UK4G Shanghai Workshop

# Energy Efficient Spectrum Allocation for Green Communications in Two-tier Cellular Networks


Liqiang Zhao

State Key Laboratory of Integrated Services Networks

Xidian University

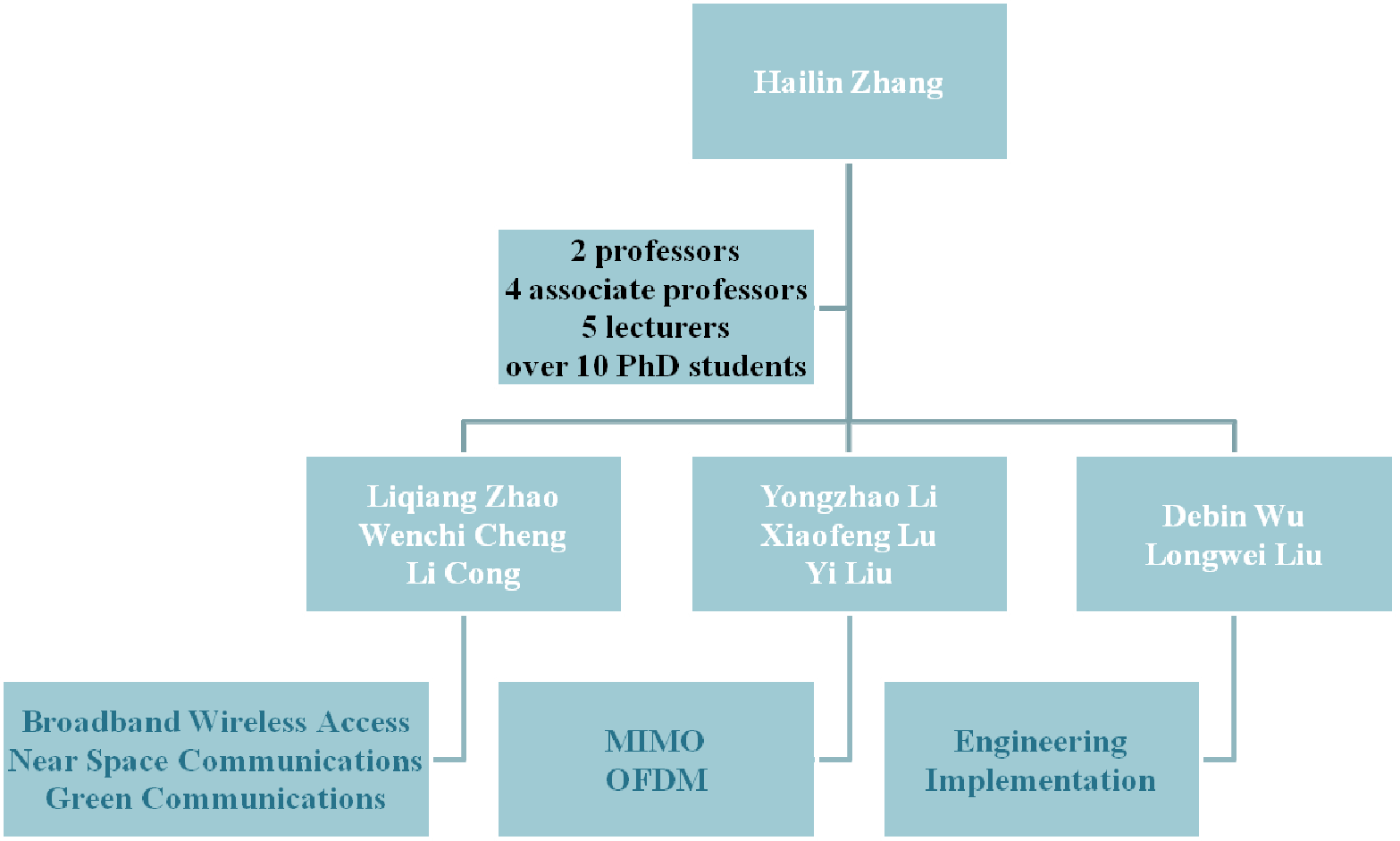
CHINA


1. *Introduction to Our Team*

2. Green Radio

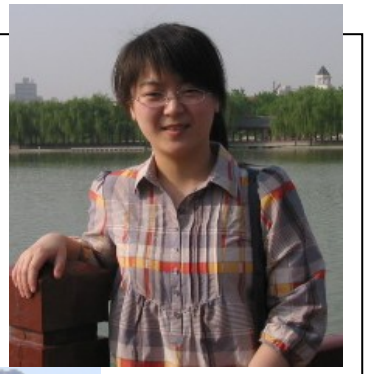
3. Green Networks

4. Problems & Perspective


Hailin Zhang
2 professors
4 associate professors
5 lecturers
over 10 PhD students
Liqiang Zhao
Wenchi Cheng
Li Cong
Yongzhao Li
Xiaofeng Lu
Yi Liu
Debin Wu
Longwei Liu
Broadband Wireless Access
Near Space Communications
Green Communications
MIMO
OFDM
Engineering
Implementation

- His current research focuses on Broadband Wireless Access, Near Space Communications, and Green Communications.
  - He has won many research projects funded by a number of sources: government and direct industrial funding.
  - His participation in various projects has yielded a number of concrete results including enormous high-level publications, patents, etc.
- Due to his excellent works in research, he was awarded by the Program for New Century Excellent Talents in University, Ministry of Education, China, in 2008.

- Miss Li Cong
  - Cooperative communications
  - Game theoretic dynamic resource management

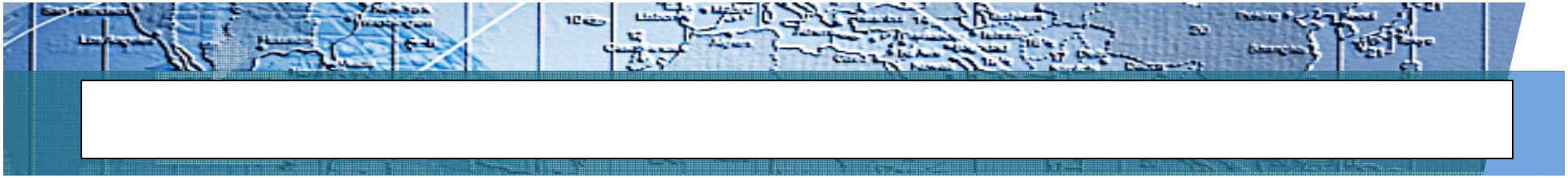


- Mr. Wenchi Cheng
  - Green cellular networks
  - MIMO detection

- Mr. Zhiyuan Ren
  - Green radio
  - Linear power amplifiers

- Our research covers almost the whole spectrum of broadband wireless access.
  - Key Technologies of Broadband Wireless Integrated Access Systems
  - Key Technologies of MIMO Systems
- Our research covers an interdisciplinary research topic, introducing game theory from mathematics and economics into wireless communications.
  - Research on Game-theoretic MAC Protocols in WSNs

- Our research covers near space communication systems and key technologies, such as network architecture, routing and MAC protocols, and PHY technologies.
  - Near Space Communication Systems and Heterogeneous Networks Convergence
    - High altitude stratospheric platforms (HAPs)
    - low-medium altitude platforms (LMAPs)




## Green Radio

- Power efficient hardware and hardware-related designs
- Power efficient digital signal processing
- RF techniques

## Green Networks

- Power efficient network architecture and strategies

- Embodied or manufacturing energy
  - Cooperating with Dr. Iztok Humar, University of Ljubljana, Slovenia, to develop embodied energy models for LTE
- Operating energy
  - Reducing number of active BSs/APs/FAPs
    - Wenchi Cheng, Liqiang Zhao, Hailin Zhang, “Load Concentration： A New Strategy for Green Cellular Networks in Low Traffic Regime”, submitted to Infocom 2010
  - Reducing operating energy in an active BS/AP/FAP
    - Wenchi Cheng, Hailin Zhang and Liqiang Zhao, “Energy Efficient Spectrum Allocation for Green Radio in Two-tier Cellular Networks”, to appear IEEE GlobeCom 2010

1. Introduction to Our Team

2. *Green Radio*

3. Green Networks

4. Problems & Perspective

1

• Eliminating the nonlinear distortion of amplifiers

2

• Increasing power efficiency of amplifiers, e.g., the output power back-off of amplifiers

Patents

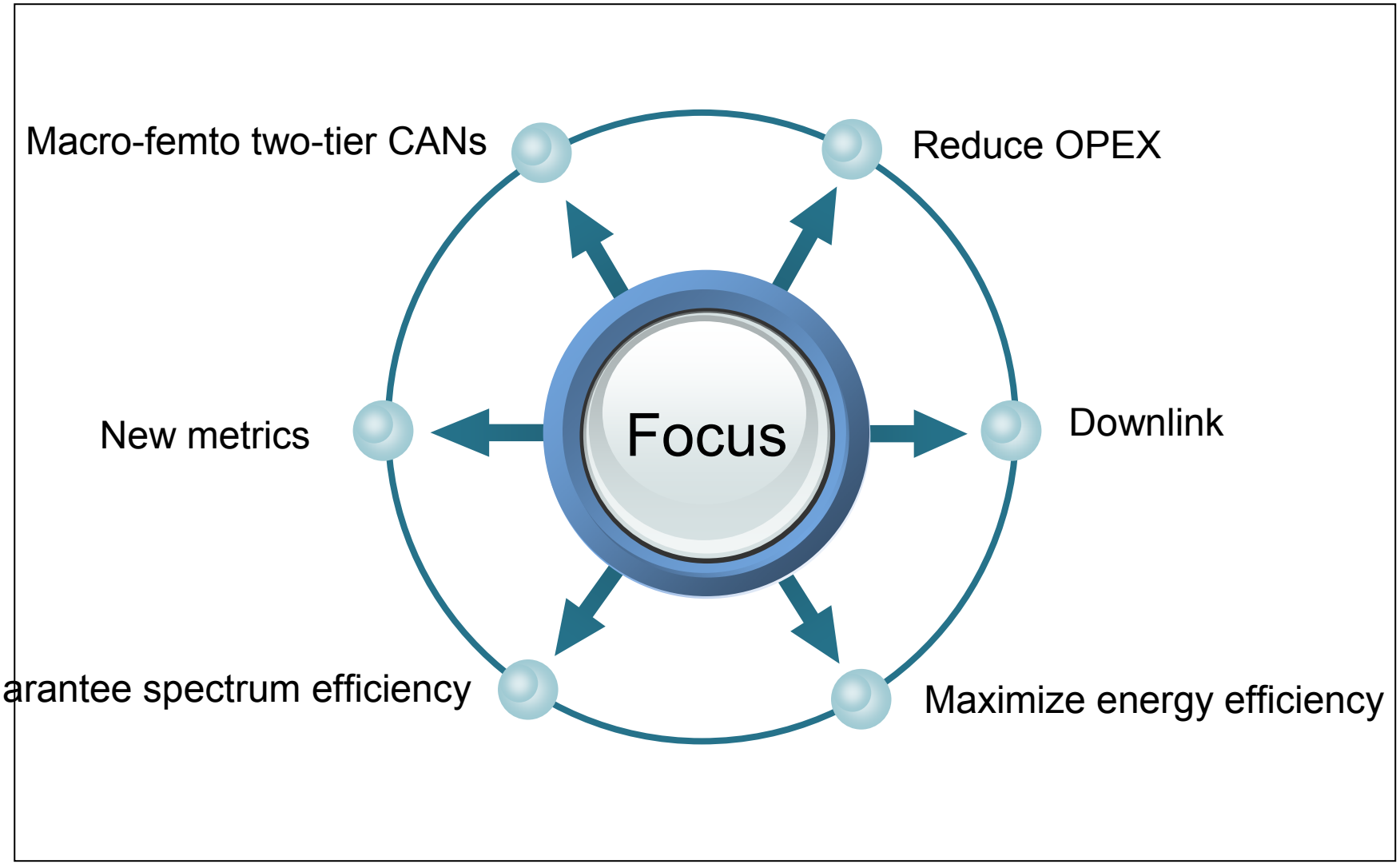
- A linearization device and method in wideband multicarrier communication systems
- A frequency-time predistorter and method in wideband communication systems

1. Introduction to our team

2. Green Radio

3. *Green Networks*

4. Problems & Perspective

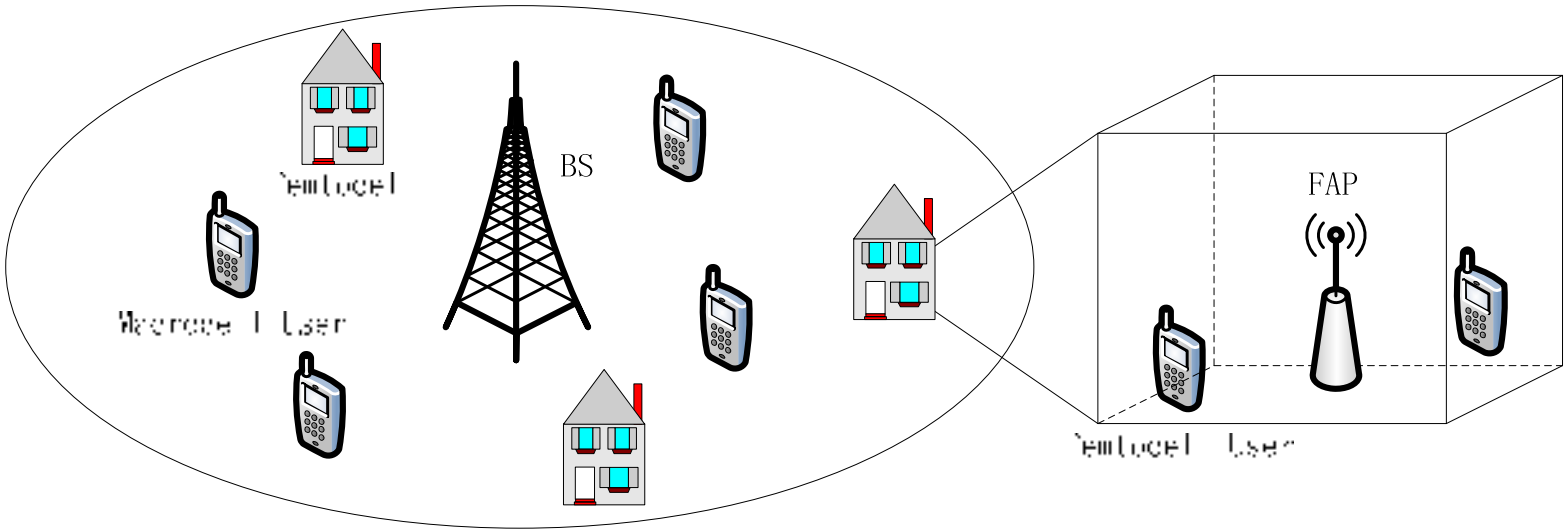

Macro-femto two-tier CANs
Reduce OPEX
New metrics
Focus
Downlink
Guarantee spectrum efficiency
Maximize energy efficiency

- In wireless communications, a user aims at transmitting its packets successfully under its QoS requirements over a certain distance to its receivers.
  - The utility metrics should include the successfully transmitted packets in bit, QoS metrics (such as bandwidth in b/s, delay and jitter in second, and packet loss rate) and the transmission distance in meter.
  - The resource metrics should time in sec, frequency in Hz, code, space in antenna, and power in W.

$$\arg\max Efficiency = \arg\max {Utility} \Big/ {Consumed\ resources}$$

$$s.t. \begin{cases} Bandwidth > Bandwidth_{\min} \\ Delay < Delay_{\max} \\ Jitter < Jitter_{\max} \\ PacketLossRate < PacketLossRate_{\max} \end{cases}$$

- Metrics
  - Bandwidth efficiency: b/s/Hz
  - Power efficiency: b/s/W
  - Power efficiency: b/s/TENU
  - Spectrum efficiency : b/s/Hz/$m^3$
  - Energy efficiency: green factor (b/s/W/subchannel)




- Consumer installed indoor or femtocell access points, which mainly solve the indoor coverage problem.
  - Advantages: Better coverage for indoor environment, lower transmitting power for indoor users and eliminate the serious effects of wall path losses for energy consumption.
  - Disadvantages: From nearby users serviced by the other tier, interferences increase the energy consumption of macro-femto cells.

- For reducing the interference between femtocells, we use random partial bandwidth.
  - The frequency access ratio, $r_f$, is defined as the ratio of the number of active subchannels for each FAP to the number of the total subchannels for each FAP.

$$r_f = \frac{F_a}{F_f}$$

where $F_a$ is the number of active subchannels for each FAP, and $F_f$ is the number of total subchannels for FAPs.

- Throughput of macrocell users

$$T_m = \sum_{i=1}^{I-1} i \cdot [Z_m(\Gamma_{i+1}) - Z_m(\Gamma_i)] + I \cdot [1 - Z_m(\Gamma_I)]$$

- Throughput of femtocell users

$$T_f = \sum_{l=1}^{L-1} i \cdot [Z_f(\Gamma_{i+1}) - Z_f(\Gamma_i)] + I \cdot [1 - Z_f(\Gamma_I)]$$

- System throughput of two-tier cellular networks

$$T_c = W[rT_m + (1-r)N_f r_f T_f]$$

where $N_f$ is the mean number of femtocells per macrocell.

- We can obtain the optimal spectrum allocation to maximize the defined green factor.

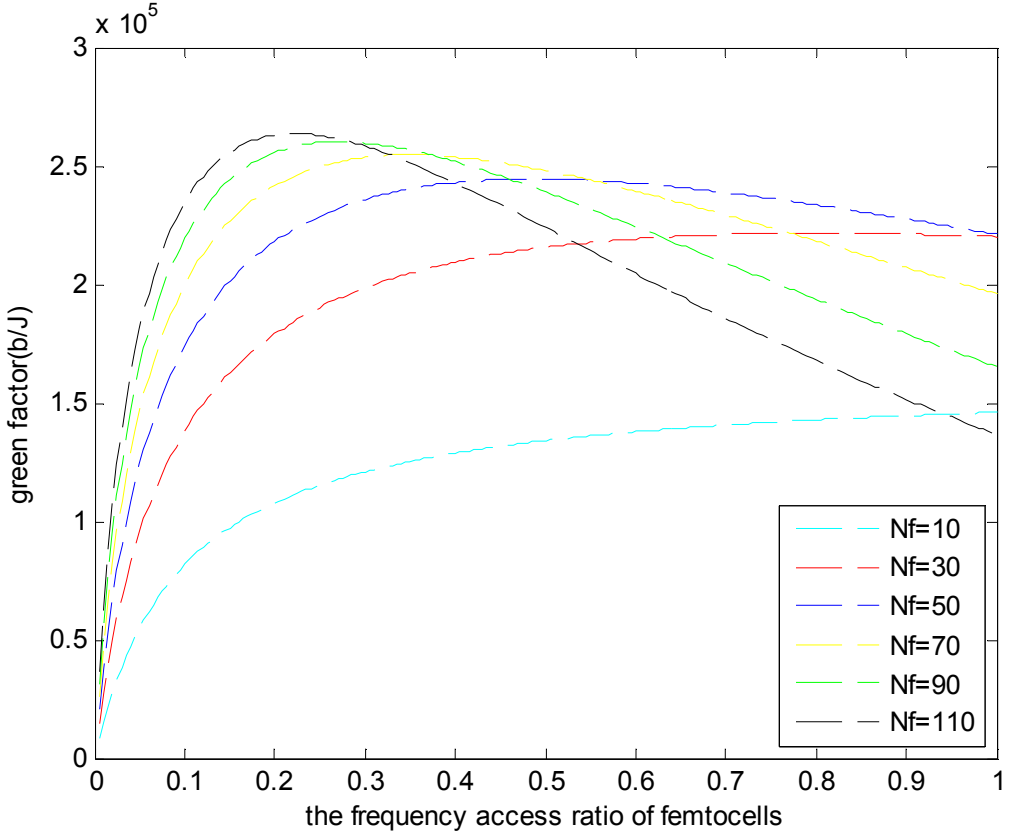
$$\max\ green\ \ factor = \max \frac{W[rT_m + (1-r)N_f r_f T_f(r_f, N_f)]}{P_{system}}$$

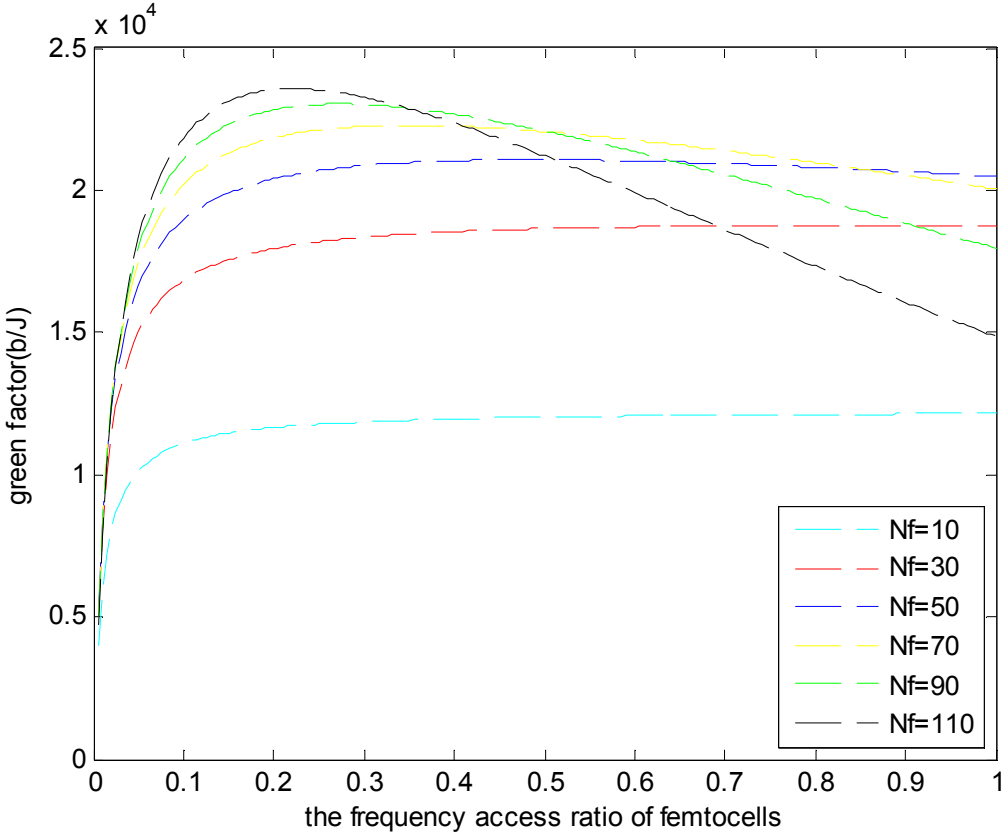
under throughput constraint:

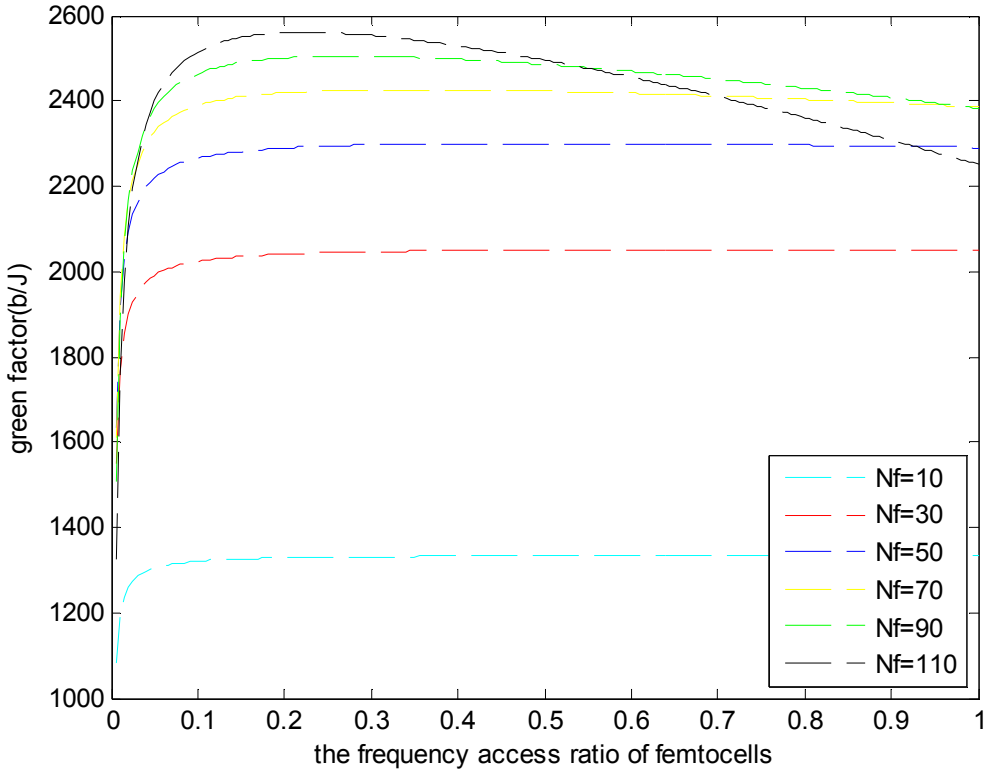
$$\eta = 1 - \frac{\frac{T_m rF}{U_m}}{\frac{T_m rF}{U_m} + \frac{T_f(r_f, N_f)(1-r)Fr_f}{U_f}}$$

where $\eta$ is the ratio of the macrocell user throughput to the femtocell user throughput.

- Green factor ~ $N_f$, $r_f$, $\eta$
  - $N_f$: the mean number of femtocells per macrocell.
  - $r_f$: the ratio of the number of active subchannels for each FAP to the number of the total subchannels for each FAP.
  - $\eta$: the ratio of the macrocell user throughput to the femtocell user throughput


x 10^5
3
2.5
2
1.5
1
0.5
0
green factor(b/J)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
the frequency access ratio of femtocells
Nf=10
Nf=30
Nf=50
Nf=70
Nf=90
Nf=110


x 10^4
2.5
2
1.5
1
0.5
0
green factor(b/J)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
the frequency access ratio of femtocells
Nf=10
Nf=30
Nf=50
Nf=70
Nf=90
Nf=110


green factor(b/J)
the frequency access ratio of femtocells
2600
2400
2200
2000
1800
1600
1400
1200
1000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Nf=10
Nf=30
Nf=50
Nf=70
Nf=90
Nf=110

- When $N_f$ is less than 30, the green factor increases with the increasing of $r_f$. When $N_f$ is large than 50, the green factor firstly increases, then decreases with the increasing of $r_f$.
- The maximal green factor is increasing with the increasing of $N_f$. However, due to the different $r_f$ to achieve the maximal green factor of different $N_f$ , adjustment of $r_f$ is needed to improve energy efficiency.
- When $\eta$ is small (e.g., 0.01 or 0.1), the maximal green factor for different $N_f$ will be obtained with different $r_f$ . While $\eta$ is relatively large( e.g., 0.5), the maximal green factor can be obtained at almost $r_f$ =0.2 for different $N_f$.

1. Introduction to our team

2. Green Radio

3. Green Networks

4. *Problems & Perspective*

- Energy consumption model
  - Cooperating with Iztok Humar to integrate his embodied energy model with our operating energy model for LTE/LTE+
- Green technologies for operating energy
  - Reducing operating energy of users
    - An idea from Qualcomm
    - Cooperating with Prof. Xi Zhang, Texas A&M University

# Thank You !