

TREND: The FP7 Network of Excellence on Green Networking

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Towards Real Energy-efficient Network Design

The FP7 Network of Excellence on Green Networking

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TREND rationale and motivations



*The aim of **TREND** is to establish the **integration** of the EU research community in green networking, with a **long term** perspective to consolidate the European leadership in the field*

TREND at a glance

- **12 partners** (2 manufacturers + 3 telecom operators + 7 university groups) + Collaborating Institutions, all with significant previous experience in the technical topics
- duration: **3 years**
- estimated effort: **446 person/months**
- project budget: 4.4 MEuro (79% for RTD activities, 14% for other activities, 5% for project management)
- EC contribution: **3.0 MEuro**

TREND partners



- (1) POLITECNICO DI TORINO
- (2) **ALCATEL - LUCENT BELL LABS FRANCE**
- (3) **HUAWEI TECHNOLOGIES DUESSELDORF GmbH**
- (4) **TELEFONICA INVESTIGACION Y DESARROLLO SA**
- (5) **FRANCE TELECOM SA**
- (6) **FASTWEB SPA**
- (7) UNIVERSIDAD CARLOS III DE MADRID
- (8) INTERDISCIPLINARY INSTITUTE FOR BROADBAND TECHNOLOGY
- (9) TECHNISCHE UNIVERSITAT BERLIN
- (10) ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
- (11) CONSORZIO NAZIONALE INTERUNIVERSITARIO PER LE TELECOMUNICAZIONI
- (12) PANEPISTIMIO THESSALIAS



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4

Current Collaborating Institutions



Current CIs

- Politecnico
- Univers
- Fonda
- Tec
-
-
- IC
- In
- T
- Bos

**If you wish to become a
CI of TREND,
please contact me**

Pending CIs

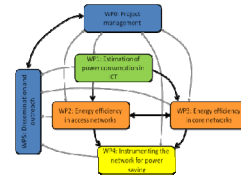
- activities
- Tsinghua University, Beijing (China)
- Federal University of Juiz de Fora (Brazil)



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5

TREND organization



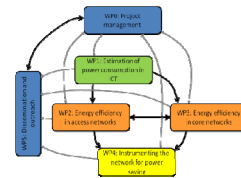
■ 6 workpackages:

- WP1: Assessment of power consumption in ICT (IBBT)
- WP2: Energy efficiency in access and home networks (UTH)
- WP3: Energy efficiency in core networks (FT)
- WP4: Instrumenting the network for power saving (A-LBLF)
- WP5: Dissemination and outreach (UC3M)
- WP6: Project organization and management (PoliTO)

■ Integration enablers:

- Integrated Research Actions and Joint Experimental Activities
- mobility and joint publications
- joint education and dissemination

TREND organization



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WP1

Power Consumption of Base Stations

Alberto Conte

ALCATEL-LUCENT BELL LABS FRANCE

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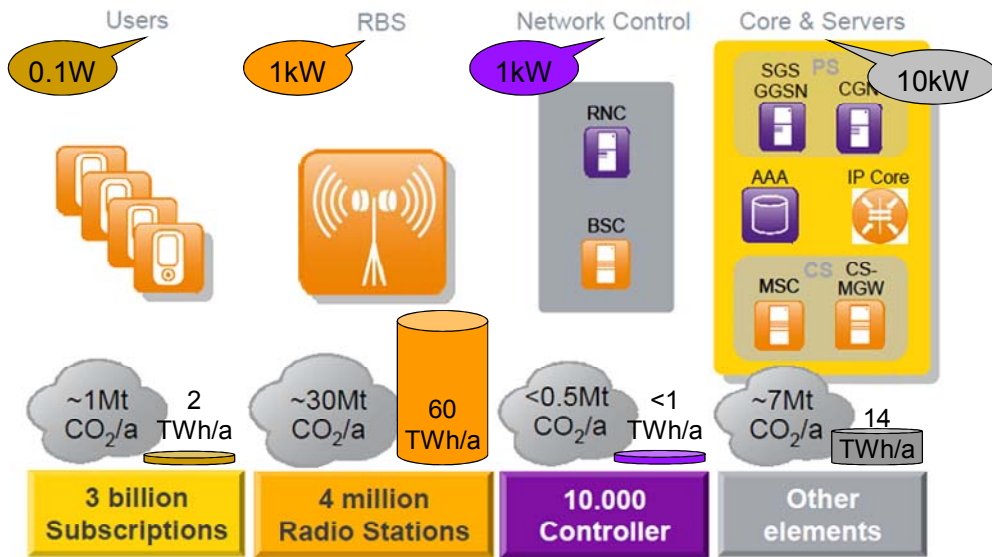
Important note

- The data in the next slides are intended for an introductory presentation
- The data in the next slides refer to realistic abstract cases and are not representative of specific ALU equipment



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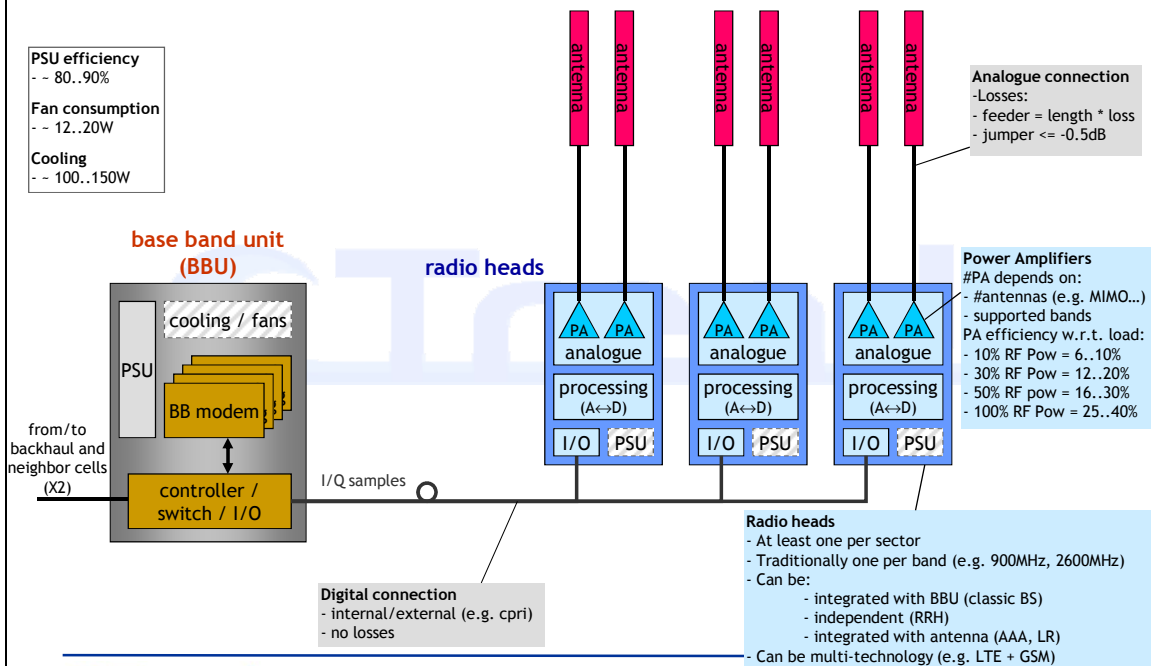
Mobile Communications: where is the power going ?



CO₂ emission from cellular networks

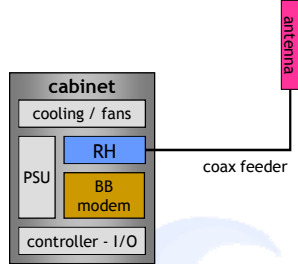
Based on: ETSI_RRS05_024_NSN

Base station functional components

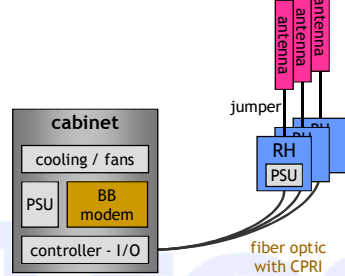


Possible options for grouping functions

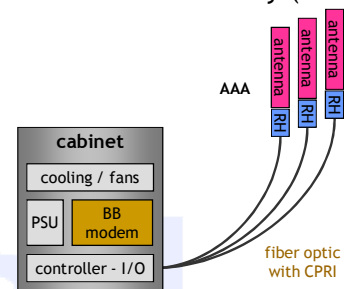
Classic BS



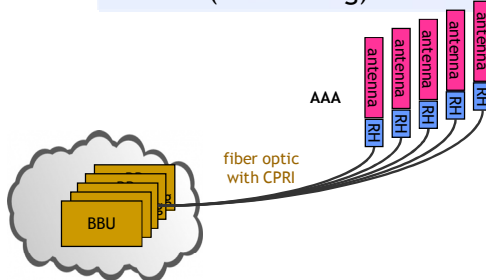
Classic RRH



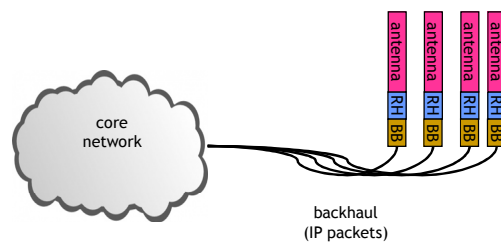
Active Antenna Array (AAA)



BB in the cloud (or hoteling) + AAA



All-in-one (e.g. small cells / femtos)



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PSU = Power Supply Unit

Rules of thumb on BB grouping

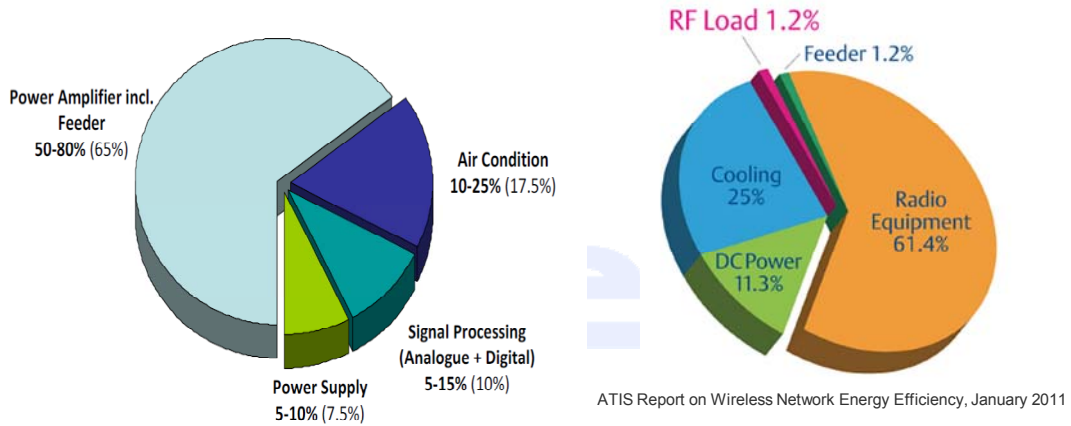
- BBU in the cloud (or in large cabinets = hoteling)
 - Well adapted for multi-cell processing (like network-MIMO)
 - High CPRI BW required + fiber distance limited due to latency limits
 - BB pooling => energy savings by matching load with # of active BBUs
- All-in-one
 - BB processing can be small, cheap and integrated (e.g. on SoC)
 - Best choice for small cells (price constrained)
 - Lack of BB pooling. Duplication of "common" functions (e.g. synchronization)



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Power Consumption of Radio Access Equipment

Who is consuming what ?



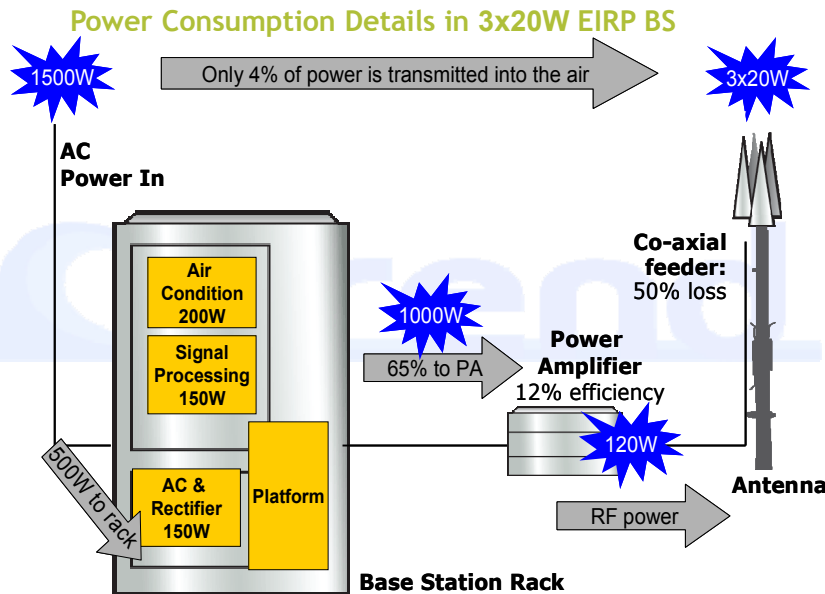
Study on Energy Efficient Radio Access Network Technologies, 2009
 Alcatel-Lucent / TU Dresden Vodafone Chair Mobile Communications Systems
 Figure 3-5 Percentage contribution of total BS power consumption (mean in brackets)



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Macro BS energy consumption breakdown

- Toy example



IMPORTANT NOTE
 This is just a toy example
 not reflecting specific
 equipment figures

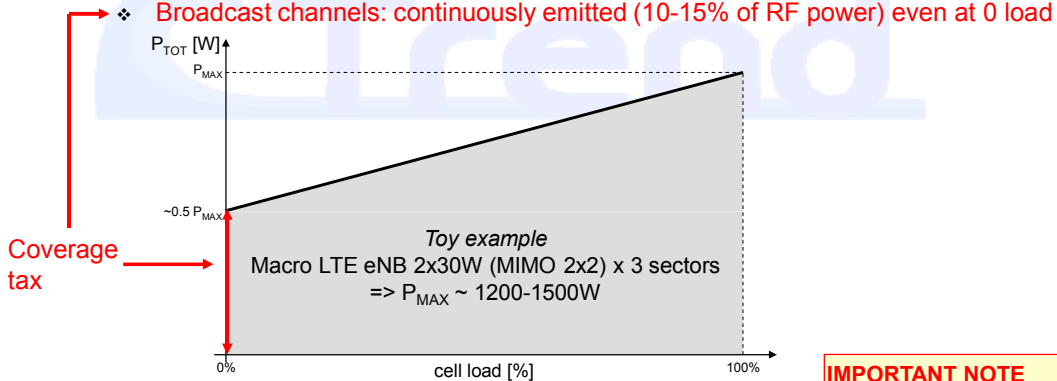


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Base Station power consumption figures - LTE case (eNB)

■ BS consumption analysis

- BBU, PSU, cooling/fans consumption is poorly dependent on cell load
- RH: ~60% of its consumption scales with data traffic load
 - The remaining ~40% is not dependent on data traffic load
 - ❖ HW consumption
 - ❖ **Broadcast channels: continuously emitted (10-15% of RF power) even at 0 load**



ETSI definitions

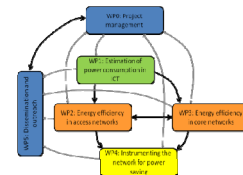
- "low load" = 10% RF power (no data – only common ch)
- "medium load" = 30% RF power (data + common ch)
- "busy hour" = 50% RF power (data + common ch)
- "average" = 6/24 low + 10/24 medium + 8/24 busy = 31.7%

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IMPORTANT NOTE

This is just a *toy example* not reflecting specific equipment figures

TREND organization



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WP2

Optimal Sleep Modes in Cellular Networks

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Luca Chiaraviglio

Delia Ciullo

Michela Meo

POLITECNICO DI TORINO

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Context & Goals

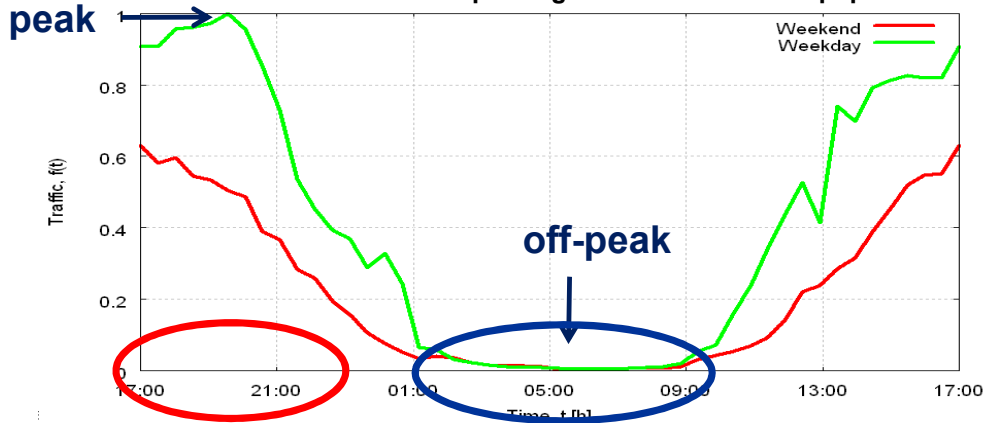
- In dense urban environments, cellular access networks planning is driven by capacity needs
- Capacity deployment determines energy consumption but full capacity is not always needed

Can Base Station sleep modes help us in reducing access network energy consumption?

How to decide the use of sleep modes?

Network planning with sleep modes

Normalized cellular traffic trace during one week,
data available at:
<http://anrg.usc.edu/www/index.php/Downloads>



**high capacity to
carry all the traffic**

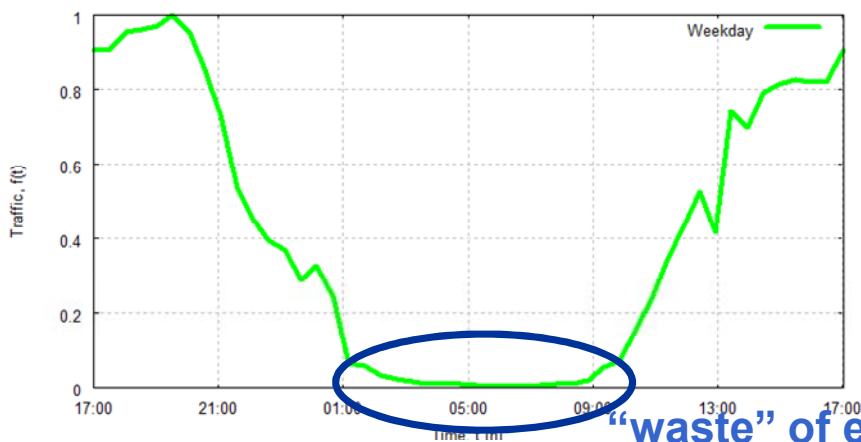
**over-provisioning
("waste" of capacity)**



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Network planning with sleep modes

Since energy consumption only marginally depends on load,
over-provisioning → waste of energy



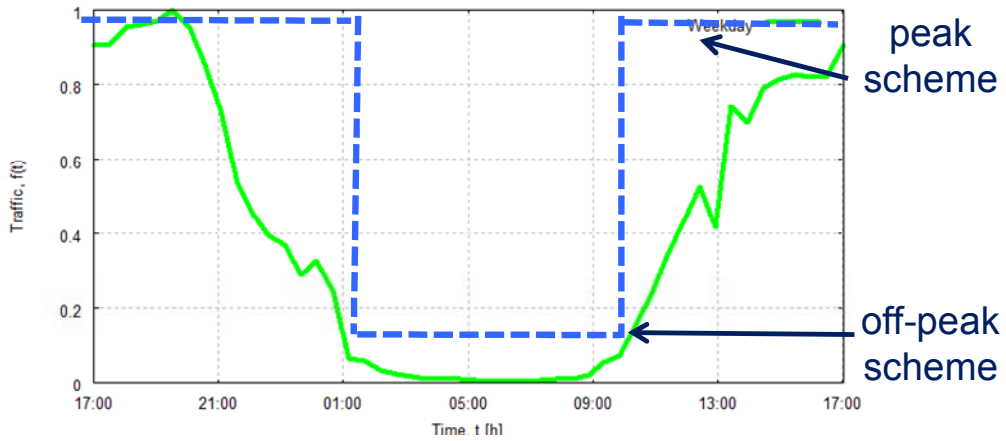
Adapt capacity to traffic by using sleep modes



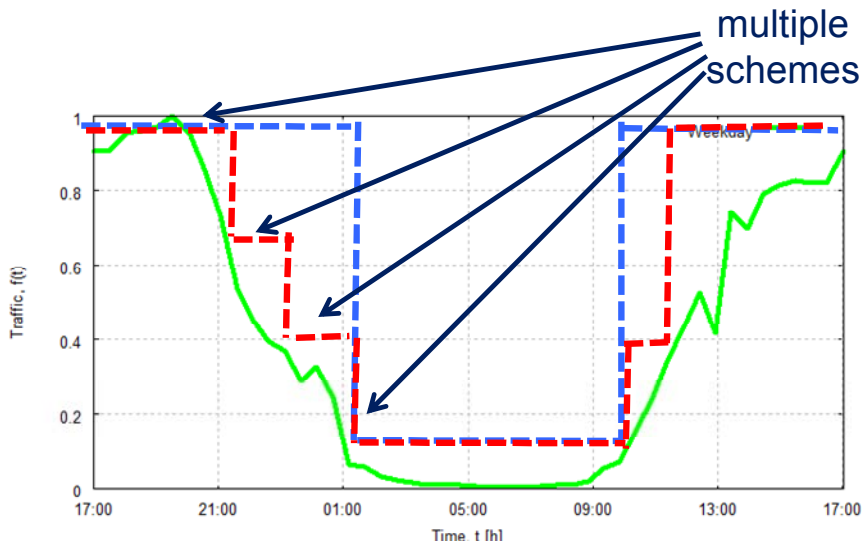
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Network planning with sleep modes

- Use two planning schemes
- Swap between two schemes

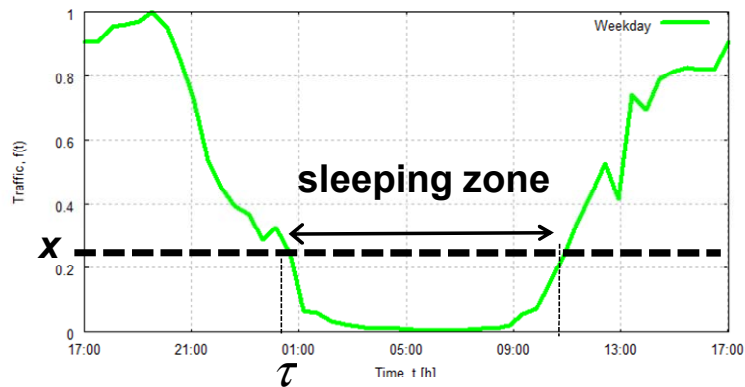


Can we do better?



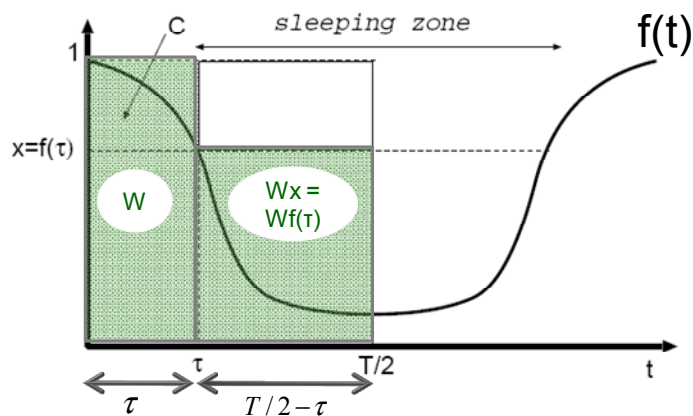
Deciding switching schemes

A fraction x of the cells can carry all the traffic when traffic is a fraction x of the peak



Actual saving depends on x (fraction of cells that remain on) and duration of sleeping zone

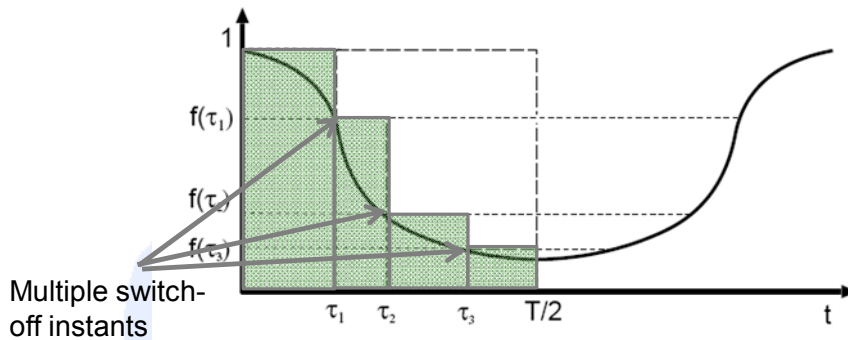
Optimal single switch-off scheme



The optimal choice of τ minimizes the green area

$$C(\tau) = 2 \left[W\tau + Wf(\tau) \left(\frac{T}{2} - \tau \right) \right]$$

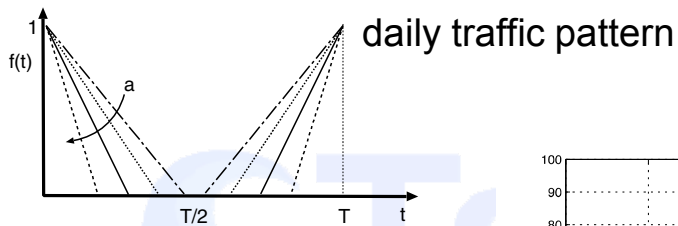
Multiple switch-offs



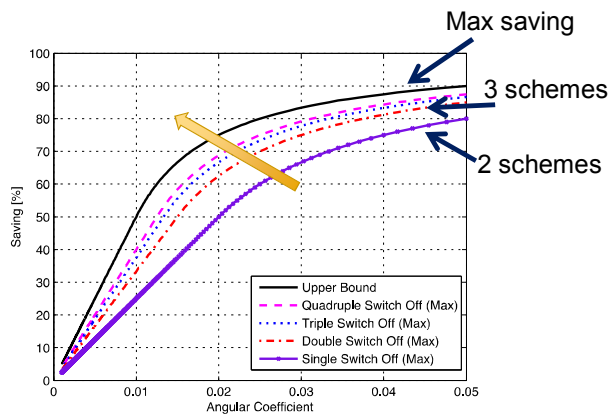
Again, the optimal choice minimizes the area

Lower bound on consumption:
$$C^* = \int_0^{T/2} f(t) dt$$

How much can we gain with multiple schemes?



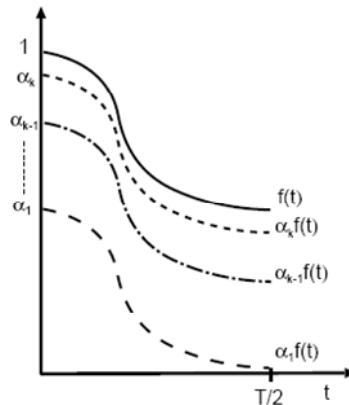
Little saving with more than 2 or 3 schemes



Heterogeneous networks

- Cells of different size and load coexist
- An umbrella cell (macro) can carry the traffic when K micro-cells are switched off

On the cells:
*Same pattern,
different actual load*



Optimal switch-off order

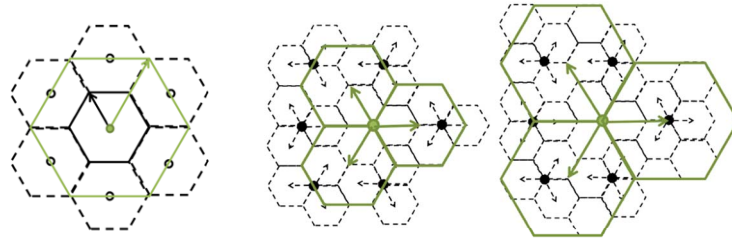
What is the optimal switch-off order?



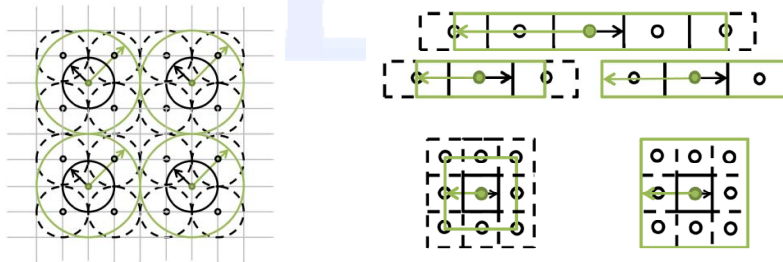
We analytically prove that the optimal ordering consists in switching off cells according to their load:

from the least-loaded to the most loaded
(**Least-Loaded** policy)

What is the effect of layout constraints?



Hexagonal: omnidirectional/three-sectorial configurations



Crossroad

Manhattan layouts (linear/squared)

Single switch-off

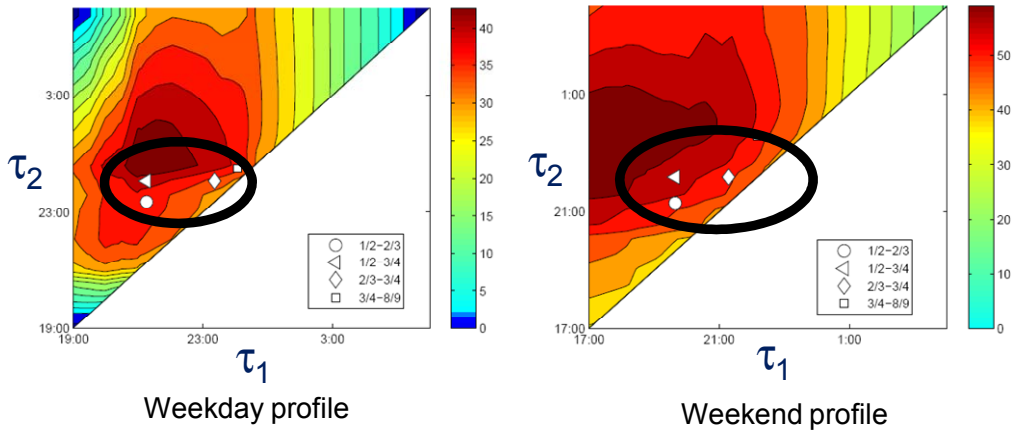
Results depend on the traffic profile and layout constraints:
for the weekday profile

Switch off scheme	BS saving [%]	Network saving [%]
(1,2) Manhattan/linear	60.2	30.1
(2,3) Manhattan/linear		31.7
(3,4) Hexagonal/squared		32.2
(4,5) Crossroad		33.8
(8,9) Hexagonal/squared	36.9	33.4

Network savings of the order of 30%

Double switch-off

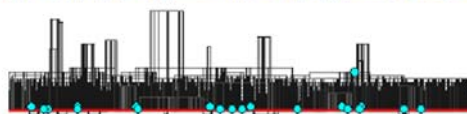
Real layout constraints limit benefits



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Case-study: Scenario by Alcatel-Lucent

- 1 macrocell, 40 W per sector
- 8 microcells, 1 W
- 12 femtocells, 20 mW



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Case-study: Switch-off policies comparison

Switch-off scheme	Saving [%]
Single (8/9)	40.8
Double (5/9)-(8/9)	45.7
Triple (3/9)-(5/9)-(8/9)	46.9
Maximum (Least-Loaded)	48.7

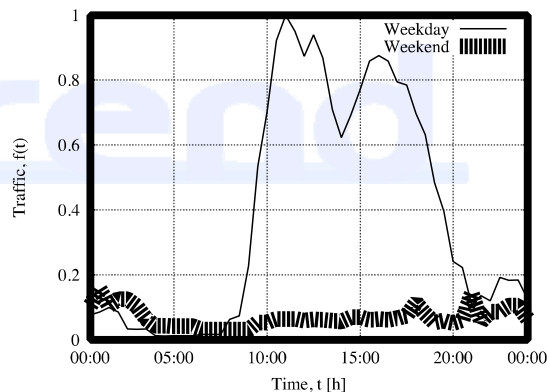
- ✓ Significant savings can be achieved with only one switch-off per day, the benefit of multiple switch-offs is minor!
- ✓ The optimal order to switch-off BSs consists in turning off them in increasing order of load (*Least-Loaded*)

Large differences in different areas

- Savings depend on the traffic profile, that can be highly dependent on the area

Business:

- Fast transitions
- Peaks during the day
- Large difference weekday/weekend

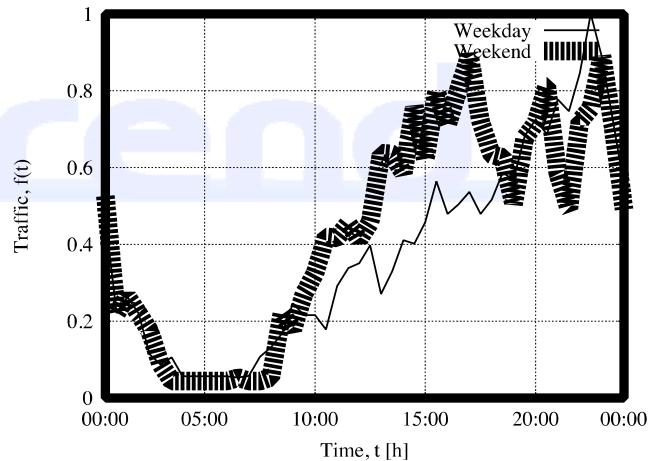


Large differences in different areas

- Savings depend on the traffic profile that can be highly dependent on the area

Consumer:

- Long transitions
- Peaks in the evening
- Little difference weekday/weekend



Possible energy saving

Switch-off scheme	Business WE	Business WD	Residential WE	Residential WD
Upper Bound	91.40%	61.86%	50.10%	59.90%
$N = 3$	89.85%	50.96%	40.06%	49.21%
$N = 2$	89.28%	46.57%	34.55%	44.91%
$N = 1$	84.30%	42.01%	26.61%	33.90%

Conclusions

- **Results:**
 - A large portion of the total network energy consumption can be saved with BS sleep modes
 - significant savings can be achieved with only one switch-off per day, while the benefit of multiple switch-offs is minor
 - optimal order to switch-off BSs consists in turning off cells in increasing order of load
- Our results provide a tangible motivation for mobile operators to implement sleep modes in their networks



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Thank you

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