GREENING OF MOBILE NETWORKS : MYTHS AND OPPORTUNITIES

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EPFL
May 31st – June 1, 2010

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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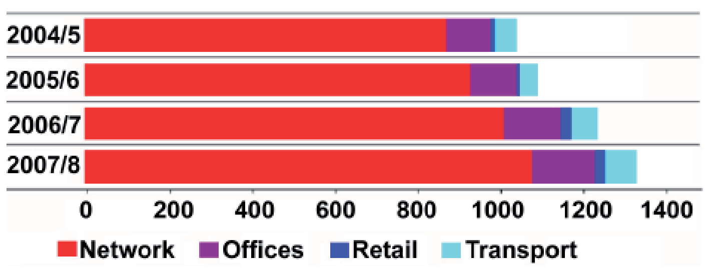
EuropeanWireless2010

- Energy consumption facts
  - Germany: total 200M € yearly
    - 1.8 TWh ~ 0.34 % of Germany total
  - UK: Vodafone 20M £ yearly
    - 0.2 TWh ~ 0.06 % of UK total (times 3 operators!)
  - Significant share on OPEX (OPerating EXpense)
    - Europe: 18%, India: 32%
  - Worldwide: ca. 60 TWh yearly ~ 0.3 % in total
- Corresponds to ca. 38 million tons of CO_2 emissions

Radio Network Is A Major Electricity Consumer

- 80% of electricity spent on radio network alone
  - i.e. base stations (BTS)
  - a typical network has thousands BTSs (Vodafone UK ~ 12k)



- Radio network energy efficiency = challenge

Traffic Proportional Energy Consumption

- Today's equipment power consumption is largely traffic insensitive
  - Power amplifiers, non idling processors
- Tomorrow's equipment will be much more energy proportional

- In the rest of this section I focus on operation and design

Save Energy by Shutting Down Base Stations

Optimal Energy Savings in Cellular Access Networks

Marco Ajmone Marsan, Luca Chiaraviglio, Delia Ciullo, Michela Meo
Electronics Department, Politecnico di Torino, Italy

GreenComm'09

Energy Efficient Management of two Cellular Access Networks

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GreenMetrics'09

- Savings up to 25-30% can be achieved
- Network sharing allows shutting down entire network at off peak periods

Save Energy by Optimal Network Design


Energy Profile Aware Routing

Juan Camilo Cardona Restrepo*+, Claus G. Gruber*, and Carmen Mas Machuca+

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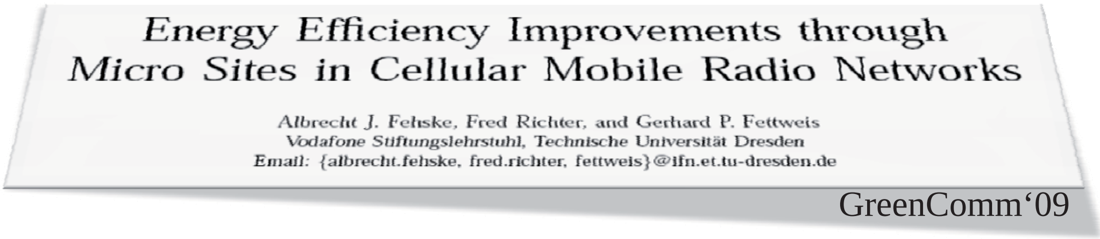
GreenComm'09

- Design and route according to energy consumption (optical switching vs IP routing)


Energy Efficiency Improvements through Micro Sites in Cellular Mobile Radio Networks

Albrecht J. Fehske, Fred Richter, and Gerhard P. Fettweis
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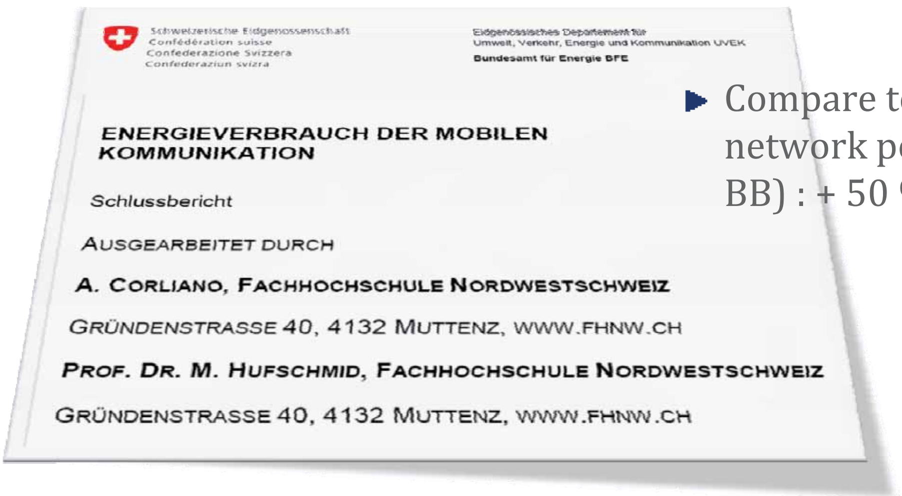
GreenComm'09

- Femto cells to reduce energy consumption of down and up link

- Femto Cells:
  - Assume 20 % swiss households equipped with 3G femtocell, 15W
  - Increases power consumption of households by 0.5 %
  - Compare to existing mobile phone network power consumption (RF + BB) : + 50 %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Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK
Bundesamt für Energie BFE

ENERGIEVERBRAUCH DER MOBILEN KOMMUNIKATION

Schlussbericht

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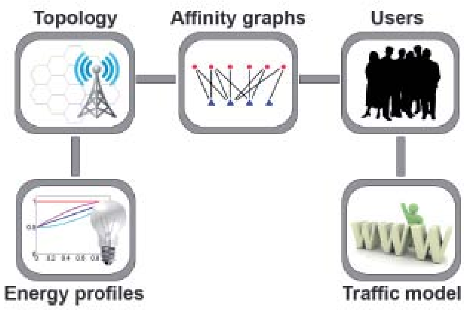
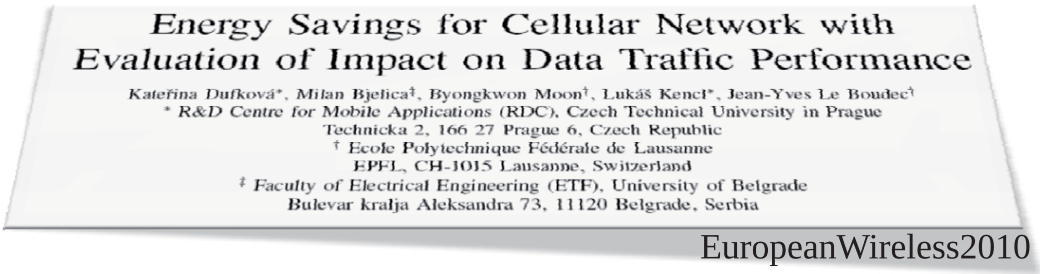
Online Dynamical Allocation



- Idea:
  - Predict aggregate traffic
  - Decide resource allocation every say 2-5 mn
  - Optimize network predicted cost subject to quality of service
  - Efficient for data traffic


Energy Savings for Cellular Network with Evaluation of Impact on Data Traffic Performance

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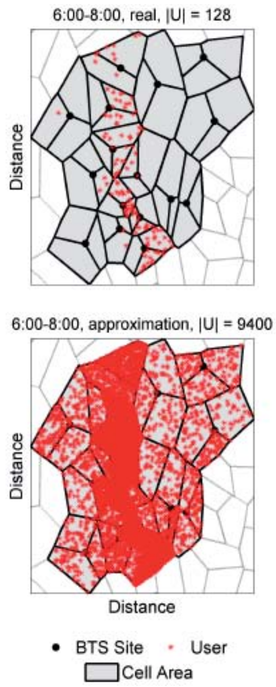
EuropeanWireless2010

Experimental Results

- Trace based sets of users
  - Obtained by active tracking of user-cell associations in a real network
  - Only a small fraction of users in the area
  - Represents spatial distribution of users!
- Artificially generated sets of users
  - Use above as a spatial multinomial probability distribution
  - Draw sample of desired size

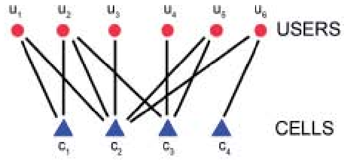
Statistics:

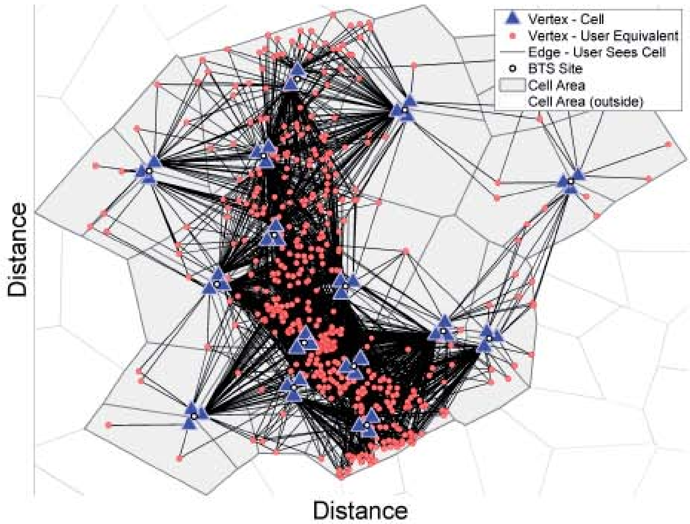
- up to 9400 users
- i.e. up to mean 200 users per cell



Optimal Allocation of Users to Cell by Binary Integer Programming Heuristic

- Relations between cells and users
- Modelled as a bipartite graph





- Vertices = $\{\text{cells} \cup \text{users}\}$
- Edges = $\{(\text{user,cell}) \mid$ user can connect to cell$\}$

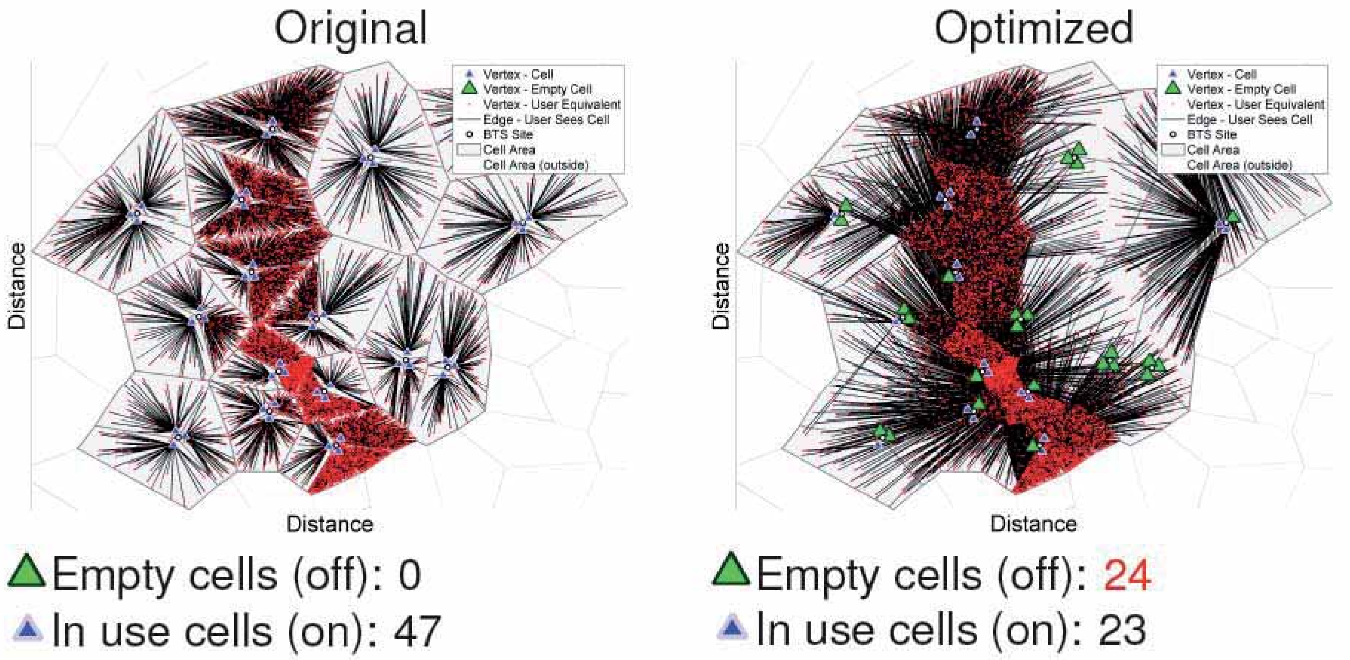
Traffic Model

- Data traffic only
- Web workloads generated by SURGE
- Cell $\sim$ single uplink and downlink processor sharing queue
  - service rates $R_{UP} = 2$ Mbps, $R_{DOWN} = 14.4$ Mbps (HSDPA)
  - fixed network delay 100 ms

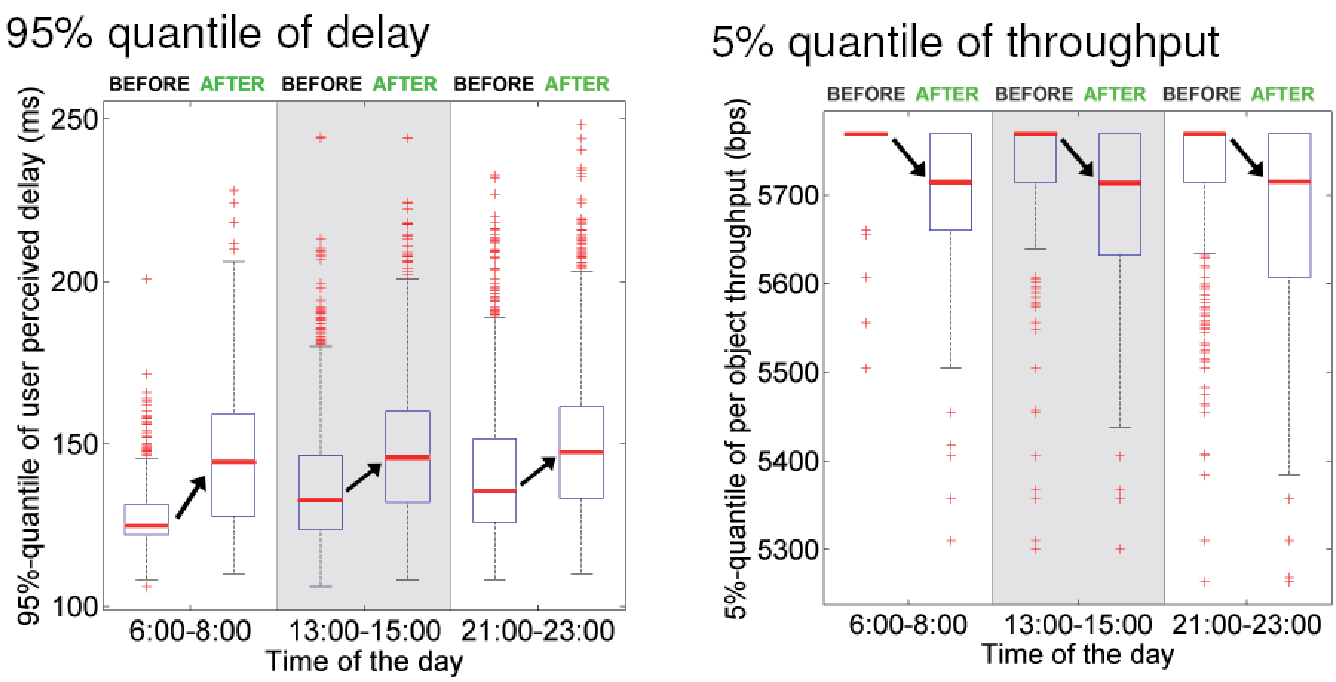
Estimate the maximum safe number of users (K) per cell

- load offered by a single active user
- during simulation time, not all users are going to be active
  - Network activity level
  - Time-Of-Day activity level
- maximum number of active users associable to a cell (technology dependent)

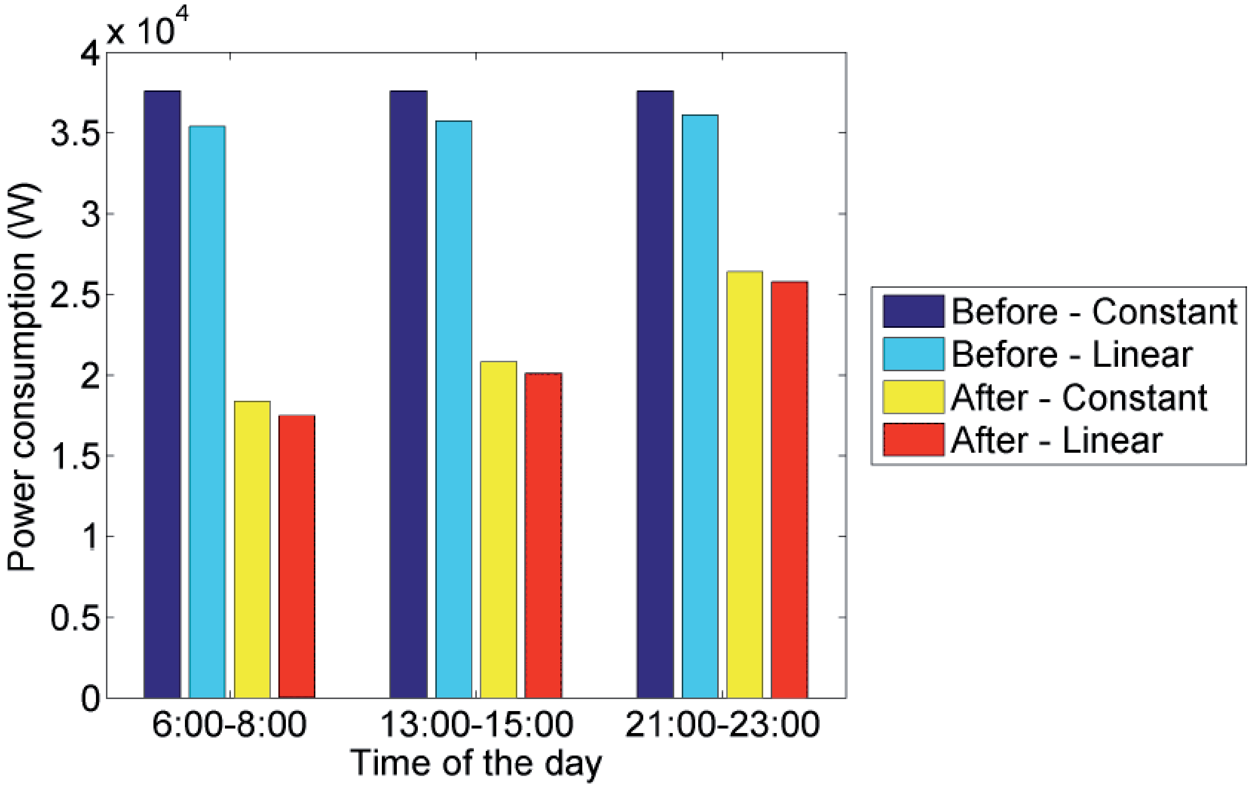
Example of Result



Impact on Network Performance

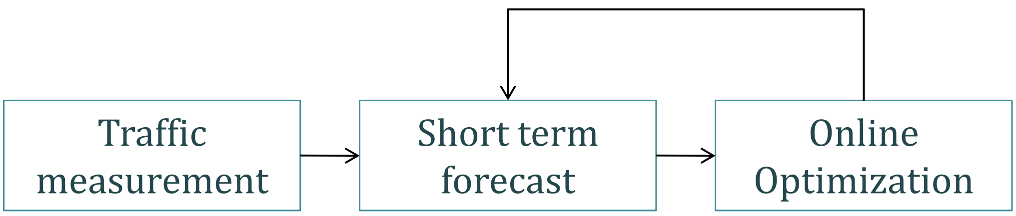


Energy Savings up to 40%



Next Steps: Dynamical Allocation of Resources

- Planning / design
  - Exploit heterogeneous power performance tradeoffs (micro-sites, optical fiber vs embedded electronics)
- Online operation



Online Optimization with Mean Field

- Most practical cases produce NP hard problems
- A natural alternative is Markov Decision Processes
  - Similar complexity issues
- Mean Field Approximation of MDPs is a promising direction
  - Transforms discrete state space in continuous one
  - Threshold based policies can be computed

Mean field for Markov Decision Processes: from Discrete to Continuous Optimization

Nicolas Gast — Bruno Gaujal — Jean-Yves Le Boudec

INRIA RR 7239; April 2010

Take Home Message

- Greening mobile networks saves significant amounts of energy

- Is possible by smart design and allocation of resources

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I Had A Dream ...

The goal: the 2000-Watt Society
© Armin Braunwald
www.energiestiftung.ch

- 2000 W society = energy expenditure per capita as it was in 1960 in Western Europe

  (in CH; = 63.1 GJ per year per capita)

- Today: 5000 – 6000 W

- Realistic Goal for 2050: 3500 W
  [*The 2000 Watt Society –Standard or Guidepost?* Energiespiegel Nr 18, April 2007, PSI, Switzerland]

Mobile Networks can contribute, too…

6.15 am on a chilly morning in a London suburb. Abigail is ch… airport to catch the flight taking her abroad to a 3-day confe… usual, to turn off her computer and the Internet connection. F… system will switch off the PC, the WiFi hotspot that covers… modem, to turn all the system up again at Abigail's request… Abigail is enthusiastic about this system, which saves her m… electricity bill. Abigail does not know, but her ISP is even more… on the operator's side are hefty.

4.30 pm on a sunny afternoon in Paris. Benoit and his colleag… company's NY branch. A sudden glitch in the voice and vid… Benoit knows what that glitch is, because he helped design the… in one of the network routers that are used for the connection, … power needed for a redundant idle protection path, so that som… to reroute the packet flow. Benoit smiles with satisfaction, consi… noticed, and that his company is saving a lot of money. He will …

3.30 am of a rare rainy night in Madrid. Carlos is walking hom… their favorite cervezeria. The city is desert. He calls his moth… knows she is waiting for him awake. He is always short of mo… knows that this call will cost him almost nothing, since a new… operators, that recently agreed to leave just one of their cellular… low traffic, and accept any roaming customer, charging extre… saving allows an important reduction of their network OPEX.

[Fabio Neri et al., working document, May 2010]

Alcatel-Lucent alternative energy pilot site in Villarceaux, France.

[*Key Challenges for Green Networking*
by Ulrich Barth, Patty Wong, Didier Bourse
ERCIM News, Vol 79, Oct 2009]

Intelligent Management of Energy Consumption and Production

- *Managing End-User Preferences in the Smart Grid*, C. Wang and M. d. Groot, E-energy 2010, Passau, Germany, 2010

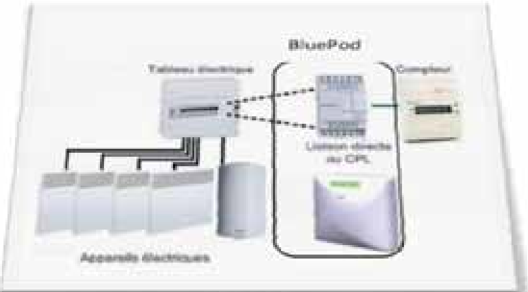


Table 1: Example User Preference Matrix

Appliance	Preference	$t_0 - t_1$	$t_1 - t_2$	$t_2 - t_3$	$t_3 - t_4$
a_0	1	1kW			
	2		1kW		
	3			1kW	
a_1	1	2kW	2kW	2kW	2kW
	2	2kW		2kW	
	3	1kW	1kW	1kW	1kW

VOLTALIS
The e-power company

- www.voltalis.com

One Day in the Life of Robert Longirod

- We are in May 2050, in the 3500W society
- Robert Longirod is telecom engineer at the swiss branch of Huawei Technologies

A fatal exception 8E has occurred at 0028:C881E33670F in UXD DXC 32 883FA2332EBD. The current application will be terminated.

Home automation controller hung yesterday night. Hot water was not replenished overnight.

Robert is a philosoph and takes a cold shower.

Now is time for a good, hot, espresso. Robert imagines the smell of the first coffee of the day and smiles …

…but no coffee !

Robert re-programmed his end user preferences in the smart grid yesterday night and made a mistake !

Fortunately, the fridge works and there is some orange juice left.

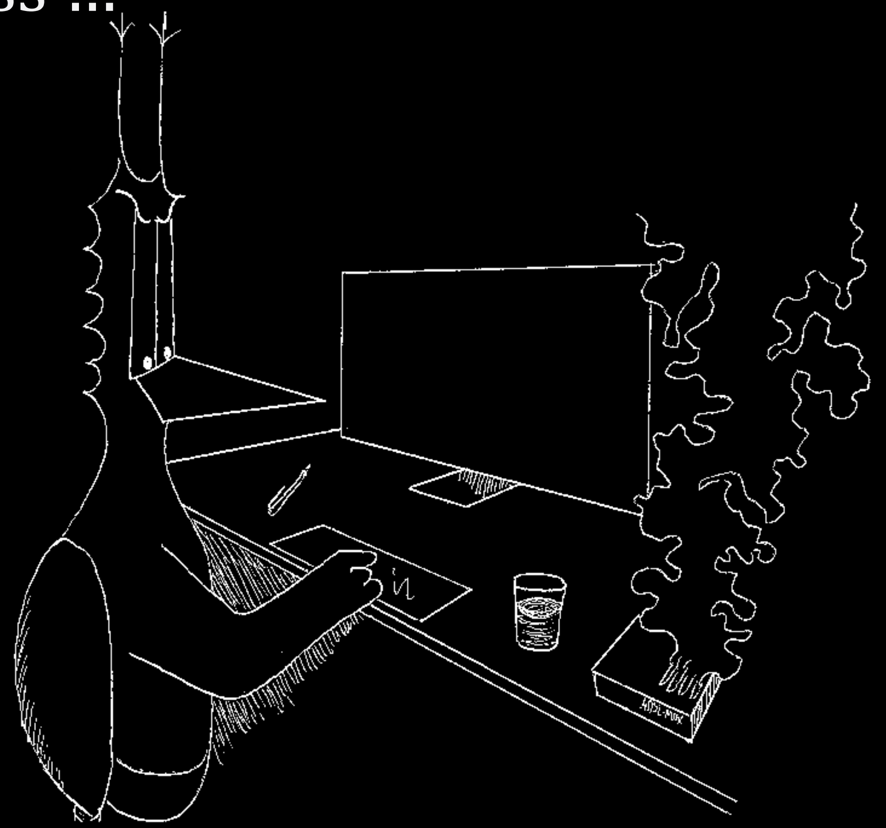
Robert now walks to his lounge and prepares to work. Today, Robert is telecommuting – this saves time and energy.

Strange, the lounge is dark – shutters are blocked closed … the home automation controller, of course !

Not a serious problem anyhow; the shutters can be opened manually.

Robert sits at his table and opens his desktop …

The femtocell has burnt, no internet access …



Robert is a bit worried. There is an important meeting at 10:00 scheduled with two co-workers.

« If I am not at that meeting, it is George who will get the work. I must be there »

Robert decides to do something exceptional: drive to work !

In the garage …

The e-car is not charged.

The batteries were used to power the grid. Normal, Robert did not plan to go anywhere today…

Robert cycles to work

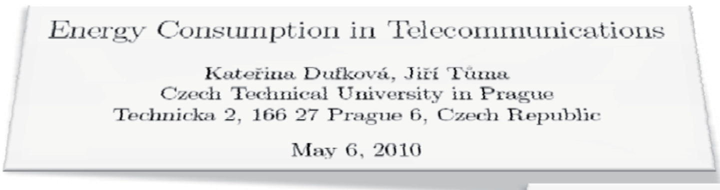
While pedalling back home in the evening, he hopes that the washing machine did its job…

Smart energy management issues

- man machine interactions
  - Difficult
  - Apple
- reliable hardware and software
- can we make Airbus grade equipment at low cost ?

Impact of Saving Energy in Radio Network

- Saving energy in radio access network is a must
  - Savings by putting access points to sleep could save 7.5% electricity consumption of mobile operators worldwide[Marsan2010]
- But global impact is modest
  - 0.01% to 0.03% of total electricity consumption [Dufkova 2010]
  - 0.001% to 0.004 % of primary energy sources



Energy Consumption in Telecommunications

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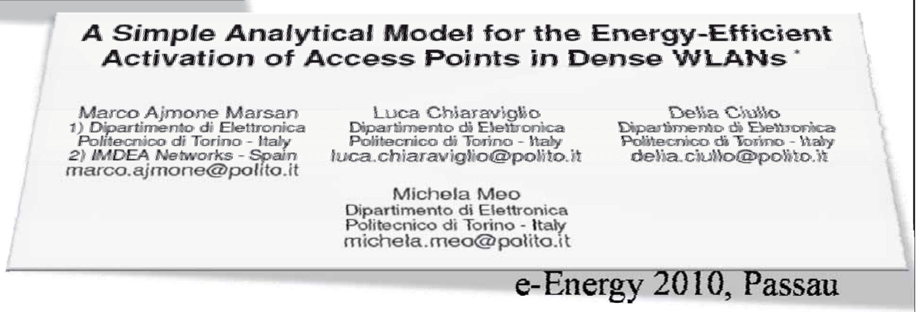
May 6, 2010



A Simple Analytical Model for the Energy-Efficient Activation of Access Points in Dense WLANs*

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e-Energy 2010, Passau

The Myth of e-cars

Q:

- Replace all cars and trucks of Switzerland by electrical vehicles. What is the impact on the power grid ?

  excluding air transport

A:

- x 2

  ≥ 6 new nuclear plants + cover the country with windmills + put solar cells on all roofs
- Source: Prof. Hubert Kirrmann, ABB / EPFL

Take-Home Message

- Transportation and domestic usages are major energy consumers and have a major problem
- Energy management is much harder than often envisioned

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Roadmap for Green Telecom

- We need to continue making the telecom infrastructure
  - Sober
  - Energy proportional
- However, the telecom infrastructure can help reduce energy consumption dramatically
  - Home, office and workshop automation
  - Transportation
- Availability and reliability of the telecom grid is vital

The 2000 W society will need

telecom infrastructure that is

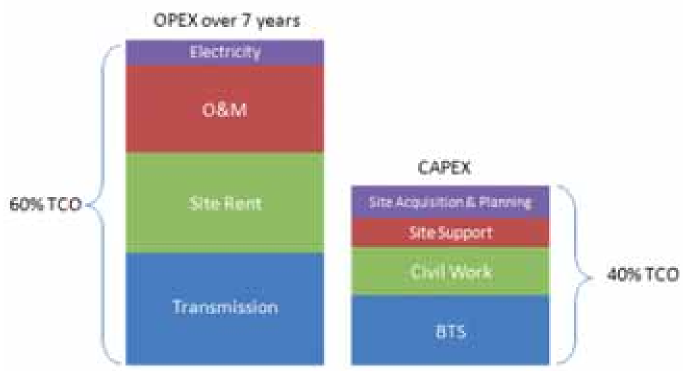
- Low cost
- Pervasive
- Easy to use (and program to)
- Reliable

Cost of deploying and maintaining pervasive, 4G

Radio Access Network

"traditional RAN will become far too expensive for mobile operators to keep competitive in the future mobile internet world. Therefore, the RAN should be re-architected to adapt to the new environment"

China Mobile Research Institute
White Paper 1.0.0 March 2010



Energy Consumption in Telecommunications

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May 6, 2010

for mobile networks, a portion of 10 % of the overall power consumption corresponds to the cellular user whereas 90 % is by the operator OPEX [17]. Further investigations show that the radio network alone consumes approximately 80% of total energy spent by a mobile network operator (e.g. 75 % for Vodafone Czech Republic), making it an outstanding candidate for savings.

Base Stations become Commodity

OPEN BASE STATION ARCHITECTURE INITIATIVE

BTS SYSTEM REFERENCE DOCUMENT
Version 2.0

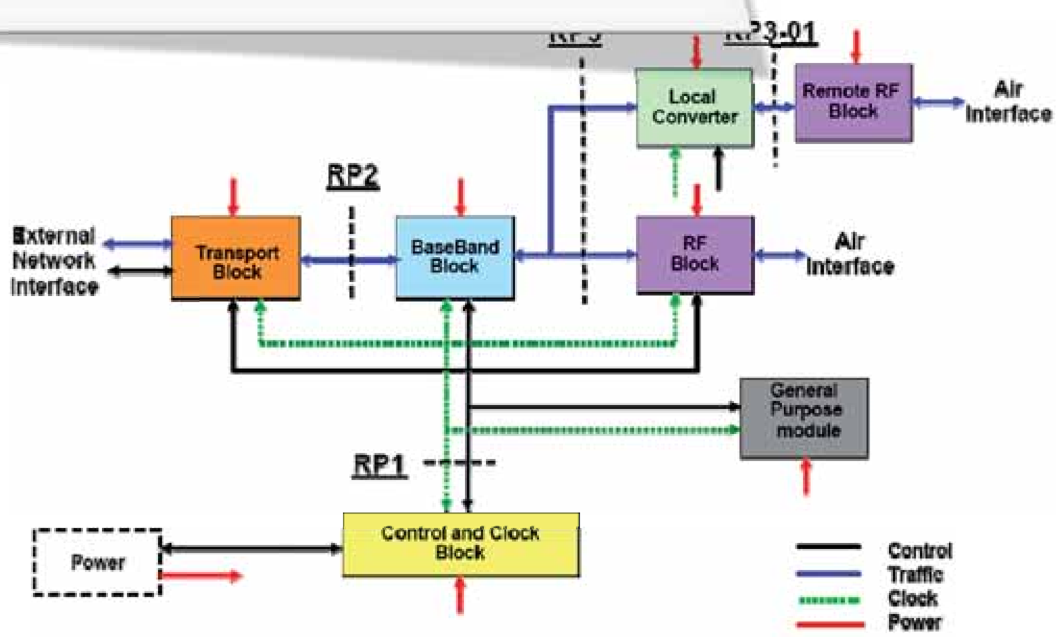
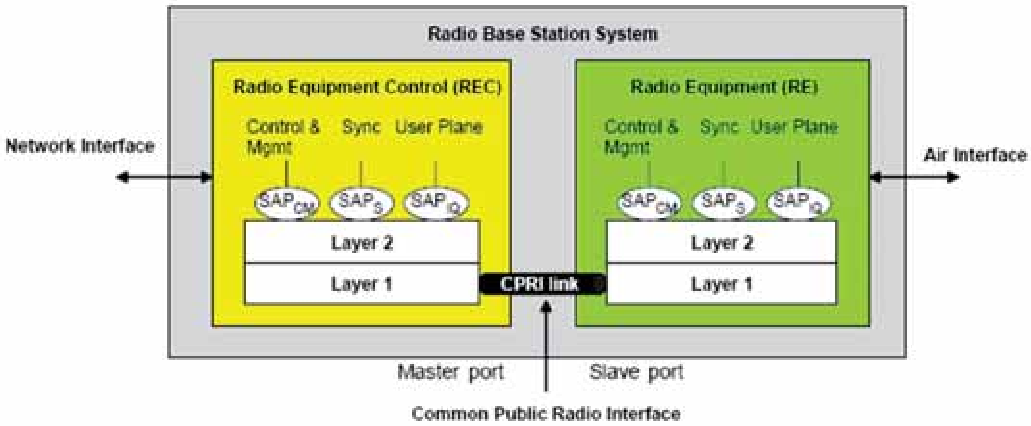


Figure 3.2-1 BTS Reference Architecture

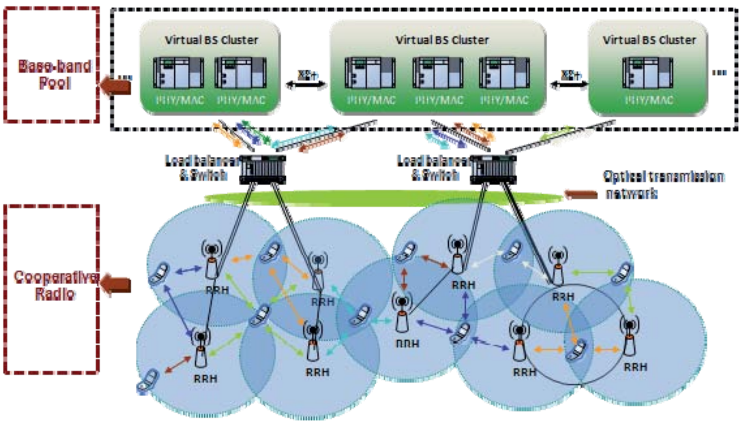
CPRI Specification V4.1 (2009-02-18)

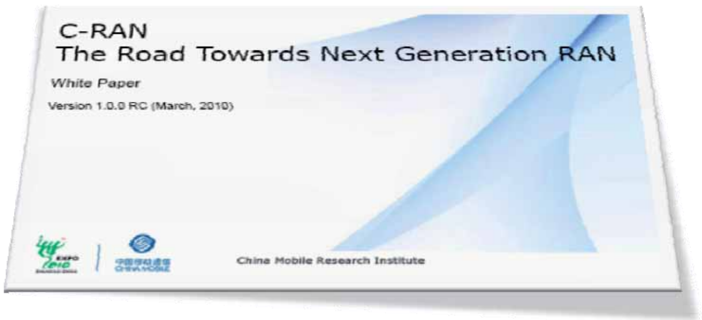
Interface Specification

Common Public Radio Interface (CPRI); Interface Specification



Reduce Cost of Radio Access Network by Separating RF from Processing





- Simple Radio access network
- Processing (inc. PHY) and datain a small number of processing / data centers

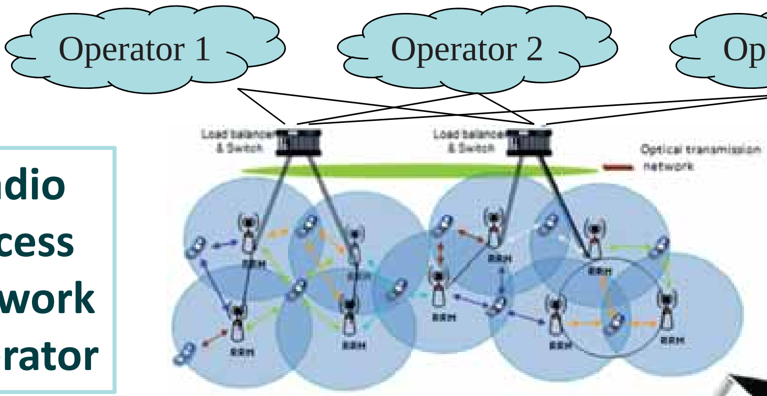
  [China Mobile Research Institute White Paper 1.0.0 March 2010]
- Low CAPEX + OPEX

  low energy data center techniques

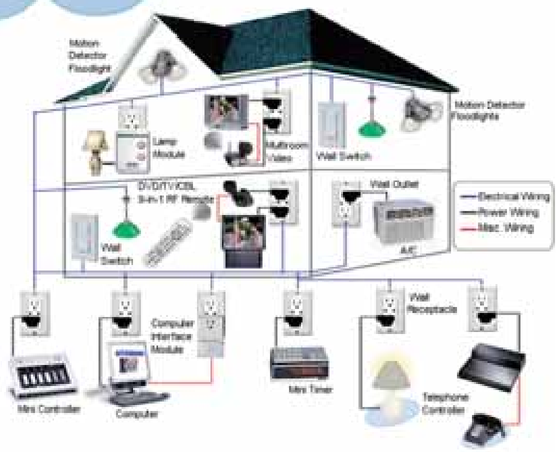
Radio Access Network Sharing

- In countries with competing telecoms, deployment of multiple 4G nets might be a problem
  - Range
  - E-smog
  - Real estate
  - Energy efficiency
- Radio access network sharing is an option

Radio Access Network Operator (RANO)



Radio Access Network Operator



Radio Access Network Operator (RANO)

Benefits

- Reduced energy consumption of radio network
- Reduced costs of telecom services vital for energy saving

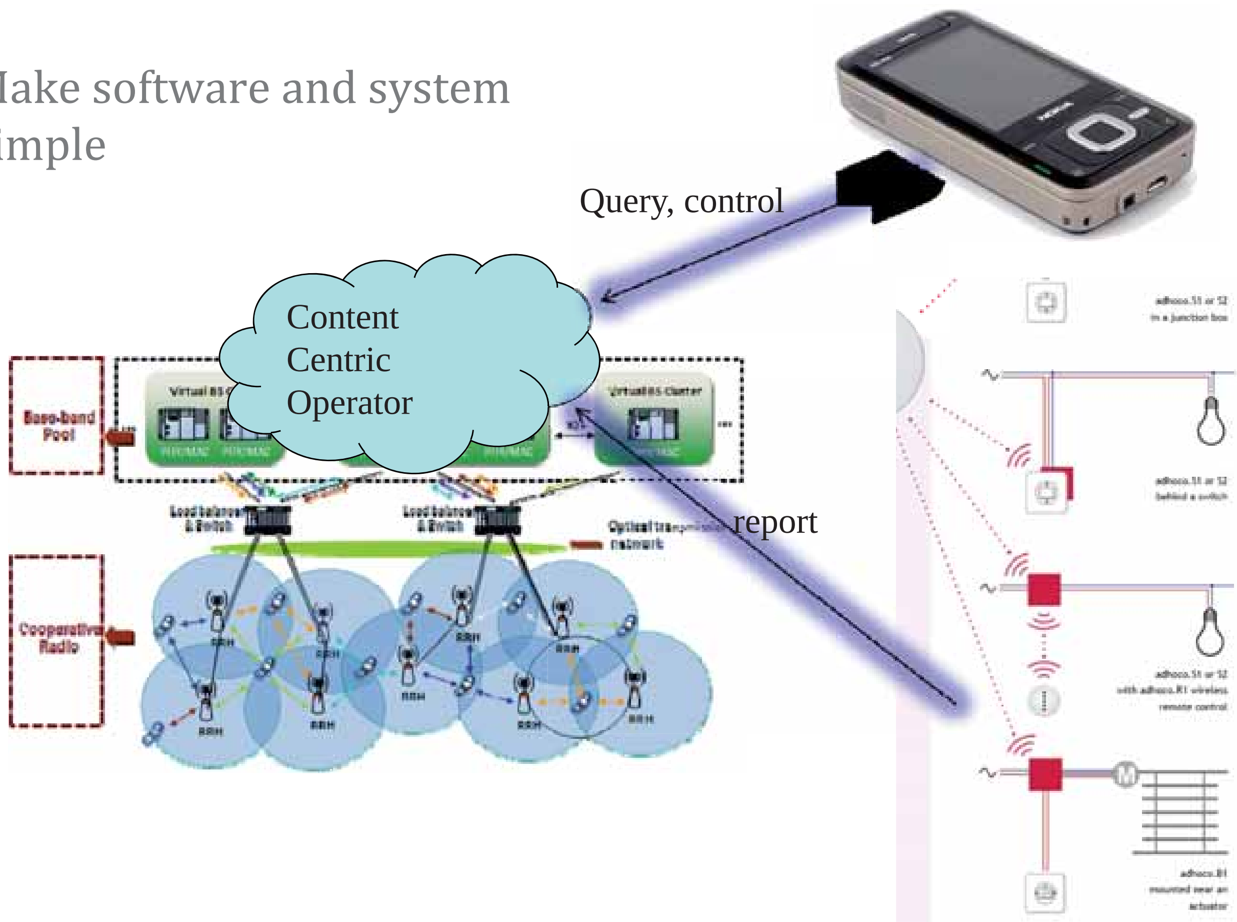
Issues

- Nature of operator (local community, private company, monopoly ?)
- Competition versus social optimum

Complexity of (secure) software

Cloud Computing

- Make software and system simple



Content Centric Networking

Networking Named Content

Van Jacobson, Diana K. Smetters, James D. Thornton, Michael F. Plass, Nicholas H. Briggs, Rebecca L. Braynard

Palo Alto Research Center
Palo Alto, CA, USA

DV/DRP: A Content-Based Networking Protocol For Sensor Networks

Cyrus P. Hall[†] Antonio Carzaniga[†,‡] Alexander L. Wolf[†,‡]

- Replace connection and end-host naming by secure object naming
- Expected to simplify design and operation

Weights…

- Mobile networks of the future will be *energy sober* with energy consumption proportional to traffic
  - Traffic proportional equipment
  - Smart design and adaptive resource allocation
- Minor impact on the energy problem

- Mobile networks are vital to the 2000 W society and must be *simple* and *reliable*.

  Research on new paradigms
  - Network sharing, Radio Access Network Operator
  - Simple and secure content centric networking
- Major impact on the energy problem

The Line

- Greening mobile networks is a must

- But do not cross the line
  - Network operation and usage must be simple and reliable