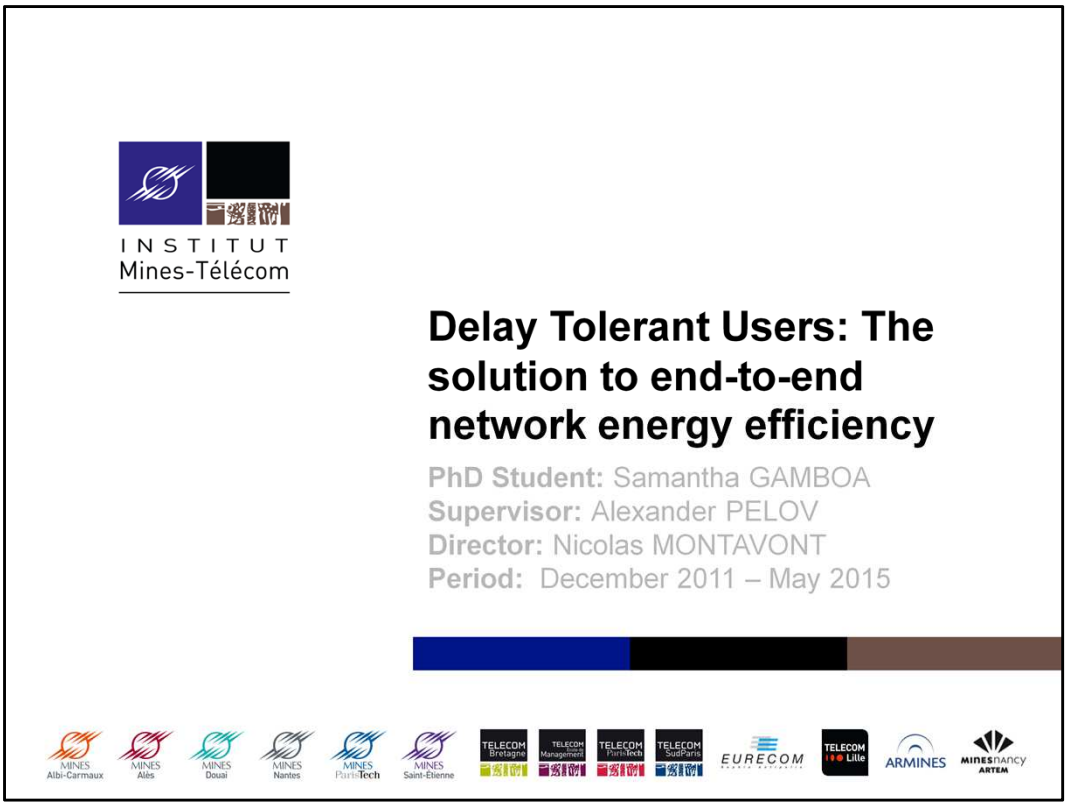
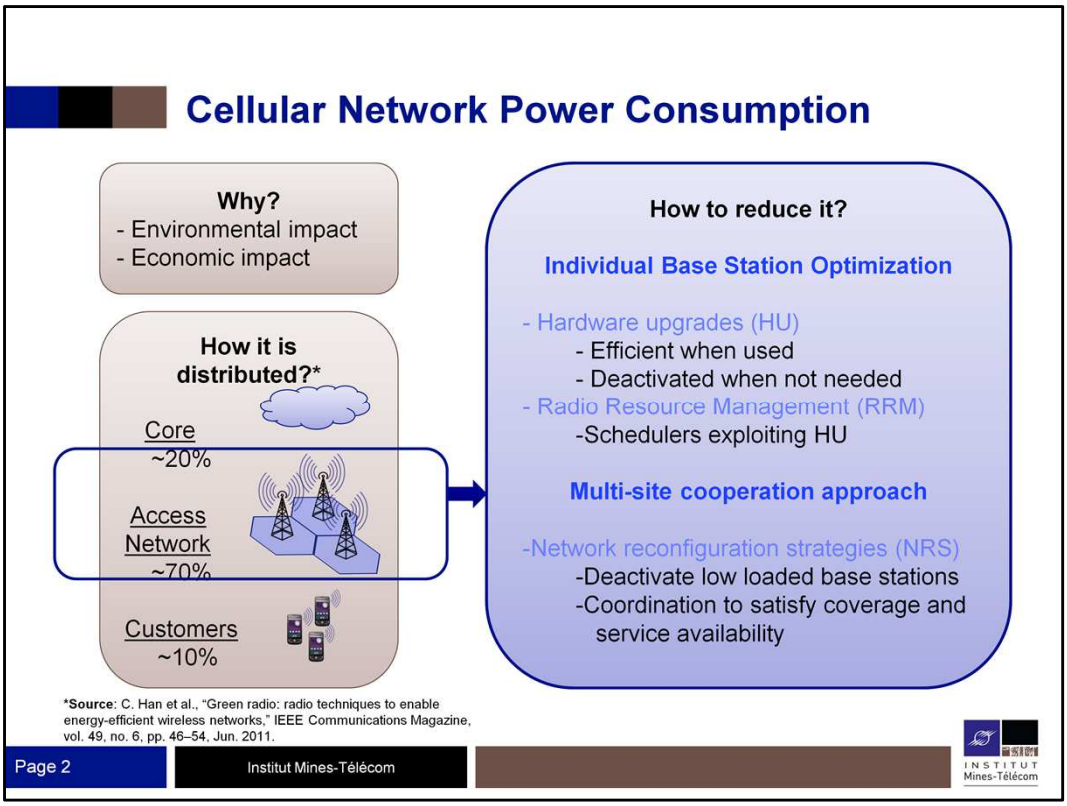
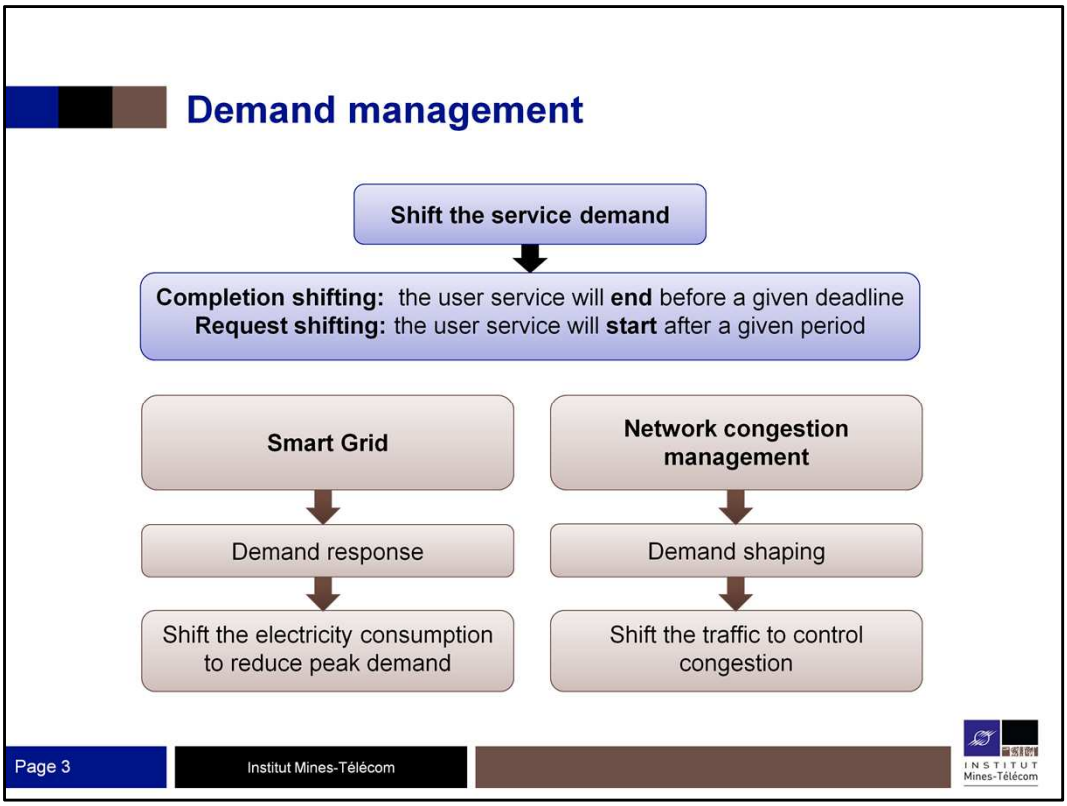


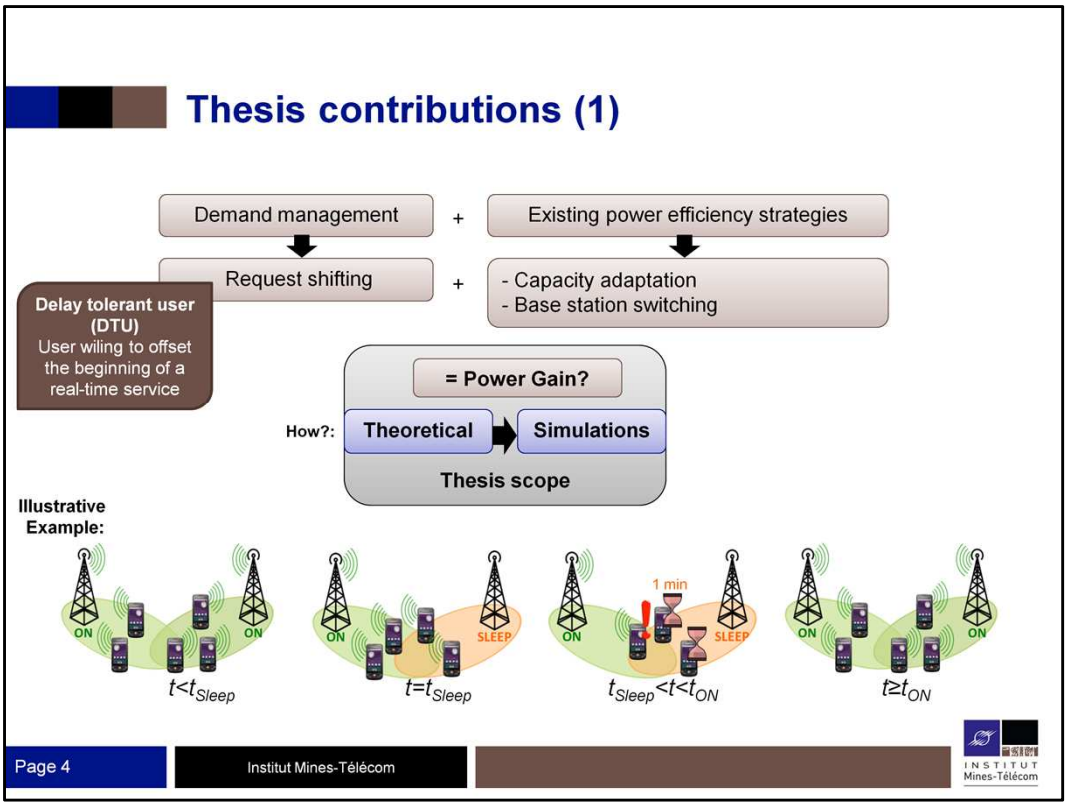
The objective of this thesis was to improve the energy efficiency of cellular networks but going outside of the traditional optimization techniques.
In particular, we combine some demand management techniques, already employed in other domains, with existing power efficiency techniques **to further reduce the** cellular networks energy consumption.



Lets start with the energy consumption of cellular networks.
First: **Why to reduce it?**
Environmental impact: It is well know that cellular networks represents a non negligible part of the global CO2 emissions
Economical impact: The electricity is expensive and represents a considerable part of the operational expenditures of the cellular operators
How this energy is distributed? 20% core network, 10% of customer equipment
And the bigger contributor is the access network with 70%. So we will focus in this part of the network.
How to reduce access network power consumption?
We can reduce the power consumption of each node or base station site: integrating hardware that is more efficient when used and that can be deactivated when it is not needed
And we can also integrate power efficient schedulers that maximize the benefits of these improved hardware
And we can further reduce the consumption if we can deactivate some nodes and satisfy network coverage and service availability using NRSs



On the other hand,
We want to use some demand management that are used also in other domains: Smart grid and the network congestion management
From the **smart grid** the concept is called **Demand Response**, and consists in **shifting the electricity consumption** to reduce peaks in the demand and balance the energy consumption and generation
From the **network congestion management**, the concept is called **demand shaping**, and it consists **in shifting the network traffic** to avoid congestion periods in which the capacity of the network is not enough to satisfy all requests
Finally, there are two types of shifting:
Completion shifting, in which what is important is to now when the service is completed, for example, you want that the download of that movie finishes in one hour because you want to see it then
And there is the **Request shifting**, in which what is important is to now when the service will start, for example, you want to start a video call with your grand mother in one minute, and not be interrupted after it starts



So, the **proposal** of my thesis is to **combine**, the demand management techniques with existent power efficiency strategies to reduce the power consumption in cellular networks

Using as demand management technique, the request shifting. In this way we will have in the network some Delay tolerant users

And as **power efficiency strategy** we can **have for example:** capacity adaptation or base station switching

And the **purpose** is to study if there is any **gain** on doing it

The **path** to study this strategy is this one, going from:

Theoretically, investigating if there is actually some gain and defining the possible **bounds for it**, after evaluate **more realistic system models** using simulations, after evaluate the feasibility of the strategy: from sociological studies to technical evaluations.

To finally **adapting the strategy to real hardware** in controlled environment to finally integrate it in a real network

My thesis focused in the two first steps

1. As an illustrative example of the strategy lets consider this example of two BS
2. In a given moment the BS of the right decides to enter in sleep mode. The users are now served only by the BS of the left
3. However, if there are some new service request, the users are asked to wait, lets say one minute. Impatient users are served by the BS of the left
4. Finallly theBS of the right is turn On, and all users are served normally

Thus, the delay tolerance of the users allowed to extend the periods when the BS was Off

Thesis contributions (2)

- **We proposed two user demand management strategies using request shifting**
  - Persistent delay
  - Opportunistic delay
- **We developed their theoretical models using Markov chains**
- **We estimated the power consumption when they are applied**
  - We can further increase the gain by 15 percentage points
- **NS-3 simulation validated the theoretical results and showed the trade-off between the application of both types of strategies**

Thesis outcome

- **Conclusion**
  - Novel strategy combining demand management and power efficiency strategies
    - Do represent further power gains for cellular networks
- **Dissemination**
  - Two scientific papers presented in international conferences Globecom 2013 PIMRC 2014
  - One scientific paper accepted in WiOpt 2015
  - One scientific paper submitted to the IEEE System Journal
- **Perspectives**
  - Integration with smart grid
    - Application of the strategies to provide ancillary services when needed by the electricity suppliers
    - Adaptation of the models to maximize the utilization of renewable energy in hybrid-powered cellular networks
  - Smarter power efficiency algorithms
    - Further increase the gain

Finally, I'm currently working in the application of the model in the smart grid environment
First, to help cellular operators to reduce the energy consumption when required by the electricity grid
And finally to maximize the use of renewable energy when available to power the base stations

Thank you!

Contact:
samantha.gamboa@telecom-bretagne.eu