Aalto University
School of Science
and Technology

T-110.4100 Computer Networks
Green ICT

18.10.2011

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External sources:

- Y. Xiao: Green communications. T-110.5116 lecture. Aalto. 2010.
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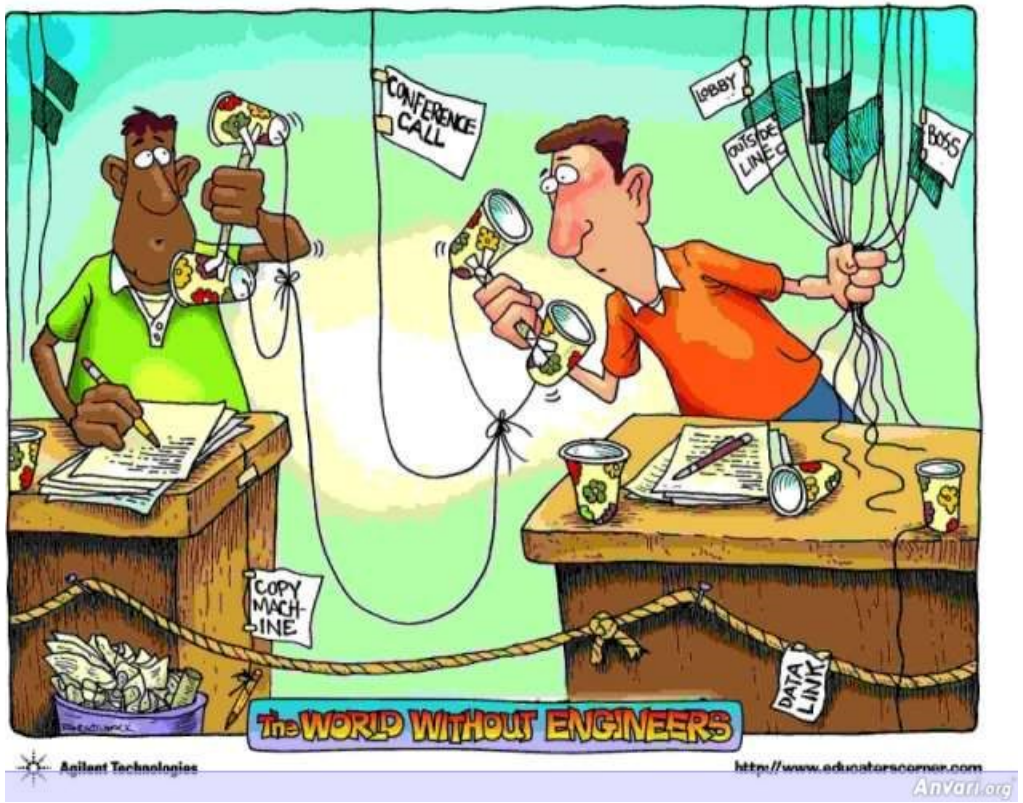
Which one is Green ICT?

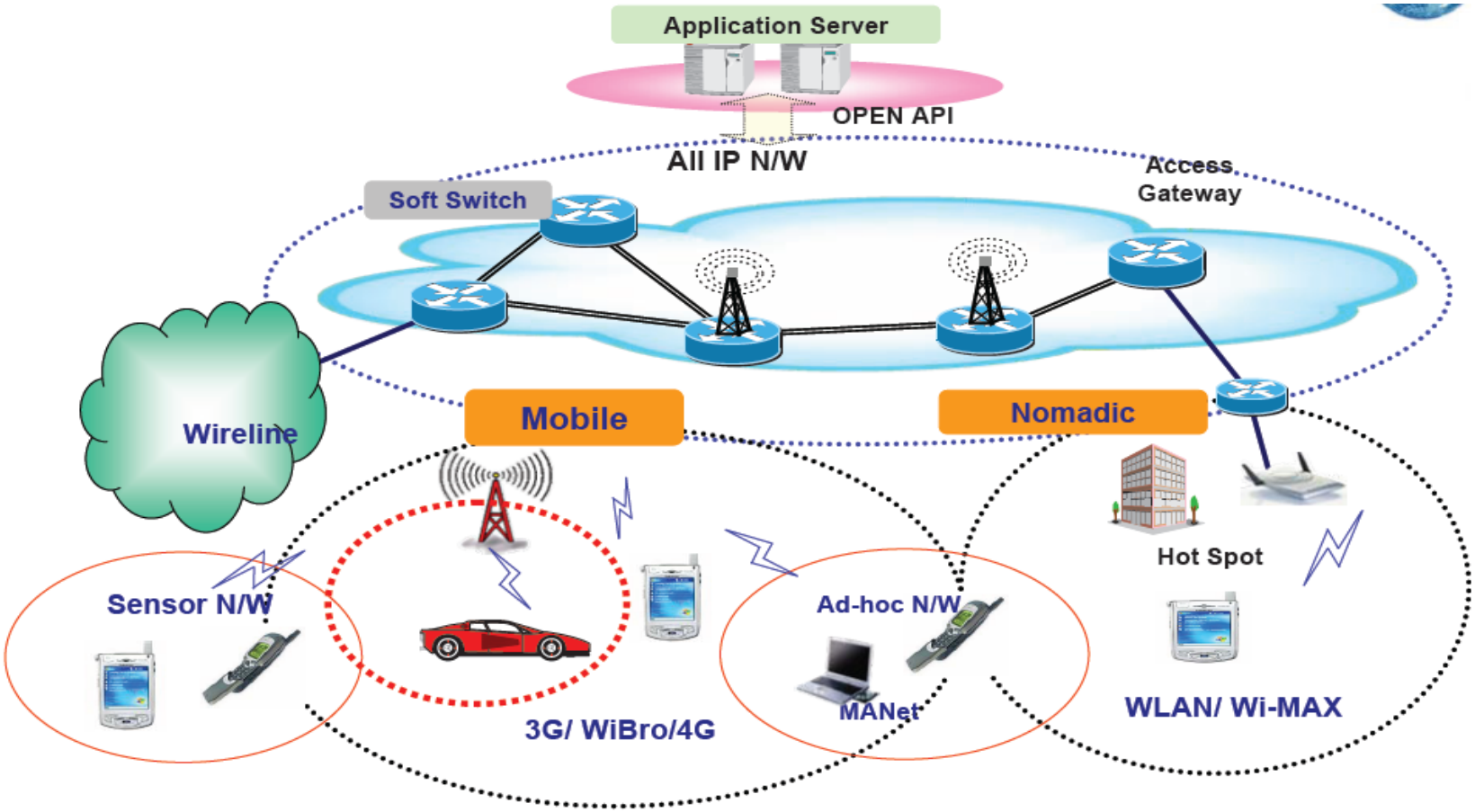
Source: Google image



What is Green ICT?

- ICT systems for efficient gardening?
  - No
- Green ICT
  - Reduce energy consumption of ICT
  - Green comes from energy and emissions
- What's involved?
  - Networked Equipment
    - PCs, mobile phones, data centers, set-top boxes,…
  - Network Equipment (infrastructure)
    - Routers, switches, wireless access points, …

Networking


Application Server
OPEN API
All IP N/W
Access Gateway
Soft Switch
Wireline
Mobile
Nomadic
Hot Spot
Sensor N/W
Ad-hoc N/W
MANet
3G/ WiBro/4G
WLAN/ Wi-MAX

Questions, questions, …

- Lot of different stuff
  - In network equipment
    - Routers, switches, wireless access points, …
  - At the edge
    - PCs, mobile phones, data centers, set-top boxes,…
- How much energy does all this stuff consume?
- How much could we save? … in network equipment?… at the edge (networked equipment)? And how do we do it?
- Where does the energy go?
  - Transmission
  - Computation
  - Cooling

Why we give a damn

- ICT energy consumption
  - About 12% of global power consumption
  - 60billion KWh wasted by inefficient computing every year
  - Telecom data volume increases approximately by a factor of 10 every 5 years, which corresponds to an increase of the associated energy consumption of 16-20% every year
- CO2
  - At least 2% of global CO2 emission
  - As much as airplanes, and $\frac{1}{4}$ of cars
- €€¥££
  - Data center and network operators
  - Large part of operation costs

Why especially we give a damn

- Energy constrained devices
  - Smart phones
    - Need to recharge more and more often
  - Sensors and sensor networks
    - Don't want to or cannot change batteries often
- Quality of service or availability issue
  - Not really a question of €$£¥
  - Not so much a "greenness" issue either
    - Although scale is very large...
- Our main research focus

Outline

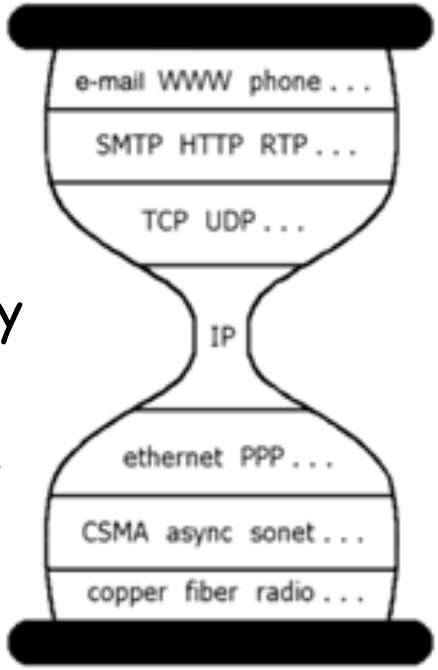
- What is Green ICT?
- Energy efficient mobile computing
- Where does the energy go on a smart phone and how can we know that?
- Examples of how to save energy of a smart phone

Low power hardware or higher capacity batteries?

- No, not really
- We don't build hardware
  - We are software guys
- Don't know that much about chemistry/material physics either
  - Leave the batteries alone…
- Our focus:
  - All layers in communication protocol stack above the physical layer
  - All the software that interacts directly or indirectly with the hardware
    - E.g. operating system

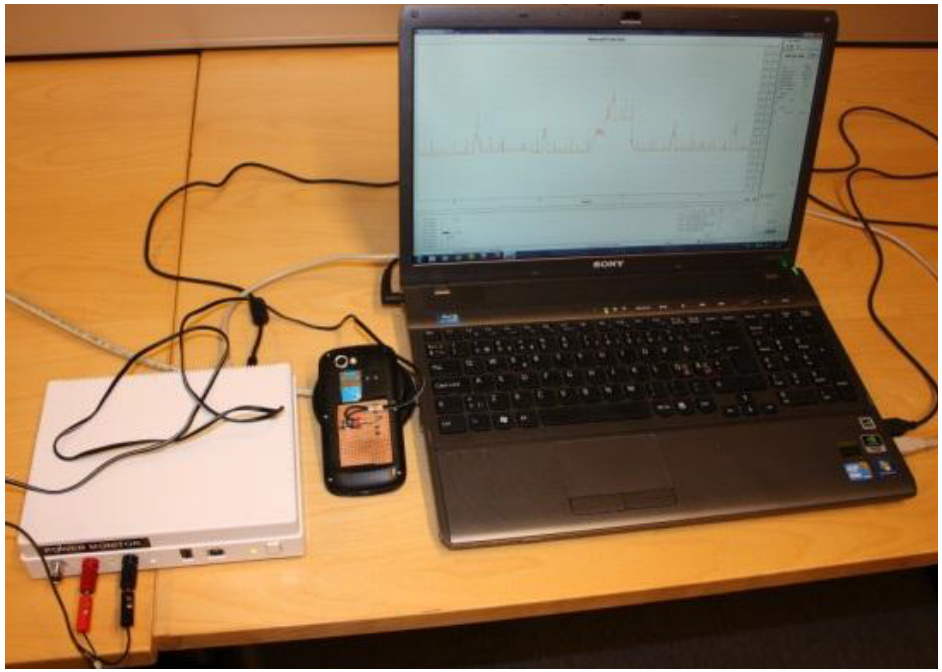
So, what is it about?

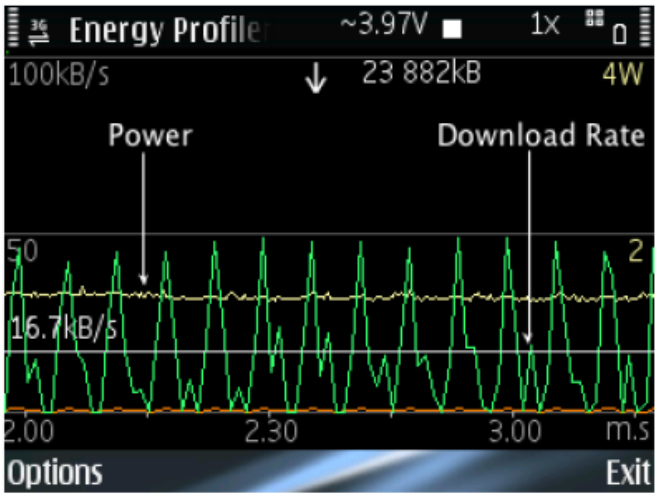
- Goals:
  - Minimize nb of Joules per bit, CPU cycle, instruction…
  - Deliver service with as few Joules as possible
    - Maybe trade off some QoS
- How?
  - Optimization of protocols for energy efficiency
    - Across the whole stack
  - Optimize power management to cooperate with protocols
- Necessary activities for doing this:
  - Power measurements
  - Power modeling



Measuring power

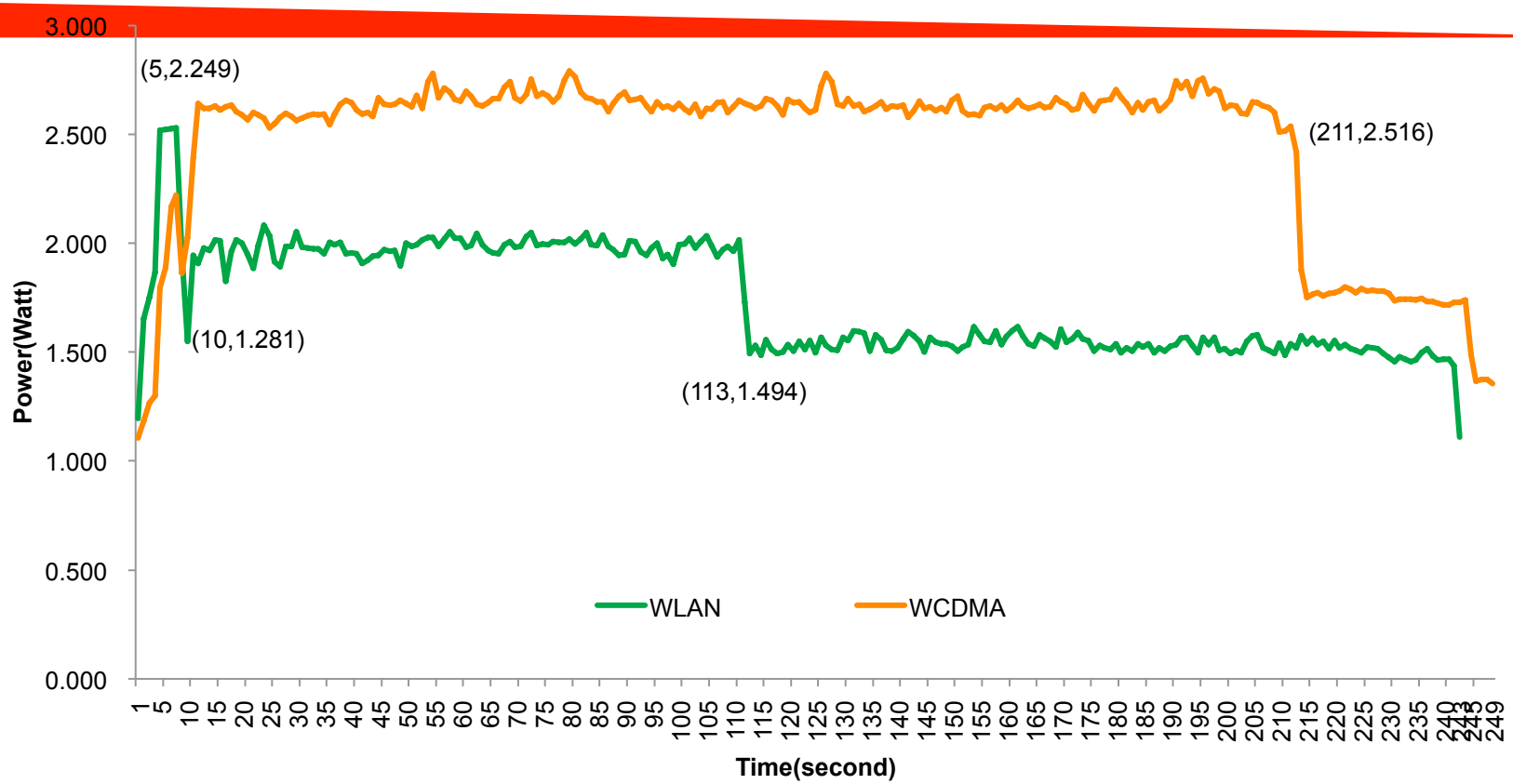
- Hardware measurements
- Can have much higher Hz
- No software overhead





- Software-based measurements
- Nokia Energy Profiler
- Easy to use
- Sampling frequency: 4Hz
- Only for Symbian ☹

Glance at the power consumption



Watching YouTube from N95

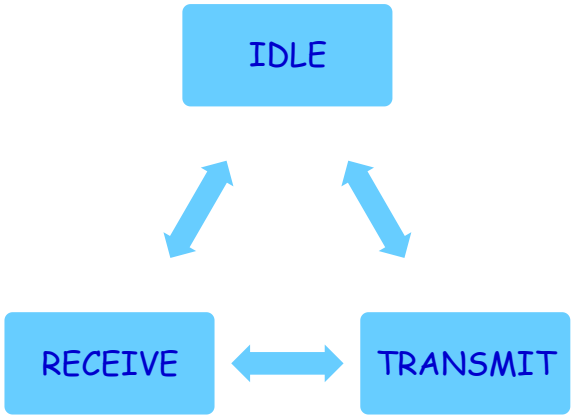
Basic questions

- How many Joules are needed for transmitting or receiving one bit?
  - Hardware dependent
  - Radio technology dependent
  - Context/environment dependent
  - Protocol dependent
- How many bits do you need to transmit or receive?
  - Depends on protocol and service design
  - Depends on context/environment

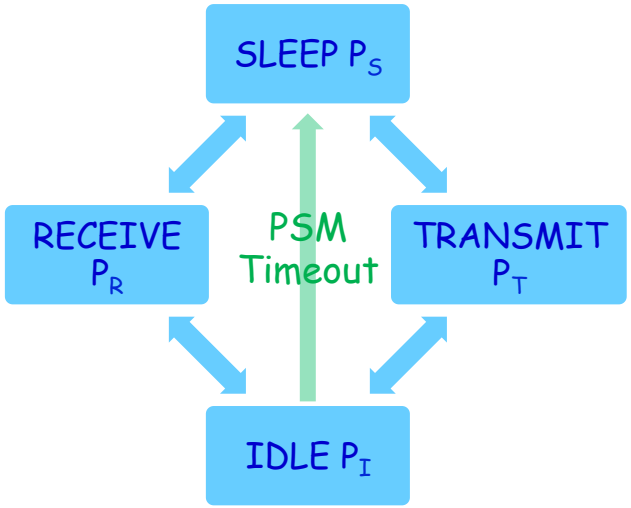
Example: WLAN

- Not a simple On/Off
- Multiple operating modes

Continuously Active Mode (CAM)



Power Saving Mode(PSM)

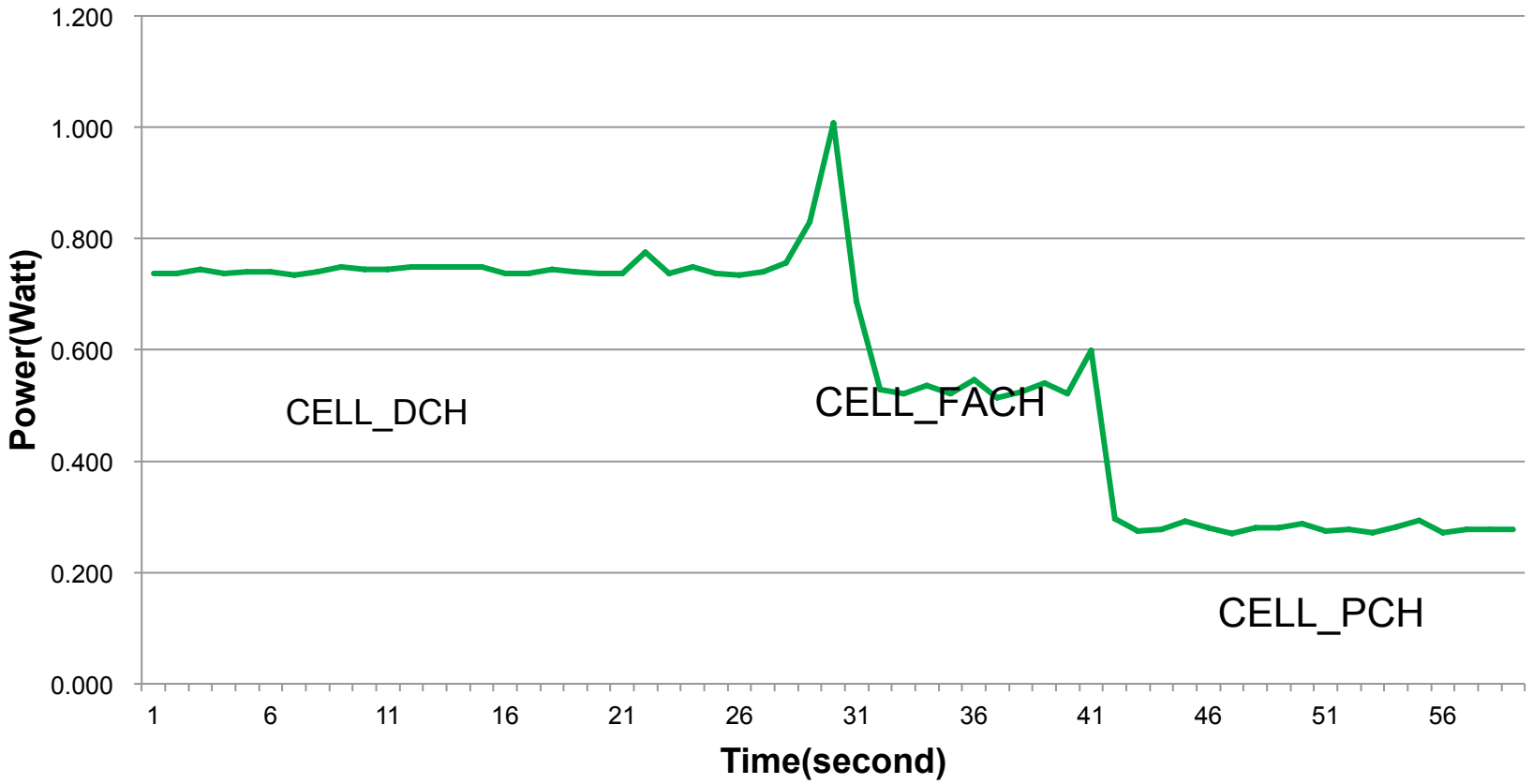


WLAN

- Power consumption ~ WNI operating mode

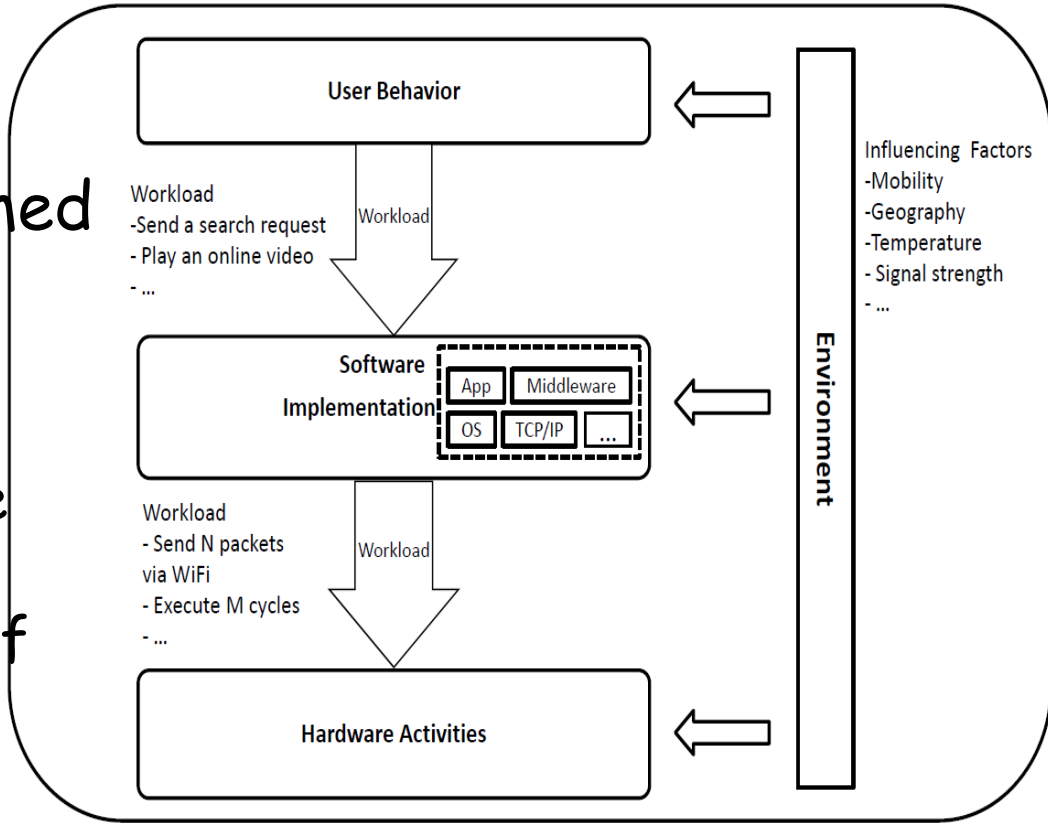
WNI operating mode	Average Power (W)		
	Nokia N810	HTC G1	Nokia N95
IDLE	0.884	0.650	1.038
SLEEP	0.042	0.068	0.088
TRANSMIT	1.258	1.097	1.687
RECEIVE	1.181	0.900	1.585

3G


1.200
1.000
0.800
0.600
0.400
0.200
0.000
Power(Watt)
CELL_DCH
CELL_FACH
CELL_PCH
1
6
11
16
21
26
31
36
41
46
51
56
Time(second)

Where does the energy go?

- Hardware consumes the energy
- Amount of energy consumed depends on
  - Hardware physical characteristics
  - Hardware operating mode
  - Workload generated by software running on top of hardware



Power modeling

- Allows to estimate energy/power consumption even when direct measurement is impossible
  - Impractical: external instruments usable only in lab settings
  - Software not available
- Why interesting?
  - Understand and improve energy consumption behavior of existing protocols and services
    - Also in setups which aren't possible in a lab
    - Help redesign for better energy efficiency
  - Develop energy-aware protocols and applications
    - Run-time estimation of energy consumption
    - E.g., choose energy efficient paths, peers, servers

Power modeling (cont.)

- Power models describe
  - Transmission cost, computational cost, cooling cost, …
  - Power consumption of each hardware component or software component
  - Power consumption of a service
- Methodology
  - Deterministic modeling
  - Statistical modeling

Power measurement is needed for building models.

How to save energy? Some examples

- Smart data compression

  Yu Xiao, Matti Siekkinen, and Antti Ylä-Jääski. **Framework for energy-aware lossless compression in mobile services: the case of E-mail.** In Proceedings of the ICC 2010. May 2010.

- Proxy-based traffic shaping for audio streaming

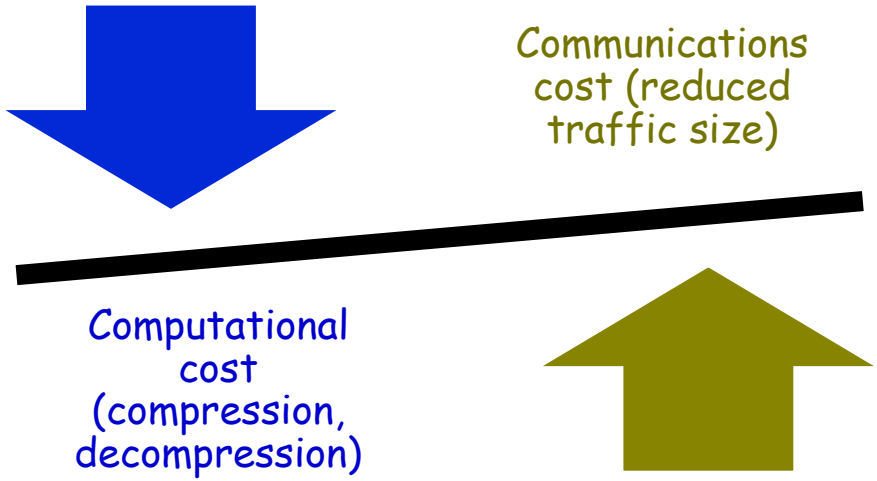
  Mohammad Hoque, Matti Siekkinen, and Jukka K. Nurminen. **On the Energy Efficiency of Proxy-Based Traffic Shaping for Mobile Audio Streaming**. In Proceedings of CCNC 2011.

- Computation offloading

  Byung-Gon Chun, Sunghwan Ihm, Petros Maniatis, Mayur Naik, Ashwin Patti. **CloneCloud: Elastic Execution between Mobile Device and Cloud.** In Proceedings of EuroSys 2011.

Smart data compression

- Communication energy consumption ~ Traffic size
- Compression can reduce amount of traffic generated
  - But computation costs also energy
- Tradeoff always exists



Compressing E-mail attachments

File Extension/ Type	*With compression*		*Without Compression*		*ce*
	Energy (J)	*Duration (s)*	*Energy (J)*	*Duration (s)*	
.doc	9.61	7.0	18.31	11.8	6.90
.bmp	5.86	5.4	15.74	9.7	2.67
.pdf	25.55	22.8	28.45	23.0	1.03
.txt	13.80	12.2	18.97	13.0	2.68
Binary data	12.8	11	17.57	11.8	2.68

- 10 – 60% energy savings possible
- Depends on compressor, content type, size of content, network conditions…

Proxy-based traffic shaping for audio streaming

- Mobile media streaming drains battery quickly
  - Constant bit rate multimedia traffic is not energy friendly with 802.11 and 3G
  - Forces the network interface to be active all the time

Mobile Internet Radio power draw on E-71 (TCP-based streaming)

Data Rate (kBps)	Start-up Time (s)	WLAN		3G	
		PSM (W)	CAM (W)	48kBps (W)	2Mbps (W)
8	18	0.53	1.06	1.30	1.30
16	10	0.99	1.07	1.30	1.30
24	10	1.04	1.07	1.27	1.35

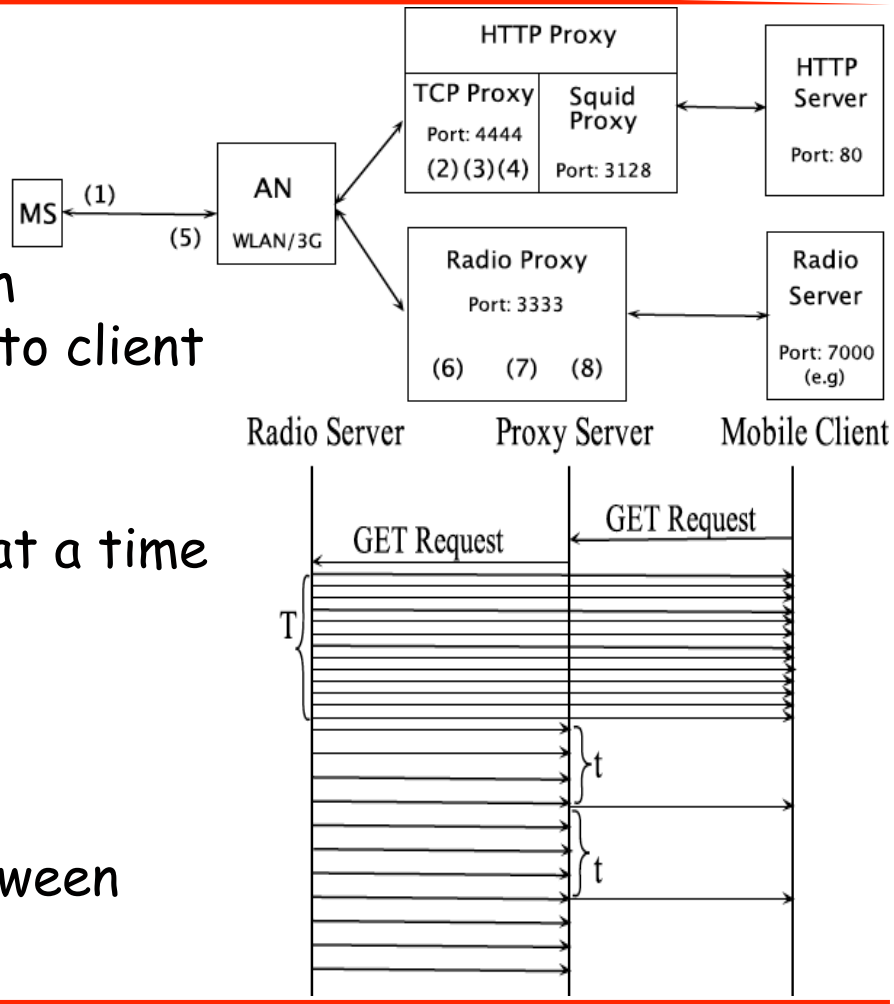
- Idea: Shape traffic into bursts so that it is more energy efficient to receive
  - Remember the linear relationship with throughput

Traffic Shaping with Proxy

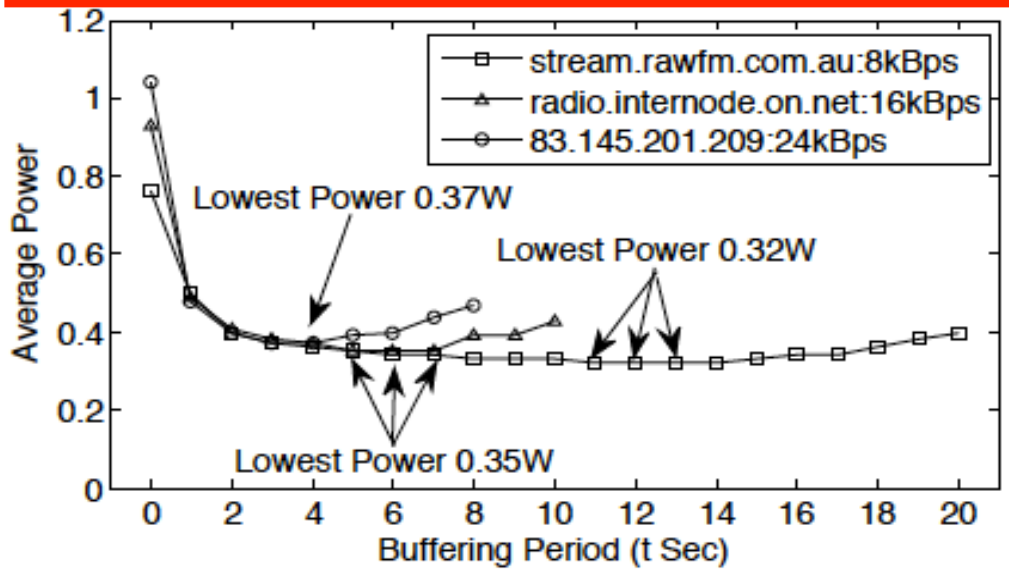
- Client sends request to proxy
- Proxy
  - forwards request to radio server
  - receives and buffers media stream
  - repeatedly sends in a single burst to client
- 802.11:
  - PSM is enabled
  - WNI wakes up to receive a burst at a time
  - Waste only one timeout per burst
- 3G:
  - Long enough burst interval (t)

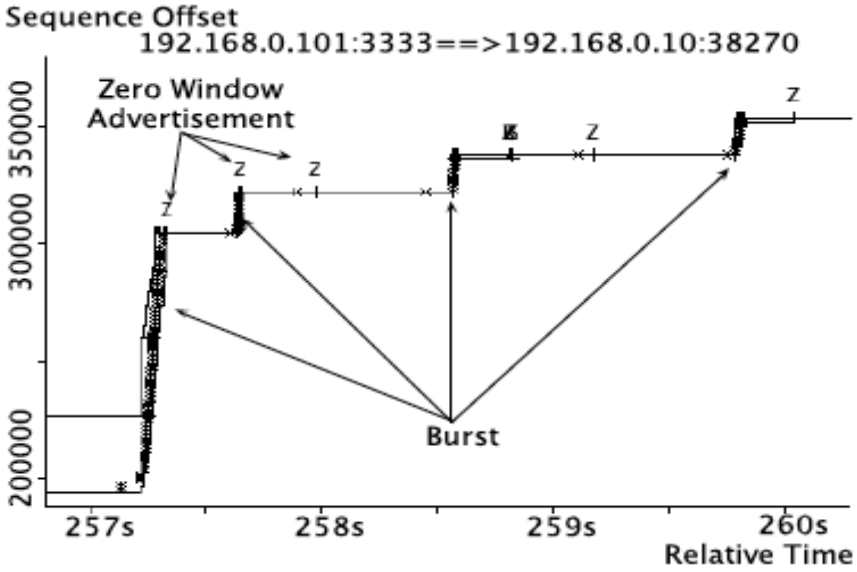
  -> inactivity timers expire

  -> switch to lower power state in between



How much energy can be saved?

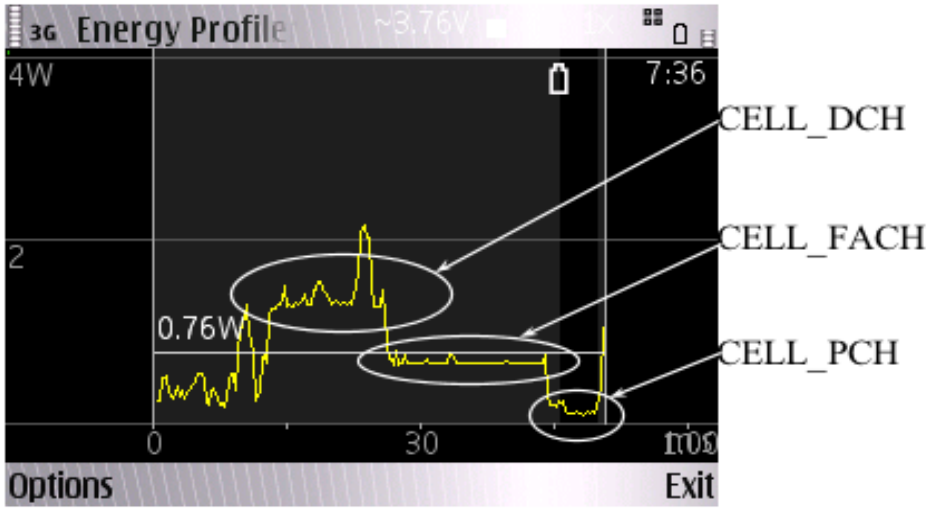


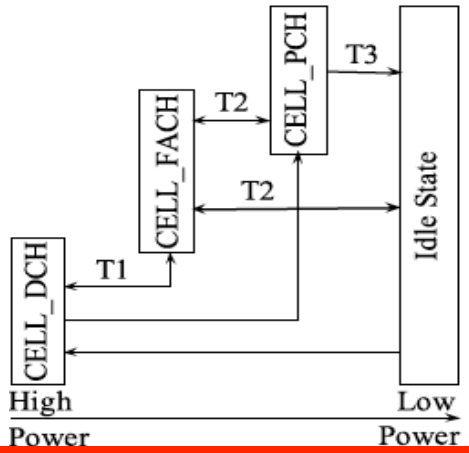


- Significant savings for audio streaming
  - Minimum power buffering period exists, almost 70% reduction
  - Due to limited TCP receive buffer at mobile client
- Video streaming via proxy from YouTube saves less than 20%
  - Already transmitted in bursts by server
  - Without server shaping, could reduce power almost 50%

What about 3G?

- 3G has long inactivity timers
  - Operator controls
  - No way to modify yourself
  - Large wasted *tail energy*
- Savings vary with
  - operator
  - mobile device
  - subscription rate
- In many cases there are no savings, but
  - Fast Dormancy comes soon
    - Optimization in 3G standard
    - Will be in use in near future
  - LTE will also have better power mgmt



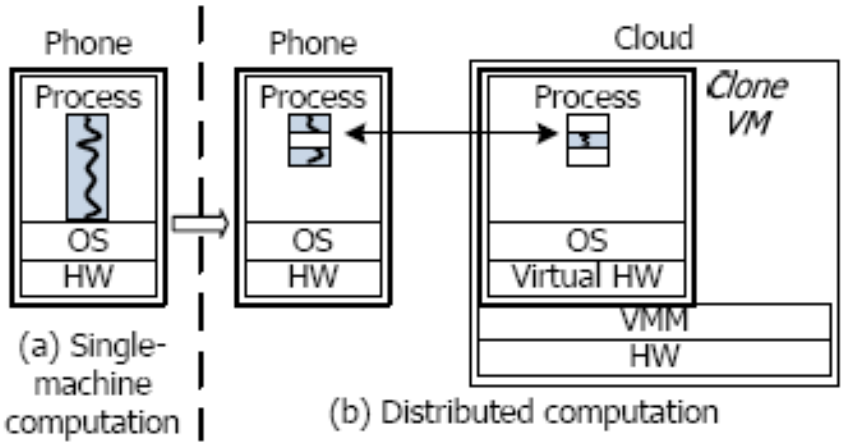


Computation offloading

- Execute parts of program on remote server
- Leverage same tradeoff as with previous example
  - Transferring required state to server and back consumes energy
  - But we save computation energy
- Dynamical decision making
  - Figure out on the fly which parts of program are worth offloading
  - Need accurate models for communication and computation energy consumption
- Several proposed frameworks exist
  - MAUI, CloneCloud
  - Research prototypes

CloneCloud

- Intel's CloneCloud offloads Android program code
- Works directly on bytecode
  - No need for source code
- Modified Dalvik VM
- Dynamic thread migration between phone and cloud



Byung-Gon Chun and Petros Maniatis. Augmented Smart Phone Applications Through Clone Cloud Execution. Proceedings of HotOS XII, 2009.

What else could be done?

- Data centers
  - Liquid cooling for servers, use the hot water to heat other premises
  - Run servers in (freezing) cold areas
  - Renewable energy
  - Execute things where energy is cheap
- Mobile devices
  - Smarter (cooperative) scheduling to reduce contention
  - Leverage alternative low-power radios (e.g. Zi-Fi or Blue-Fi)
  - Energy harvesting
    - Kinetic, solar, ambient radiation, …

Want to learn more?

- Come to my course: T-110.5111 – Computer Networks 2
  - Lecture with more technical details
  - Possibility to take practical assignment on this topic

- Come talk to us about…

  Doctoral thesis,
  Master thesis
  Special assignment
  Seminar
  …

Thanks!

Questions?