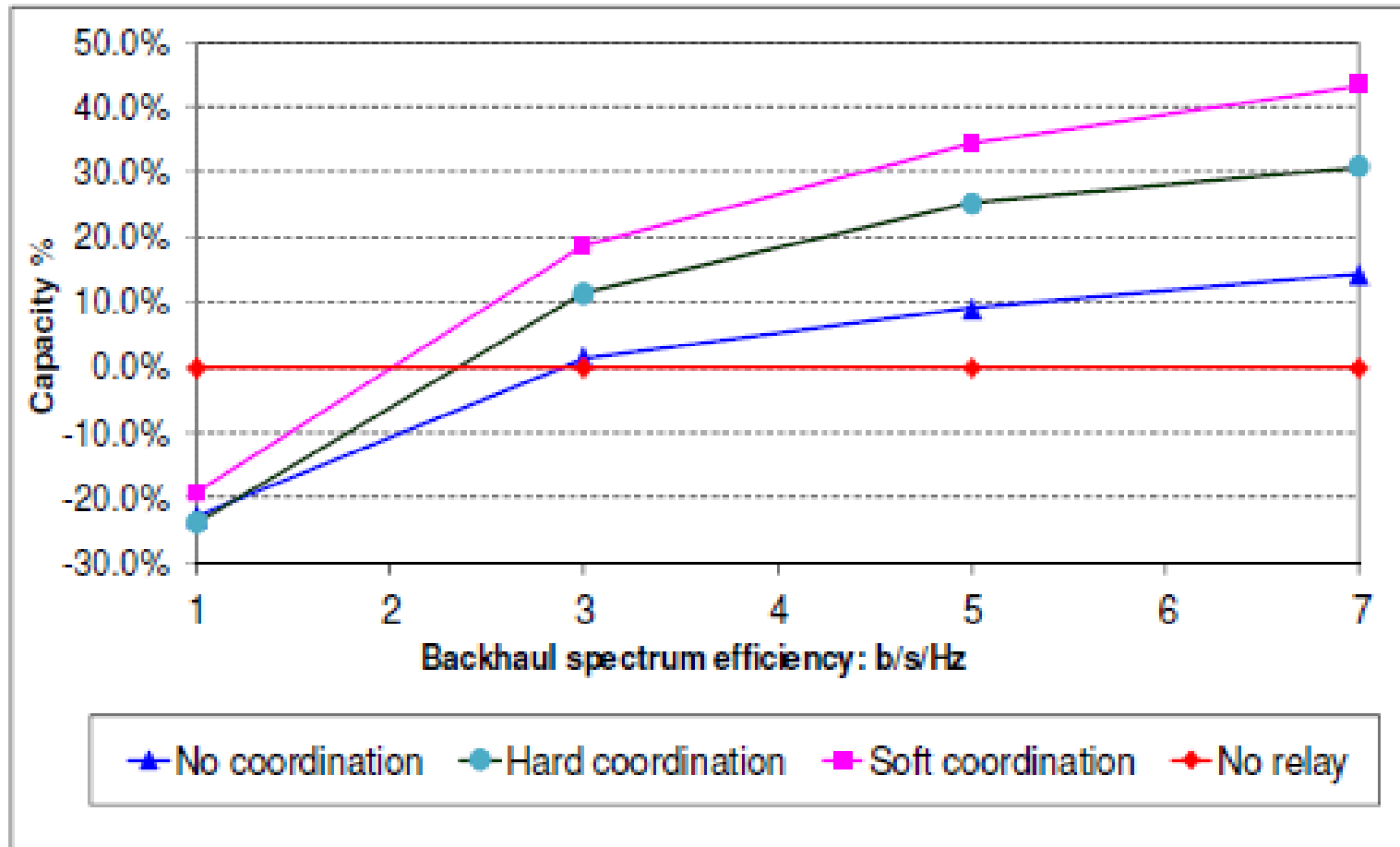


RE + eICIC

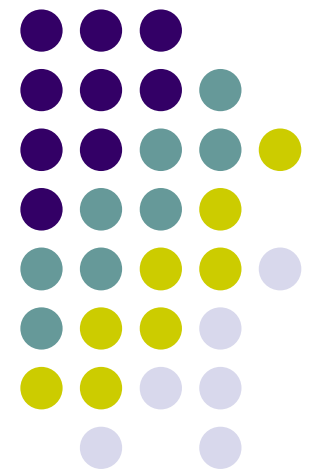




Relay capacity



Hetnet Mobility





LTE IDLE mobility

- The Idle mode is a power-conservation state for the UE, where typically the UE is not transmitting or receiving packets.
- Idle mode UE does not inform the network of each cell change. The network knows the location of the UE to the granularity of a few cells, called the Tracking Area (TA).
- Idle mode mobility is a UE based mobility.
 - Normally called cell selection/reselection.
- The purpose of cell selection/reselection is to ensure that the terminal in Idle mode is camped on the best cell in terms of signal strength and quality.

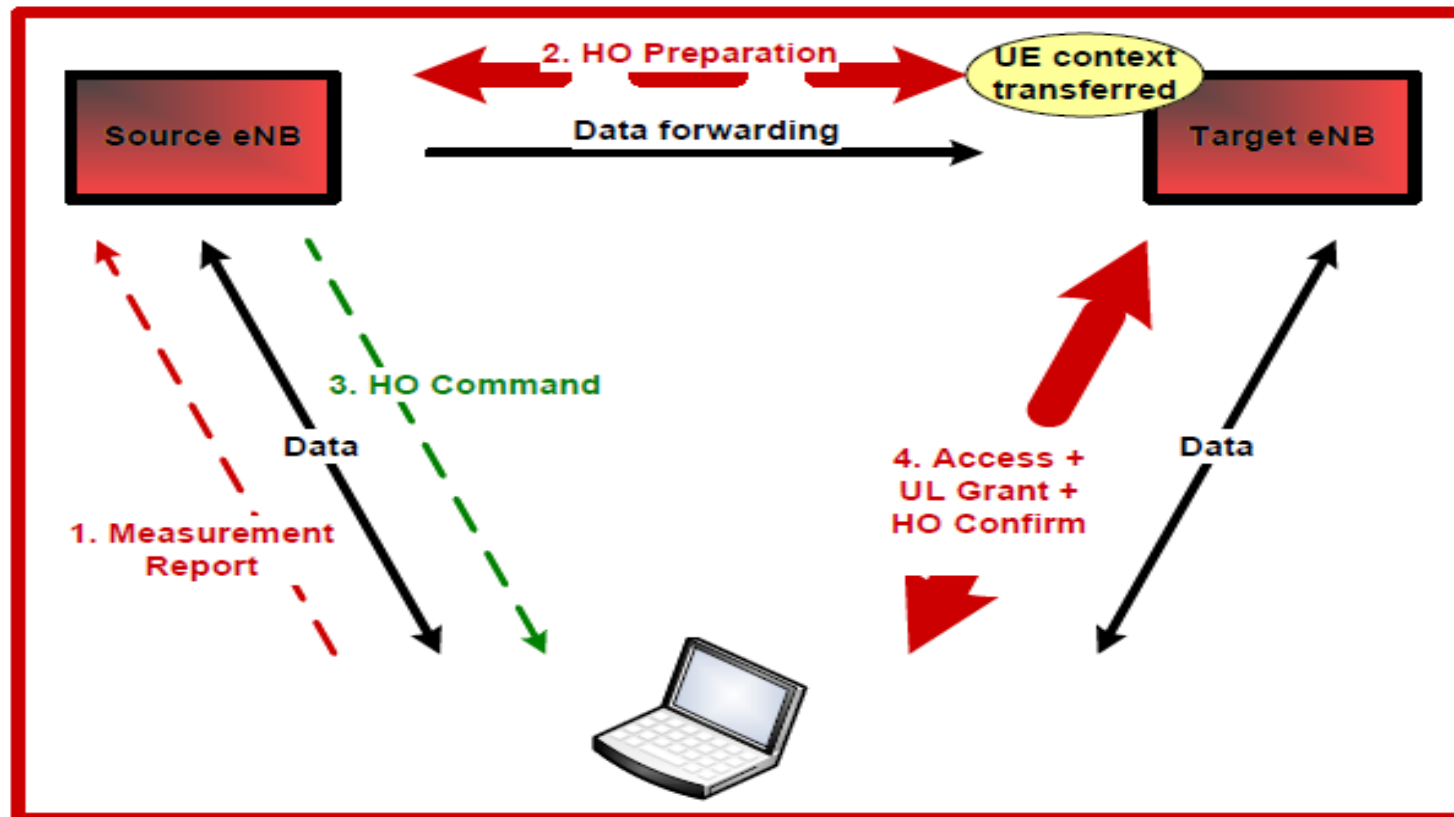


LTE active mode mobility - handover

- In Active mode, the network knows the cell to which the UE belongs and can transmit/receive data from the UE.
- UE active mode mobility is mainly a network controlled mobility.
 - Normally it is called handover.
- The E-UTRAN decides when to make the handover and what the target cell is.
- During handover, the source cell, based on measurement reports from the UE, determines the target cell and queries the target cell if it has enough resources to accommodate the UE.
- The target cell also prepares radio resources before the source cell commands the UE to handover to the target cell.



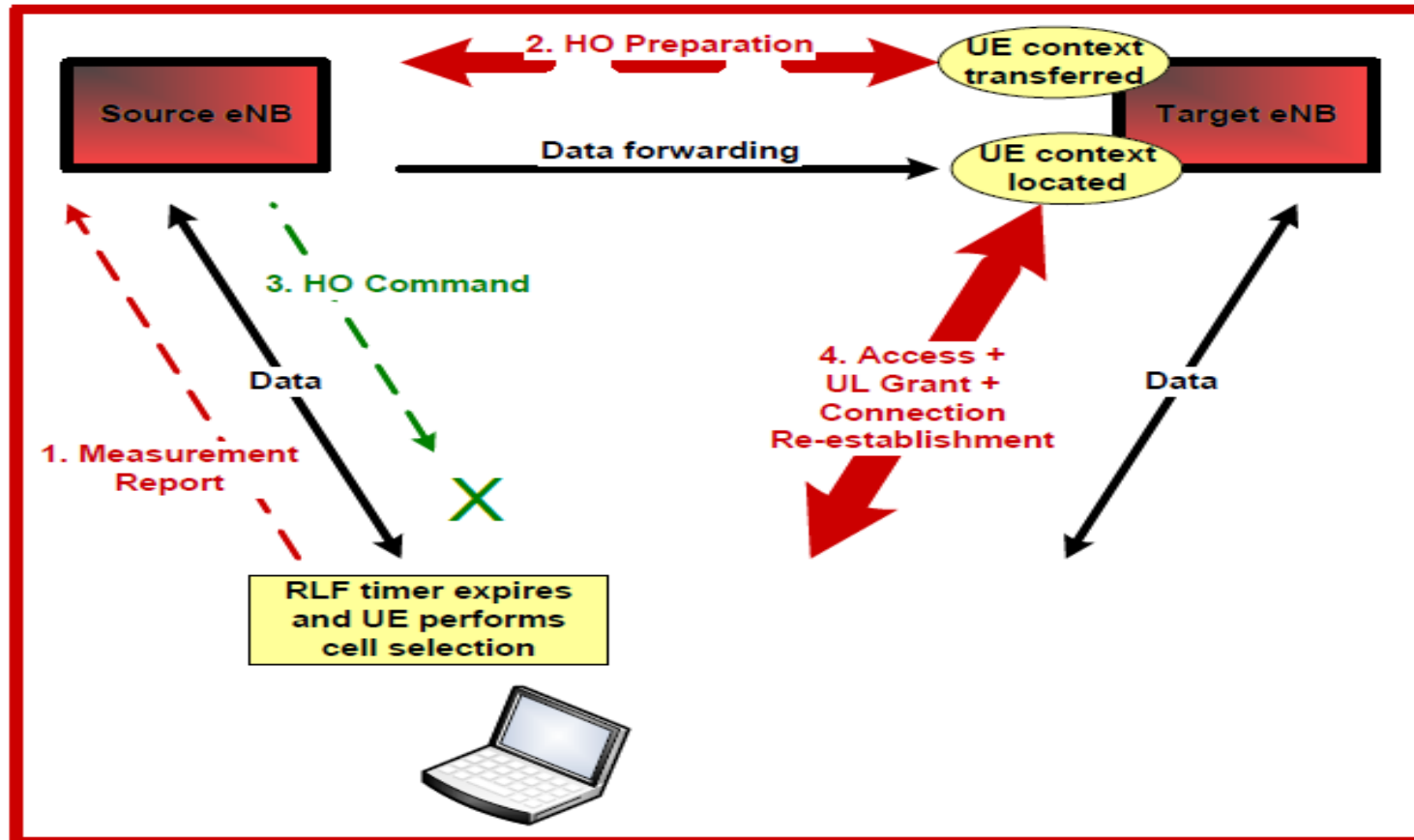
Backward Handover



Source: "LTE Mobility Enhancement", Qualcomm Technical Report.



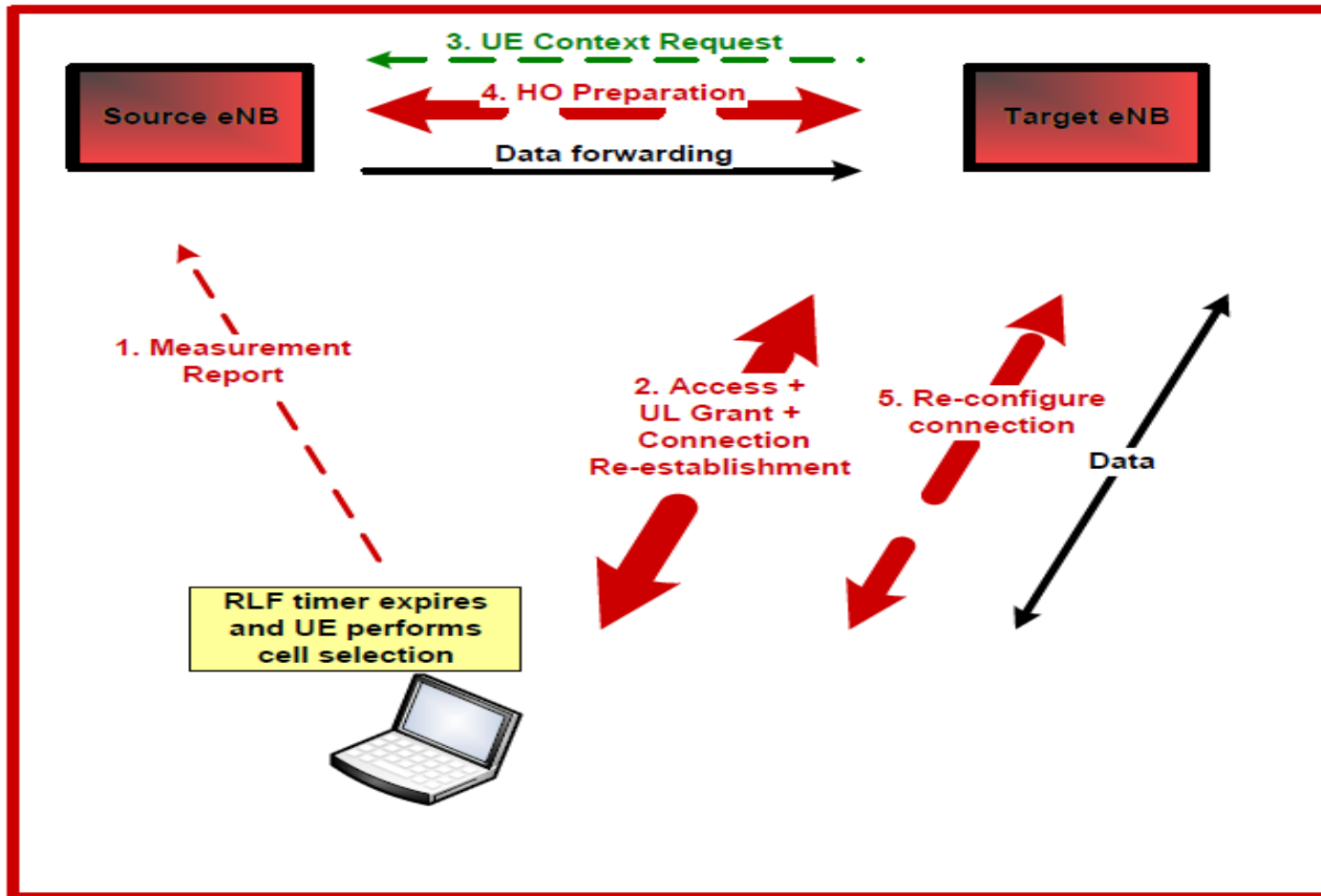
RLF during handover



Source: "LTE Mobility Enhancement", Qualcomm Technical Report.



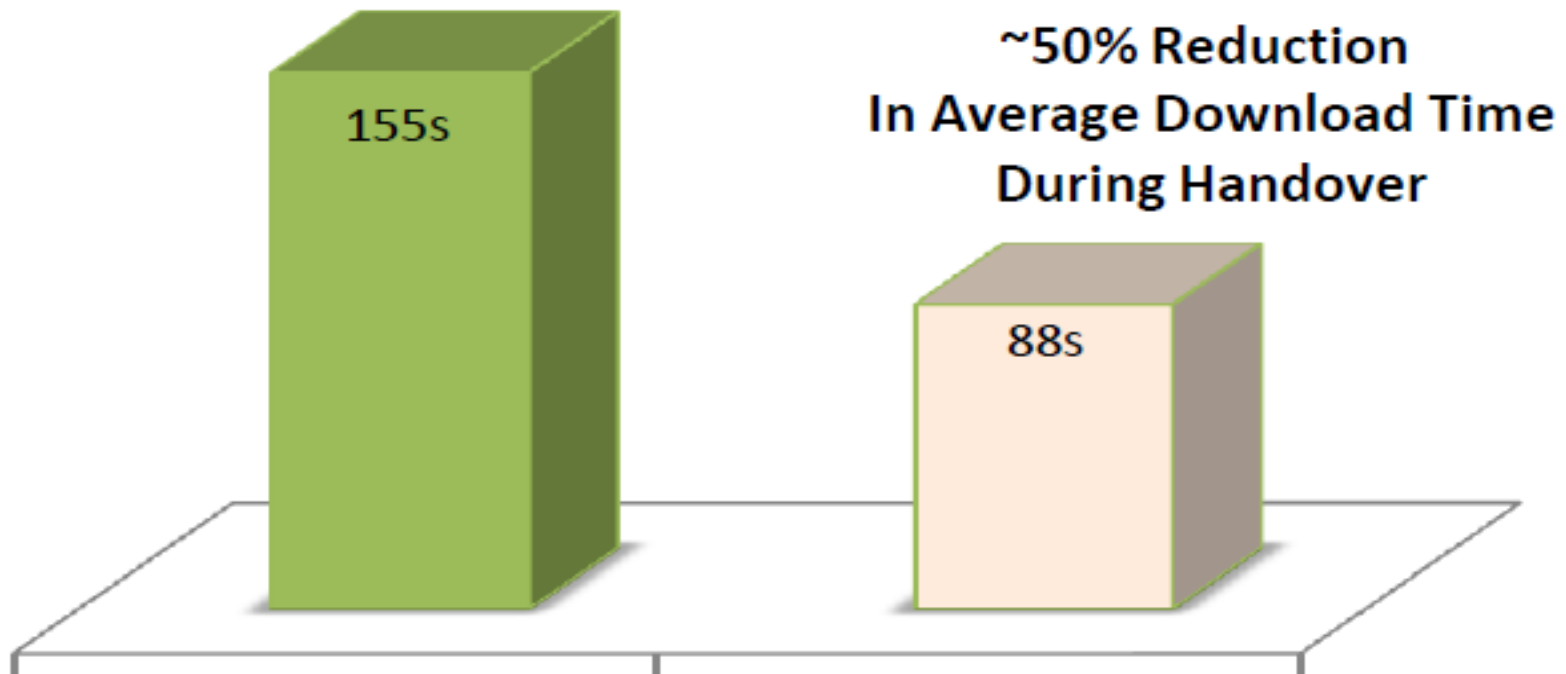
Forward handover



Source: "LTE Mobility Enhancement", Qualcomm Technical Report.



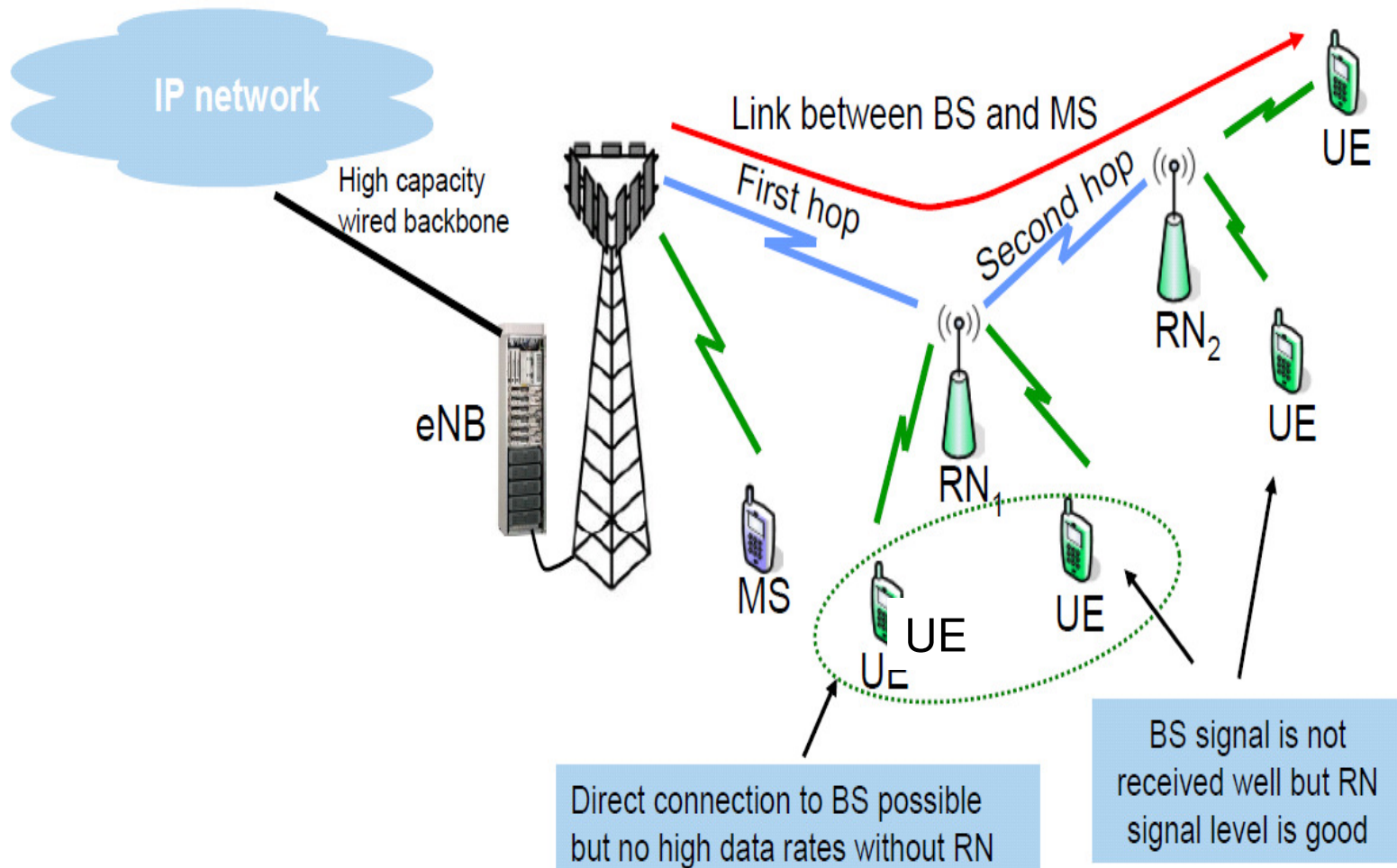
Backward vs. Forward handover



Source: "LTE Mobility Enhancement", Qualcomm Technical Report.



Cell Selection



Cell selection is critically important in a relay network



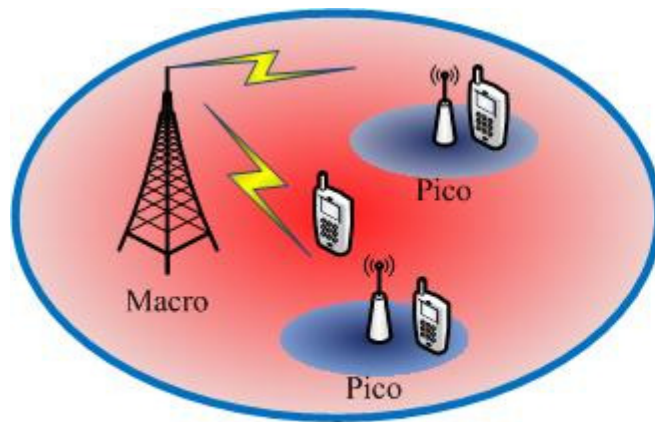
Mobile association issues in hetnets

- In conventional cellular systems, UE associates with a base station that has the best DL SINR.
- In a Hetnet, UEs with larger Macro SINR may have lower path loss to micro nodes thus causing significant UL interference at the lower power base stations.
- Thus micro-cell coverage is significantly limited in the presence of macro coverage.

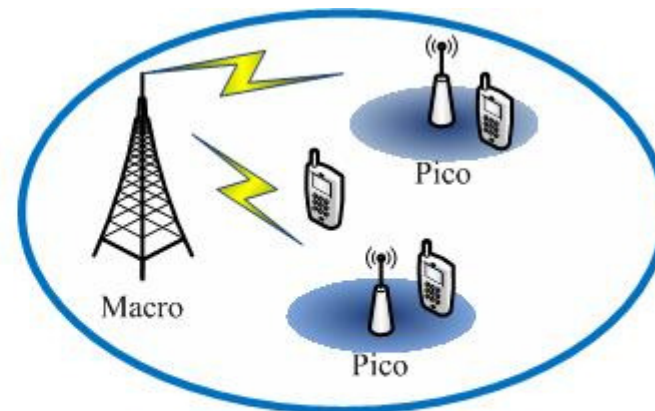


Range expansion

- ❖ Range Expansion increases footprint of co-channel Picos/Femtos
 - Allows more UEs to be served by low power eNBs
 - More equitable distribution of capacity among Macros and Picos/Femtos
- ❖ Full Range Expansion can be supported in LTE-Advanced
 - Large bias to compensate the power difference between Macro and Pico
 - Enabled by resource partitioning and enhanced UE receiver

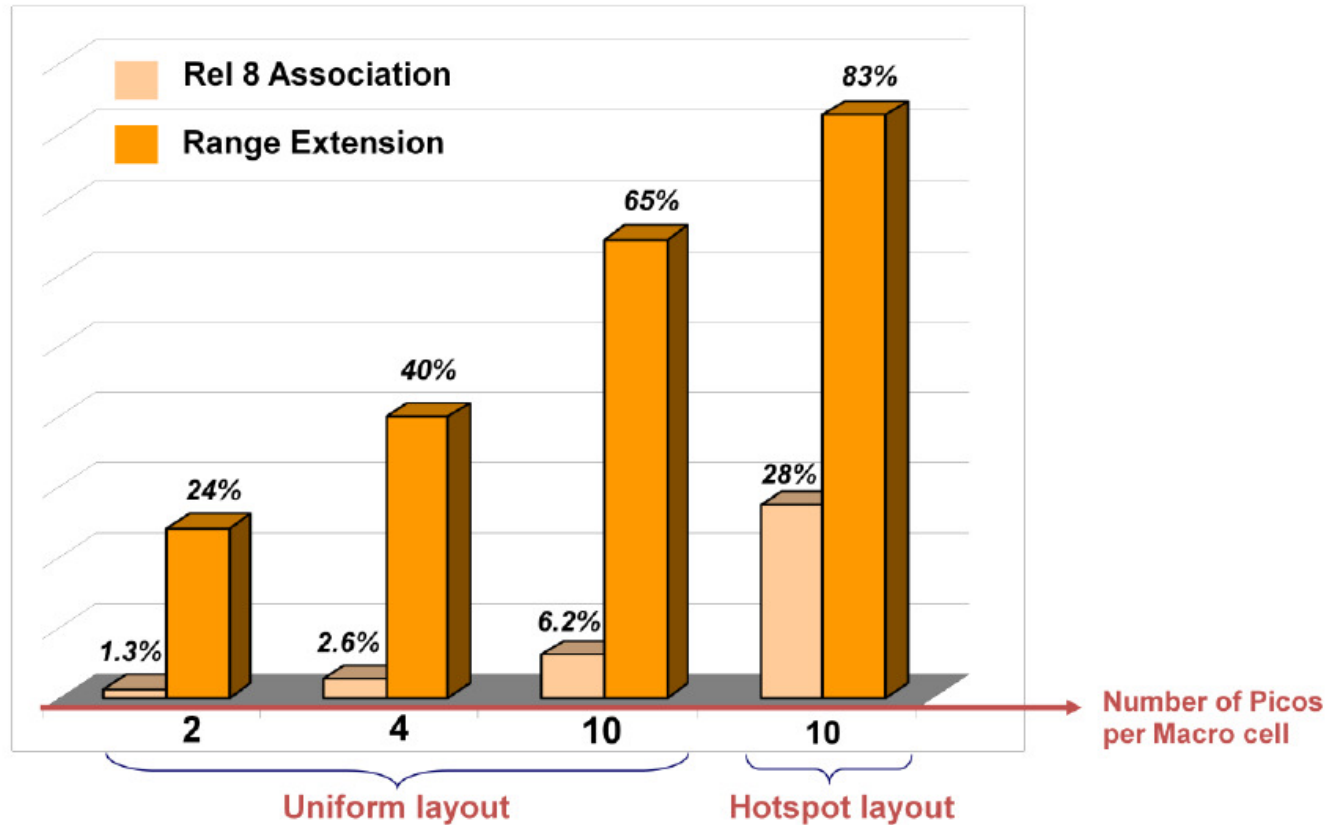


In subframes reserved for Macros
Limited footprint of Picos due to Macro signal



In subframes reserved for Picos
Increased footprint of Picos when Macro frees up resource

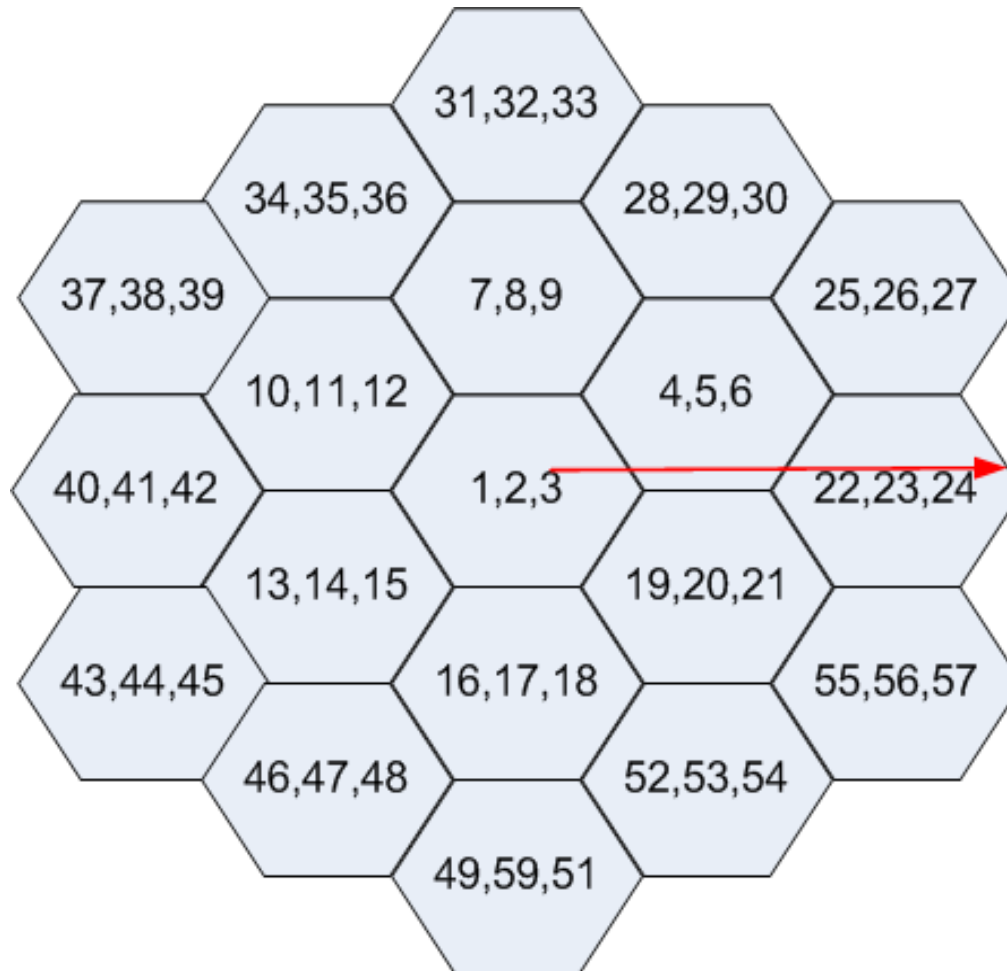
Range expansion association statistics



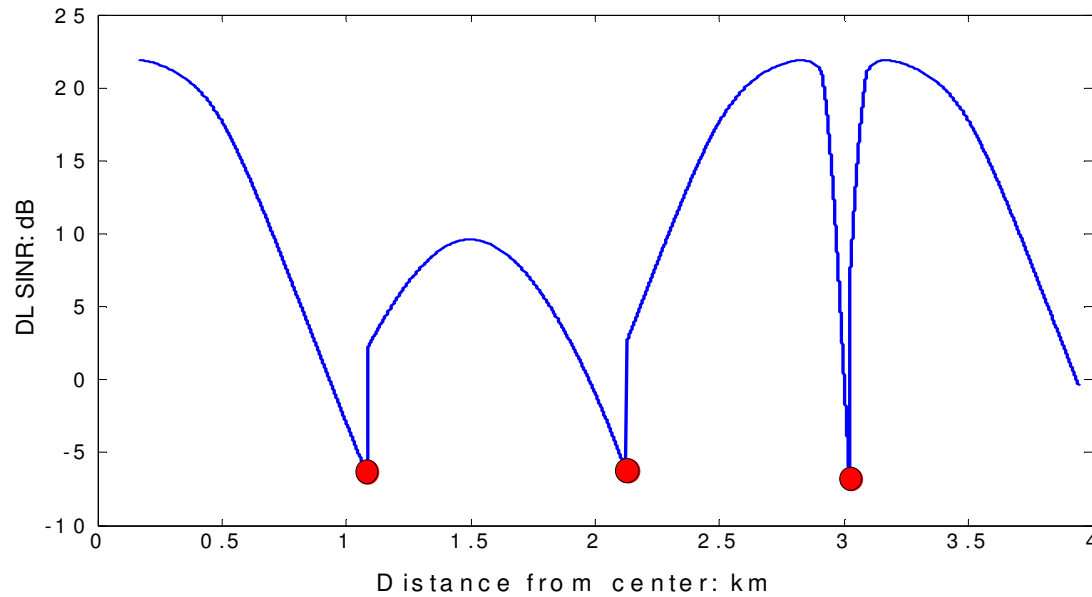
Source: "LTE Advanced: Heterogenous Networks", Qualcomm White Paper



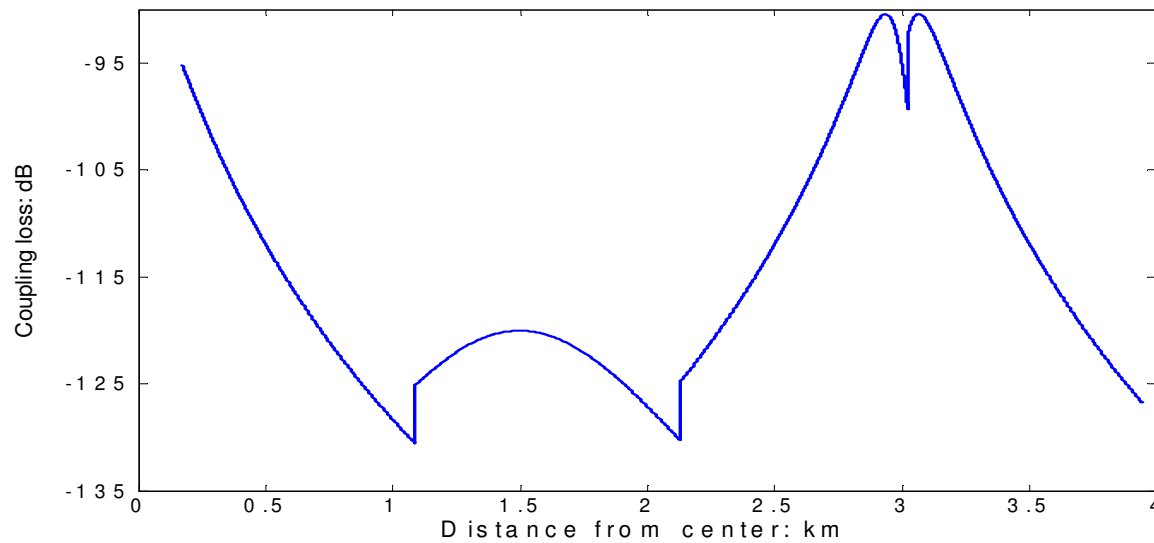
LTE hetnet mobility example



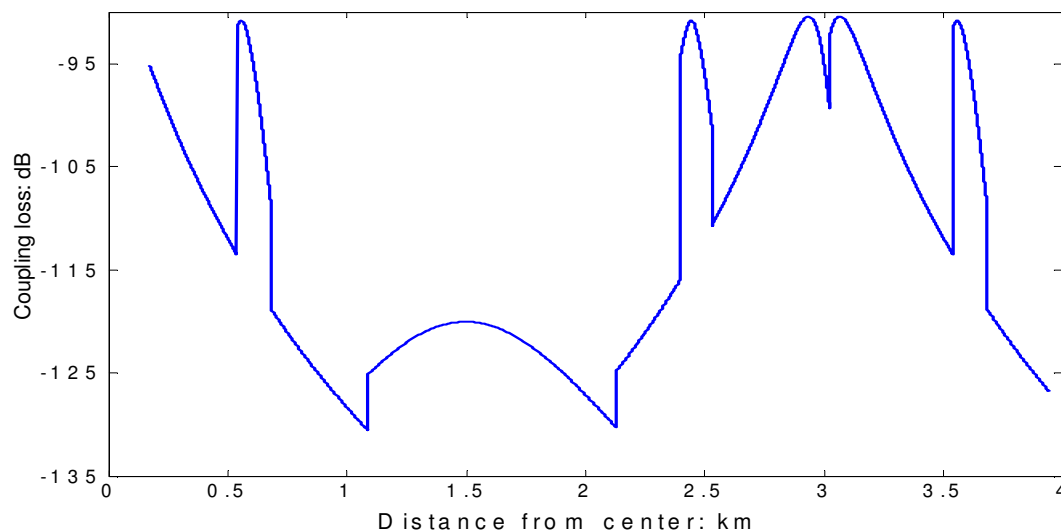
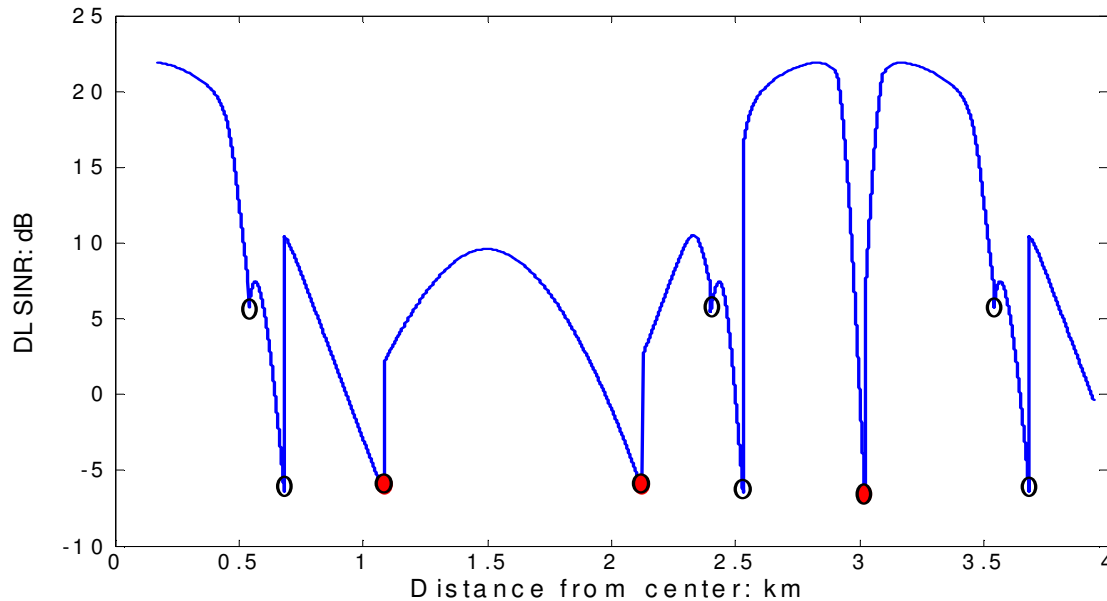
Handover in a homogenous network



Num. of Handovers	3
Avg. SINR	11.3 dB
Avg. CL	114.3 dB



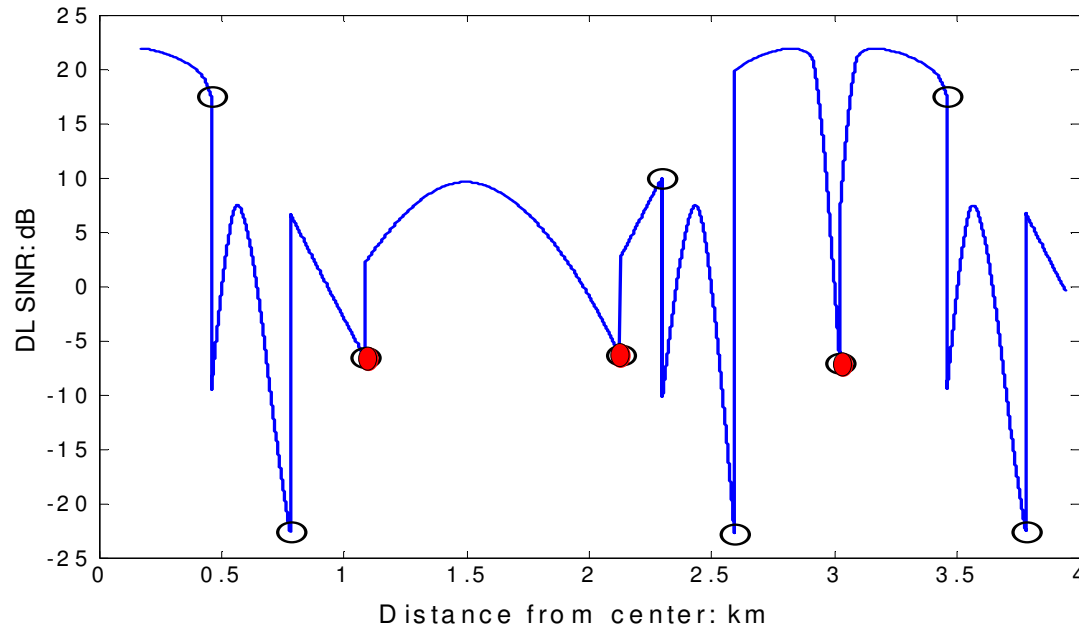
Handover in hetnet with best power cell selection



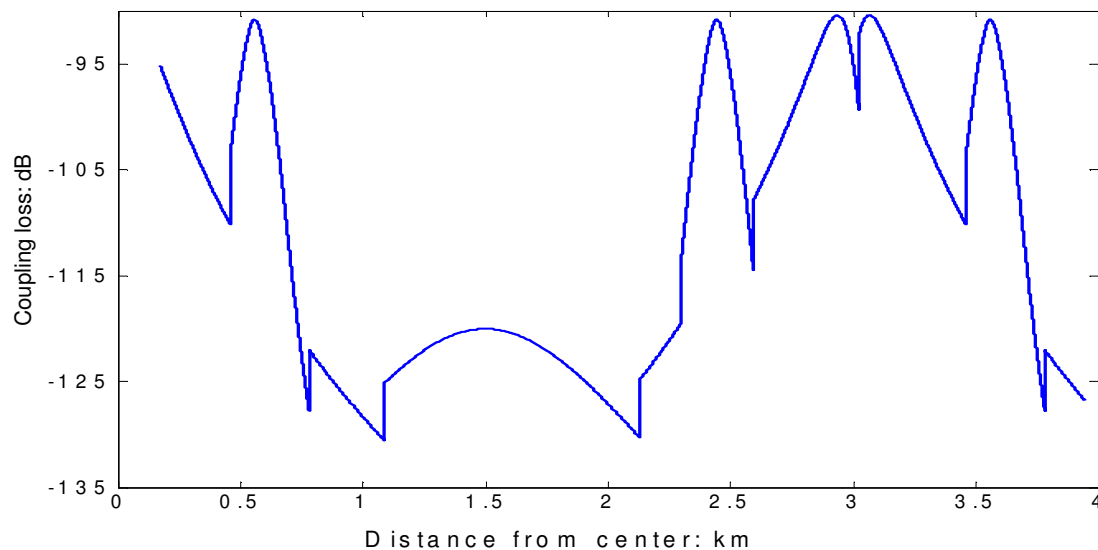
Num. of Handovers	9
Num of eNB handovers	3
Num of RN handovers	6
Avg. SINR	9.74 dB
Avg. CL	112.2 dB

- Handover is based on DL power.
- Compared with no relay, number of handovers is increased.
- With relay, the average UE DL SINR actually decreases.
- With relay, the average coupling loss improves.

Handover in hetnet with range expansion cell selection



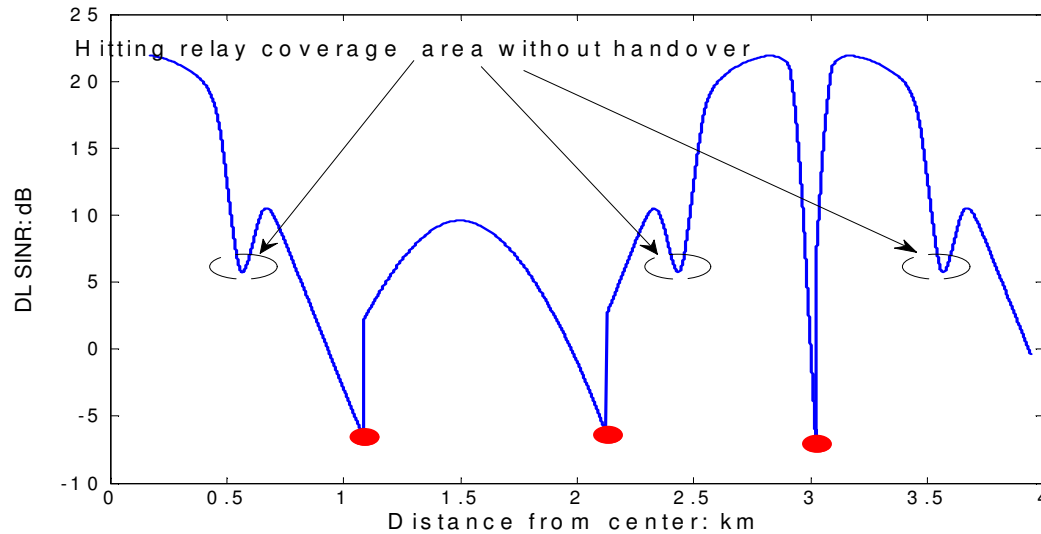
Num. of Handovers	9
Num of eNB handovers	3
Num of RN handovers	6
Avg. SINR	7.05 dB
Avg. CL	111 dB



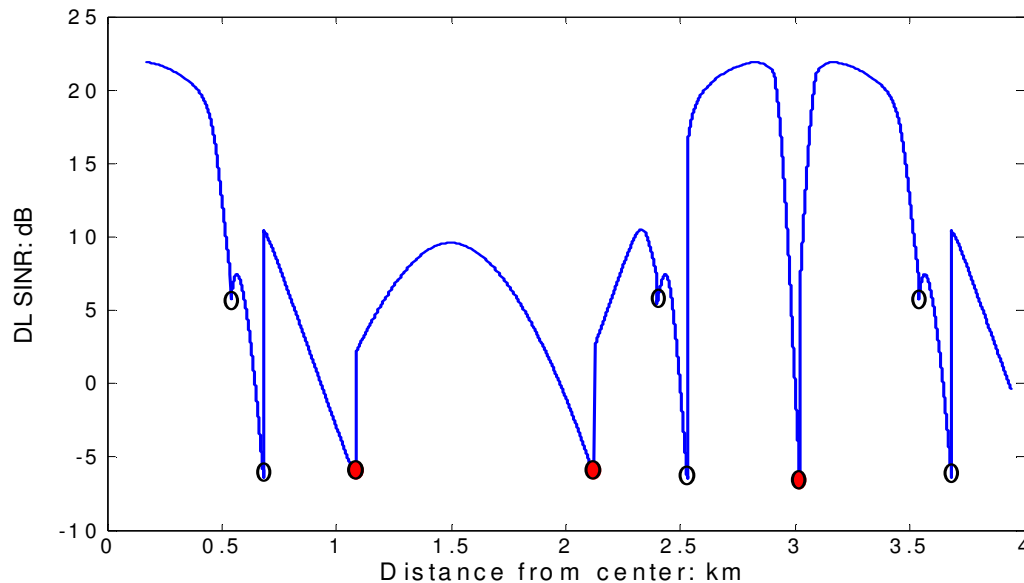
- Handover is based on pathloss.
- Compared with DL power based handover
 - Number of handovers is pretty much the same.
 - The average UE DL SINR actually decreases.
 - The average coupling loss improves.



Handover for high mobility UEs



	no relay	with relay
Num. of Handovers	3	9
Num of eNB handovers	3	3
Num of RN handovers	0	6
Avg. SINR	10.6	9.74
Avg. CL	114	112.2



- For UEs moving with high speed in a relay network
 - Choosing target cells only among macro-eNBs reduces the number of handovers greatly.
 - By doing so, the SINR and coupling loss are still comparable.



Hetnet mobility research

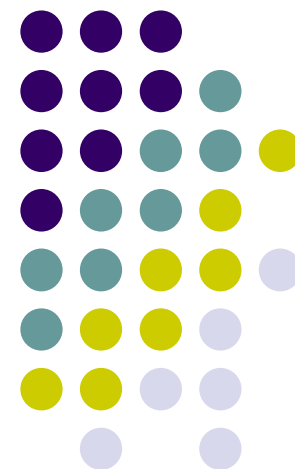
- Seamless and robust mobility of users from LTE macro to small BTS-layer, and vice versa, shall be supported to enable offload benefits. Scenarios with more BTS-layers and multiple carriers also means that there are more potential error cases, and therefore additional re-establishment procedures could help improve the overall system robustness.
- Efficient small cell discovery is important to ensure efficient offload from macro to small cells, and is therefore recommended to be studied in more details – especially for case where cells are on different carriers. Today autonomous UE mobility state estimation is based purely on number of experienced cell changes, but without explicitly taken the cell-size into account. This may cause some unfortunate effects in HetNet scenarios, so it is suggested to study related improvements; e.g. to ensure good solutions for avoiding high-mobility users on small BTS layer.

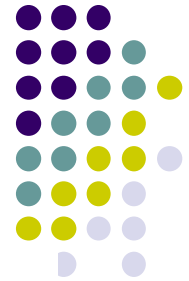


Hetnet mobility research items

- Identify and evaluate strategies for improved small cell discovery/identification.
- Identify and evaluate HetNet mobility performance under established Rel-10 eICIC features e.g., Almost Blank Subframe
- Further study and define automatic re-establishment procedures that can help improve the mobility robustness of HetNet LTE networks. Evaluate performance benefits of enhanced UE mobility state estimation and related functionalities, and other possible mobility solutions to take different cell-sizes into account.
- Robust mobility functionality under various supported assumptions for the availability of UE measurements (including DRX functionality) shall be ensured/taken into account as well as UE power consumption and complexity
- Further study and define mobility enhancements for Home eNodeBs with multiple carriers (or CA) with CSGs (potentially different CSG on different carriers)

SON in Hetnet

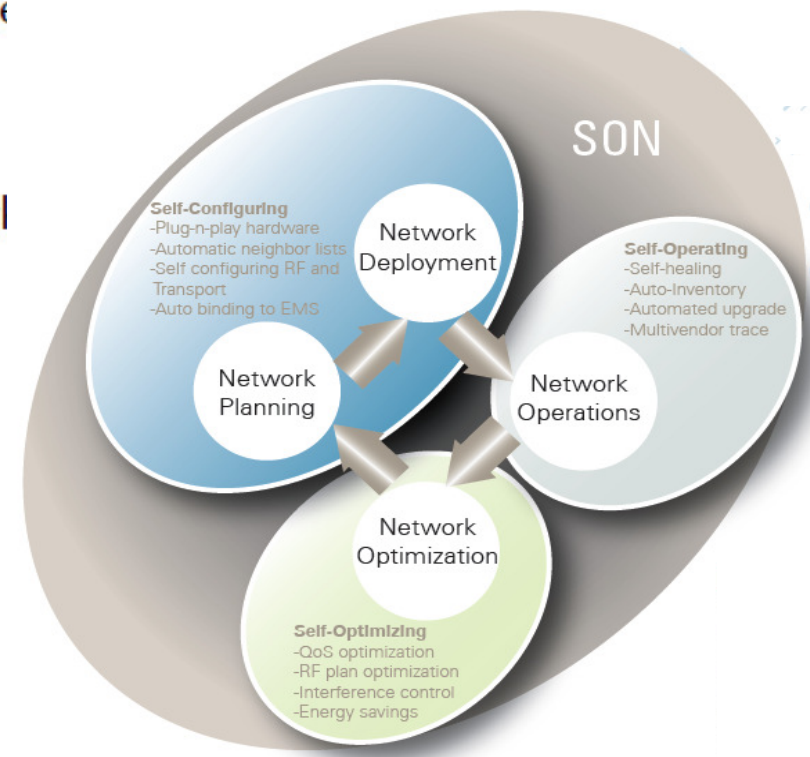




Main driver for SON

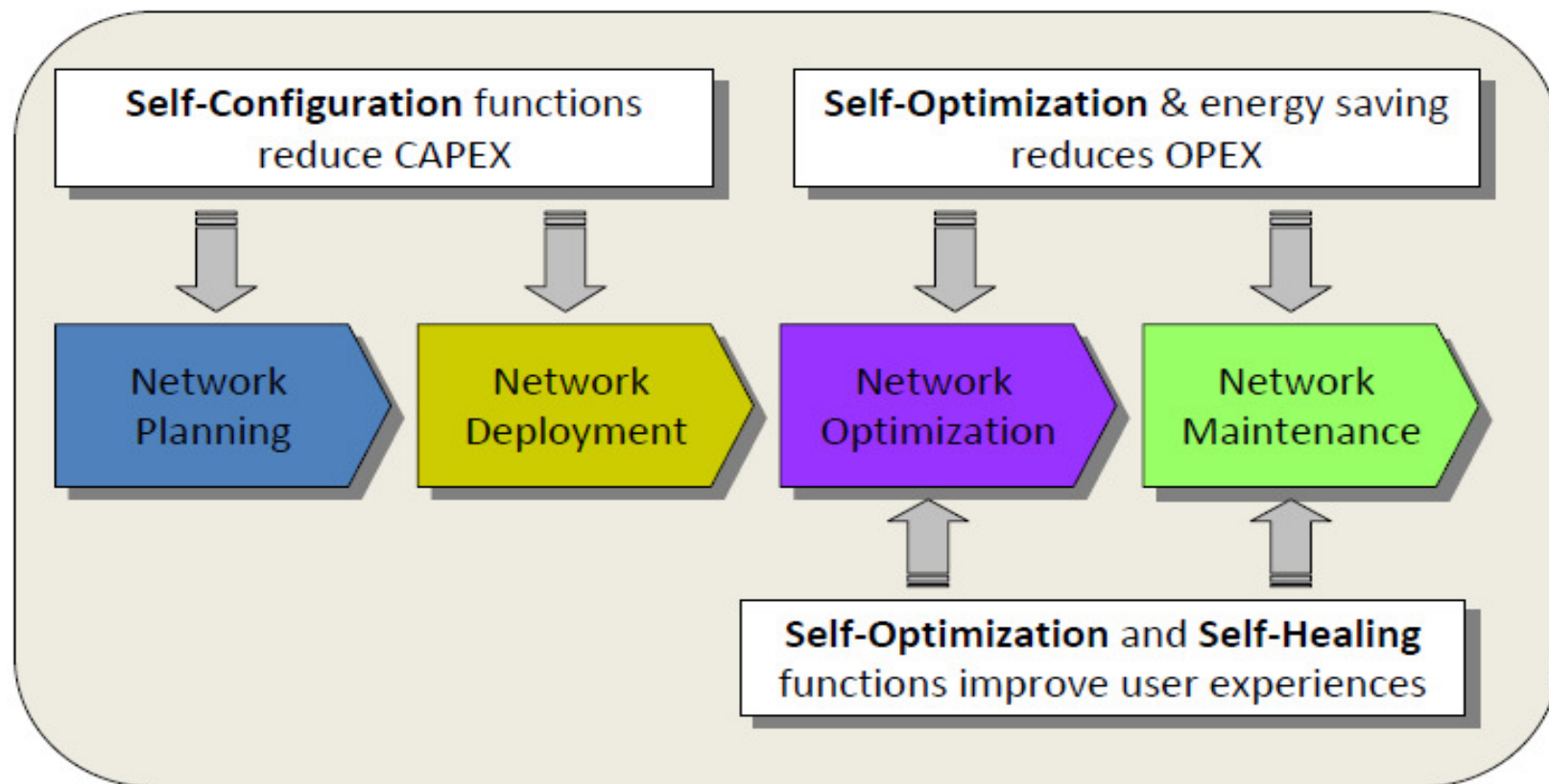
- ▶ Rollout of the LTE leads to
 - rapidly expanding number of Base Stations (new sites)
 - parallel operation of 2G, 3G and LTE
 - much higher complexity in network infrastructure and network management (Operation & Maintenance)

- ▶ Self-Organizing Network (SON) aims to configure and optimize the LTE network automatically by
 - **Self-Configuration**
 - **Self-Optimization**
 - **Self-Healing**





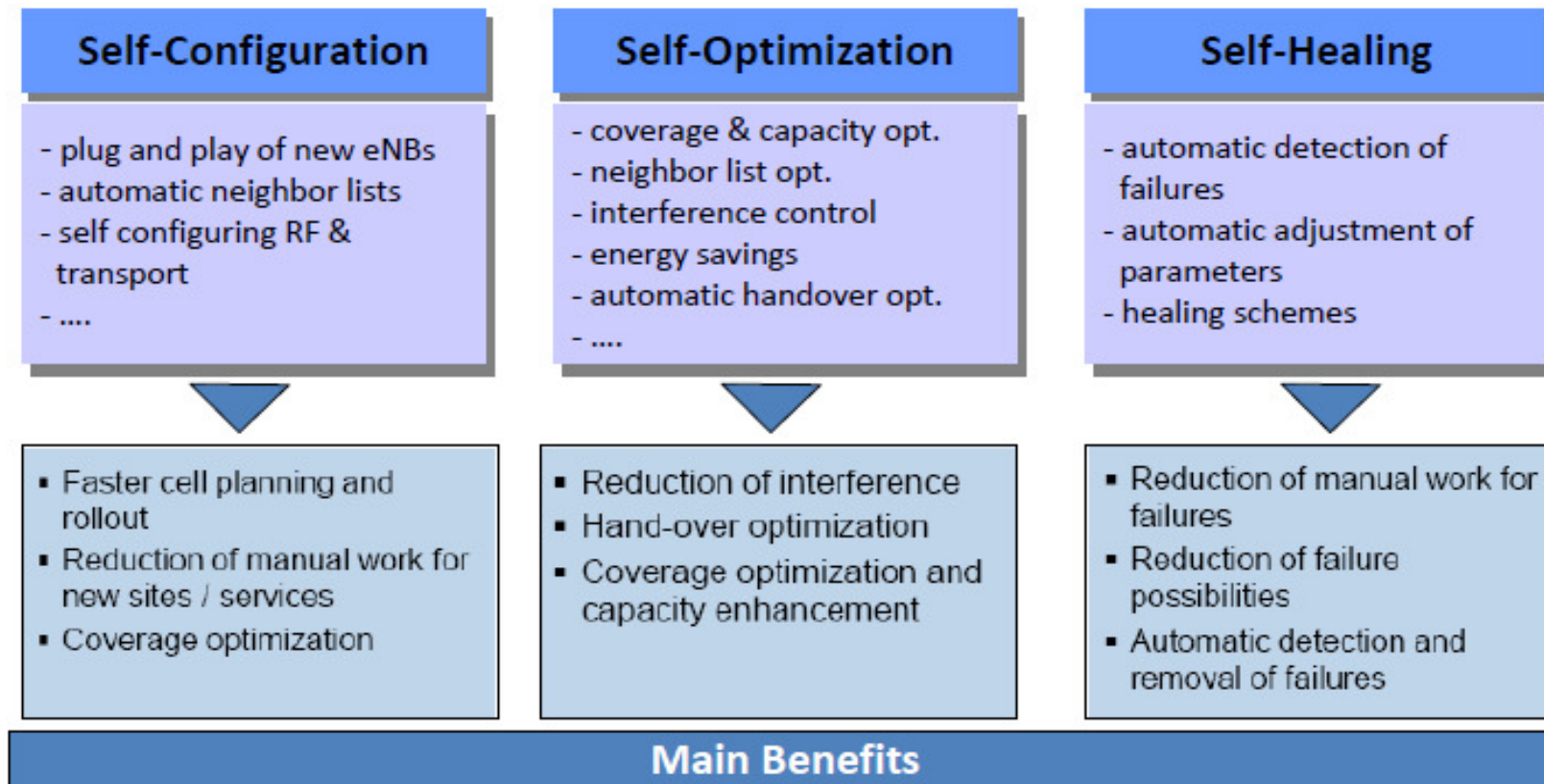
Main Objective of SON



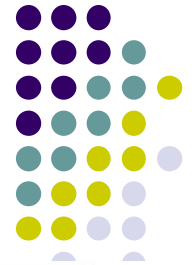
Source: "Overview and Research Aspects of LTE SON", ITG FG5.2.1 Workshop



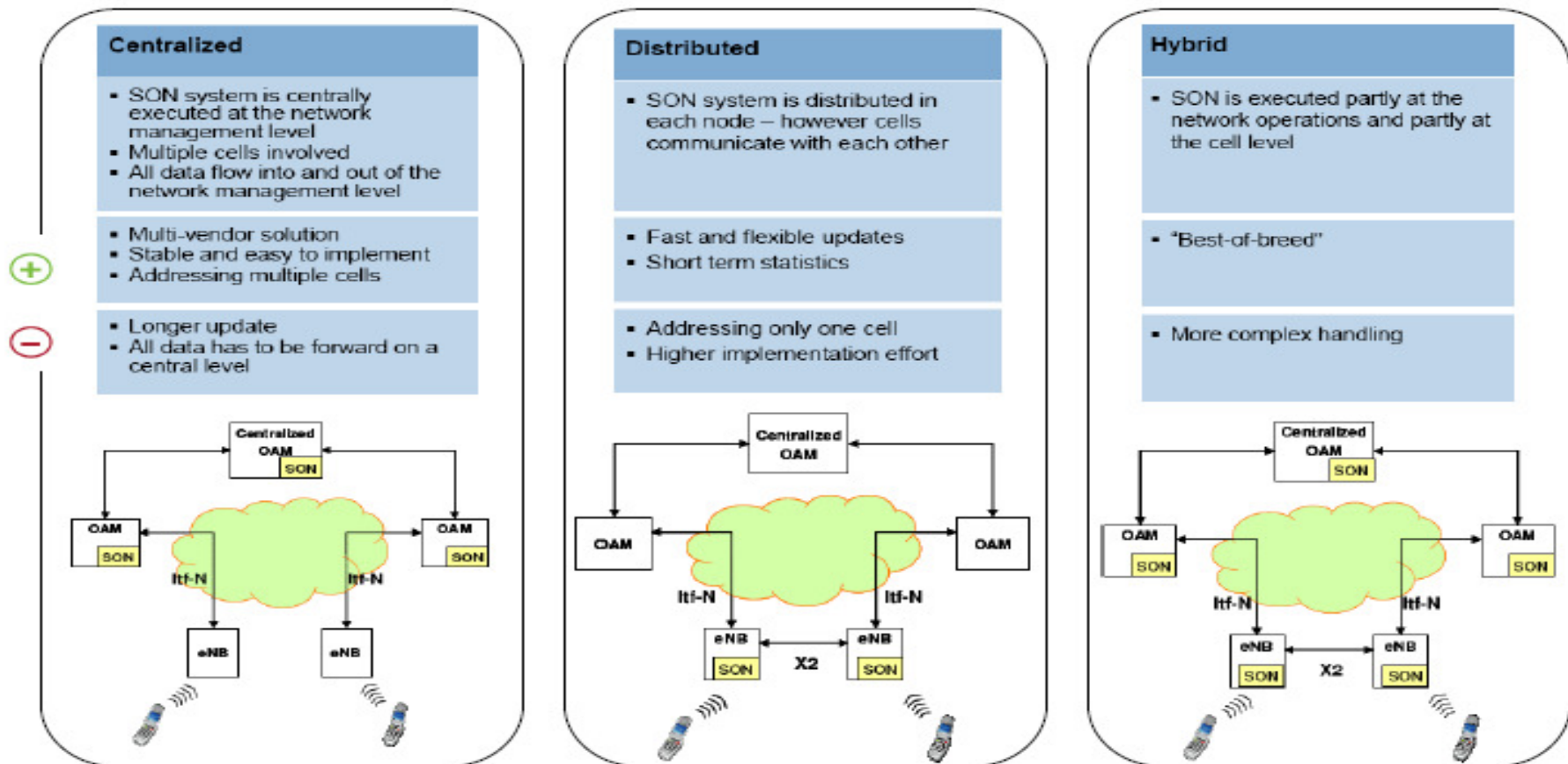
Functionalities of SON



Source: "Overview and Research Aspects of LTE SON", ITG FG5.2.1 Workshop



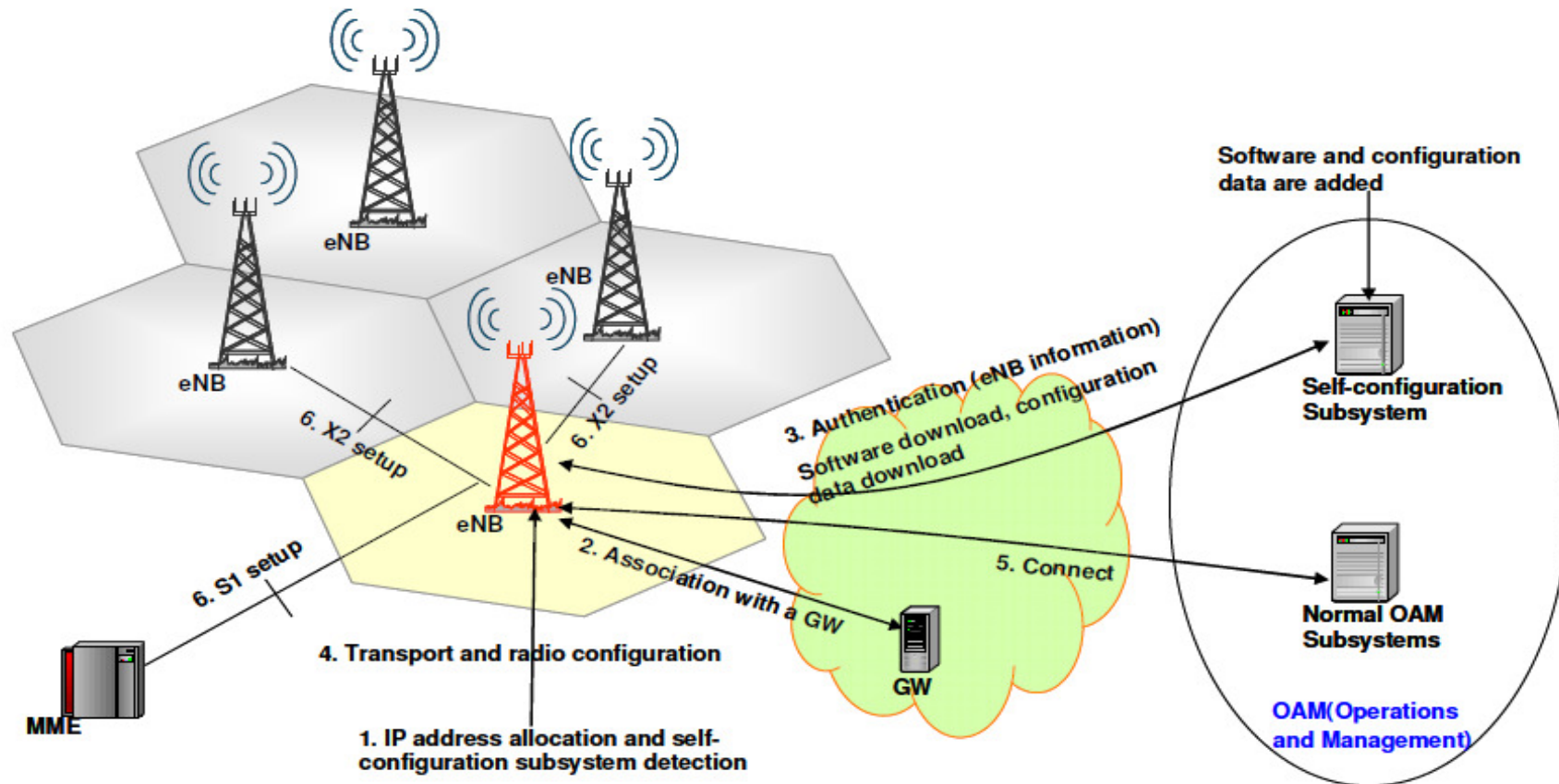
SON architecture



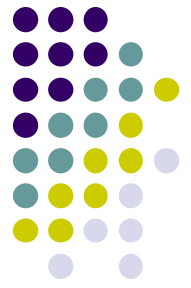
Source: “Overview and Research Aspects of LTE SON”, ITG FG5.2.1 Workshop



SON Procedure



Source: "Overview and Research Aspects of LTE SON", ITG FG5.2.1 Workshop



Main SON considerations

General considerations for all SON functions

- ▶ Define required measurements at the eNB and UE
 - Define the required measurement parameters
 - Define the measurement frequency for each parameter

- ▶ Define algorithms to trigger parameter adjustments
 - Determine the thresholds to trigger parameter adjustments
 - Determine the frequency of parameter adjustments

- ▶ Define rules of coordination and cooperation among different SON functions

- ▶ Design SON architecture
 - Centralized SON, or distributed SON, or hybrid SON



SON at LTE RAN (1)

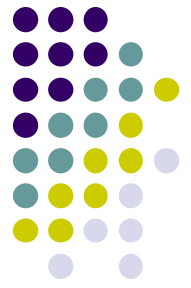
- ▶ **Mobility Load Balancing Optimization:** to optimize cell reselection/HO parameters to cope with the unbalanced traffic load
 - **What shall be the proper load definition?**
 - radio load, transport network load, or even the processing load
 - Split between uplink and downlink
 - Split between different QCI
 - **Algorithm for load balancing**
 - The algorithm can be based on radio load, or transport network load or both of them
 - If both radio load and transport network load are considered, which one will have higher priority?
 - The algorithm shall also consider differentiation among QCIs
 - **How to adjust parameters for cell reselection?**



SON at LTE RAN (2)

- ▶ **Coverage and Capacity Optimization:** to optimize the network coverage and maximize the system capacity
 - Solutions to **detect the coverage and capacity problems automatically** based on eNB measurements and UE reports
 - **Design a radio planning tool** to solve the problems
 - **Interference reduction**

- ▶ **Mobility Robust Optimization:** to automatically adjust the mobility parameters
 - Solutions to **solve the mobility problems**, e.g.
 - To identify a non-suitable cell
 - To identify problematic settings of cell selection/reselection parameters
 - Minimize HOs when a UE is transited from idle to active mode



SON at LTE RAN (3)

- ▶ **Energy Saving:** to cut on operation expenses by energy saving
 - **Switch off cells** (especially needed when a larger number of Home eNBs are deployed in the network)
 - Main issue: when to active and deactivate the eNBs and how?
 - **Adapt the transmission power**
 - Adapt the transmission power while also ensuring no influence on the coverage, handover and load balancing
 - **Adapt the multi-antenna schemes:** some of the antennas can be switched off to save the power
 - Adapt among SIMO, MIMO, Beamforming to achieve the maximum capacity with the minimum transmission power



SON at LTE Transport network

- ▶ Introduction of SON for the LTE Transport Network
 - To optimize the transport resources (i.e. capacity) utilization
 - To save the operation costs (for manual configurations) and bandwidth costs with optimized resource utilization

Possible Aspects:

- ▶ Automatic transport QoS optimization
- ▶ Automatic transport capacity allocation
- ▶ Load balancing in the transport network (e.g. applying traffic engineering methods)
- ▶ Transport admission and congestion control optimizations



SON at LTE Transport Network

- ▶ Transport SON functions:
 - **Dynamic bandwidth allocation**
 - Bandwidth allocation shall follow the changes in traffic load
 - estimating effective bandwidth
 - when to trigger the bandwidth update and how
 - **Dynamic tuning of QoS parameters**
 - e.g. DiffServ model parameters, scheduler parameters, buffer management parameters per QoS class
 - **Optimal configuration/re-configuration of eNB connectivity with the S-GW**
 - for the Multi-S1 scenario (i.e. one eNB connected with multiple GWs), how to configure/re-configure in case of one S-GW fails
 - **Optimal load balancing**
 - e.g. to apply MPLS (Multiprotocol Label Switching) Traffic engineering method

Why SON in hetnet



Challenges of complex topology(macro/pico/femto)

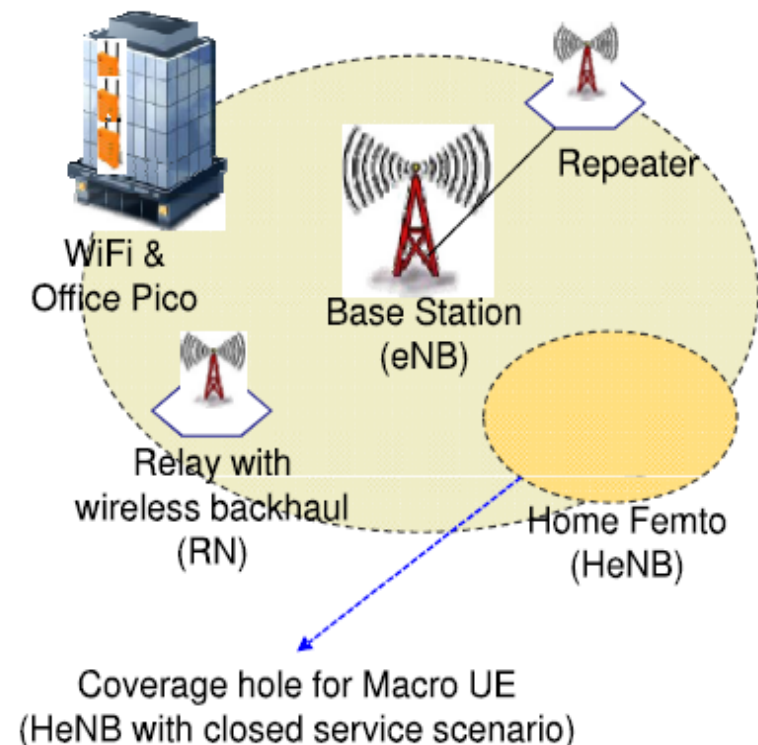
- Overlay network
- Complex topology and interference between nodes
- Optimization of “many” nodes
- Automated solutions is necessary to prevent OpEx increase

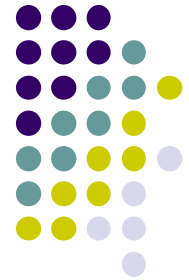
Problem:

Co-channel interference between macro-femto

- Coverage hole around femto AP(HeNB)
- Enhanced inter-cell interference cancelation (eICIC) is necessary
- 3GPP study item on heterogeneous network (HetNet) was created in April 2010.

Source: “SON in Heterogeneous Network”, by SK Telecom”





SON in hetnet

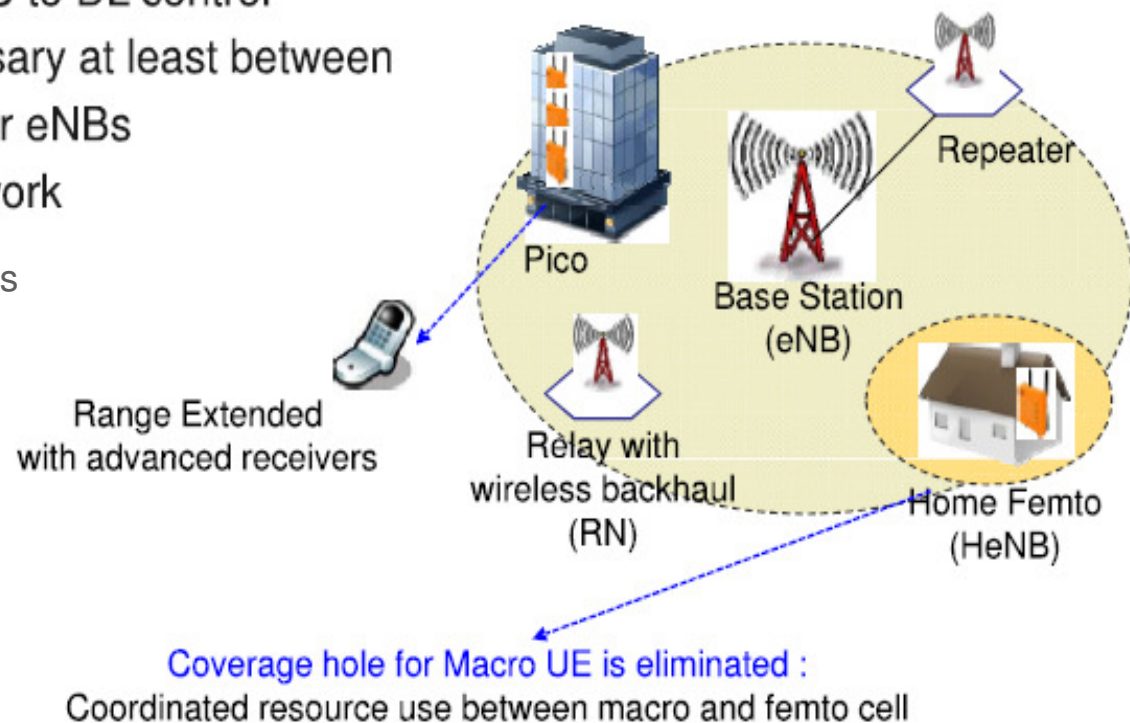
Range Extension(RE)

- UE ability to connect and stay connected to a cell with low SINR
- Achieved with advanced UE receivers - DL interference cancellation (IC)

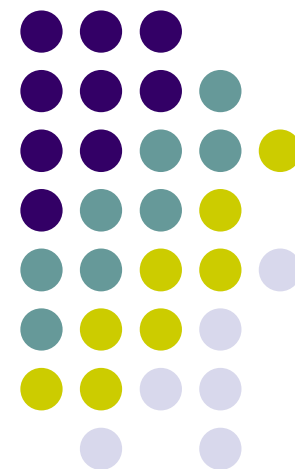
Enhanced Inter-Cell Interference Cancellation(eICIC)

- Effective extension of ICIC to DL control
- Synchronization is necessary at least between macro eNB and low power eNBs
- No impact on legacy network

Source: "SON in Heterogeneous Network", by SK Telecom"



Advanced Services





Advanced Services

- Machine-to-Machine communications
- Edge Cloud



What is M2M

- **Definition:**

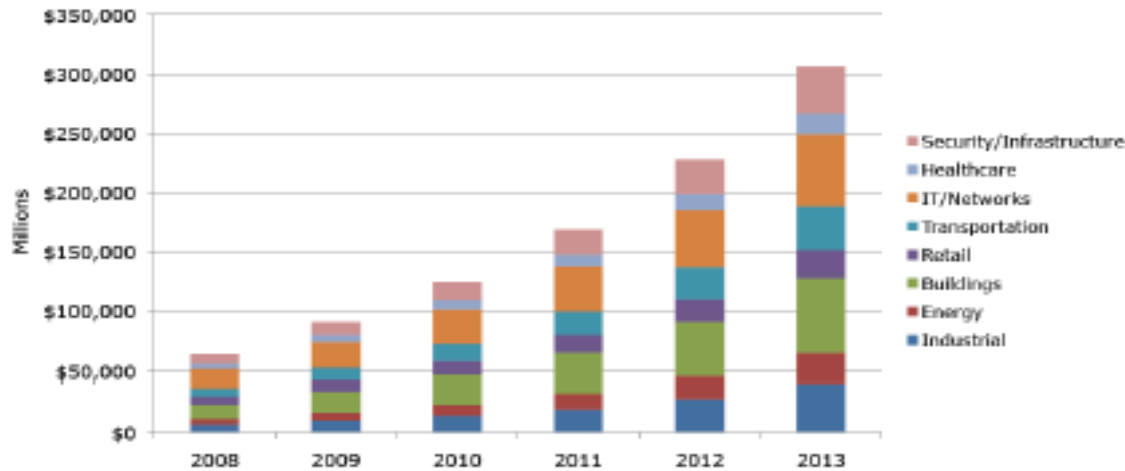
- Data communication between devices or device and server that may not require human interaction

- **Characteristics:**

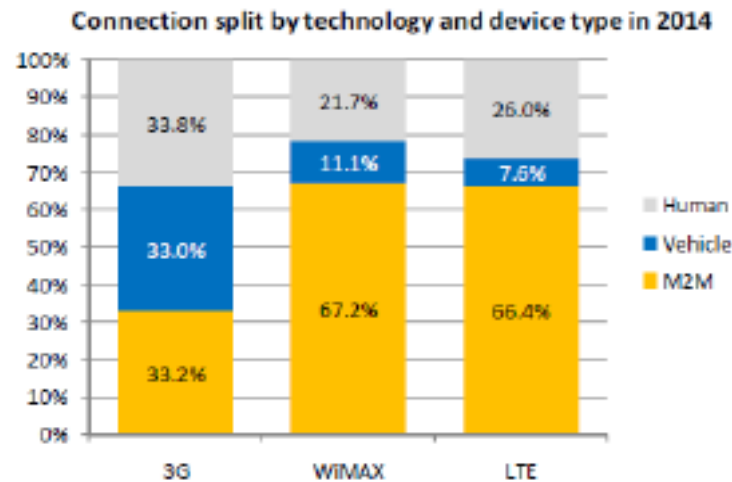
- Different business scenarios
- Potentially very large number of devices
- Small bursts per M2M device
- Device-originated connectivity
- Larger percentage of uplink traffic
- Lower cost and energy for M2M devices
- Coexistence with other RFs in neighboring M2M network



M2M Market



* Harbor Research (2009)

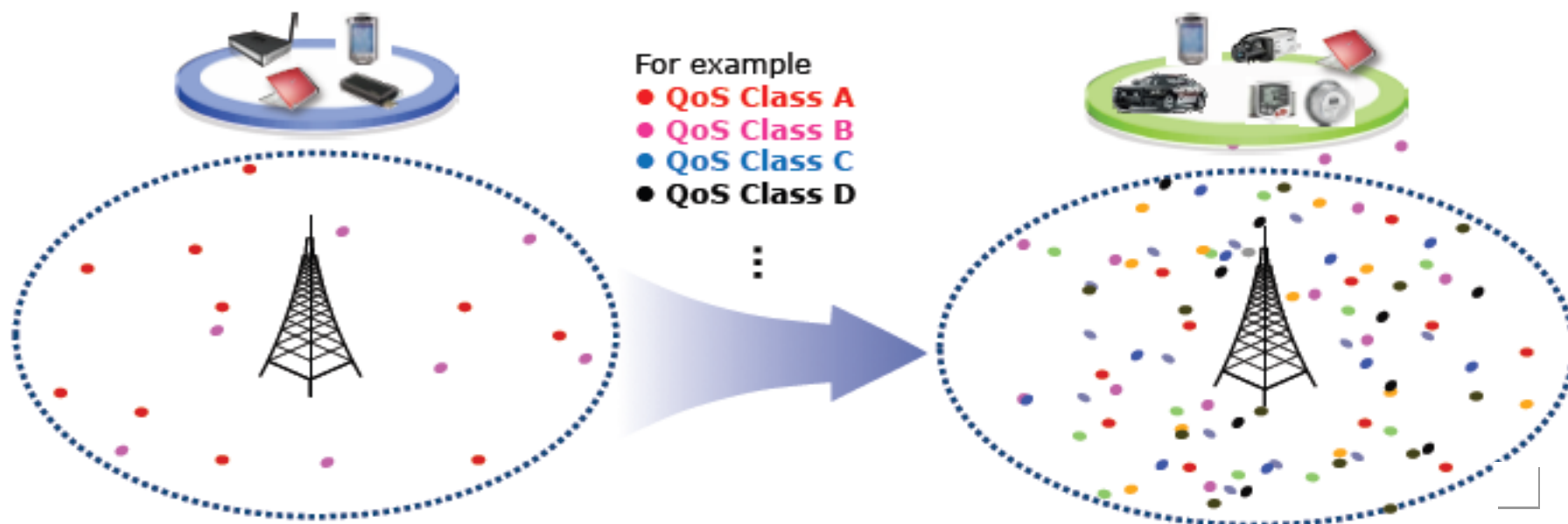


* SENZT FILI Report (2008)



M2M services

Service Area	M2M apps w/use cases requiring WAN range
Security & Public Safety	Surveillance systems, Control of physical access (e.g. to building), Car/driver Security
Tracking & Tracing	Fleet management, Order management, Pay as you drive, Asset Tracking, Navigation, Traffic Info, Tolls
Payment	Point of sales, Vending machines, Gaming machines
Healthcare	Monitoring vital signs, Supporting the aged or handicapped Web access telemedicine points, Remote diagnostics
Remote Maintenance/Control	Sensors, Lighting, Pumps, Valves, Elevator control, Vending machine control, Vehicle diagnostics
Metering (ex. Smart Grid)	Power, Gas, Water, Heating, Grid control, Industrial metering
Consumer Devices	Digital photo frame, Digital camera, eBook



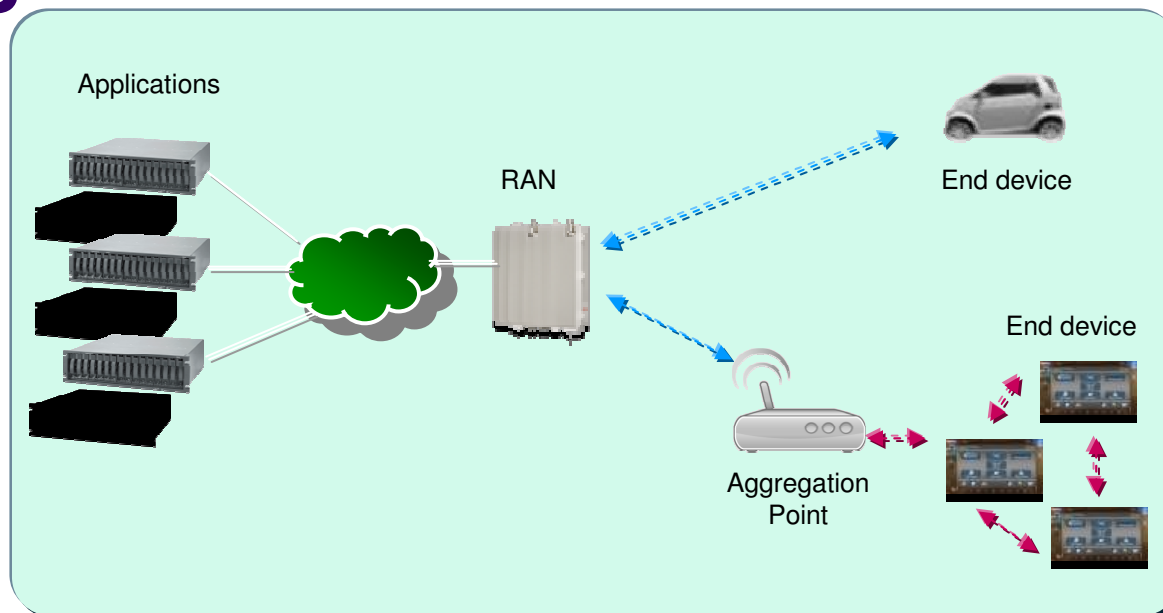


M2M features

HetNets

Features	M2M Apps	Standards Changes							
		M2M Coop. & Comm.	Sleep & Idle Mode	Mobility Mgmt	Link Adaptation	Burst Mgmt, BW Request & Allocation	HARQ & ARQ	Frame Structure & Zoning	Network Entry
Extremely low power	Metering Tracking Health Remote Maint & Ctrl	✓	✓	✓	✓	✓			
High Reliability	Security Metering Health Remote Maint & Ctrl	✓	✓	✓	✓	✓	✓	✓	
Access Priority	Health Remote Maint & Ctrl		✓			✓	✓	✓	
Active QoS Maintenance	Consumer Equipment	✓			✓	✓			
Mass device transmission	Security Metering Tracking Health	✓			✓	✓	✓	✓	✓

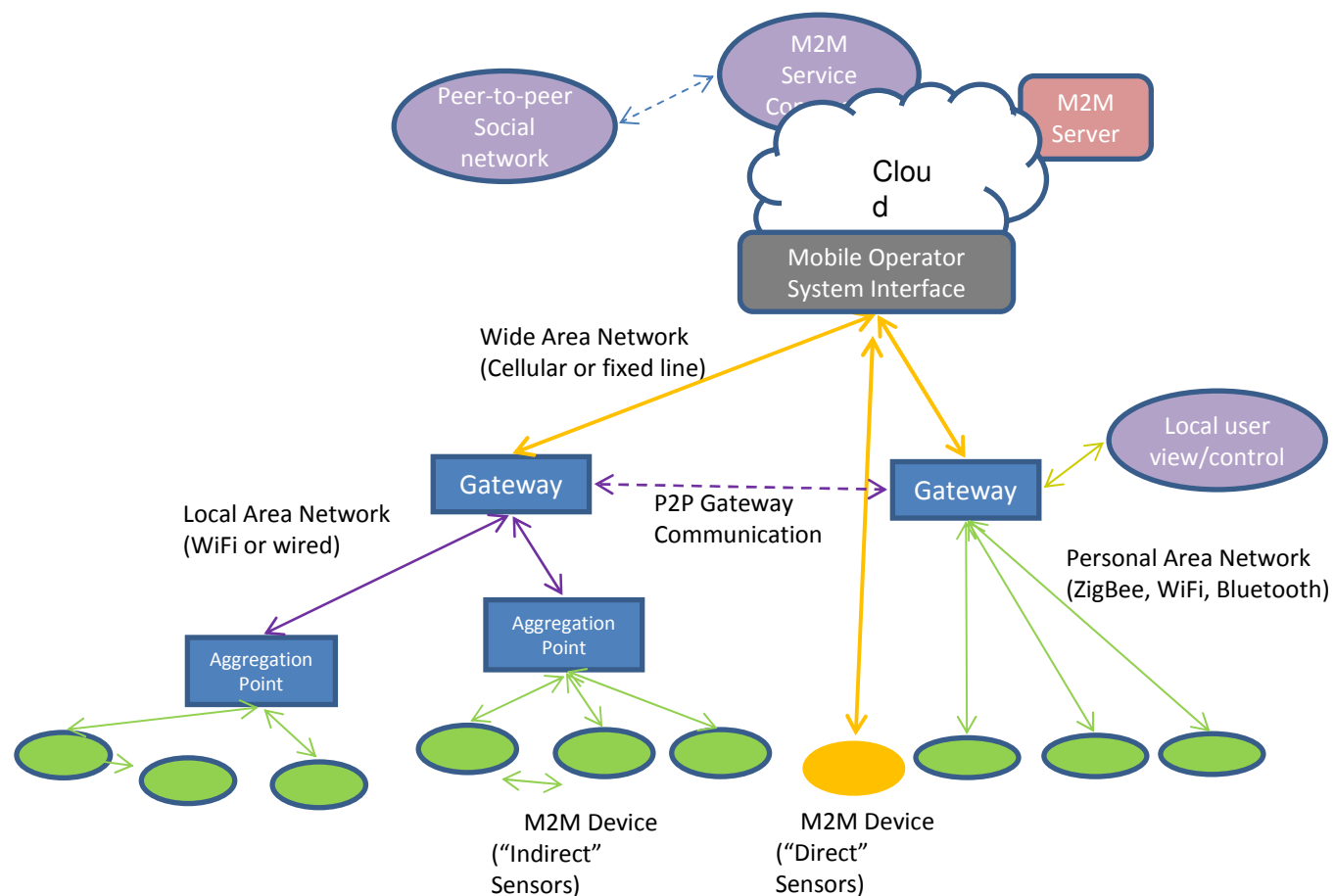
Network elements to support M2M features



Machine-2-machine services are enabled by HetNets

- Femtocells can serve as aggregation points for low-cost short range devices (**Mass device transmission**)
- Device co-operation/relaying can improve link from obstructed devices (**Reliability**)
- Mobile hotspots can aggregate data from sensors (ex. body area network, cars), and send to cloud for processing (**Low power**)

M2M Network Architecture



- Many M2M apps require communication between devices on differing networks
- M2M networks will need to be hierarchical (multi-tier), interwork efficiently with other RATs (multi-RAT), and support low cost devices (energy efficient)

M2M: Smart Vehicle

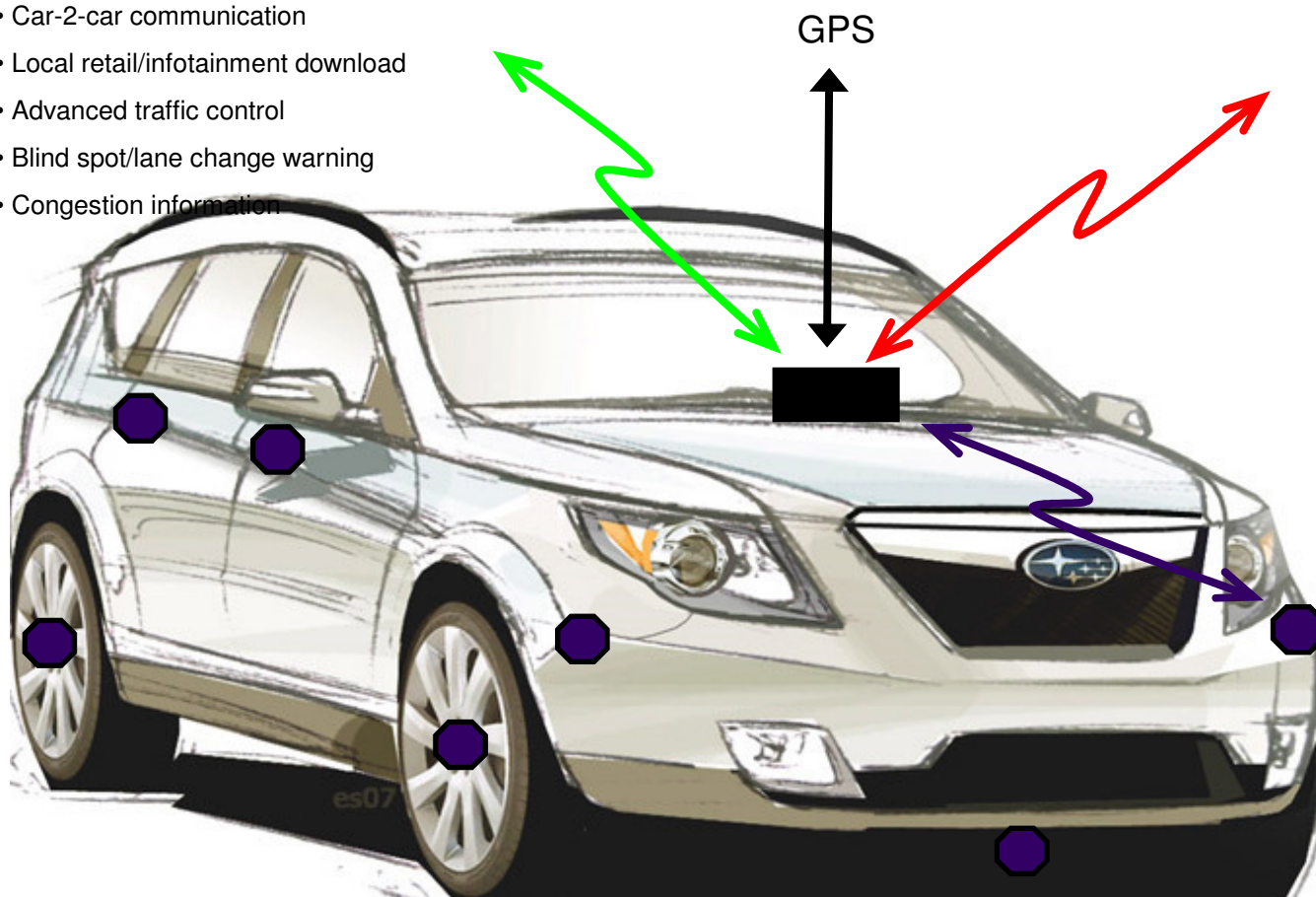
- Services include infotainment, safety, security, diagnostics...

WLAN

- Smartphone/laptop web access
- Car-2-car communication
- Local retail/infotainment download
- Advanced traffic control
- Blind spot/lane change warning
- Congestion information

WWAN

- WLAN "backhaul"
- Infotainment
- Emergency call/crash report
- Vehicle tracking
- Secured access



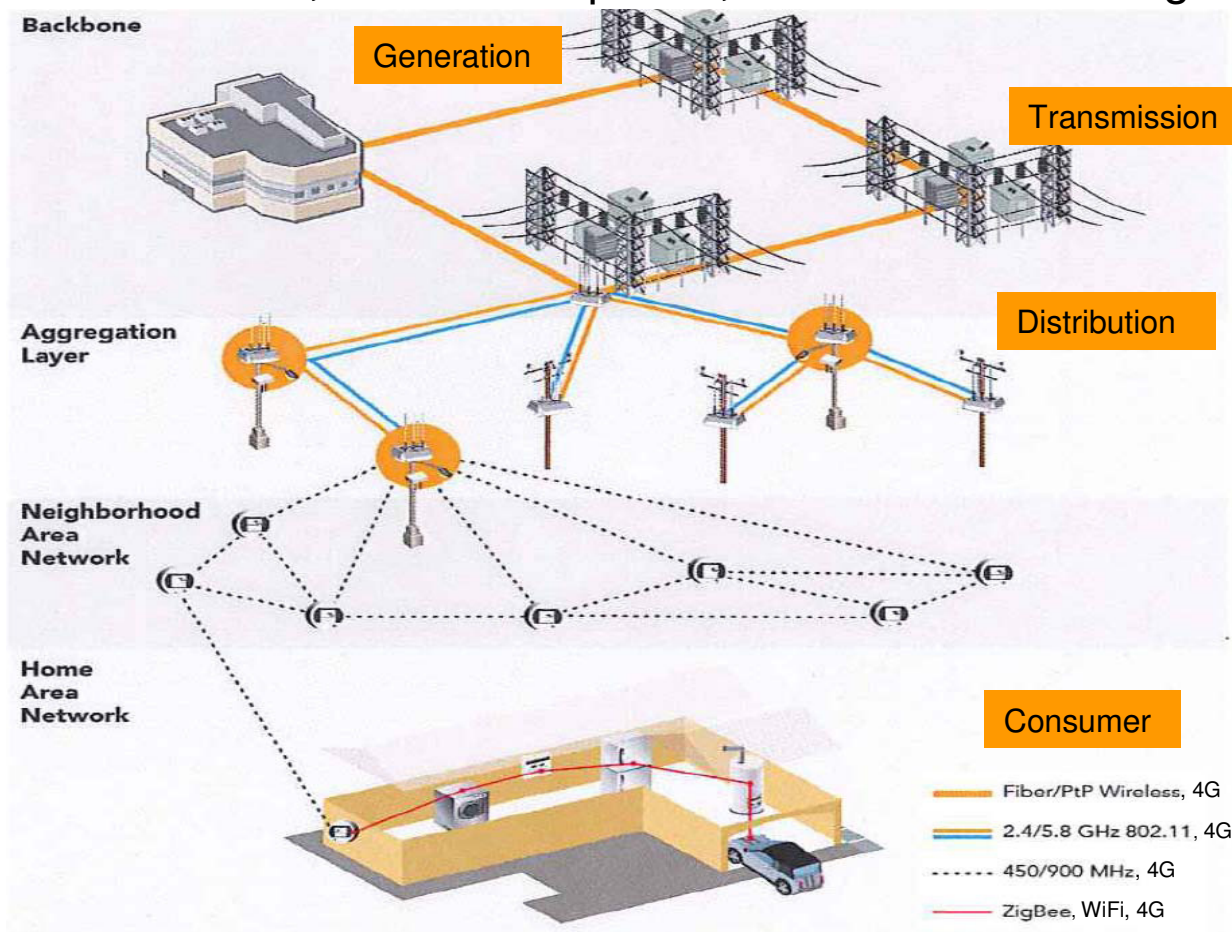
WPAN

- Crash sensors
- Diagnostics
- Tamper/access monitoring



M2M: Smart Grid

- Services include home energy network, smart metering, distribution automation, demand response, wide area monitoring and control



WWAN

- Distribution Automation
- Field & Neighborhood Area Network
- Home Area Network

WLAN

- Home Area Network
- Field Area Network (mesh)

WPAN

- Home Area Network (appliances)

Smart Grid Communications Network Layers

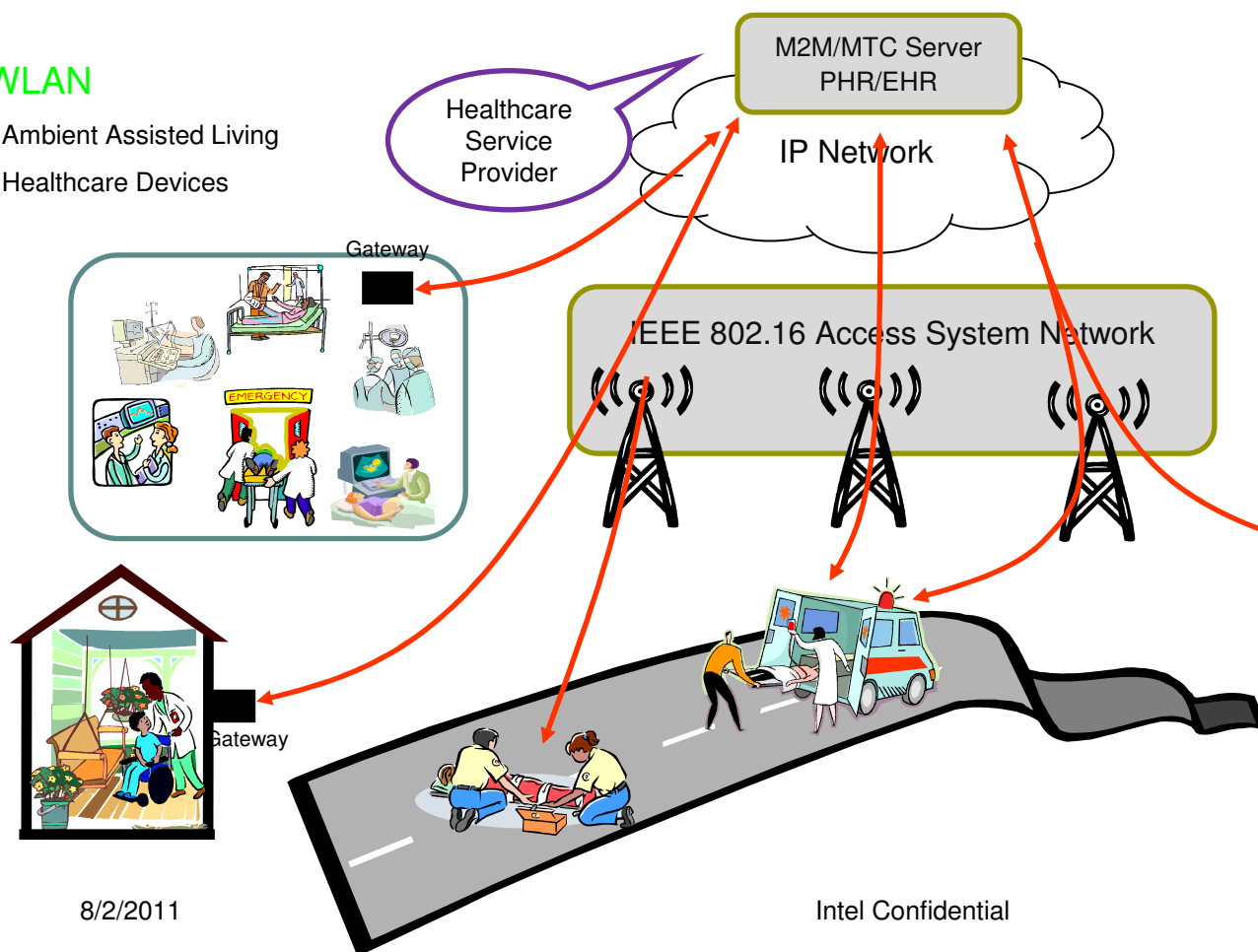


M2M: Mobile Health

- Services include remote patient health monitoring and care, critical condition and/or emergency situation, maintenance and diagnostics of healthcare devices

WLAN

- Ambient Assisted Living
- Healthcare Devices



WWAN

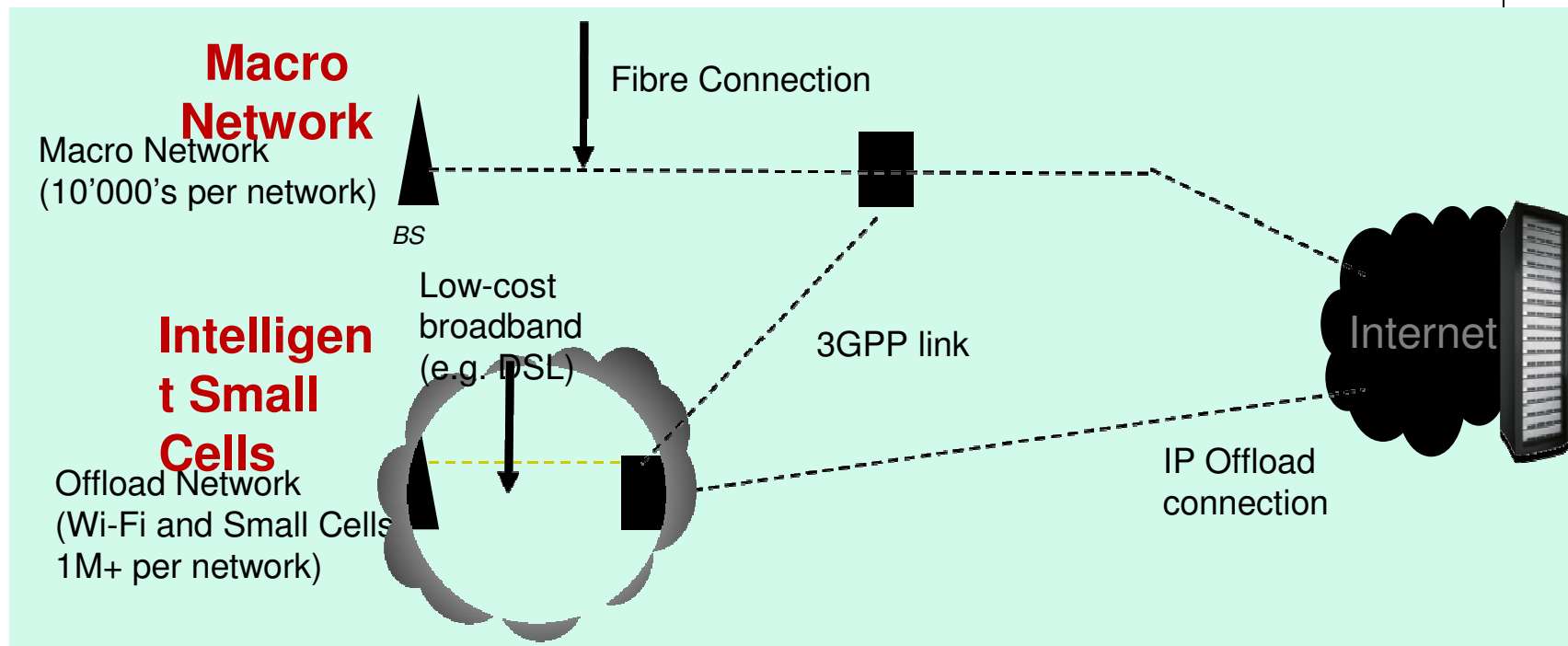
- Emergency Care
- Backhaul for BAN
- Exchange of Medical Records

WPAN

- Body area networks
- Smart Medication Bottle



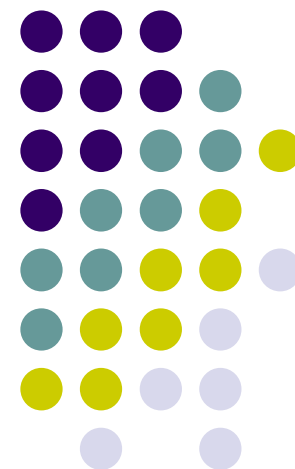
Edge Cloud



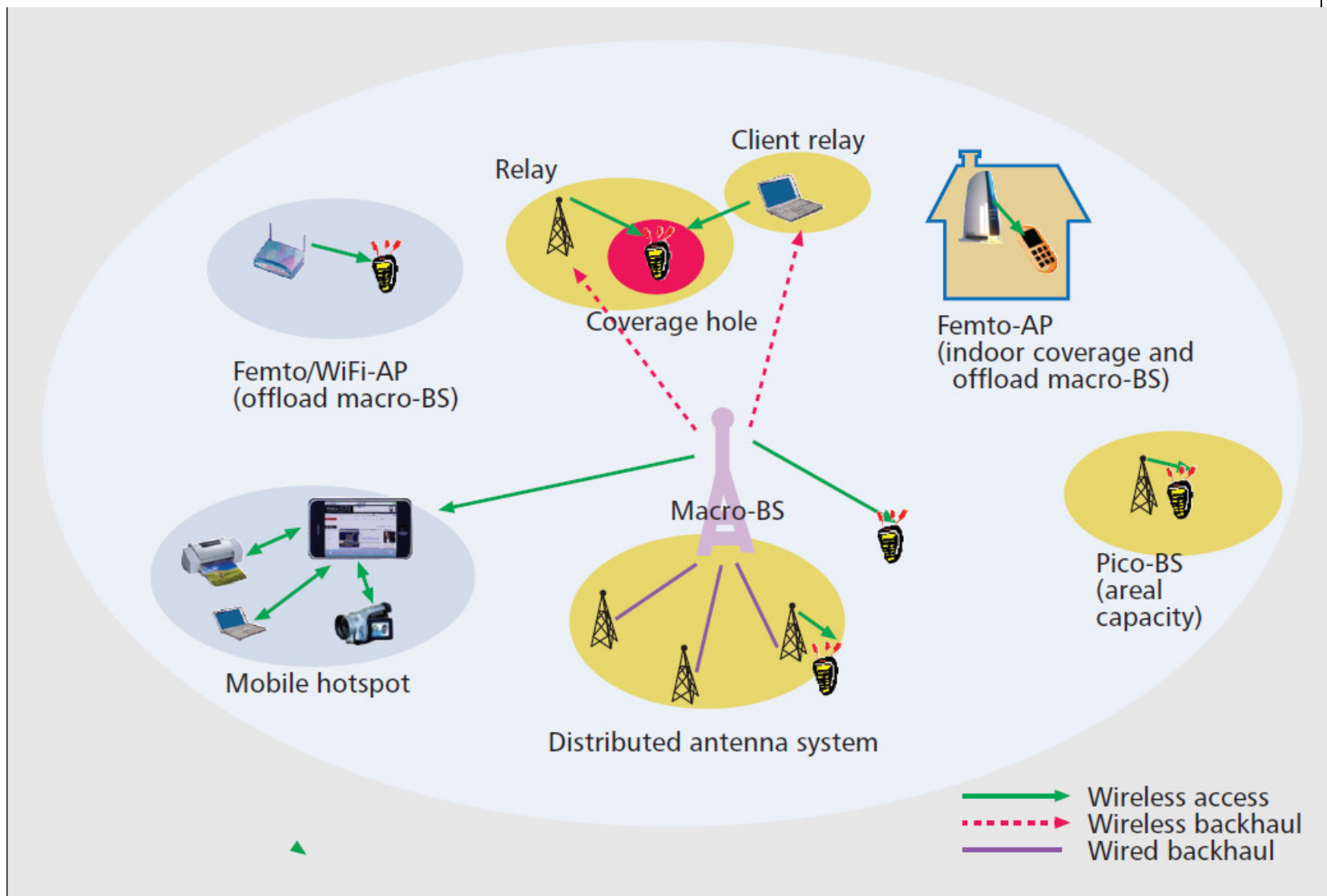
Intelligent Small cells at Network edge

- Ensure network resource usage is optimized and user experience is maximized
- Enable services that require low latency, local content (new revenue), such as Data Caching, Location Services, Deep Packet Inspection, Video
- Leverage cheap memory for content caching, reducing load on core network
- Leverage processor virtualization technology to implement core BS functions on Host VM, and new service functions on additional VMs

Conclusions



HetNet: Macro + Low power nodes



HetNets will play a key role in future of mobile broadband



- Support shift from spectral efficiency to network efficiency
 - High capacity at low cost (Capex, Opex)
 - Flexible deployment and self-management
 - Low power & emissions (Green)
 - Enable mass devices to connect to cellular network
 - New services at network edge (Content)
- HetNet advances will need to be coupled with intelligent multimode devices with sophisticated connection management technology
- Active area of research in enabling technologies: mobility, interference, self-organization, multi-RAT interworking
- Standardization is under way to realize benefits of HetNets

Backup slides

