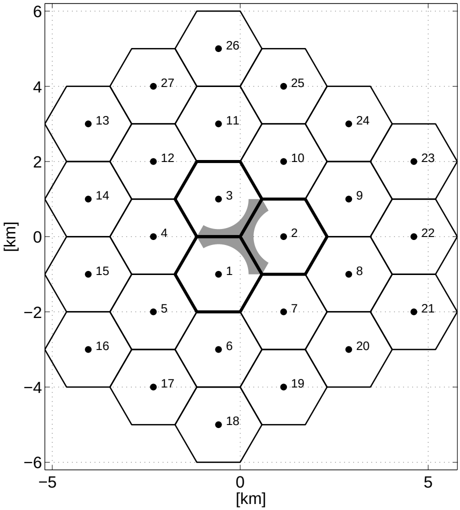
Coordinated Resource Allocation in Downlink MIMO OFDMA Cellular Networks: a Unified Approach to Rate and/or Energy Efficiency Maximization

Stefano Buzzi[1], Luca Venturino[1], Alessio Zappone[2]

[1]CNIT/ University of Cassino and Lazio Meridionale, Italy
[2]Technical University Dresden, Germany

October 24, 2013

The considered system: a downlink multi-cell OFDMA system with multiple antennas



System Model

- Multiple antennas on BSs and mobile terminals
- A cluster of BS shares information on channel quality measurements
- and allocates transmit power, beamforming vectors, and linear receivers at the mobile terminals
- to maximize the rate or the energy efficiency, with a unified approach

System Model

- Multiple antennas on BSs and mobile terminals
- A cluster of BS shares information on channel quality measurements
- and allocates transmit power, beamforming vectors, and linear receivers at the mobile terminals
- to maximize the rate or the energy efficiency, with a unified approach

System Model

- Multiple antennas on BSs and mobile terminals
- A cluster of BS shares information on channel quality measurements
- and allocates transmit power, beamforming vectors, and linear receivers at the mobile terminals
- to maximize the rate or the energy efficiency, with a unified approach

System Model

- Multiple antennas on BSs and mobile terminals
- A cluster of BS shares information on channel quality measurements
- and allocates transmit power, beamforming vectors, and linear receivers at the mobile terminals
- to maximize the rate or the energy efficiency, with a unified approach

Transmission Rate

- The achievable transmission rate for user k receiving data from BS m on subcarrier n can be expressed as

$$\mathrm{R}_{m,k}(n) = B \log_2(1 + \mathrm{SINR}_{m,k}(n))$$

where B is the bandwidth assigned to each frequency slot.
It depends on the quantities to be optimized

Transmission Rate

- The achievable transmission rate for user k receiving data from BS m on subcarrier n can be expressed as

$$\mathrm{R}_{m,k}(n) = B \log_2(1 + \mathrm{SINR}_{m,k}(n))$$

where B is the bandwidth assigned to each frequency slot.
It depends on the quantities to be optimized

The Power Model

- The power consumed by BS m on slot n is modeled as

$$\mathrm{P}_m(n) = \theta_m(n) + \gamma_m(n) \sum_{k \in \mathcal{K}_m(n)} \|w_{m,k}(n)\|^2 \tag{1}$$

  where $\|w_{m,k}(n)\|^2$ is the power radiated to user k, the scaling coefficient $\gamma_m(n) \geq 1$ accounts for the amplifier and feeder losses, and the offset term $\theta_m(n) > 0$ accounts for the power consumption due to signal processing and battery backup.

- Both $\theta_m(n)$ and $\gamma_m(n)$ generally scale with the additional losses incurred by the power supply and/or the cooling equipment. Also, $\theta_m(n)$ usually scales with the number of transmit chains (i.e., transmit antennas per BS).

The Power Model

- The power consumed by BS m on slot n is modeled as

$$\mathrm{P}_m(n) = \theta_m(n) + \gamma_m(n) \sum_{k \in \mathcal{K}_m(n)} \|w_{m,k}(n)\|^2 \tag{1}$$

  where $\|w_{m,k}(n)\|^2$ is the power radiated to user k, the scaling coefficient $\gamma_m(n) \geq 1$ accounts for the amplifier and feeder losses, and the offset term $\theta_m(n) > 0$ accounts for the power consumption due to signal processing and battery backup.
- Both $\theta_m(n)$ and $\gamma_m(n)$ generally scale with the additional losses incurred by the power supply and/or the cooling equipment. Also, $\theta_m(n)$ usually scales with the number of transmit chains (i.e., transmit antennas per BS).

Performance Figures (1/3)

- The first performance figure is the average rate (AR) on the frequency slots of each coordinated BS, which is given by

$$\mathrm{AR} = \frac{1}{NM} \sum_{n=1}^{N} \sum_{m=1}^{M} \mathrm{R}_m(n) \tag{2}$$

where

$$\mathrm{R}_m(n) = \sum_{k \in \mathcal{K}_m(n)} \mathrm{R}_{m,k}(n)$$

is the achievable transmission rate of BS m on slot n.

Performance Figures (2/3)

- The second performance metric is the global energy efficiency (GEE), defined as the ratio between the AR on the frequency slots of each coordinated BS and the corresponding average consumed power (AP), i.e.,

$$\mathrm{GEE} = \mathrm{AR}/\mathrm{AP} \tag{3}$$

where

$$\mathrm{AP} = \frac{1}{NM}\sum_{n=1}^{N}\sum_{m=1}^{M} \mathrm{P}_m(n).$$

Performance Figures (3/3)

- The last performance metric is the average energy efficiency (AEE) on the frequency slots of each coordinated BS, which is given by

$$\mathrm{AEE} = \frac{1}{NM} \sum_{n=1}^{N} \sum_{m=1}^{M} \frac{\mathrm{R}_m(n)}{\mathrm{P}_m(n)}. \tag{4}$$

Unified Design

- AR, GEE, and AEE can be recast as a weighted sum of the transmission rates on the frequency slots of each coordinated BS, i.e.,

$$f(\mathcal{W}, \mathcal{V}) = \sum_{n=1}^{N} \sum_{m=1}^{M} q_m(n) \mathrm{R}_m(n) \tag{5}$$

where

$$0 < q_m(n) = \begin{cases} (NM)^{-1}, & \text{if } f = \mathrm{AR} \\ (NM\mathrm{AP})^{-1}, & \text{if } f = \mathrm{GEE} \\ (NM\mathrm{P}_m(n))^{-1}, & \text{if } f = \mathrm{AEE} \end{cases} \tag{6}$$

is a weighting coefficient which depends on the considered figure of merit and is function of the transmit precoders.

Unified Design

- The problem that we solve is thus

$$\begin{cases} \arg\max\limits_{\mathcal{W},\mathcal{V}} f(\mathcal{W},\mathcal{V}) \\ \text{s.t.} \sum_{n=1}^{N} \sum_{k\in\mathcal{K}_m(n)} \|\mathbf{w}_{m,k}(n)\|^2 \leq \mathcal{P}_m, \ \forall\ m. \end{cases} \tag{7}$$

- We obtain an iterative algorithm that tries to solve the KKT conditions for the problem.

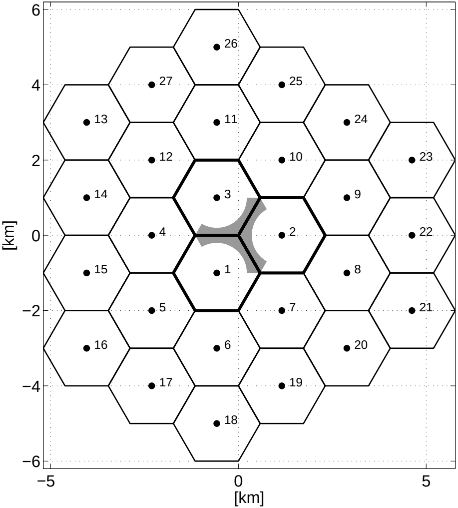
Unified Design

- The problem that we solve is thus

$$\begin{cases} \arg\max\limits_{\mathcal{W},\mathcal{V}} f(\mathcal{W},\mathcal{V}) \\ \text{s.t.} \displaystyle\sum_{n=1}^{N} \sum_{k\in\mathcal{K}_m(n)} \left\|\mathbf{w}_{m,k}(n)\right\|^2 \leq \mathcal{P}_m, \; \forall \; m. \end{cases} \tag{7}$$

- We obtain an iterative algorithm that tries to solve the KKT conditions for the problem.

Numerical Analysis



Numerical Analysis

- $P = 4$ transmit antennas at each BS.
- BSs 1, 2, and 3 coordinate their transmission on $N = 8$ frequency slots with bandwidth $B = 180$ kHz, while users are equipped with $R = 2$ antennas.
- We consider an heterogeneous power model, with $\theta_1(n) = 1$ W, $\theta_2(n) = 2$ W, $\theta_3(n) = 3$ W, $\gamma_1(n) = 2.8$, $\gamma_2(n) = 3.8$, and $\gamma_3(n) = 4.8$, which are typical values for LTE systems
- We consider spatially uncorrelated Rayleigh fading, Log-Normal shadowing with standard deviation 8 dB, and the path-loss model $\mathrm{PL(d)} = \mathrm{PL}_0 \left(d_0/d\right)^4$,
- $K = 2$ users per channel (which means a total of 48 users in the cluster)

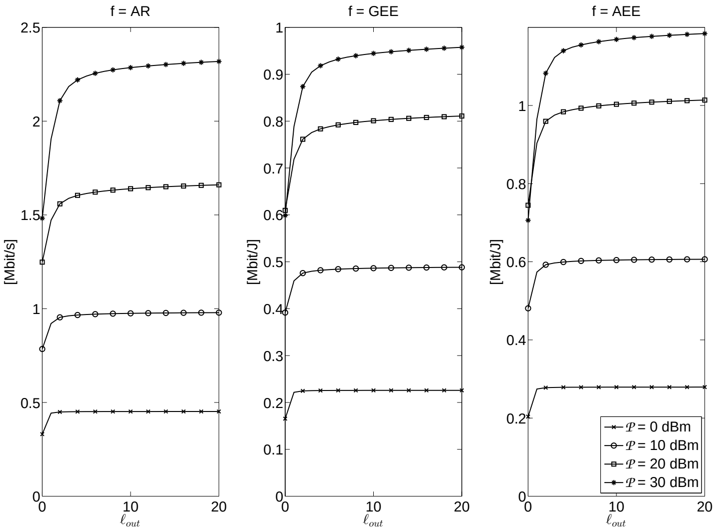
Numerical Analysis

- The noise power $r_{m,k}(n)$ at user k (which includes both the thermal noise and the out-of-cluster interference) is modeled as

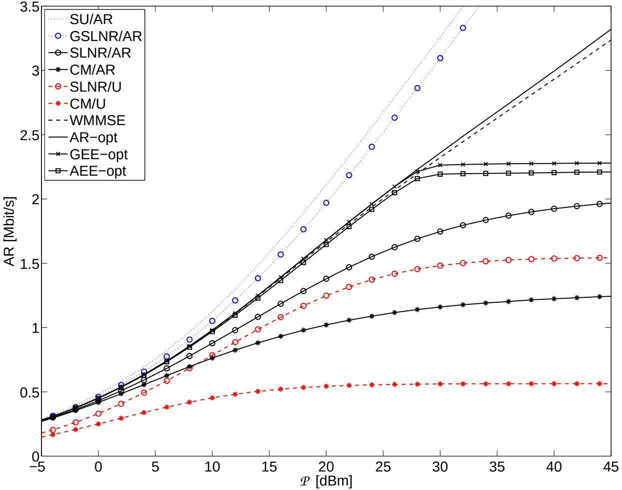
$$r_{m,k}(n) = \underbrace{F\mathcal{N}_0 B}_{\text{thermal noise}} \underbrace{+\mathcal{P}_{\text{out}}\text{PL}_0 \sum_{u\in\mathcal{U}} \left(\frac{d_0}{d_{u,m,k}(n)}\right)^4 \xi_{u,m,k}(n)}_{\text{out-of-cluster interference}} \quad (8)$$

where $F = 3$ dB is the noise figure of the receiver, $\mathcal{N}_0 = -174$ dBm/Hz is the noise power spectral density, $\mathcal{P}_{\text{out}}$ is the average power radiated by the uncoordinated BSs on each frequency slot, $d_{u,m,k}(n)$ is the distance from BS u to user k, and $\xi_{u,m,k}(n)$ represents the Log-Normal shadowing.

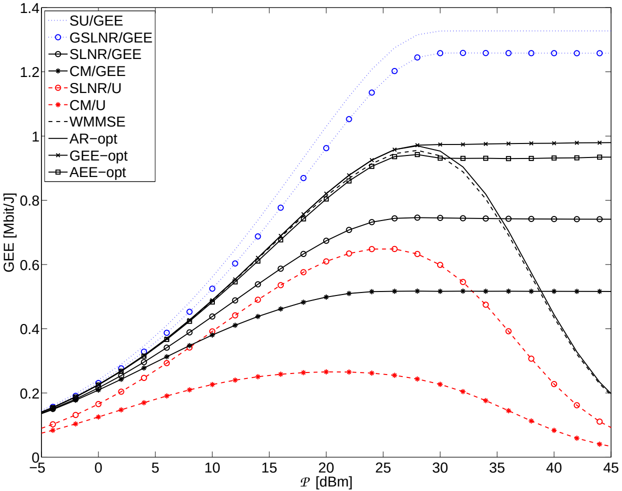
Convergence - isolated cluster



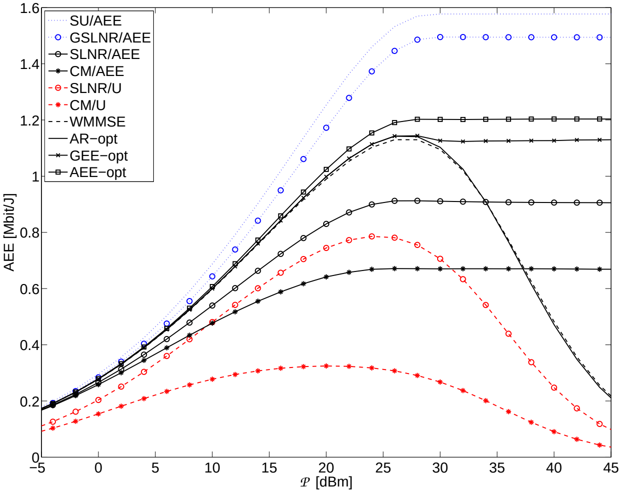
AR versus maximum available power - isolated cluster



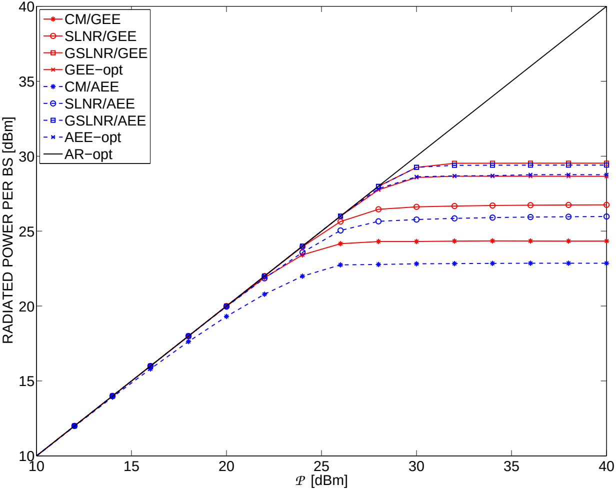
GEE versus maximum available power - isolated cluster



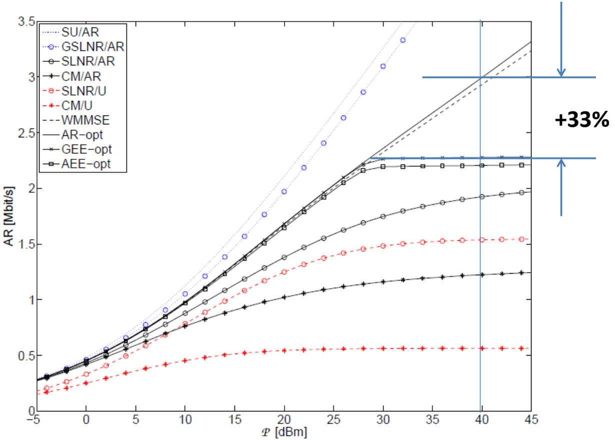
AEE versus maximum available power - isolated cluster



Radiated power versus maximum available power - isolated cluster

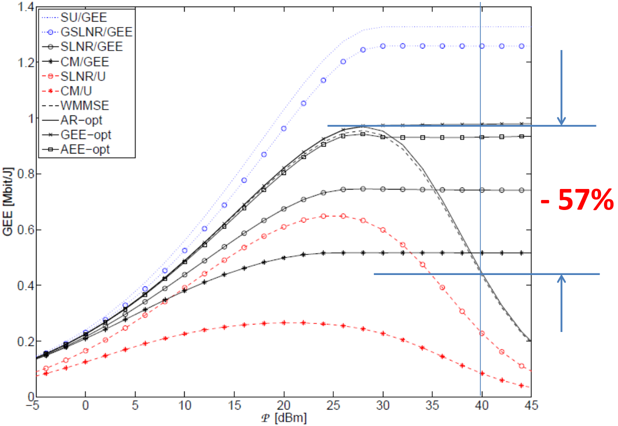


Message no. 1



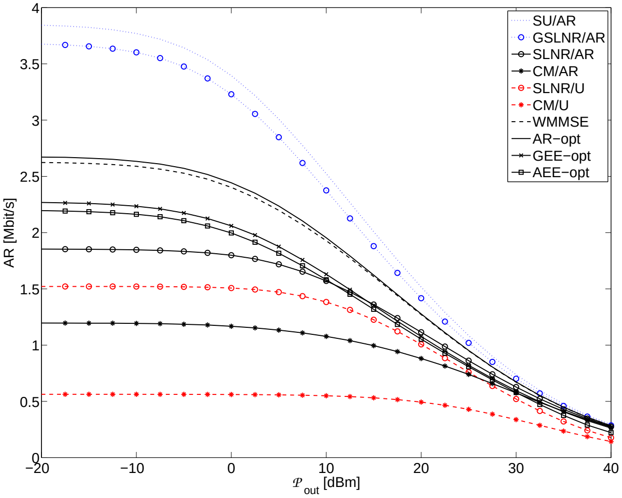
SU/AR
GSLNR/AR
SLNR/AR
CM/AR
SLNR/U
CM/U
WMMSE
AR−opt
GEE−opt
AEE−opt
AR [Mbit/s]
P [dBm]
+33%

Message no. 1

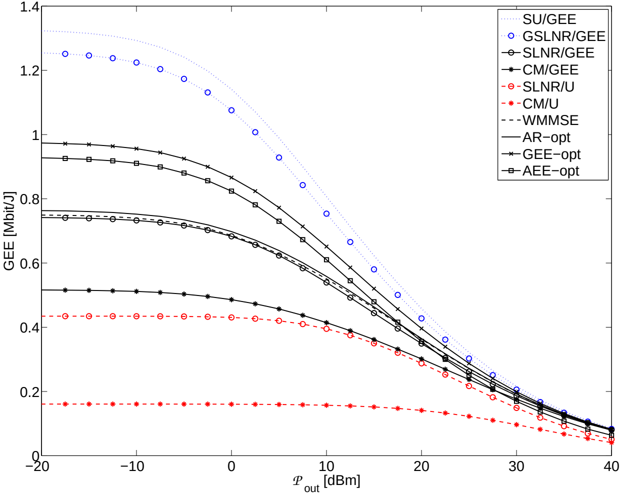


SU/GEE
GSLNR/GEE
SLNR/GEE
CM/GEE
SLNR/U
CM/U
WMMSE
AR−opt
GEE−opt
AEE−opt
GEE [Mbit/J]
$\mathcal{P}$ [dBm]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
−5
0
5
10
15
20
25
30
35
40
45
- 57%

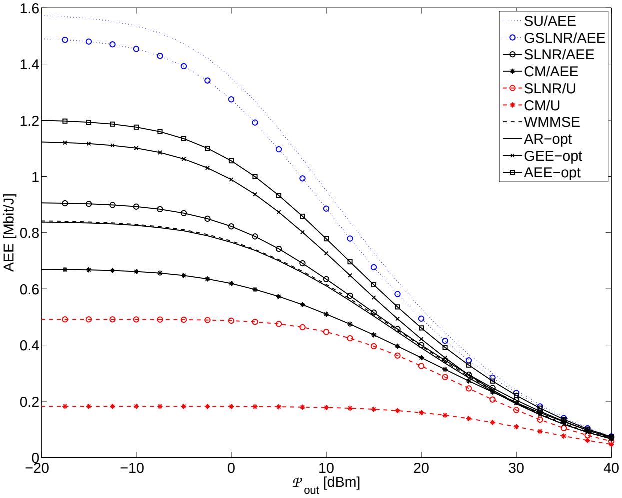
AR versus out-of-cluster power; $\mathcal{P}$ =35dBm



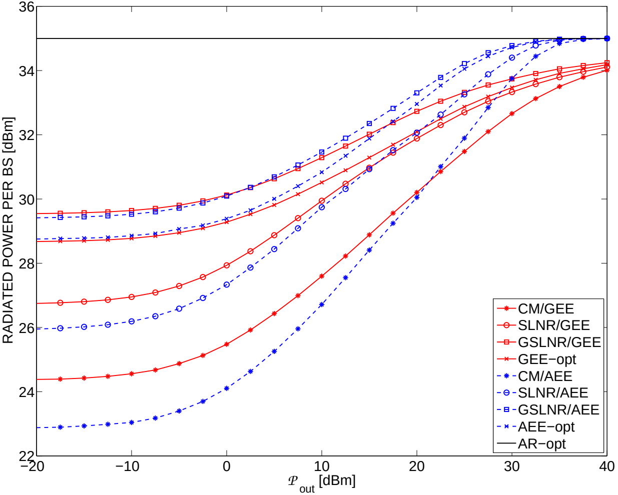
GEE versus out-of-cluster power; $\mathcal{P}$ =35dBm



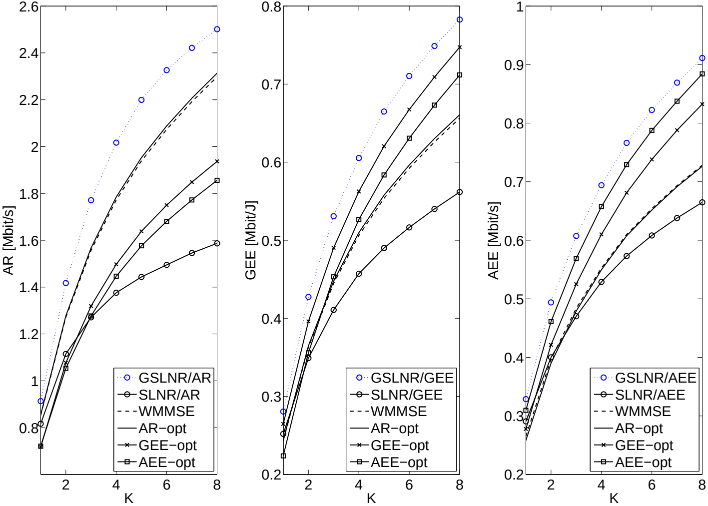
AEE versus out-of-cluster power; $\mathcal{P}$ =35dBm



Radiated power versus out-of-cluster power - Message no. 2



Performance versus K; $\mathcal{P} = 35$ dBm and $\mathcal{P}_{\text{out}} = 20$ - Message no. 3



Comments

- There is a critical value of $\mathcal{P}$. Beyond this point the rate increases but at the price of a strong reduction in energy efficiency.
- This point depends on the amount of energy consumed by the transmitter hardware
- Out-of-cluster interference has of course an effect on the cluster performance, but not very strong for the energy efficient allocation.
- Performance increases with number of users, because of multiuser diversity

Some open problems - Things to address

- Interaction between clusters
- Larger levels of coordination (e.g., CoMP)
- Non-orthogonality of carriers $\Longrightarrow$ Impact on signal processing and energy consumption

Some open problems - Things to address

- Interaction between clusters
- Larger levels of coordination (e.g., CoMP)
- Non-orthogonality of carriers $\Longrightarrow$ Impact on signal processing and energy consumption

Some open problems - Things to address

- Interaction between clusters
- Larger levels of coordination (e.g., CoMP)
- Non-orthogonality of carriers $\Longrightarrow$ Impact on signal processing and energy consumption

References

- L. Venturino, C. Risi, S. Buzzi, A. Zappone, "Energy-Efficient Coordinated User Scheduling and Power Control in Downlink Multi-cell OFDMA Networks," *Proc. of the IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2013)*, London, UK, September 2013.
- L. Venturino, C. Risi, A. Zappone, S. Buzzi, "Green Joint User Scheduling and Power Control in Downlink Multi-cell OFDMA Networks," *Proc. of the 2013 Future Network and Mobile Summit (FUNEMS 2013)*, Lisbon, Portugal, July 2013.
- L. Venturino, C. Risi, A. Zappone, S. Buzzi, "Energy-efficient scheduling and power allocation in downlink OFDMA networks with base station coordination," submitted to *IEEE Transactions on Wireless Communications*, July 2013.
- L. Venturino, S. Buzzi, "Coordinated Resource Allocation in Downlink MIMO OFDMA Systems: a Unified Design Method for Spectral or Energy Efficiency Maximization," submitted to *IEEE Transactions on Wireless Communications*, October 2013.
- L. Venturino, S. Buzzi, "Coordinated linear precoding for energy efficiency maximization in downlink cellular networks," submitted to *ICC 2014*.

References

- L. Venturino, C. Risi, S. Buzzi, A. Zappone, "Energy-Efficient Coordinated User Scheduling and Power Control in Downlink Multi-cell OFDMA Networks," *Proc. of the IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2013)*, London, UK, September 2013.
- L. Venturino, C. Risi, A. Zappone, S. Buzzi, "Green Joint User Scheduling and Power Control in Downlink Multi-cell OFDMA Networks," *Proc. of the 2013 Future Network and Mobile Summit (FUNEMS 2013)*, Lisbon, Portugal, July 2013.
- L. Venturino, C. Risi, A. Zappone, S. Buzzi, "Energy-efficient scheduling and power allocation in downlink OFDMA networks with base station coordination," submitted to *IEEE Transactions on Wireless Communications*, July 2013.
- L. Venturino, S. Buzzi, "Coordinated Resource Allocation in Downlink MIMO OFDMA Systems: a Unified Design Method for Spectral or Energy Efficiency Maximization," submitted to *IEEE Transactions on Wireless Communications*, October 2013.
- L. Venturino, S. Buzzi, "Coordinated linear precoding for energy efficiency maximization in downlink cellular networks," submitted to *ICC 2014*.

THANK YOU!!

Stefano Buzzi, Ph.D.
CNIT / Universitá di Cassino e del Lazio Meridionale
buzzi@unicas.it