Who I am

- Full-time researcher at CNRS (about 33,000 people)
- Located in Rennes, France.
- IRISA laboratory (about 1,000 people)
- Myriads team: INRIA, CNRS, University of Rennes, INSA, ENS Rennes (about 30 people)
- Energy efficiency in large-scale distributed systems

http://www.people.irisa.fr/Anne-Cecile.Orgerie

Outline

I. Introduction to (not) green ICT
II. Trails to green ICT from my research point of view
   A. Green computing history
   B. Data center level
   C. Measuring energy consumption
   D. Slowing down
   E. Switching off unused resources
   F. Efficient scheduling
   G. Exploiting renewable energy
III. Concluding remarks

Green Computing?

"Designing, manufacturing, using, and disposing of computers, servers, and associated subsystems -- such as monitors, printers, storage devices, and networking and communications systems -- efficiently and effectively with minimal or no effect on the environment."


- Green use: reduce usage of hazardous materials
- Green design: design compliant with the environment
- Green disposal: recycling e-waste with little impact
- Green manufacturing: new products without hazardous substances

Energy for dummies

<table>
<thead>
<tr>
<th>Physical measure</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (I)</td>
<td>Amperes (A)</td>
</tr>
<tr>
<td>Voltage (U)</td>
<td>Volts (V)</td>
</tr>
<tr>
<td>Power (P)</td>
<td>Watts (W)</td>
</tr>
<tr>
<td>Energy (E)</td>
<td>Joules (J) or Wh</td>
</tr>
</tbody>
</table>

Energy consumption

\[ P = U \times I \]
\[ E = P \times t \]

ICT impact?

- What is ICT carbon impact in comparison with global impact?
- What is carbon impact?
- Which part of the lifecycle of an ICT product has more carbon impact?

https://app.klaxoon.com/join/VNCJ9JX
ICT is not green

ICT is responsible for 2% to 10% of CO2 emissions


The Cloud

ICT energy consumption

3% of the global energy consumption in 2018.

Resource waste

Servers are used 6% on average.


Networks are lightly of unevenly utilized

Cloud computing in 1 slide

Cloud computing: access through networks to on-demand, self-service, configurable, shared computing resources

- Mutualization of services
- Elasticity of infrastructure
- Externalization of data

Economies of scale

Jevons Paradox: the increase in efficiency (rather than decrease in rate of consumption) is used to increase the rate of consumption.
Can we save ICT…

... without changing users’ habits


Internet of many things

Source: Cisco

Practical Internet of Things

[Source: https://www.google.fr/about/datacenters]

Let’s have a look inside

One Google Data Center (Dalles)

https://www.google.com/about/datacenters/inside/locations/the-dalles/

UPS to the rescue

Uninterruptible power supply:
- Emergency power system
- Used to protect hardware from power disruption
- Supplies energy stored in batteries, supercapacitors of flywheels (converted into alternating current)

But only for few minutes!
And then?

Engine-generator

OVH example

Roubaix site: ~ 10,000 servers

8 MVA at max: 1,600L/h of oil

Tests: every 2-3 weeks

https://lafibre.info/ovh-datacenter/test-de-groupes/

Other data centers

http://www.datacentermap.com/blog/datacenter-container-35.html

Inside the cloud

https://news.microsoft.com/features/microsoft-research-project-puts-cloud-in-ocean-for-the-first-time/from-0000qf5s40g1tz110wem1fgb0g8v

Inside the cloud

Distribution of ICT energy consumption

ICT Energy consumption in 2017

- End-devices (usage) 20%
- Networks (usage) 11%
- Data centers (usage) 17%
- Smartphones (production) 16%
- Computers (production) 11%
- TV (production) 19%
- Other (production) 6%

https://theshiftproject.org

CO2 is a different metric

But globally, it provides the same message

First eco-labels

• Energy Star: international standard for energy efficient consumer products
  • 1992, USA
  • Voluntary labeling program
  • To promote energy-efficient monitors, climate control equipment and other technologies
  • Main result: sleep mode
• TCO certification
  • 1992, Sweden
  • To promote low magnetic and electrical emissions from CRT-based computer displays

Specific eco-labels

• 80 Plus: voluntary certification program to promote efficient energy use in computer power supply units (2004):
  • More than 80% energy efficiency at 20%, 50% and 100% of rated load
  • Power factor of 0.9 or greater at 100% load
  • 80 Plus Titanium : 90% energy efficient
• RoHS: Restriction of Hazardous Substances Directive (2003):
  • Adopted in 2003, effective in 2006 in EU
  • Restricted use of six materials

Outline of my research work

1. Data center level
2. Understanding energy consumption
3. Slowing down
4. Switching off unused resources
5. Consolidation the load
6. Exploiting virtualization capabilities
7. Consuming renewable energy
8. Networking equipment

Data center level
Where is electricity consumed?
Data center example

Great part consumed by facilities
→ Cooling accounts for 30-50% of the total value

Let’s reduce the heat

• Water-based cooling


Let’s reduce the heat

• Oil-based cooling

Reduce data center cooling costs by up to 95%.

Green Revolution Cooling, https://www.grcooling.com

Let’s reduce the heat

• Free cooling

https://www.google.com/about/datacenters/inside/locations/hamina/

Water-cooled doors

• Hybrid cooling

Explosive View of Chilled Door

https://www.momman.com/molivair-chilled-door-rack-cooling-details

Water required!

Water tanks
Capacity: 900,000 liters
Google data center in South Carolina, US

https://www.google.com/about/datacenters/gallery/index.html#/tech/19
Water pipes

[Source: https://www.google.com/about/datacenters/gallery/index.html#tech/19]

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Thermal management

- Cooling costs a lot, so reduce heat production to reduce energy consumption


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Understanding energy consumption

- Mandatory to optimize the energy consumption of a resource or an application
- Mandatory to simulate or emulate energy consumption
- Other usages:
  - monitoring,
  - forecasting,
  - accounting...

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How to measure energy consumption?

- Power usage per device, per process, per service, per rack?
- Software tools: powertop
- Event counters
- Sensors

http://lesswatts.org/projects/powertop


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Intel Power Gadget

https://software.intel.com/en-us/articles/intel-power-gadget-20

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Without wattmeters

PAPI (Performance Application Programming Interface) can read RAPL (Running Average Power Limit) values

- Uses software power model, hardware performance counters, temperature, leakage models and I/O models

With an example: Grid'5000

- French experimental testbed
- 15,000 cores
- 8 sites
- Dedicated Gb network
- Designed for research on large-scale parallel and distributed systems

A monitored site: Lyon

- 78 nodes
- 50 power measurements per node and per second
- Multiple views + logs on demand

Supercomputers

N°1: Fugaku (TOP500 June 2020)
415 Petaflops, 28,335 MW, 7,299,072 cores.

Top500


Typical applications:
- Artificial intelligence
- Disaster-prevention simulations
- ...
Performance development

The Green500

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Energy spent in a server

Profiling applications

Variable workload & non-power proportionality

Ideal server vs. current server

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Wasted energy


How to measure energy efficiency?

PUE: Power usage effectiveness

\[
PUE = \frac{\text{Total Facility Power}}{\text{IT Equipment Power}}
\]

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PUE as a selling point: Google case

https://www.google.fr/about/datacenters/

Energy cost of an Internet box?

Energy cost in Joules/bit:

- When the bow is idle, it consumes 15 Watts
- At 8am, 15.15 Watts and 0.65 Mbps
- At 8pm, 16.05 Watts and 4.75 Mbps
- At max, 25 Watts and 60 Mbps

Facebook live dashboard

https://www.facebook.com/ForestCityDataCenter/app_288655784601722
Efficiency of an Internet box

Efficiency metrics

<table>
<thead>
<tr>
<th>Conditions</th>
<th>$\mu$Joules/bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous dynamic cost</td>
<td>0.23</td>
</tr>
<tr>
<td>At 8am: 0.15 Watts 0.65 Mbps</td>
<td></td>
</tr>
<tr>
<td>Instantaneous overall cost</td>
<td>23.3</td>
</tr>
<tr>
<td>At 8pm: 15.75 Watts 0.65 Mbps</td>
<td></td>
</tr>
<tr>
<td>Daily overall cost</td>
<td>9.9</td>
</tr>
<tr>
<td>On average: 15.35 Watts 1.55 Mbps</td>
<td></td>
</tr>
<tr>
<td>Overall minimal cost</td>
<td>0.42</td>
</tr>
<tr>
<td>At max: 25 Watts 60 Mbps</td>
<td></td>
</tr>
</tbody>
</table>

Two orders of magnitude

Efficiency

Internet energy intensity

"Estimates published over the last decade diverge by up to four orders of magnitude — from 0.0064 kilowatt-hours per gigabyte (kWh/GB) to 136 kWh/GB."


Standards, Consortiums, Projects

- Energy Star
- Green Grid
- Efficient Servers
- The green 500
- ...

Slowing down

Power modes by component

Dynamic adaptation to the load:
- Hard disks: spin-down
- Processors: Dynamic Voltage Frequency Scaling (DVFS)
- Network cards: Adaptive Link Rate

DVFS principle

CPU-Level DPM
Energy consumption of IoT

Scenario: Data stream analysis from cameras embedded on vehicles to detect objects on the road

Simulation of the networking part (wireless and wired)

Real measurements for the Cloud part: various configurations, image resolutions and application accuracy

<table>
<thead>
<tr>
<th>Scenario</th>
<th>IoT</th>
<th>Network</th>
<th>Cloud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge Cloud</td>
<td>10.96 Watts</td>
<td>0.07 Watts</td>
<td>32.3 Watts</td>
</tr>
<tr>
<td>Core Cloud</td>
<td>10.96 Watts</td>
<td>0.11 Watts</td>
<td>22.8 Watts</td>
</tr>
</tbody>
</table>

Switching off unused resources

Simulating energy consumption of applications

Simulation useful because:

- No need of big infrastructure
- Testing new approaches
- Fair comparison between two methods
- Reproducible

Reproducible results:
https://gitlab.inria.fr/fheinric/paper-simgrid-energy

Simulating energy consumption
Switching off

Idea: adapt the set of active resources to the load

Issues:
- Does it reduce the life time of resources?
- How to switch resources on again?
- How much time does it take to switch?
- Switch off or sleep?
- Does the middleware consider the resources as dead?

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When can we switch off?

\[
T_s = \frac{E_s - P_{OFF}(\delta_{ON\rightarrow OFF} + \delta_{OFF\rightarrow ON}) + E_{ON\rightarrow OFF} + E_{OFF\rightarrow ON}}{P_I - P_{OFF}}
\]


On/off tools

- Suspend to disk (hibernation)
- Suspend to RAM (standby or sleep)
- Wake on LAN
- IPMI (Intelligent Platform Management Interface)
- Presence proxies
- Smart PDU (Power Distribution Unit)

Does a switched off node consume energy?

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Consolidation

Energy-efficient scheduling to switch off more resources

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4 Tasks (4 servers)

4 Tasks, 3 or 4 Servers

Consumption is reduced by 25%}

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Courtesy of Jean-Marc Menaud
Consolidation in space

Consolidation in space & time

Virtualization

Servers are used 6% on average.


Virtualization to the rescue.

Exploiting live-migration capabilities

Idea: migrating virtual machines to consolidate the load on the fewer number of physical resources

Infrastructure level & renewable energy

Follow-the-* approaches

- Follow the moon: free cooling with air from outside during cool days, and on hot weather days, computing load is shifted to other data centers
- Follow the sun/wind: use renewable energy sources

Problem

Follow-the-moon: computing load is shifted to other data centers on hot weather days.

Follow-the-sun/wind: using renewable energy sources.

Opportunistic scheduling

Renewable energy

Workload

Energy storage

![Energy storage diagram]

Real infrastructure: Parasol

![Real infrastructure: Parasol diagram]

A real example

Apple’s North Carolina iCloud data center

- 40 MW (max) of power

Renewable energy

- two 20 MW and one 18 MW solar arrays
- one 10 MW biogas fuel cells
- producing 244 million kWh annually
- daily on-site production: 60-100% of facility’s consumption

**Around 450 acres (1,800,000 m²) needed for solar farms**

Apple Environmental Responsibility Report 2016

Apple’s renewable energy use

- Apple (worldwide)
- Apple (U.S.)

100%

Apple data centers are powered by 100 percent renewable energy.

In just six years, Apple’s use of renewable energy to power its corporate facilities, retail stores, and data centers worldwide went from 16 percent in 2010 to 96 percent in 2016.


How is this possible?

**The Truth About Apple’s ‘100% Renewable’ Energy Usage**

Alex Epstein, Forbes, January 2016.

[http://tinyurl.com/yc3r7c73](http://tinyurl.com/yc3r7c73)

Apple pays off consumers and other companies to give it ‘green credits’ for its coal electricity usage

Conclusions
State of the art

Computing resources
- Node level
  - sleep state (hibernation)
  - DVFS
  - green softwares
  - hardware capabilities

- Infrastructure level
  - green sources (follow-the-sun)
  - thermal management
  - workload consolidation
  - task scheduling

Virtualization
- Virtualization layer (green hypervisors)
- VM migration
- Cloud level

Wasted energy

- GreenCloud: A Packet-level Simulator of Energy-aware Cloud Computing Data Centers
  - D. Kliazovich, P. Bouvry, and S. U. Khan

Complex tradeoffs and modularity

System design is full of complex tradeoffs
- Peak vs. average performance
- Peak vs. average load
- General-purpose vs. dedicated
- High vs. best effort availability
- Backward compatibility

System functionality as independent modules
- Modularity and interaction
- System components designed separately (CPU, network interface...)

Sources of energy waste

- Peak vs. average performance scenario
- Low average system utilization
- Benchmarks stress worst-case performance workloads
- Systems optimized for these scenarios

- Good performance for a multitude of different applications
- Union of maximum requirements of each application class
- E.g. smartphone vs. MP3 player
- Legacy solutions

- Overprovisioning to plan for the future
- Ensure enough capacity
- Redundancy to increase availability

Performance and general purpose

Growth and availability

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Design process structure

- Hardware and software separately
- Divided system functionality across components
- Layers
  - Local optimizations not optimal for global efficiency
  - E.g. worst-case assumption at each layer

Energy efficiency at design stage

- Replacement with a more power-efficient alternative
- Holistic solutions
  - Look at problem with broad scope
  - Cross-layer interaction
  - Optimize energy efficiency for the common case
  - Design only for required functionality and requirements

Energy efficiency at runtime

- Trade off some other qualities for energy
- Disable or scale down unused resources
- Combination of multiple tasks in a single energy event
- Spend someone else’s power
- Spend power to save power
- Monitor energy consumption to be energy-aware
- Predict resource usage trends
- Control algorithms and policies

ICT for Green vs. Green ICT

- **ICT for Green**
  - Use ICT technologies to reduce the environmental footprint of other processes and sectors
  - E.g. smart grids, smart buildings, etc.
- **Green ICT**
  - Reduction of the ICT’s environmental footprint
  - E.g. energy-aware data centers

The (in)dispensable weather toaster

In 2017: 5 connected devices / person 20 billion devices worldwide.

The smart frying pan

In 2017: 5 connected devices / person
20 billion devices worldwide.

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Are we going on the good way?

- New functionalities
- Create new practices and needs
- Multiplication of the devices
- Capability overlap
- Health issues

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20 billion devices worldwide.


Are we going on the good way?

- New functionalities
- Create new practices and needs
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Complete life-cycle

- 1.4 billion smartphones sold in 2015.
- Average life duration of first-hand smartphones < 2 years in 2015.


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Durability and life cycle

Apple


User = person responsible

In 2014, on average, 35 applications installed per smartphone, among which: 11 are used every week and 12 are never used.

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Video games

101GB download
14 hours

Video games purchased on download
Do not fit on DVD any more

Network-hungry

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What you can do

• Completely switch off unused devices
• Remove unused applications
• Erase useless (old) emails, photos, etc.
• Be careful when sending emails (attachments, receivers)
• Be careful when coding (image size, active loops, etc.)
• Look at eco-labels when buying new equipment
• Keep devices longer if they are still working
• Avoid capability overlap
• Stay energy-aware...

Opportunities

• To think differently
• To propose new things
• To build differently
• To design a sustainable future

interstices.info

http://ecoinfo.cnrs.fr

ADEME

http://people.irisa.fr/Anne-Cecile.Orgerie

Thank you for your attention