Dense Heterogeneous Networks

Dania Marabissi

Consiglio DINFO 16 Giugno 2017

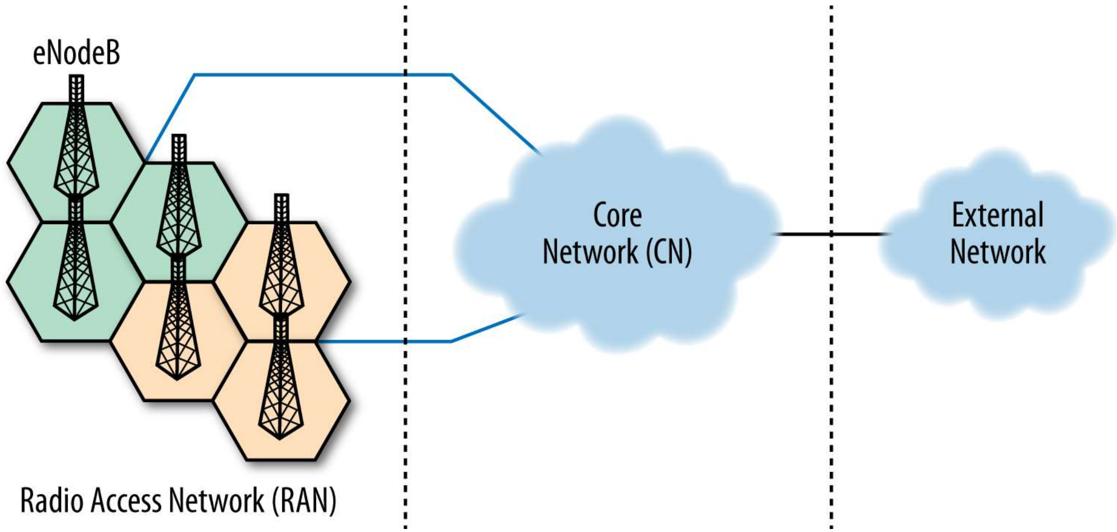
Introduction

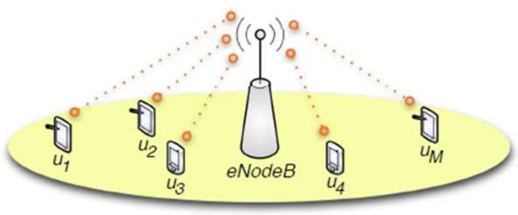
2000-2007 **Assegno di Ricerca**
2001-2004 **PhD «Ingegneria Informatica e delle Telecomunicazioni»**
2007-2013 **Ricercatore Tempo Determinato** (Legge n. 230/2005)
2014-2017 **Ricercatore a Tempo Determinato «FIR-Futuro In Ricerca»** (L. n. 240/2010, art. 24, lett. a))

Courses:
A.Y. 2002/03 **Digital Signal Processing I (2CFU)**
A.Y. 2003/04 **Digital Transmission (2 CFU)**
From A.Y. 2003/04 to 2005/06 **Laboratory of Telematic (Tutor-50 ore)**
A.Y. 2005/06 e 2006/07 **Electrical Communications III (5CFU)**
A.Y. 2015/16 **Telecommunication Networks (2 CFU)**
From A.Y. 2013/14 to 2015/16 **Foundation of Telecommunication Networks (6 CFU)**
From A.Y. 2015/16 **Digital Transmission (2 CFU)**
From A.Y. 2016/17 **Information Theory (6 CFU)**

PhD Courses:
A.Y. 2013/14 Queuing Systems and Applications (2CFU)
A.Y. 2013/14 Wireless Sensor Networks (1CFU)
A.Y. 2015/16 Adaptive resources allocation in wireless systems (2CFU)
A.Y. 2015/16 Wireless Sensor Networks (1CFU)

Introduction

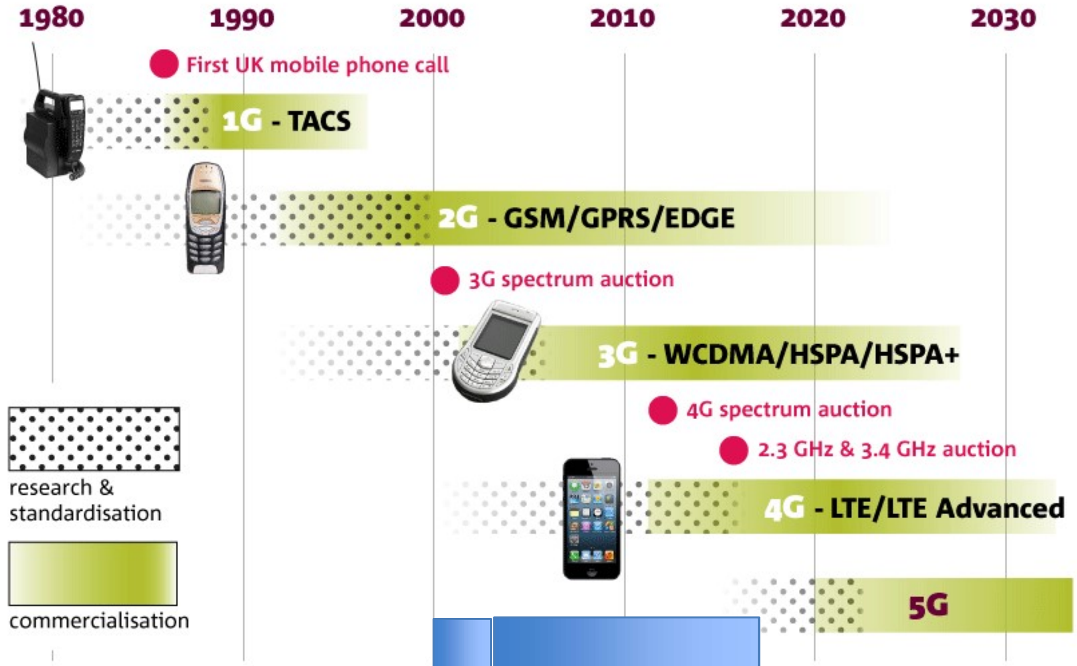




Medium Access Control Layer: resource management, access control policies

Physical Layer: transmission/reception techniques, link adaptation

Introduction



OFDM/OFDMA system: interference management, resource allocation, resource management, link adaptation, cognitive resource managment

CDMA systems: multiuser detection techniques, interference cancellation, channel estimation, multiple antenna systems

Introduction

Wireless Networks

Commercial Networks

2017/19 **GAUCHO** (PRIN)
2014/17 **HeLD** (FIR)
2006/08 **TOWN** (PRIN)
2006/07 **WOMEN** (PRIN)
2005/07 **GIRASOLE** (UE)
2004/07 **NEWCOM** (NoE-UE)
2003/07 **COST 289**
2002/06 **VICom** (FIRB)
2000/01 **UMTS** – Marconi Mobile

Professional Networks

Public Safety and Security

2015/16 **ISITEP** (UE)
2012/15 **WiLIFE** (Reg)
2012/15 **TETRis** (PON)
2008/09 **TWNET** (Reg)
2007/12 **IN.SY.EME** (FIRB/FAR)

Aeronautical

2010/12 **SESAR program** (UE)

Railway

2012/14 **SISSI** (Reg)

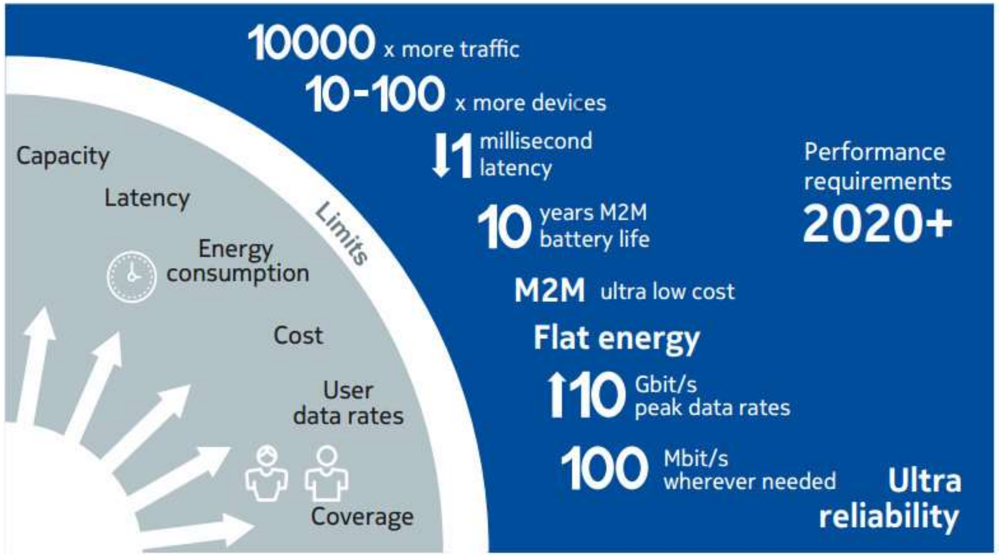
Military

2010/13 **CORASMA** (EDA)

2009/12 **ESSOR program** (EDA)
SelfNET (Leonardo SpA)

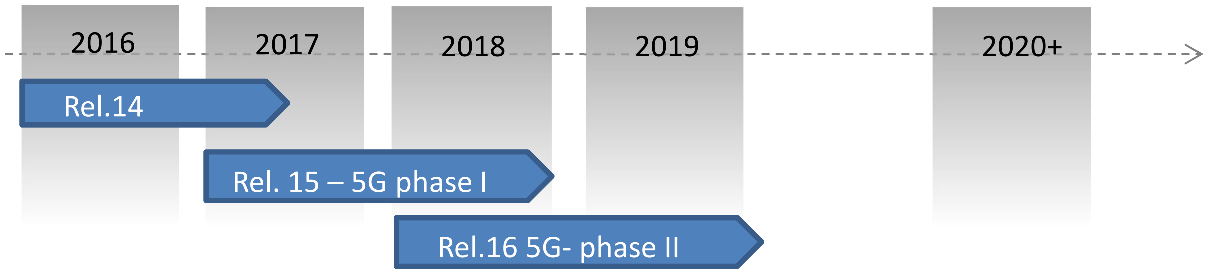
Dense Heterogeneous Networks

Wireless communications evolution



In next years it is expected:

- 1000x increase in data traffic (capacity);
- a typical user will consume 1 Gbyte of data per day;
- massive machine-to-machine (M2M) communications
- 90% of data traffic will be originated indoor



How to increase the capacity

Radio link is approaching its theoretical limit.
Capacity requires increases in all dimensions: *Antennas, Spectrum, Access Points*

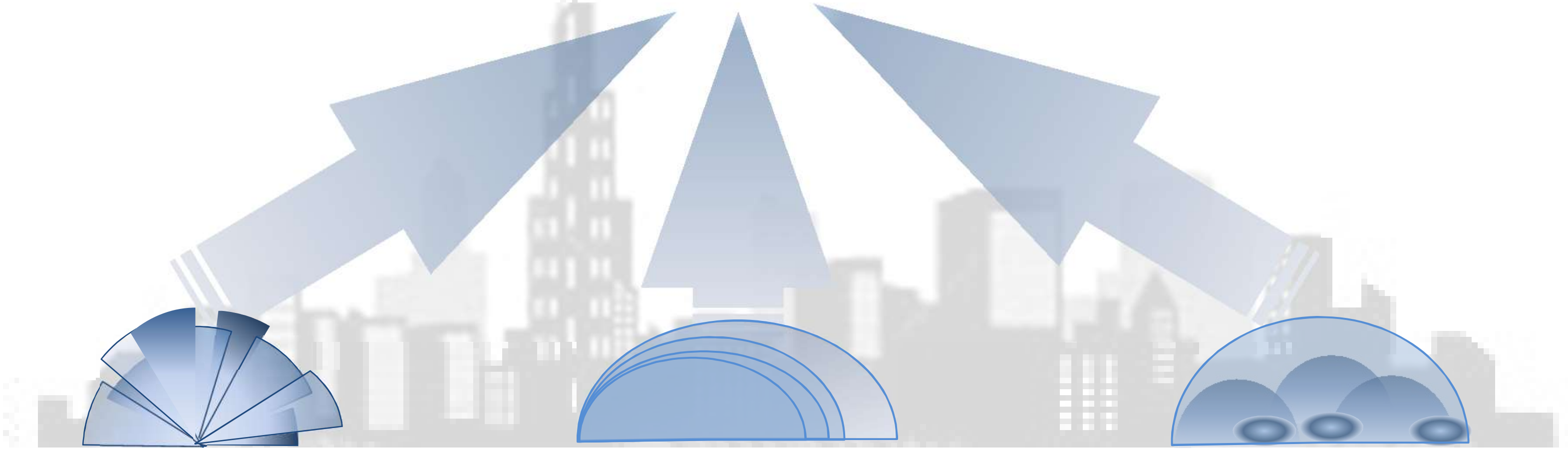
Spectrum

Signal quality

Shannon's law

$$Capacity = W \cdot \log_2\left(1 + \frac{signal}{noise + interfernce}\right)$$

Higher Capacity and Higer Efficency



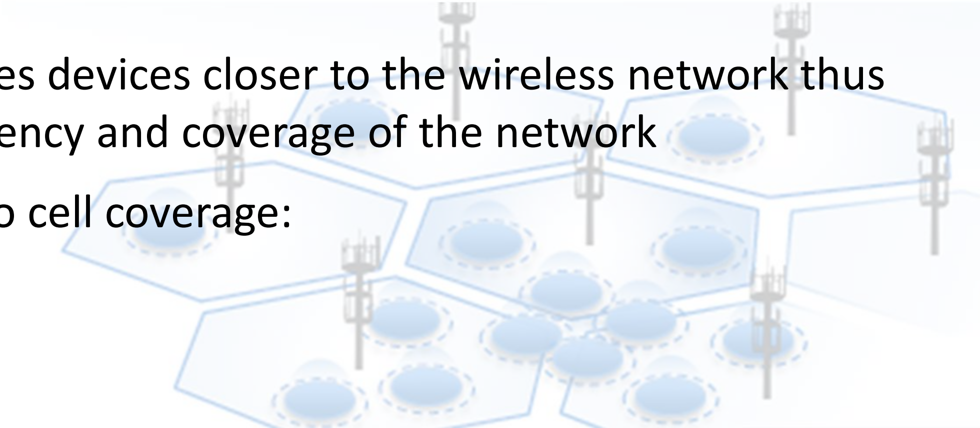
More Antennas
more radio links: Massive MIMO

More Spectrum
- Carrier aggregation across multiple carriers and multiple bands
- mmWave communications

Access points densification
Heterogeneous network topology
With advanced interference management
Coordination/cooperative strategies

Access point densification

Small-cells are distributed within the coverage area of a traditional macro cell base station.
Access points densification moves devices closer to the wireless network thus increasing spectral/energy efficiency and coverage of the network



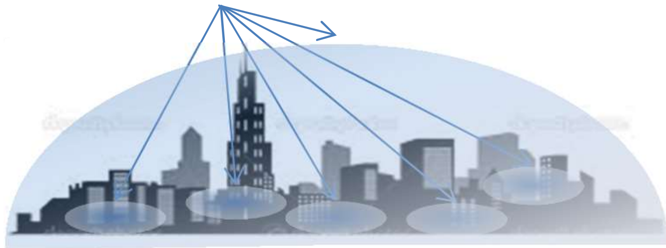
Low range cells within the macro cell coverage:

- *Capacity Increase*
- *Enhanced User Experience*
- *Better macro cell offload*
- *Higher efficiency*

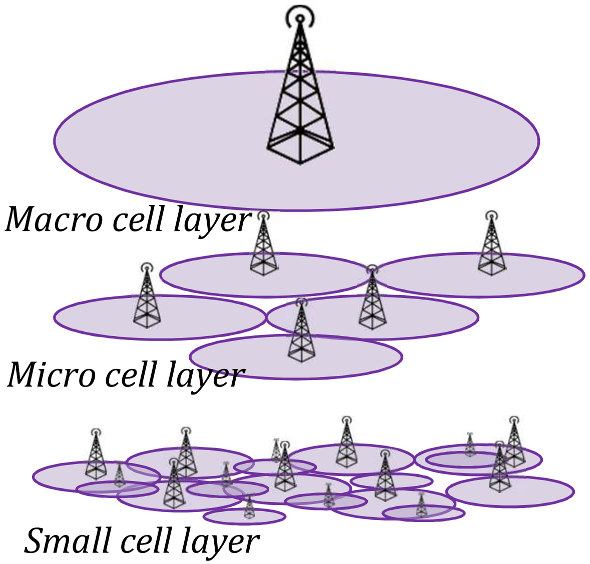
The same resources are *re-used* in the same area and hence, the Shannon's limit theoretically increases linearly with the number of overlapped cells (M)

$$Capacity = \quad \cdot \log_2\left(1 + \frac{signal}{noise + interfernce}\right)$$

$$Capacity \approx (M+1)W \cdot \log_2\left(1 + \frac{signal}{noise + interfer}\right)$$



Heterogeneous Networks



Hierarchical structure

Small cells are access nodes with small transmission power that can operate in three different access modes: *open, closed*, and *hybrid.*

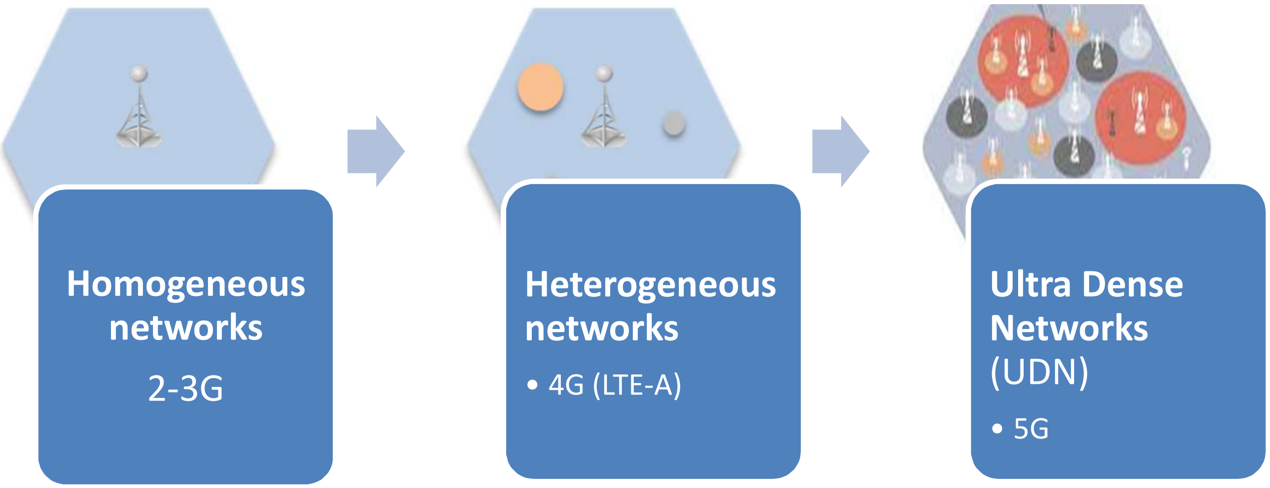
Different types:

1) fully-functioning base stations (picocells and femtocells)
   - *Distributed deployment*

2) macro-extension access points (relays and Remote Radio Heads)
   - *Centralized deployment*

Type of small cell	Deployment Scenario	Coverage	Power	Access Scenario	Backhaul
Picocells (fully-functioning)	indoor/outdoor (planned)	up to 100 meters	indoor ($\leq$ 100 mW) outdoor (0.25 – 2 W)	Open Access	Ideal
Femtocells (fully-functioning)	indoor (unplanned)	10 – 30 meters	$\leq$ 100 mW	Open/Closed/Hybrid Access	Non-Ideal
Relays (macro-extension)	indoor/outdoor (planned)	up to 100 meters	indoor ($\leq$ 100 mW) outdoor (0.25 – 2 W)	Open Access	Wireless (in-band/out-of-band)
RRHs (macro-extension)	outdoor (planned)	up to 100 meters	outdoor (0.25 – 2 W)	Open Access	Ideal

Ultra Dense Networks



UDNs definition:
- where there are more cells than active users

Or

- where the cell density is higher than 100 cells/Km^2

Fundamental features of UDN:

- ❖ Many small cells are in the vicinity of a given user
- ❖ Idle mode capabilities
- ❖ Dense and irregular deployment
- ❖ Drastic interference between neighboring cells

Extreme and user-centric reuse of system bandwidth

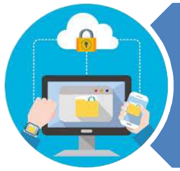
Application scenarios

Small cells can be deployed anywhere by operators or end-users.
→ To enhance the traffic throughput of H2H communications
→ To efficiently support M2M communications
→ To extend coverage (cell-edge, indoor)

Residential environment (Indoor)

M2M communications can be larger than H2H communications.

Closed Access Small Cells → in-home connectivity and smart home support



Enterprise (Indoor)

Dominated by H2H communications.

Hybrid Access Small Cells.

Hot Spots (Indoor/Outdoor)

Dominated by H2H communications (indoor and outdoor)

Open Access Small Cells

Industry 4.0 (Indoor/Outdoor)

M2M communications - Assurance of reliable and low-latency communications

Closed Access Small Cells

Research Challenges of Network Ultradensification

Interference:
Dense and Irregular Access Points deployment under a universal frequency reuse scheme leads to a challenging interference landscape:

- *High number of AP with different characteristics*
- *Power unbalancing*
- *Open and closed access policies*
- *Different priorities in resource usage*
- *Cooperation among different APs*

Conventional network planning and radio resource management cannot be applied

Innovative resource management and frequency reuse techniques are required

Interference management can take place in the frequency domain, time domain, space domain, power domain, or a mix of them

- Coordinated or Cooperative approaches
- Cognitive approaches

Challenging due to high number of nodes

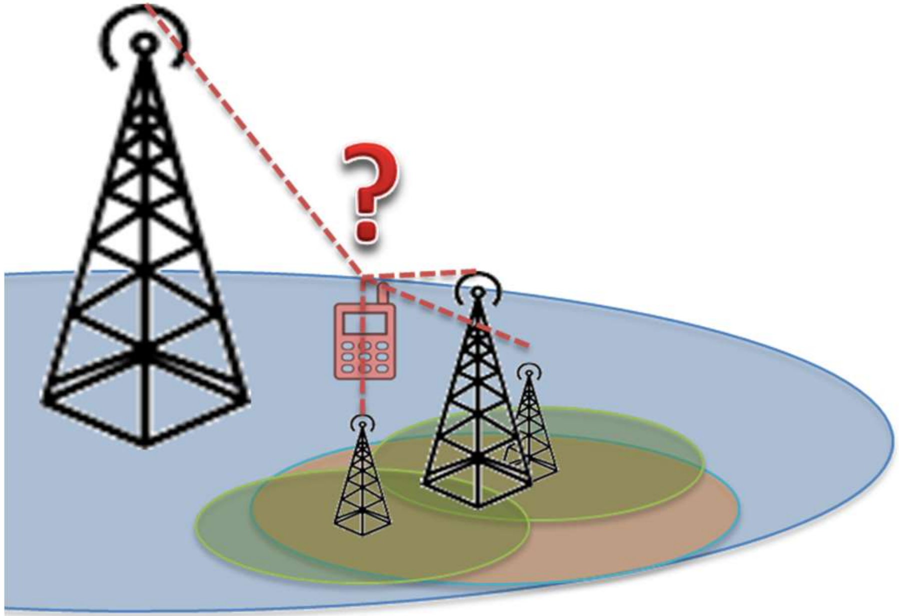
Research Challenges of Network Ultradensification

Cell Association and Load Balancing

The association of users to cells is crucial to efficiently distribute the traffic in the network:

- *high interference*
- *presence of many access points*
- *idle mode*
- *backhaul issues*
- *mobility management*

→ *new association policies*



- Range Expansion: bias in the small cell measured SINR; applicability to UDN must be evaluated
- Dual Connectivity (macrocell and small cell): distributes the traffic but more interesting the signalling plane and the data plane might be split (robust and efficient mobility management).
- Multicell (cluster of small cells): distributes the traffic amongst them thus aggregating higher data rate

Research Challenges of Network Ultradensification

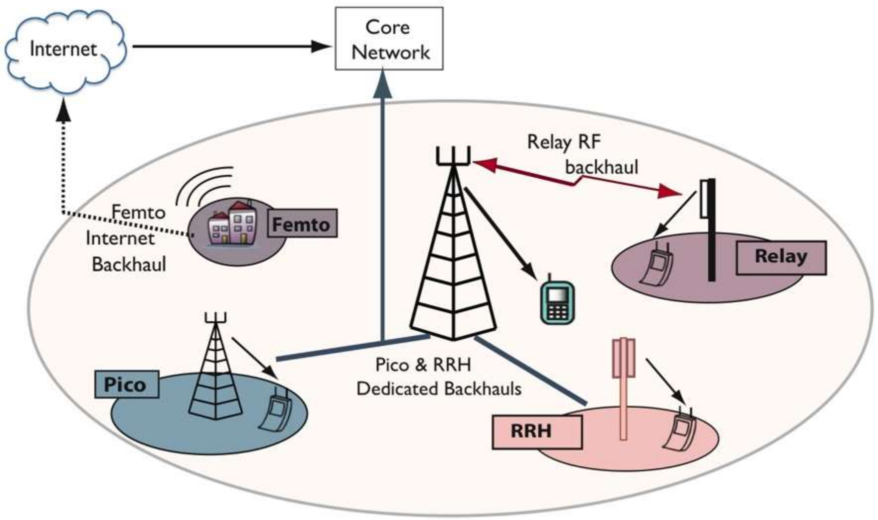
Backhauling

Different backhaul technologies with different capabilities are available to small cell networks: *wired* or *wireless* (integration *with mmWave and massive MIMO communications)*

The promised radio interface capacity of the small cells might be bottlenecked by the backhaul capacity:

→ *impacts on user association*

→ *cooperation and coordination capabilities can be limited*



Research Challenges of Network Ultradensification

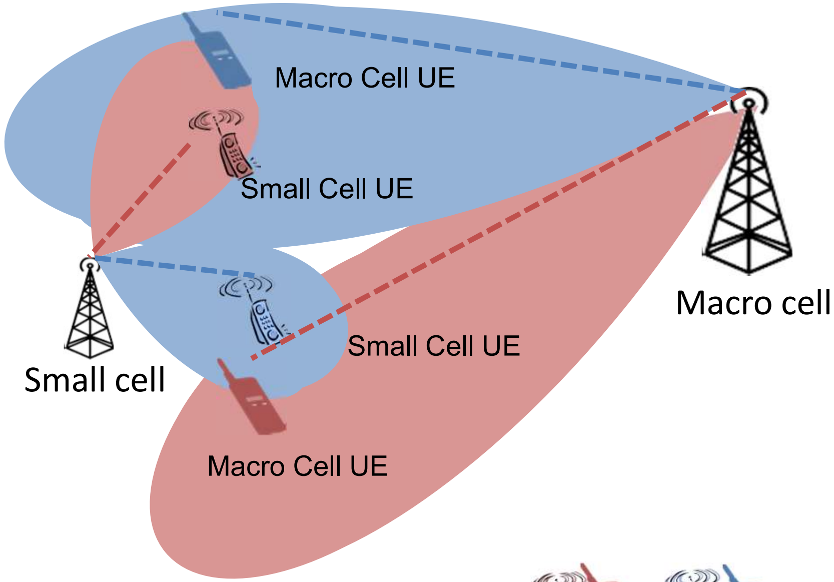
Energy efficiency and Deployment cost

Network densification leads CAPEX and OPEX increase, but:

- can be shared by operators and users
- for a small cell are much less than in a traditional cell

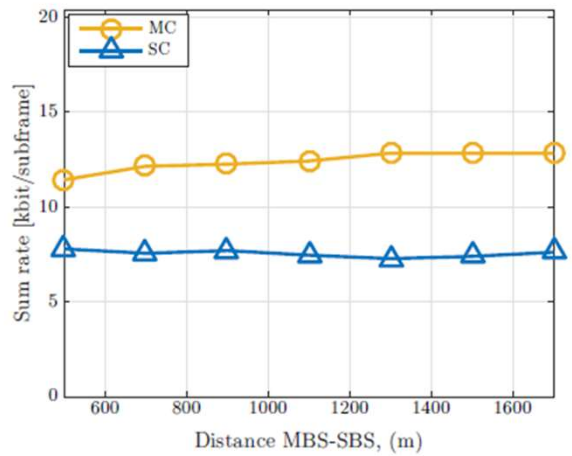
The immense number of small cells, despite the small transmit power of each, would consume a massive energy.
The impact of this energy consumption is an interesting factor to consider in the deployment of UDNs

Ex. Coordinated communications: Coordinated Scheduling /Coordinated Beamforming



For each pair (MUE-SUE) the most suitable beamforming weights are derived.
Each resource element is allocated to the most suitable pair in order to maximize the joint throughput.

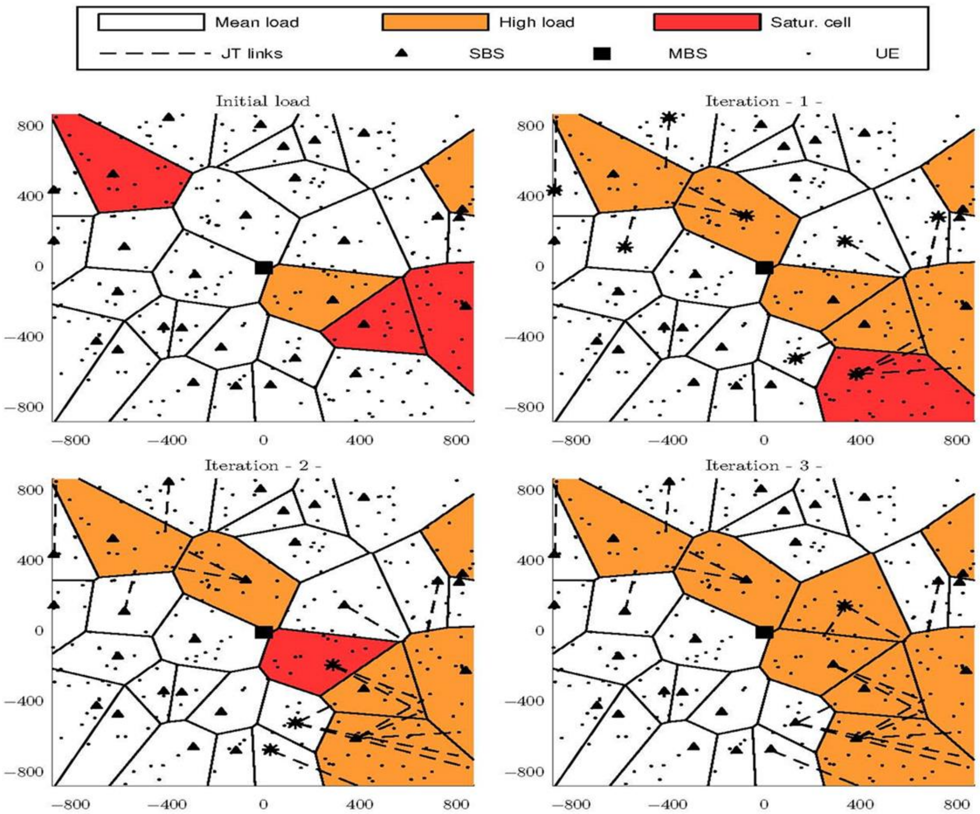
Results demonstrate that interference is completely removed → SINR depends only the propagation conditions



Macro and Small cell UE pairs: ( ) ( )
Can be allocated on the same resources without interference

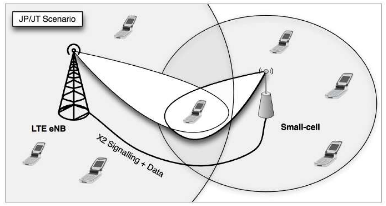
- G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "LTE-A Femto-Cell Interference Mitigation with MuSiC DOA Estimation and Null Steering in an Actual Indoor Environment", *IEEE International Conference on Communications* , June 2013, Budapest, Hungary.
- G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "Angular Interference Suppression in Cognitive LTE-A femtocells", *International Wireless Communications & Mobile Computing Conference ,* Aug.2014, Nicosia, Cyprus.
- G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "Resource Allocation schemes for Cognitive LTE-A Femto-cells using Zero Forcing Beamforming and Users Selection", *IEEE Global Telecommunications Conference* , Dec. 2014, Austin, Texas (USA).
- G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "Coordinated Scheduling and Beamforming Scheme for LTE-A HetNet Exploiting Direction of Arrival", *IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications ,* Sept. 2014, Washington DC (USA).

Ex. Cooperative Communications: Cell Association – Load distribution – Interference reduction

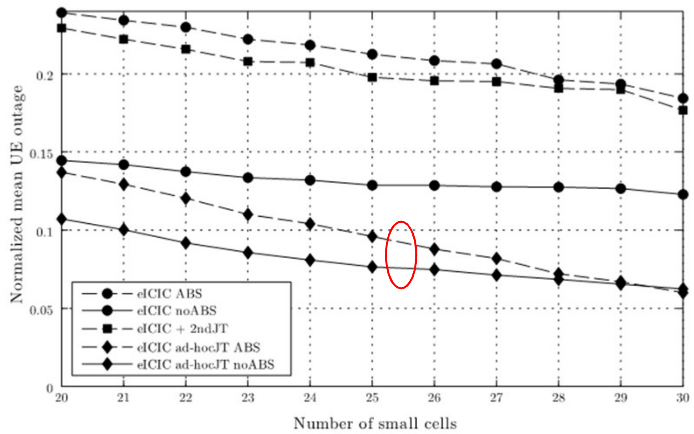


Iterative procedure to reduce the "*unsatisfied UE requests*":

- Overloaded cells are selected
- Each cells selects the UEs that can benefit from Cooperation and ask for cooperation to the neighbor cells

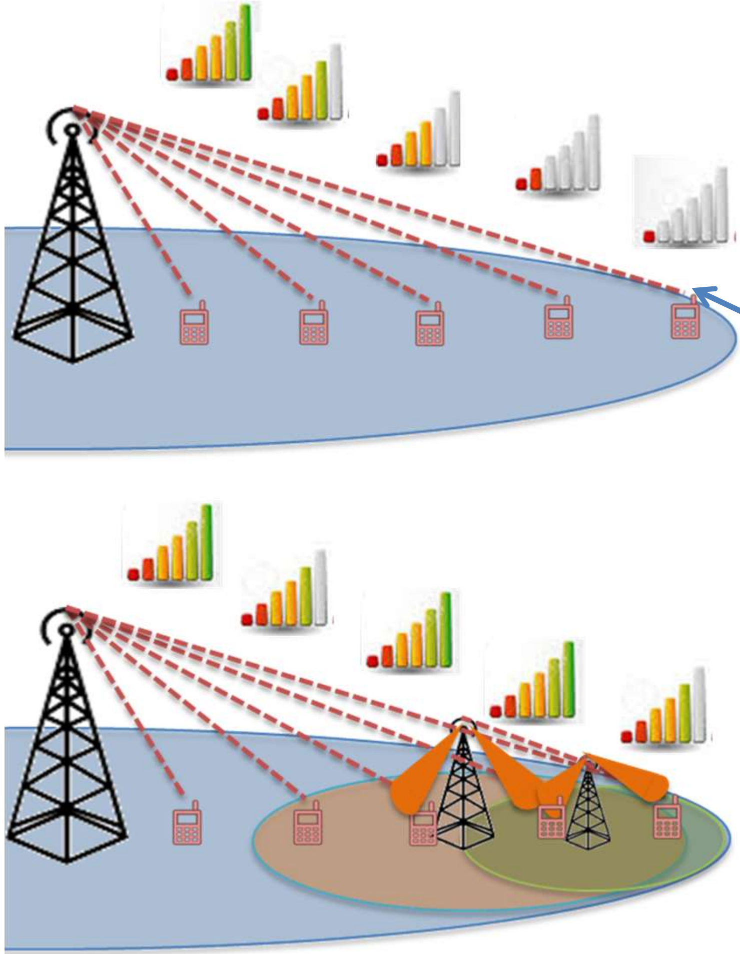


- Load is spread in the neighbor cells

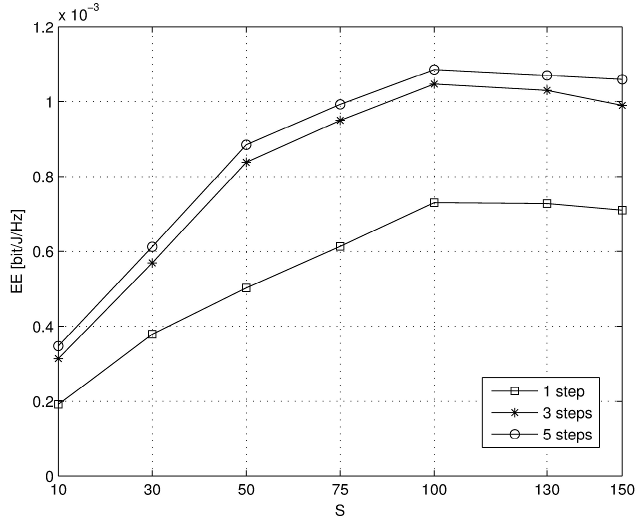


- D. Marabissi, G. Bartoli, R. Fantacci, M. Pucci, "An Optimized CoMP Transmission for a Heterogeneous Network Using eICIC Approach", *IEEE Transactions on Vehicular Technology*, Vol.65, No.10, pp.8230–8239, Oct.2016.

Ex. Energy Efficiency of multicast communications



Small cells are opportunistically activated focusing their radiated power toward the users that have worst propagation conditions



→ *Increase of energy efficiency*
→ *Limit to "densification"*

- G. Bartoli, L. Carlà, R. Fantacci, D. Marabissi "Efficient Multicast Beamforming in HetNet with an Opportunistic Cells Activation", *IEEE Global Telecommunications Conference* , Workshop on 5G Heterogeneous and Small Cell Networks, Dec. 2015, San Diego, CA (USA)
- D. Marabissi, G. Bartoli, R. Fantacci, L. Micciullo, "Reduced Power Cooperative Multicast Transmission in UDNs", Submitted to IEEE *Global Telecommunications Conference 2017*
- D. Marabissi, G. Bartoli, R. Fantacci, L. Micciullo "Energy efficient cooperative multicast beamforming in ultra dense networks", *submitted to IET communications 2017*

Conclusions

It is possible to conclude that *network densification cannot continue endlessly*
→ It is needed an extensive research activity to understand the fundamental limit of network densification for realistic system models to capture the reality of dense networks.

1) analytical system modeling/characterization: to provide insights on the fundamentals of UDNs operation
2) algorithmic radio resource management/user association: detailed system-level simulation models to capture the effect of realistic traffic models and propagation conditions and to investigate the potential of advanced radio resource management algorithmic approaches.

Network density should be optimized to make the best of this paradigm

HetNet related publications

BOOKS

a. D. Marabissi, R. Fantacci "Cognitive Interference Management in Heterogeneous Networks", *Book Series: Springer Briefs in Electrical and Computer Engineering*, 2015

INTERNATIONAL JOURNAL

a. G. Bartoli, R. Fantacci, K.B. Letaief, D. Marabissi, M. Pucci, N. Privitera, J. Zang, "Beamforming for Small Cells Deployment in LTE-Advanced and Beyond", *IEEE Wireless Communications – Special Issue on Enhancing Spectral Efficiency for LTE-Advanced and Beyond Cellular Networks*, Vol. 21, No.2, pp.50-56, April 2014
b. G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "Physical Resource Block clustering method for an OFDMA cognitive femtocell system", *Physical Communication, Elsevier*, Vol.11, pp.67-77, June 2014
c. A. Tani, R. Fantacci, D. Marabissi "A low-complexity cyclostationary spectrum sensing for Interference Avoidance in femto-cells LTE-A based Networks", *IEEE Transactions on Vehicular Technology*, Vol. 65 No. 4, pp. 2747–2753, April 2016
d. R. Fantacci, D. Marabissi, "Cognitive Spectrum Sharing: an enabling wireless communication technology for a wide use of smart systems", *Future Internet, MDPI - Special Issue on Ecosystemic Evolution Feeded by Smart Systems*, Vol.8, No. 2, pp. 1.17, May 2016
e. C. Alippi, R. Fantacci, D. Marabissi, M. Roveri "A Cloud to the Ground: The New Frontier of Intelligent and Autonomous Networks of Things", *IEEE Communications Magazine*, Dec. 2016
f. D. Marabissi, G. Bartoli, R. Fantacci, M. Pucci, "An Optimized CoMP Transmission for a Heterogeneous Network Using eICIC Approach", *IEEE Transactions on Vehicular Technology*, Vol.65, No.10, pp.8230–8239, Oct. 2016
g. G. Bartoli, D. Marabissi, R. Pucci, L.S. Ronga, "AI based Network and Radio resource management in 5G HetNets", *Journal of Signal Processing Systems, SPRINGER*, First Online: Jan. 2017
h. R. Fantacci, F. Gei, D. Marabissi, L. Micciullo "Dynamic PSS and Commercial networks spectrum sharing in the time domain", *Transactions on Emerging Telecommunications Technologies*, Vol.28, N. 3, 1 March 2017.
i. D. Marabissi, G. Bartoli, R. Fantacci, L. Micciullo "Energy efficient cooperative multicast beamforming in ultra dense networks", *submitted to IET communications 2017*

HetNet related publications

INTERNATIONAL CONFERENCES

a. G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "LTE-A Femto-Cell Interference Mitigation with MuSiC DOA Estimation and Null Steering in an Actual Indoor Environment", *IEEE International Conference on Communications* , June 2013, Budapest, Hungary.
b. G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, C. Armani, L. Niccolai "Cognitive suppression of multipath interference in angular domain", *European Conference on Communications Technologies and Software Defined Radio,* June 2013, Munich, Germany.
c. G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "Angular Interference Suppression in Cognitive LTE-A femtocells", *International Wireless Communications & Mobile Computing Conference ,* Aug.2014, Nicosia, Cyprus.
d. G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci "Adaptive muting ratio in enhanced Inter-Cell Interference Coordination for LTE-A systems", *International Wireless Communications & Mobile Computing Conference*, Aug.2014, Nicosia, Cyprus.
e. G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "Coordinated Scheduling and Beamforming Scheme for LTE-A HetNet Exploiting Direction of Arrival", *IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications ,* Sept. 2014, Washington DC (USA).
f. G. Bartoli, R. Fantacci, D. Marabissi, M. Pucci, "Resource Allocation schemes for Cognitive LTE-A Femto-cells using Zero Forcing Beamforming and Users Selection", *IEEE Global Telecommunications Conference* , Dec. 2014, Austin, Texas.
g. G. Bartoli, D. Marabissi, R. Pucci, L.S. Ronga, "Cross-layer Resource Allocation for 5G Heterogeneous Software Defined Networks", *European Conference on Communications Technologies and Software Defined Radio ,* Oct. 2015, Erlangen, Germany.
h. G. Bartoli, L. Carlà, R. Fantacci, D. Marabissi "Efficient Multicast Beamforming in HetNet with an Opportunistic Cells Activation", *IEEE Global Telecommunications Conference* , Workshop on 5G Heterogeneous and Small Cell Networks, Dec. 2015, San Diego, CA (USA).
i. G. Bartoli, R. Fantacci, D. Marabissi, "Efficient coordinated beamforming and scheduling approaches for heterogeneous networks", *AIET International Annual conference ,* Oct. 2016, Capri.
j. D. Marabissi, G. Bartoli, R. Fantacci, L. Micciullo, "Reduced Power Cooperative Multicast Transmission in UDNs", Submitted to IEEE *Global Telecommunications Conference 2017*

Thank you for your attention