Mobile P2P
Energy-efficiency issues on mobile phones

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Slow growth in battery capacity

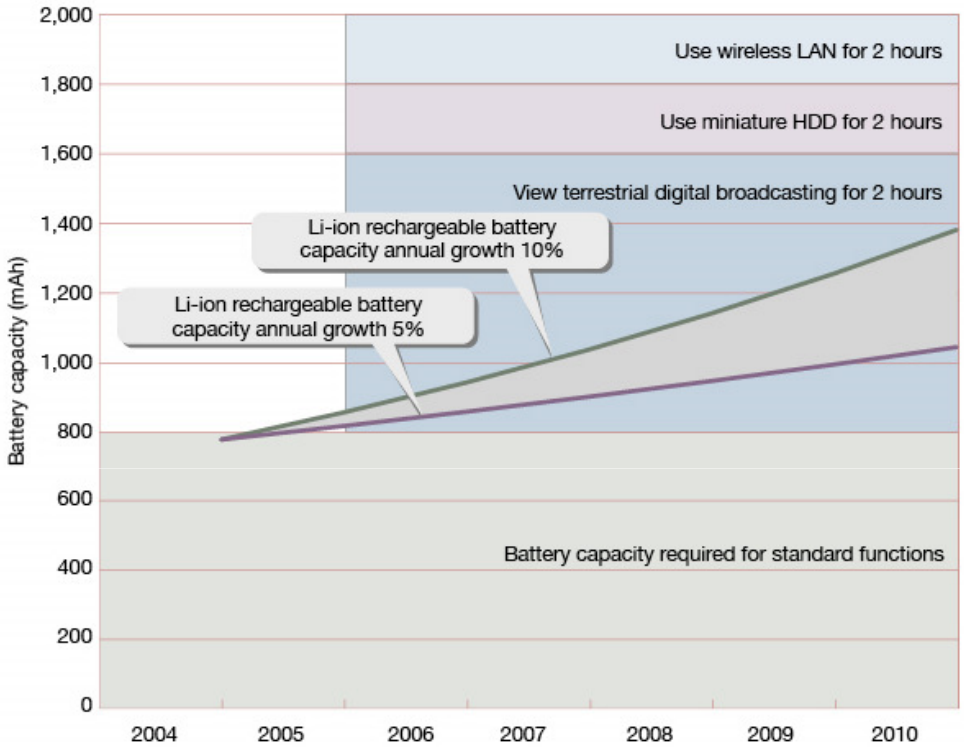
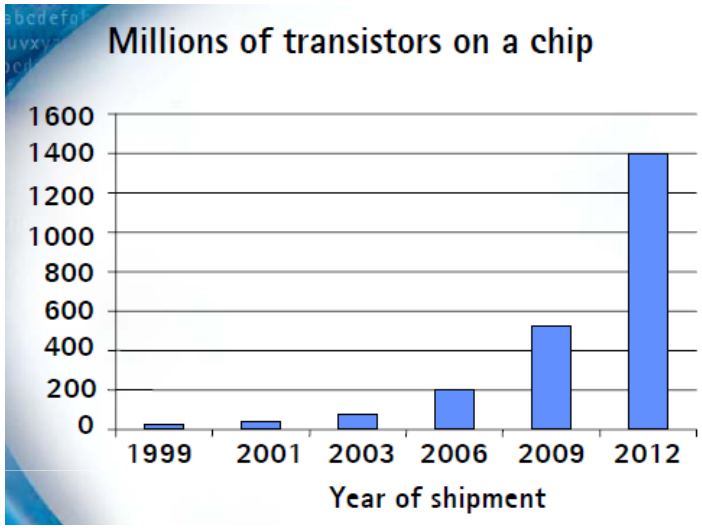


Fig 2 Underpowered Mobile Phone Batteries Even if the energy density of Li-ion rechargeable batteries continues to grow at 5 to 10% annually, they still won't provide sufficient power for tomorrow's mobile phones at their present volumes. Viewing terrestrial digital broadcasting for long periods or storing/playing video using internal HDDs will demand roughly double the battery capacity. The diagram indicates the capacity needed to run mobile phone functions for two hours. Capacity would have to be tripled to allow users to watch terrestrial digital broadcasting for four hours.

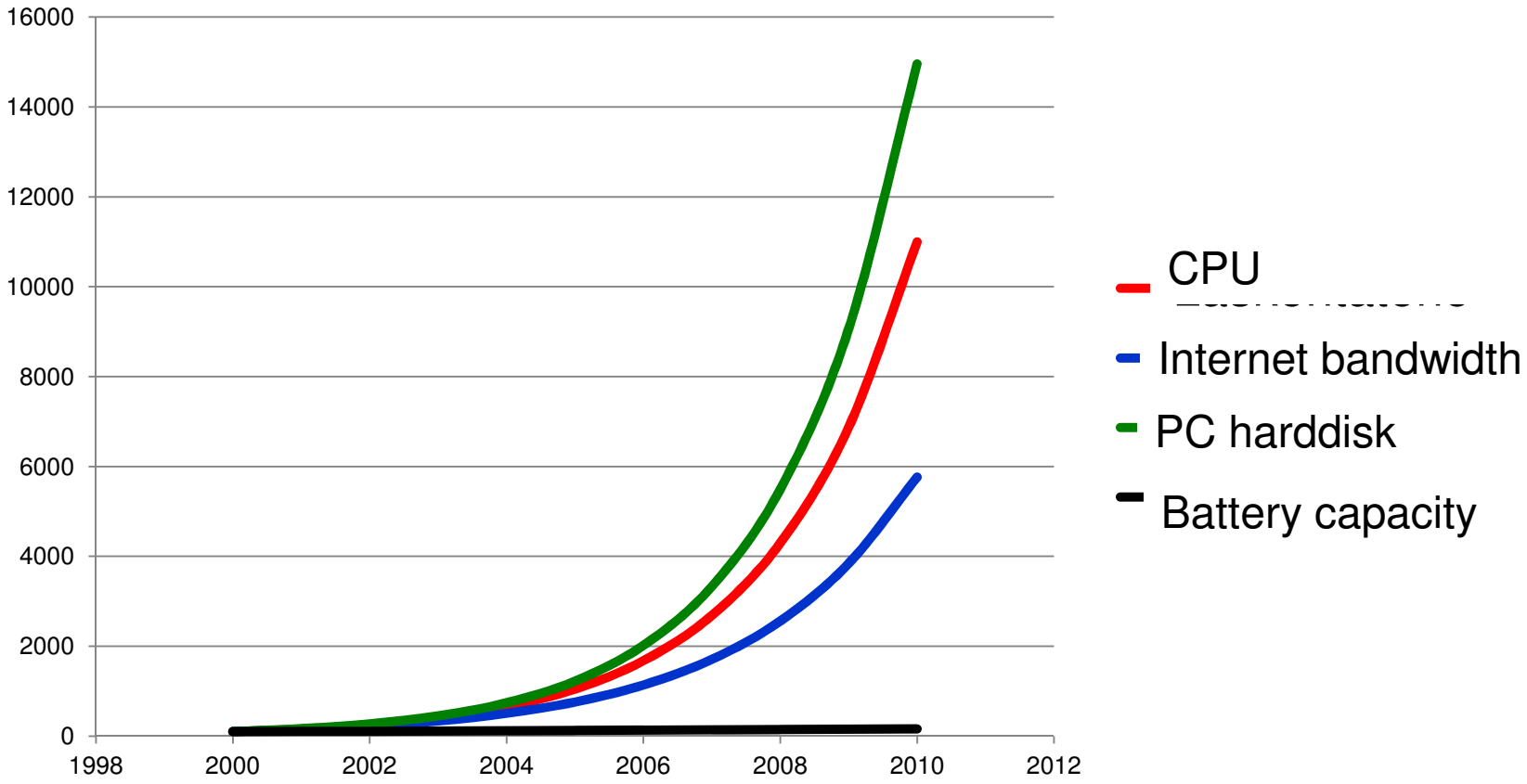
vs.

Moore's law

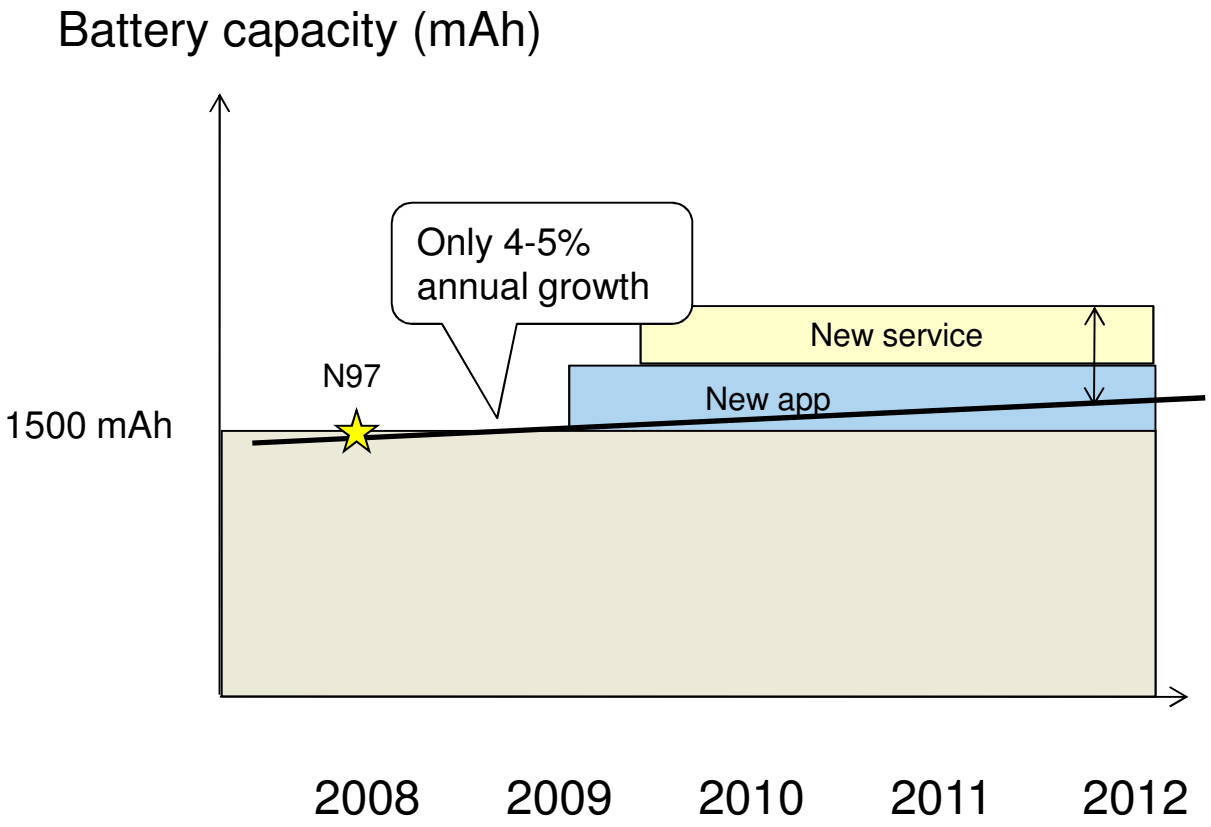


Metcalfe's law

High exponential growth of most resources – except battery capacity



Gap between Battery Capacity and App Needs



- More frequent charging
- Physically larger batteries => larger devices
- Less new services and application
- Break-throughs in battery technology
- Smarter usage of battery capacity

What energy-efficiency means for mobile user?

- Two kinds of energy-efficiencies
  - E_{mobile}
    - Energy consumption of mobile device
    - How fast your battery goes empty
    - Directly visible to the user
    - Typically a matter of convenience rather than electricity cost
      - except in cases when access to electricity grid difficult (e.g. emerging markets)
  - E_{infra}
    - Communication infrastructure (e.g. cellular access, core internet) and equipment (e.g. servers, routers, home PCs)
    - Monetary and environmental value for large-scale use
    - Typically hidden from the user
  - $C_E = w_1 E_{mobile} + w_2 E_{infra}$
    - User's subjective measure of the pain energy consumption creates
    - In practice $w_1 >> w_2$

Power consumption of streaming in 3G phone

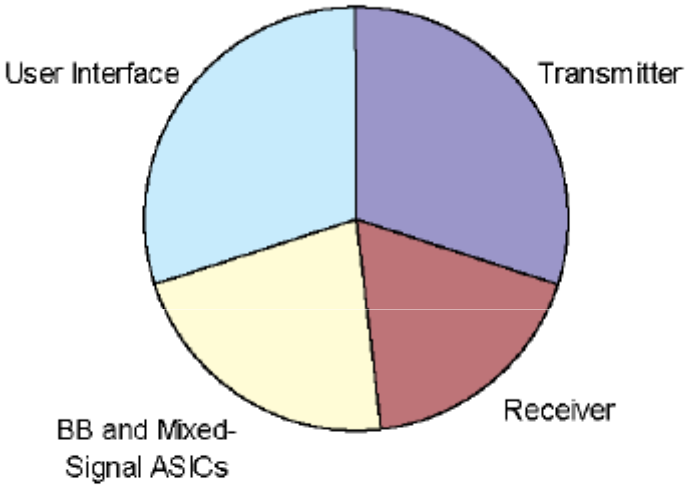


Figure 1.3.7: Power consumption break down in video streaming in a 3G phone.

Neuvo, Y., "Cellular phones as embedded systems," *Solid-State Circuits Conference, 2004. Digest of Technical Papers. ISSCC. 2004 IEEE International* , vol., no., pp. 32-37 Vol.1, 15-19 Feb. 2004

Nokia Energy Profiler

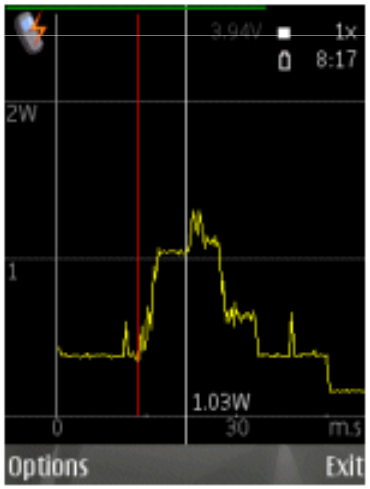
Software application. No special measurement hardware needed.

Accurate enough for most tasks (1-3% tolerance in idle states. More accurate with higher power)

S60 3rd edition and later Nokia phones

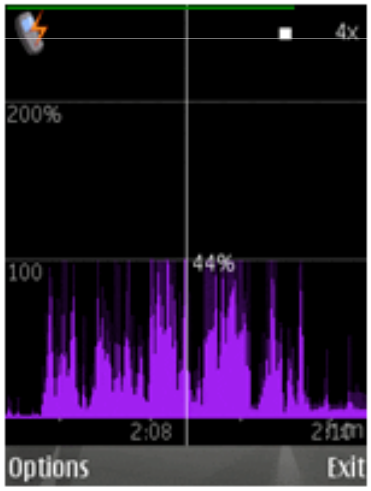
forum.nokia.com

Power

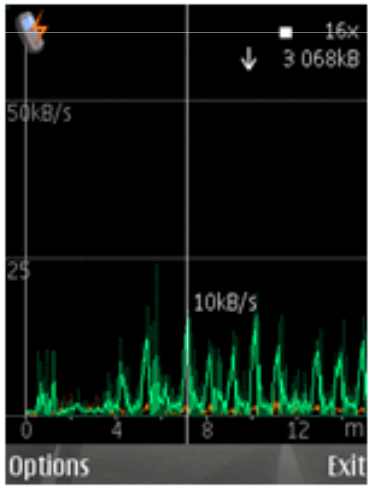


Current

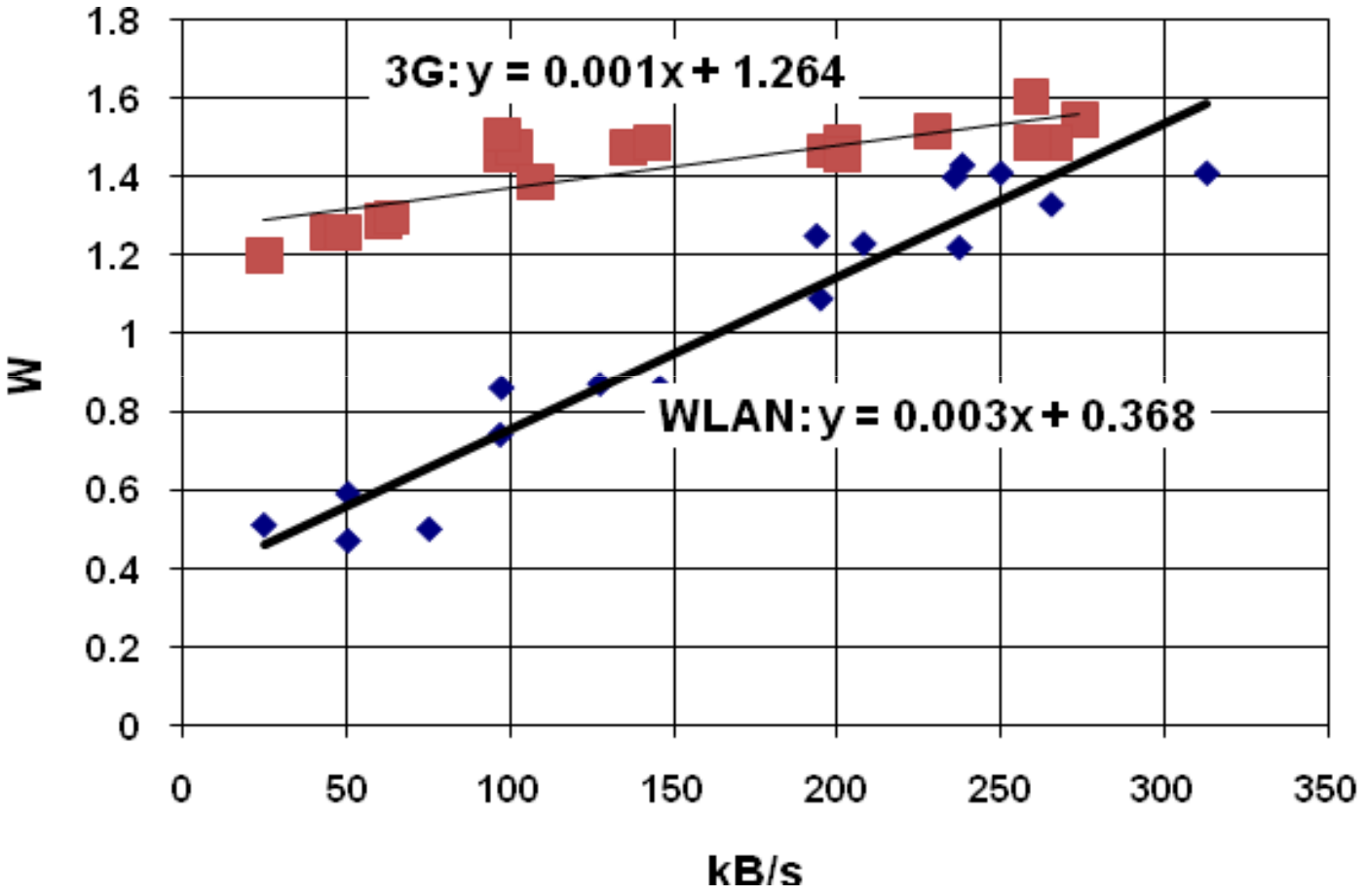
CPU usage



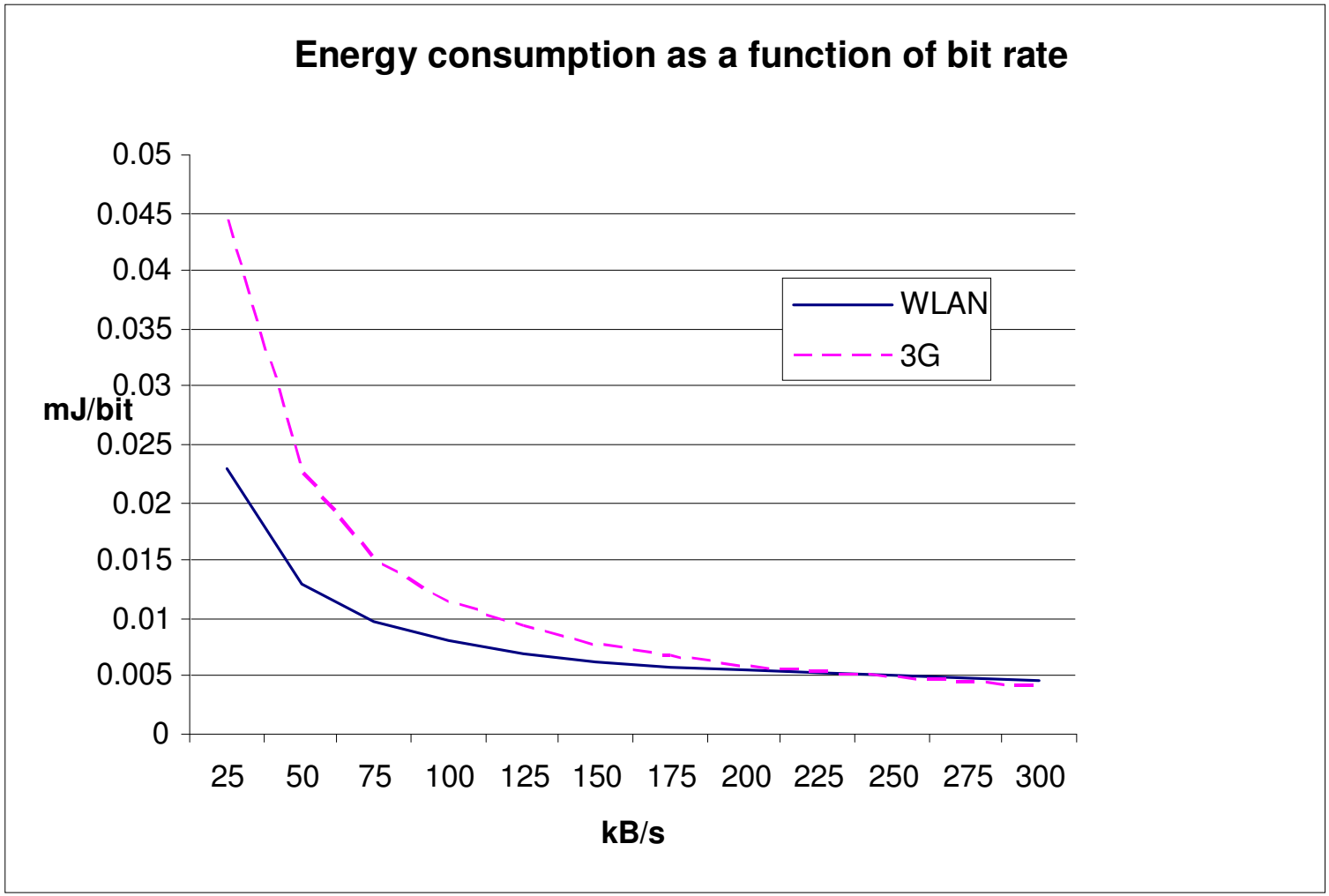
Network



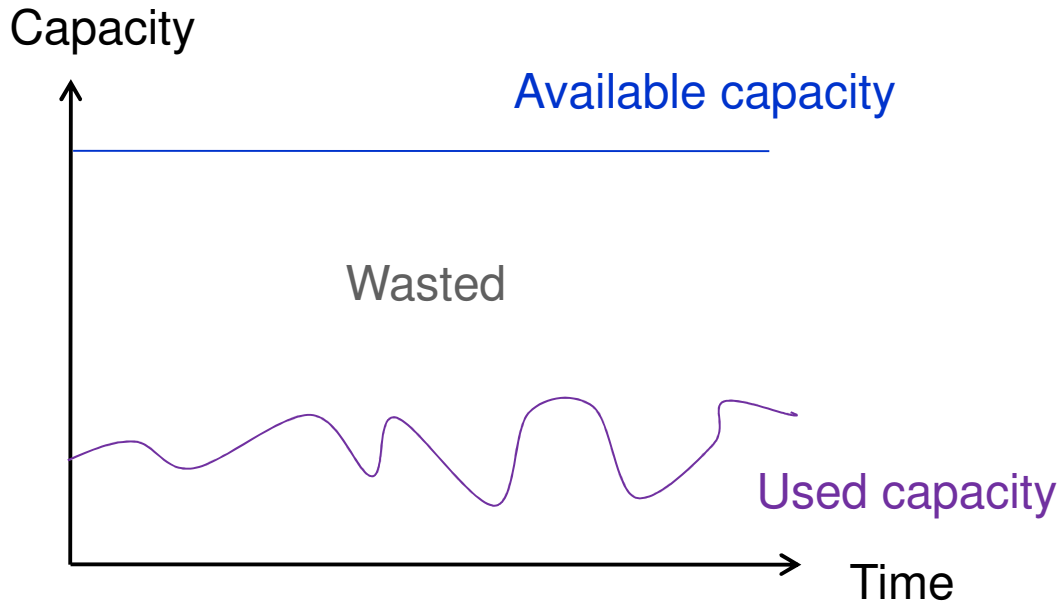
Power Consumption with Different Bitrates



Higher bit rate -> more energy-efficient

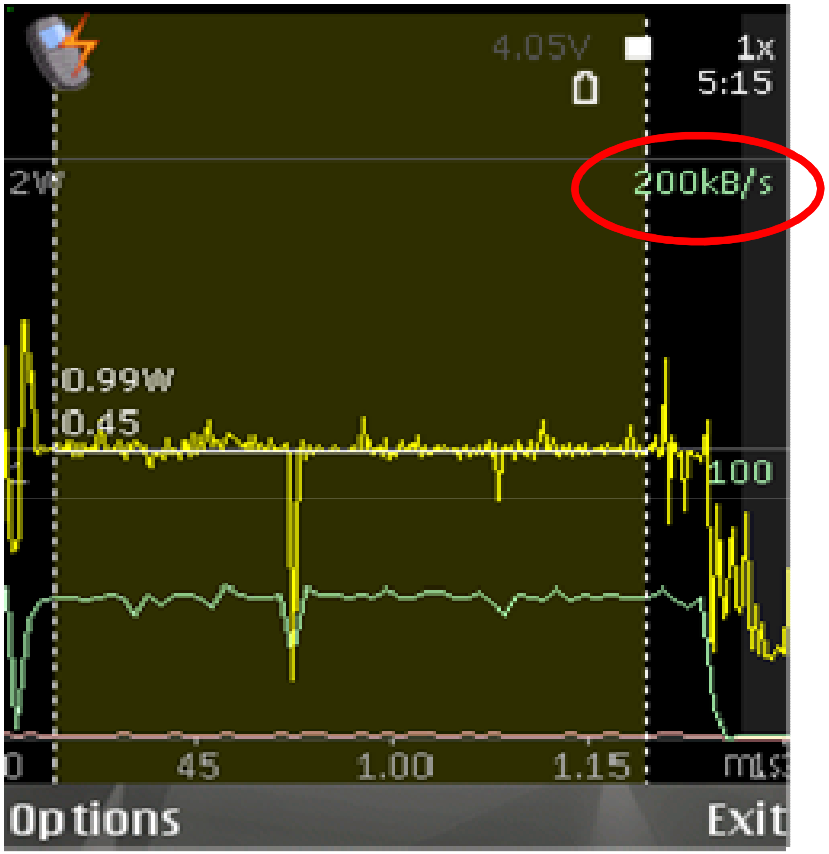


Energy wasted when capacity is not fully used

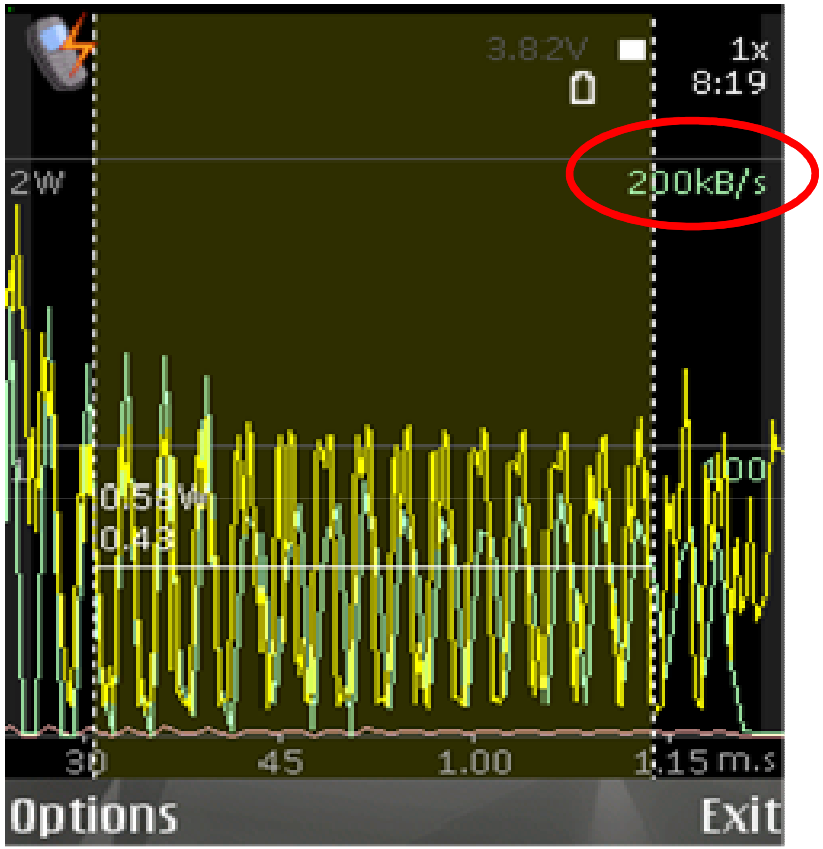


- Radio energy consumption is dominated by the power amplifier
- Roughly same power used no matter how much traffic there is (as long as some)
- Continuous low bitrate traffic (e.g. voice, audio) does not allow sleep in idle mode
- WLAN has more aggressive power save mode than 3G

Communication
Same average bitrate different traffic pattern

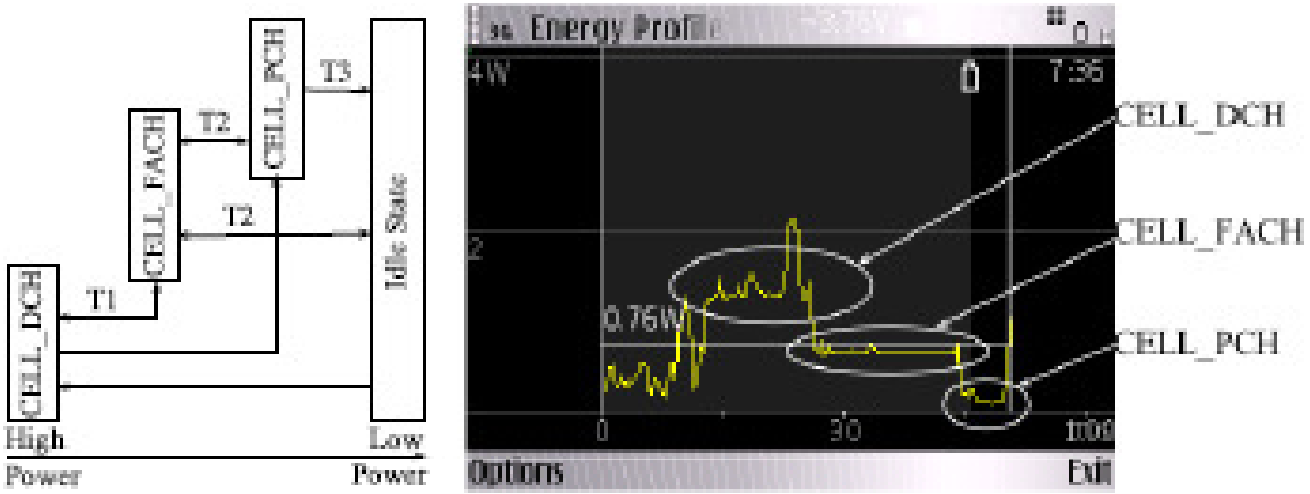


0.99W



0.53W

3G Energy Consumption (Tail energy problem)



(a) WCDMA 3G States (b) Power Consumption with Nokia E-71

Figure 1: 3G States and Power Consumption

- Data transfer in DCH (dedicated channel) state
- After data transfer is complete it takes seconds to return to idle state. The actual depends on your cellular operator (e.g. Elisa 2s+2s, some US operator 12.5s)

WLAN (WiFi) energy consumption

- Infrastructure mode quite energy-efficient (much less problems with head and tail energy)
- Ad hoc mode consumes a lot of power, even if there is no traffic
- Quite sensitive to location, moving terminal 10m can double the energy consumption

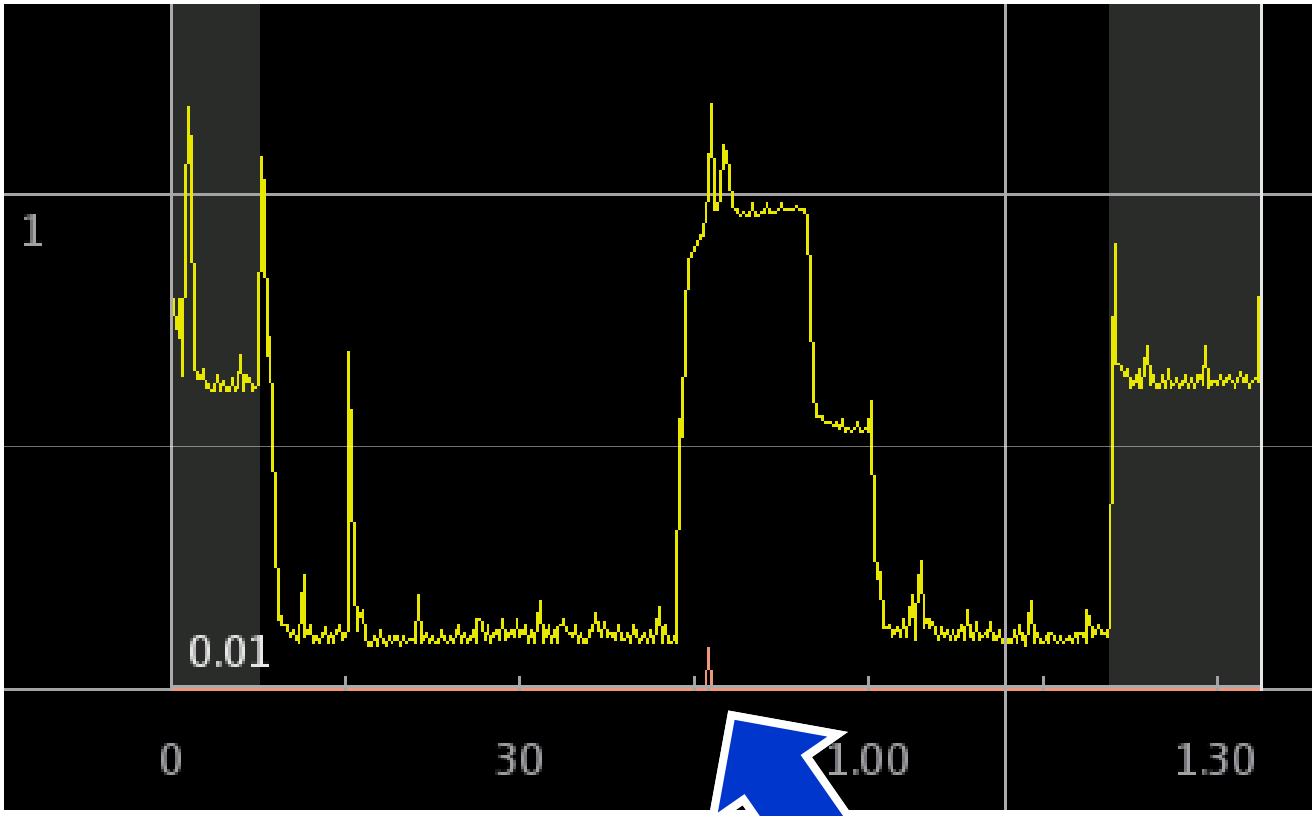
Keep-alive problem

- Mobile devices have to form the connections. The network is not able to do it.
- An idle TCP (or UDP) connection does not consume energy
- But idle connections do not stay alive for long. Therefore periodic keep-alive packets need to be sent
- Measurements with cellular networks show
  - NAT timeouts for UDP are anywhere between 30 and 180 seconds
  - NAT timeouts for TCP is anywhere between 30 and 60 minutes
  - Sending a keep-alive packet every 20s increases power consumption by a factor of 10 and more
  - Pasi Eronen, “TCP Wake-Up: Reducing Keep-Alive Traffic in Mobile IPv4 and IPsec NAT Traversal,” Technical Report, http://research.nokia.com/tr/nrc-tr-2008-002
- This problem exists not only for P2P apps but also for push email, AJAX apps, etc.

Background traffic & its energy consumption

- Internet background traffic is received to every public IPv4 address
- Unwanted IP packets, coming in sporadically from multiple senders
- Reasons:
  - malware (worms)
  - port scans
  - misconfigured devices
  - byte order problems
  - …
- The amount of unwanted traffic is on the rise

3G radio wakeup – incoming ping packet



X-axis: **time**

Yellow graph: **power**

Red graph: **incoming packet count**

(*Grey areas:* display backlight is on, starting/stopping the measurement)

Terminology:

Head energy

Tail energy

The ping packet is received at this point

How bad is the problem exactly?

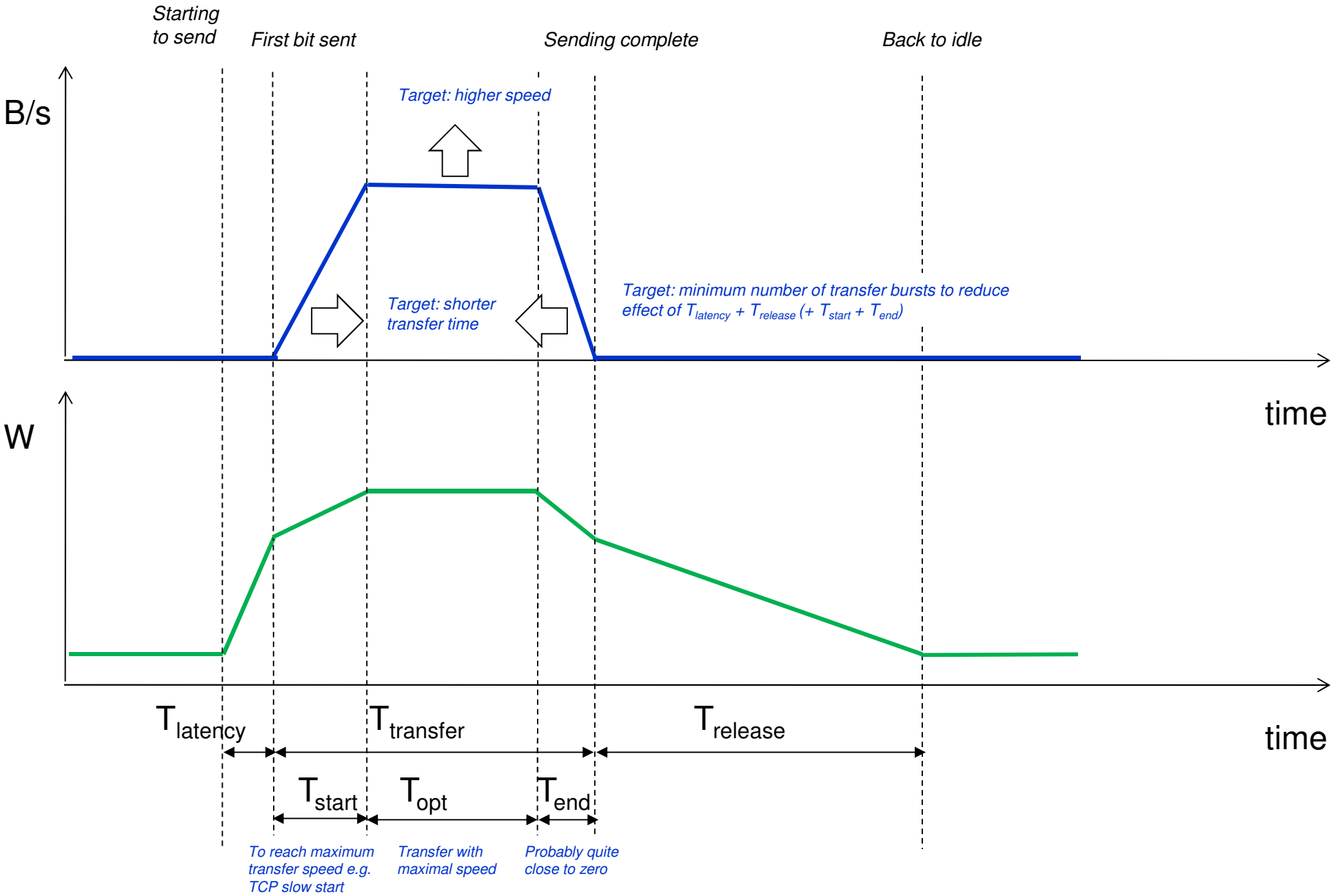
- The background traffic and energy usage were measured with a N900 on an unfiltered Elisa GPRS connection for 16 hours
  - Tools: tcpdump and Nokia Energy Profiler

	Measured energy (J)	Energy in 24h (J)	Share
Idle	6303	9504	78.77%
Data transfer	62	92	0.77%
Head & Tail	1637	2468	20.46%
Total	8002	12065	100.00%

- Transfer energy is small, but the head and tail energies are large
- A fully charged N900 battery might contain ~ 19000 Joules

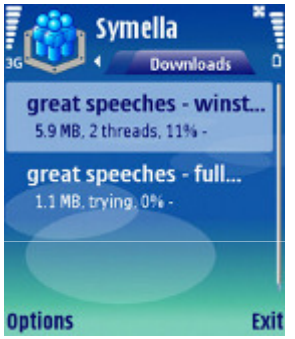
Summary

- Mobile device communication energy consumption varies
  - Bit rate
  - Traffic shape
  - Parallel activities
  - Unwanted traffic
- Opportunities to save energy in the mobile device
  - Offload tasks to cloud, use of proxies, etc.
- The savings in mobile often create additional energy consumption elsewhere
  - understanding the trade-offs would be important


Starting to send
First bit sent
Sending complete
Back to idle
B/s
Target: higher speed
Target: shorter transfer time
Target: minimum number of transfer bursts to reduce effect of T latency + T release (+ T start + T end)
time
W
time
T latency
T transfer
T release
T start
T opt
T end
To reach maximum transfer speed e.g. TCP slow start
Transfer with maximal speed
Probably quite close to zero

Energy & P2P

P2P and handheld devices



- Mainly experimental systems so far.
  - E.g. Symella, SymTorrent, MobTorrent, MobileDHT
  - Paradigm: bring existing P2P applications to mobile devices
  - Available as open source at http://amorg.aut.bme.hu/projects
- Challenges:
  - NAT and firewall traversal
  - Operator co-operation
  - High churn
  - Battery consumption
  - Billing
  - Limited resources of the handheld device
- Possibilities:
  - Taking advantage of phone context
  - Accessing data and functionality of core applications (addressbook, call log, calendar, location, …)
  - Taking advantage of the human user who can easily be alerted

Utility of participating in P2P community

$$U(C) = b(C) - c(C)$$

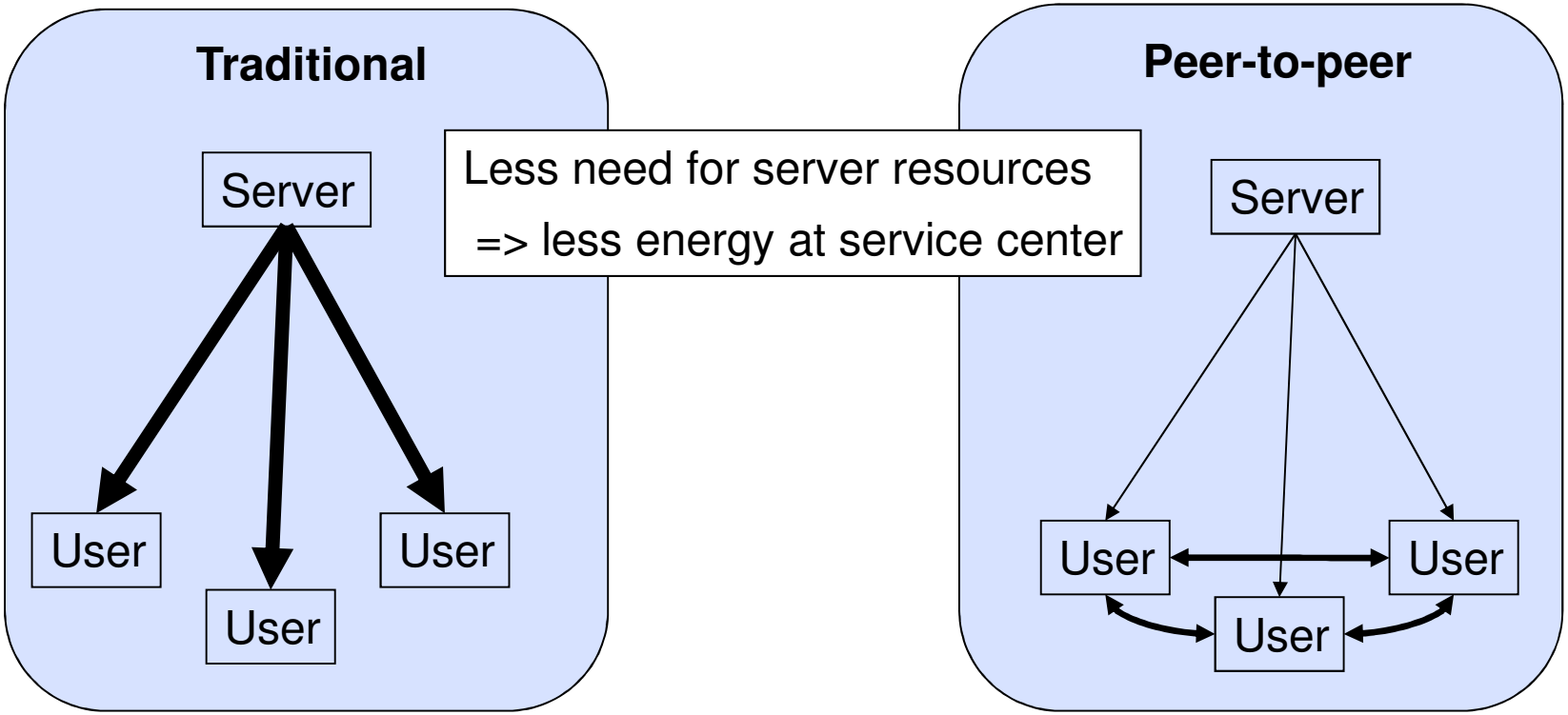
- For PC
- benefit reasonably high
- hardly any cost
- => high utility
- => low threshold to contribute

- For mobile device
- benefit reasonably high
- cost can be quite high
  - Energy
  - Phone bill
- => lower utility, or
- => strong incentive to be selfish

Karonen, O. and Nurminen, J.K., "Cooperation Incentives and Enablers for Wireless Peers in Heterogeneous Networks," IEEE CoCoNet Workshop 2008 Cognitive and Cooperative Wireless Networks collocated with IEEE ICC 2008, Beijing, China, May 2008

Suomalainen, J., Pehrsson, A. and Nurminen, J.K., "A security analysis of a P2P incentive mechanism for mobile devices," 3rd International Conference on Internet and Web Applications and Services (ICIW 2008), Athens, Greece, June 2008

Peer-to-peer content delivery & Energy consumption

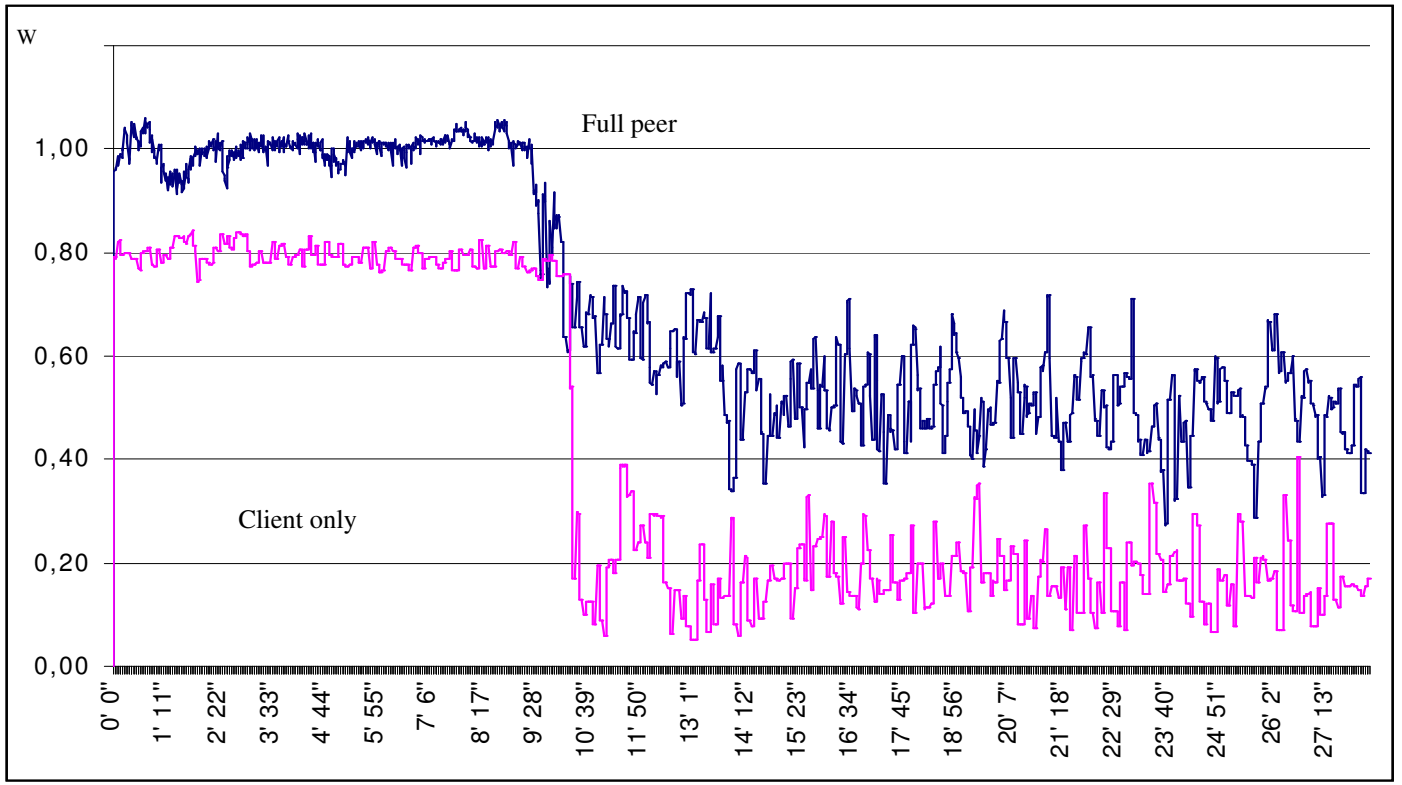


More resources from the users => Does it matter?

- Wireless users
- Combined effect of millions of users

Energy-efficient Content Sharing

Approach 1: Do less work
SymTorrent power consumption

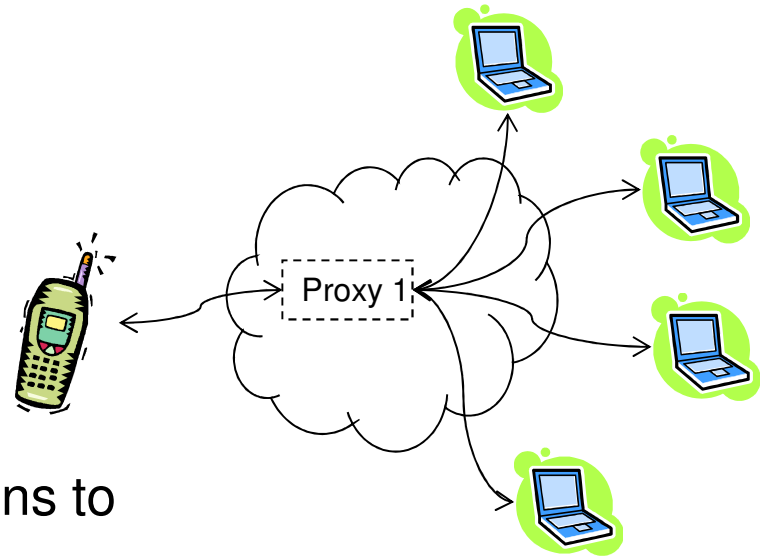


- Only act as a client. Do not server others.
- But you do not save much in the active download phase (~20% less power).
- You may actually loose energy because of the tit-for-tat mechanism as you get slower download speed

Nurminen, J.K. and Nöyränen, J., "Energy-Consumption in Mobile Peer-to-Peer – Quantitative Results from File Sharing," 5th IEEE Consumer Communications & Networking Conference CCNC 2008, Las Vegas, Nevada, January 2008

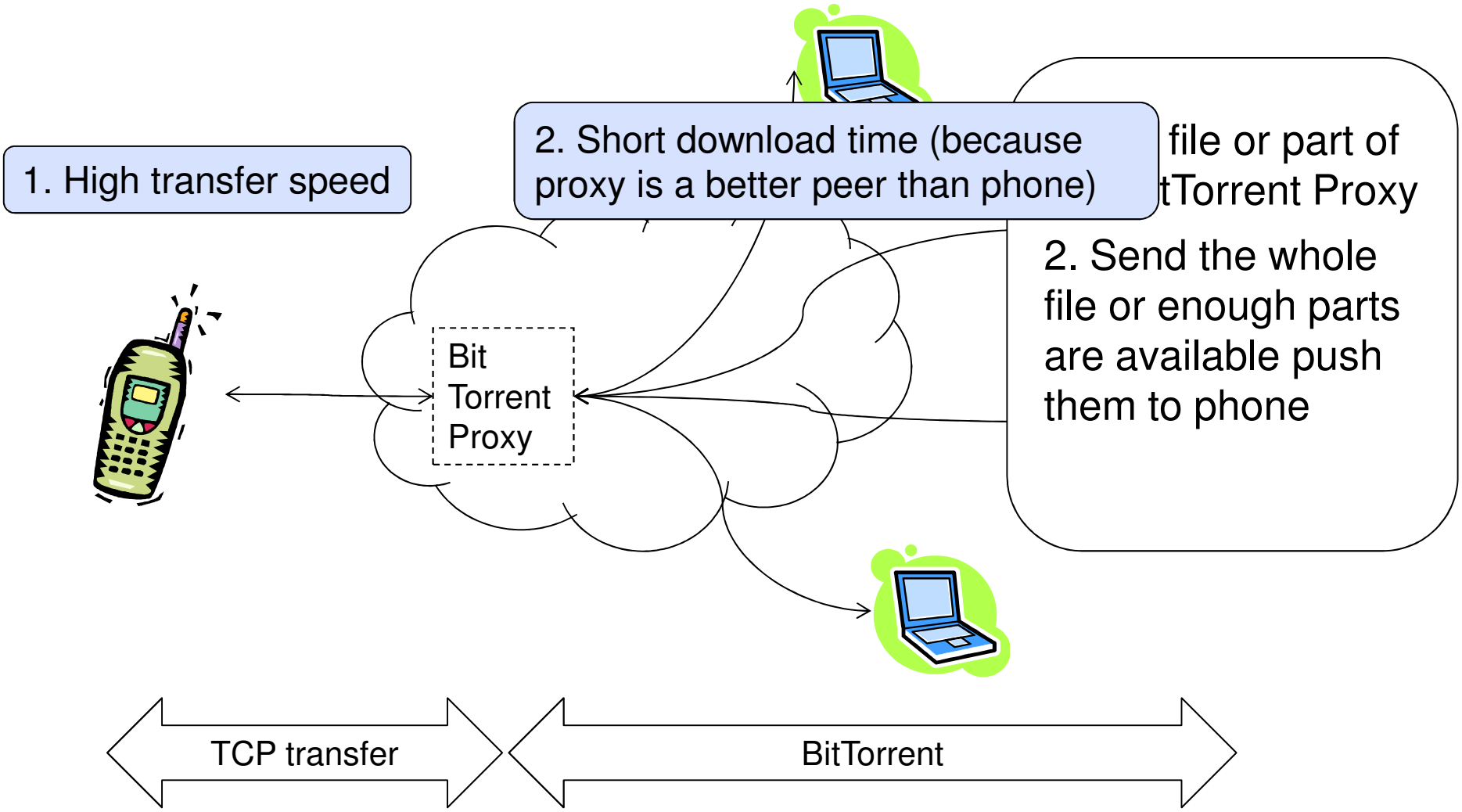
Approach 2: Proxy assisted downloading (CloudTorrent)

- How to get BitTorrent content to the phone energy-efficiently?
- BitTorrent client on mobile phone
  - Yes. This works: SymTorrent, MobTorrent, etc.
  - But it consumes quite a lot of power



- What are the implications of different proxy solutions to
  - Phone energy consumption
  - Overall energy consumption of the solution

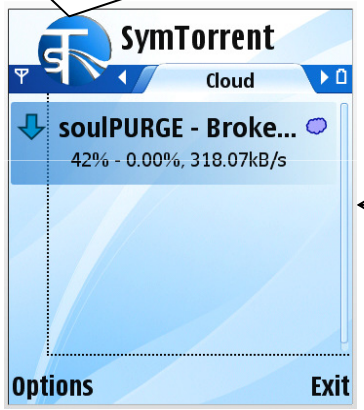
BitTorrent download through a Proxy



CloudTorrent

Updated version SymTorrent to handle torrent download via server

µTorrent & Apache on Amazon EC2



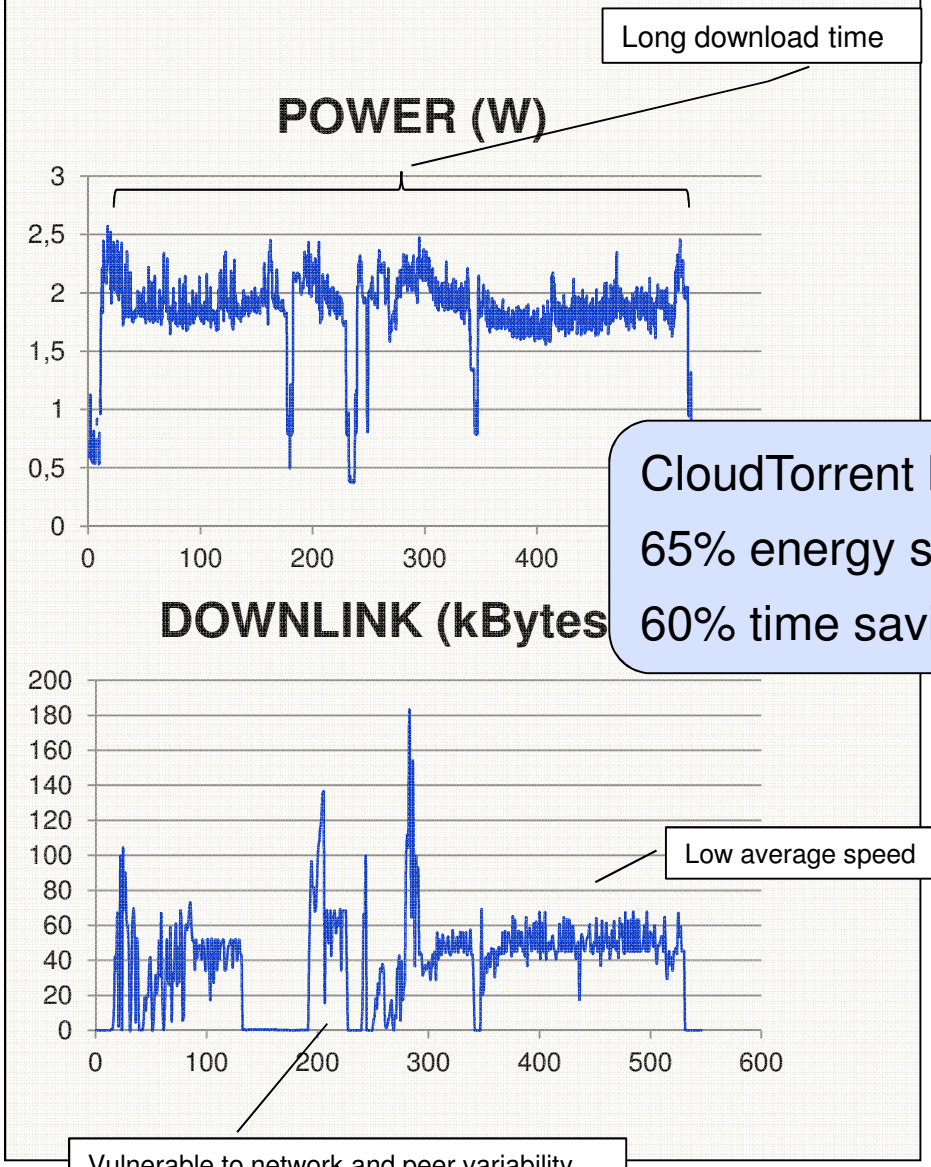
Cloud torrent server

1. Get whole file to CloudTorrent server
2. During torrent transfer poll server every nth (20) second to display progress on phone screen
3. When the whole file is available transfer over http to phone

HTTP/JSON

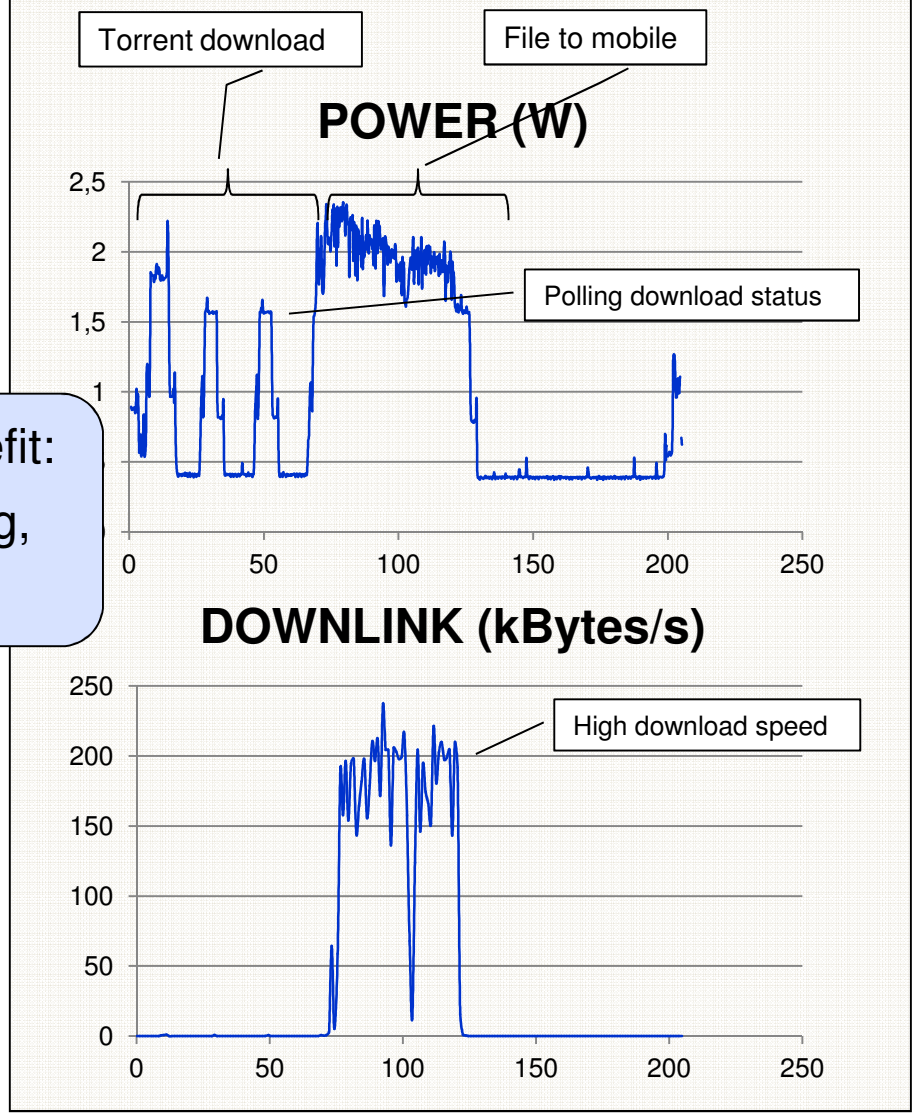
BitTorrent

BitTorrent at phone



CloudTorrent benefit:
65% energy saving,
60% time saving

CloudTorrent



Where to host the proxy?

	Amazon EC2	PC	Broadband Router	Phone
Proxy power consumption (additional)	? W	~ 10-200W	~0W	
Downlink bandwidth	Plenty	Plenty	Plenty	Limited
Uplink bandwidth	Plenty	Limited	Limited	Limited
Mass memory	Plenty	Plenty	Limited	Plenty
CPU power	Plenty	Plenty	Limited	Limited

Widely available.
Typically powered-on.
Power consumption independent of load

Typically limited by ADSL. Can be less than phone download speed.

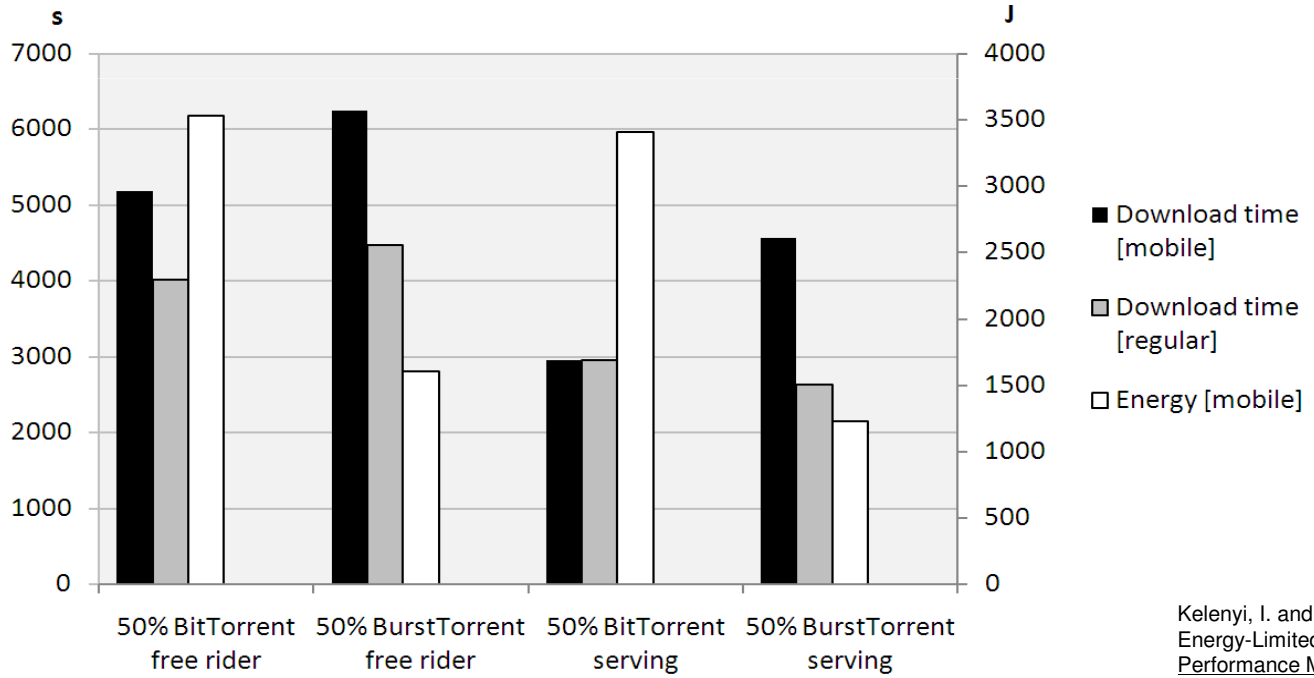
How does BitTorrent client work when the resources are limited?

Where to host the proxy?

- 3rd party hosting (e.g. CloudTorrent - Amazon EC2)
  - High costs
- Desktop computer at home
  - Higher energy consumption (15-200W)
- **Broadband router at home**
  - Most homes have them
  - They are powered on all the time
    (~ 0W extra energy consumption)
  - Most routers are Linux based
    → can run custom software

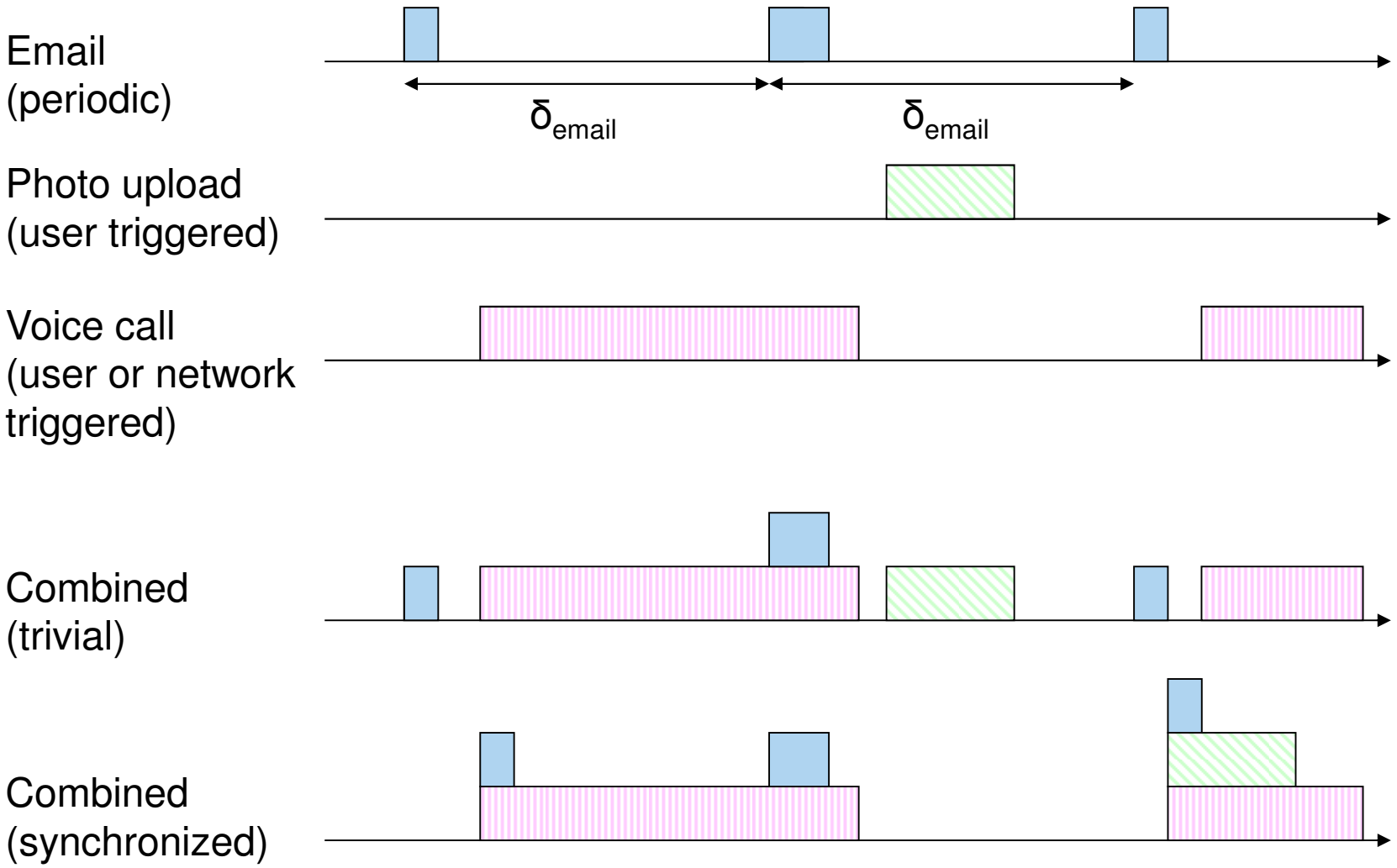
Approach 3: BitTorrent transfer in scheduled bursts

- Transferring data in high bursts brings significant energy saving
  - Power to transmit a bit reduces when the bit rate increases
- BurstTorrent extends BitTorrent protocol to allow scheduled transfers
  - This way the bandwidth utilization is optimized
  - We may also sacrifice download speed in order to save energy

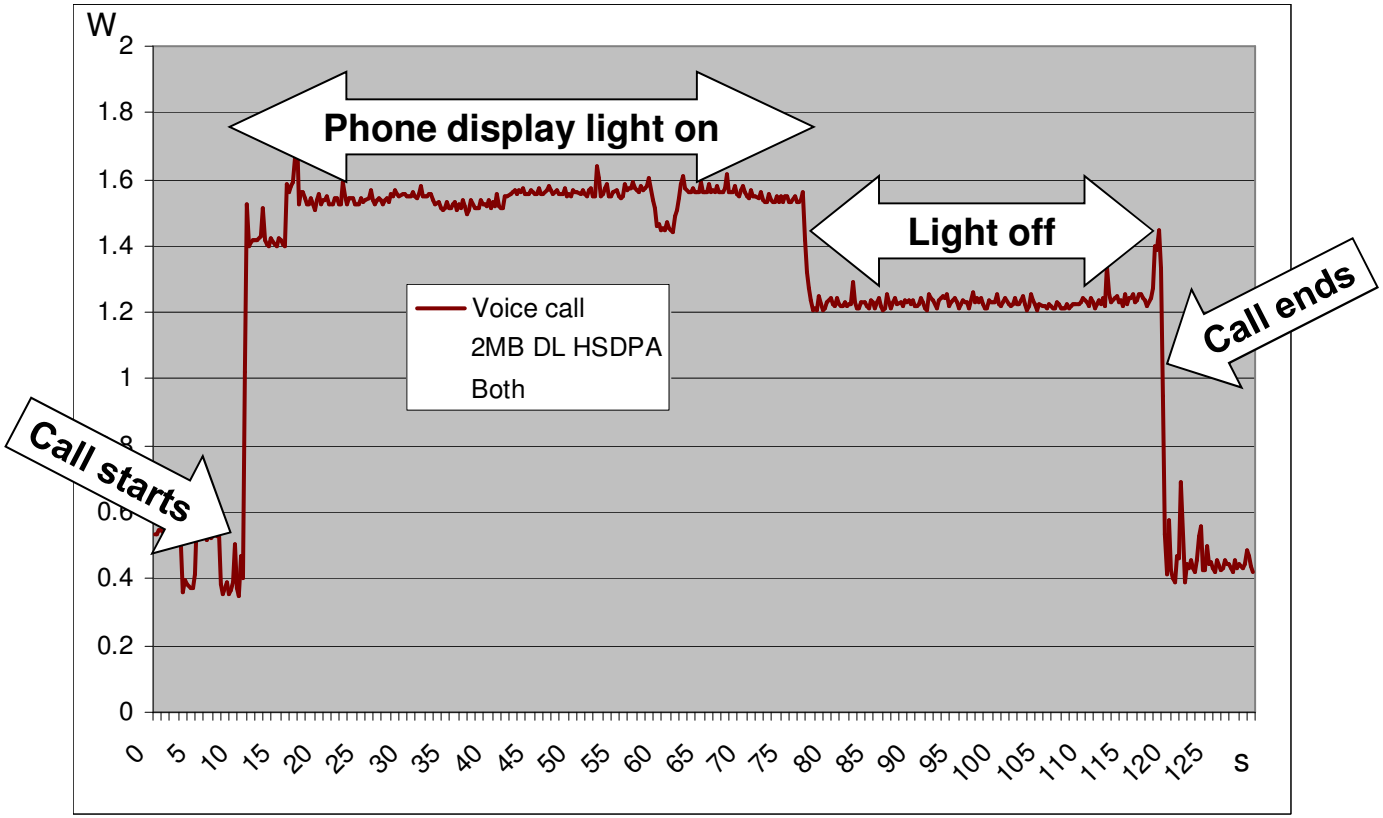


Kelenyi, I. and Nurminen, J.K., "Bursty Content Sharing Mechanism for Energy-Limited Mobile Devices," The 4th ACM International Workshop on Performance Monitoring, Measurement and Evaluation of Heterogeneous Wireless and Wired Networks (PM2HW2N), Tenerife, Canary Islands, Spain, October 2009

Approach 4: Delayed data transfer (Application Cooperation)

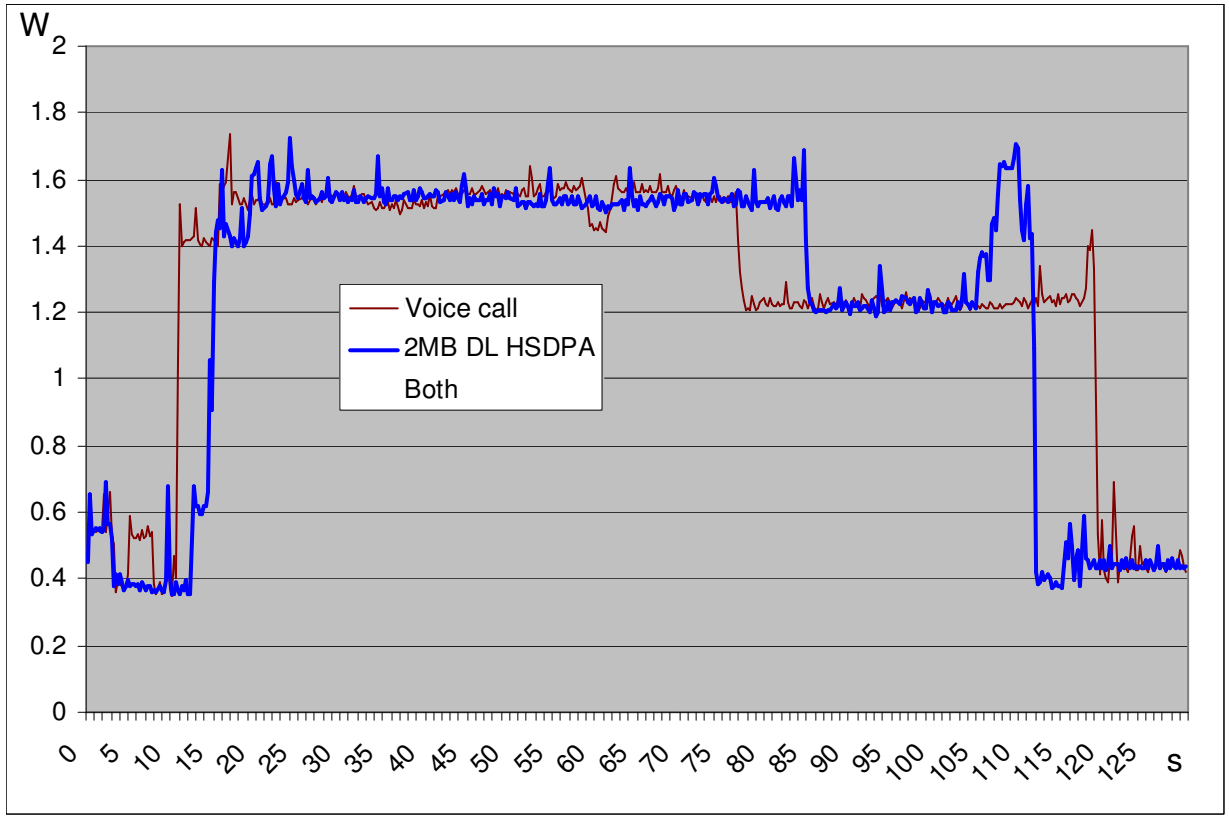


Normal voice call ~2 min



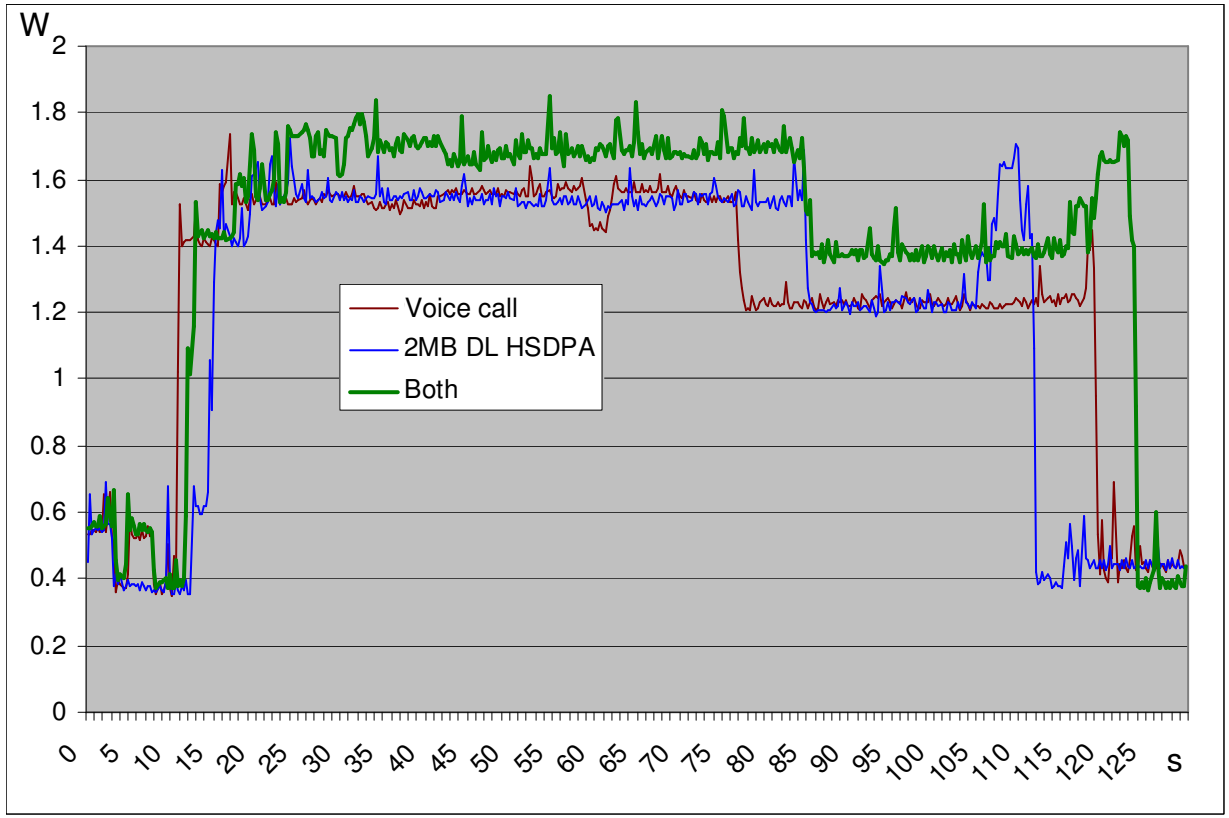
2MB email attachment download

with CDMA2100 HSDPA (3,5G)



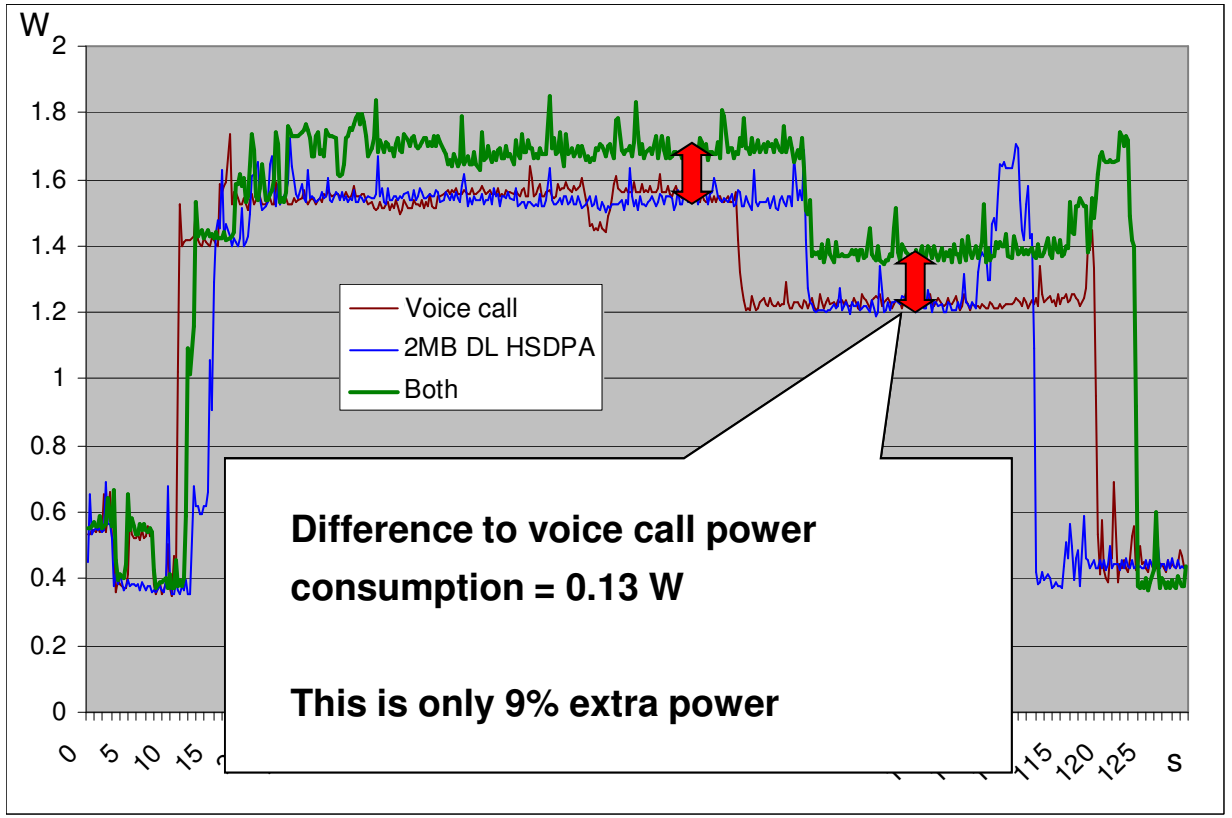
Parallel voice call and 2MB download

with CDMA2100 HSDPA



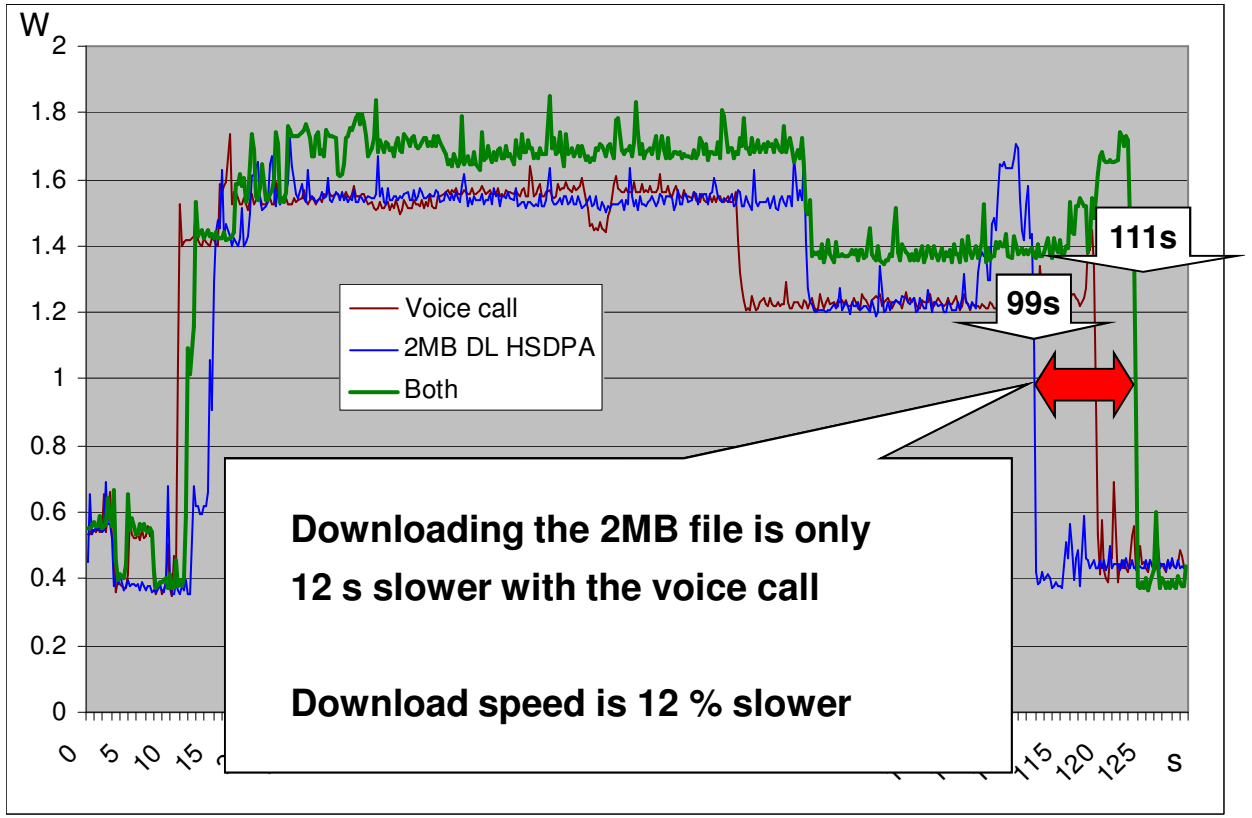
Parallel voice call and 2MB download

with CDMA2100 HSDPA



Parallel voice call and 2MB download

with CDMA2100 HSDPA

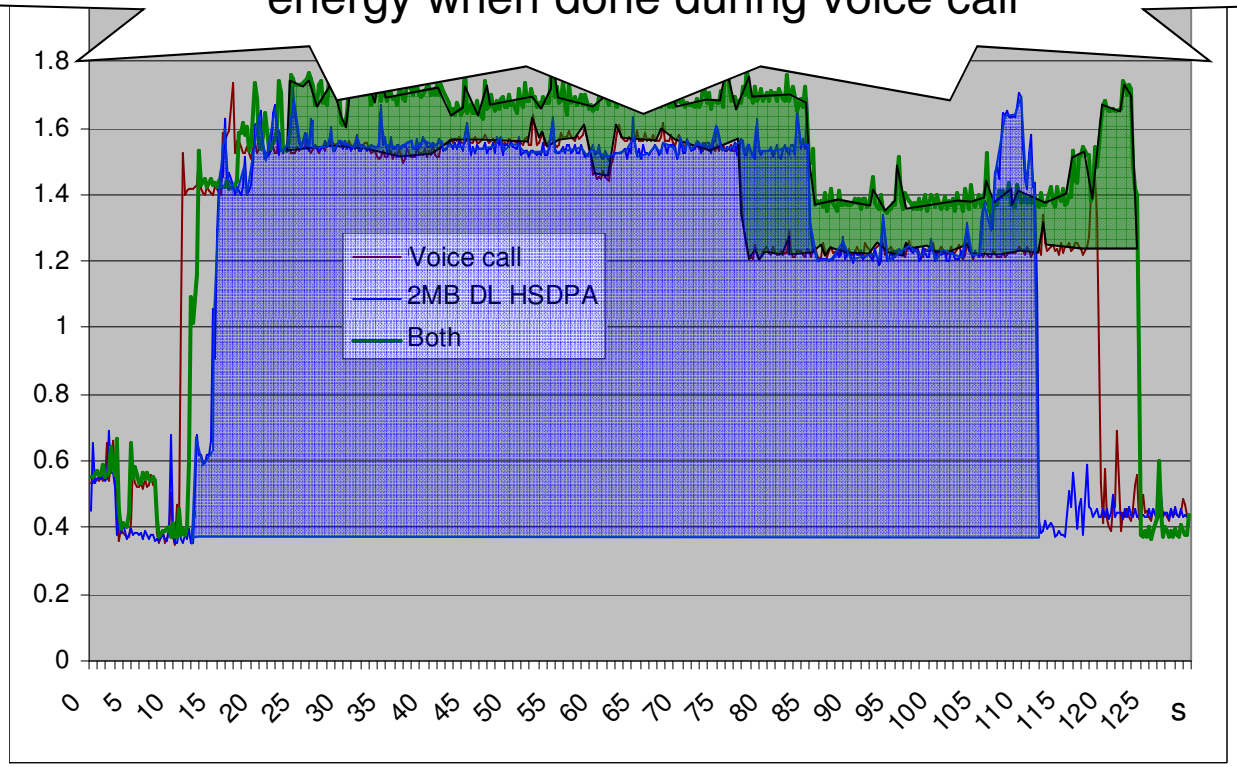


Parallel voice call and 2MB download

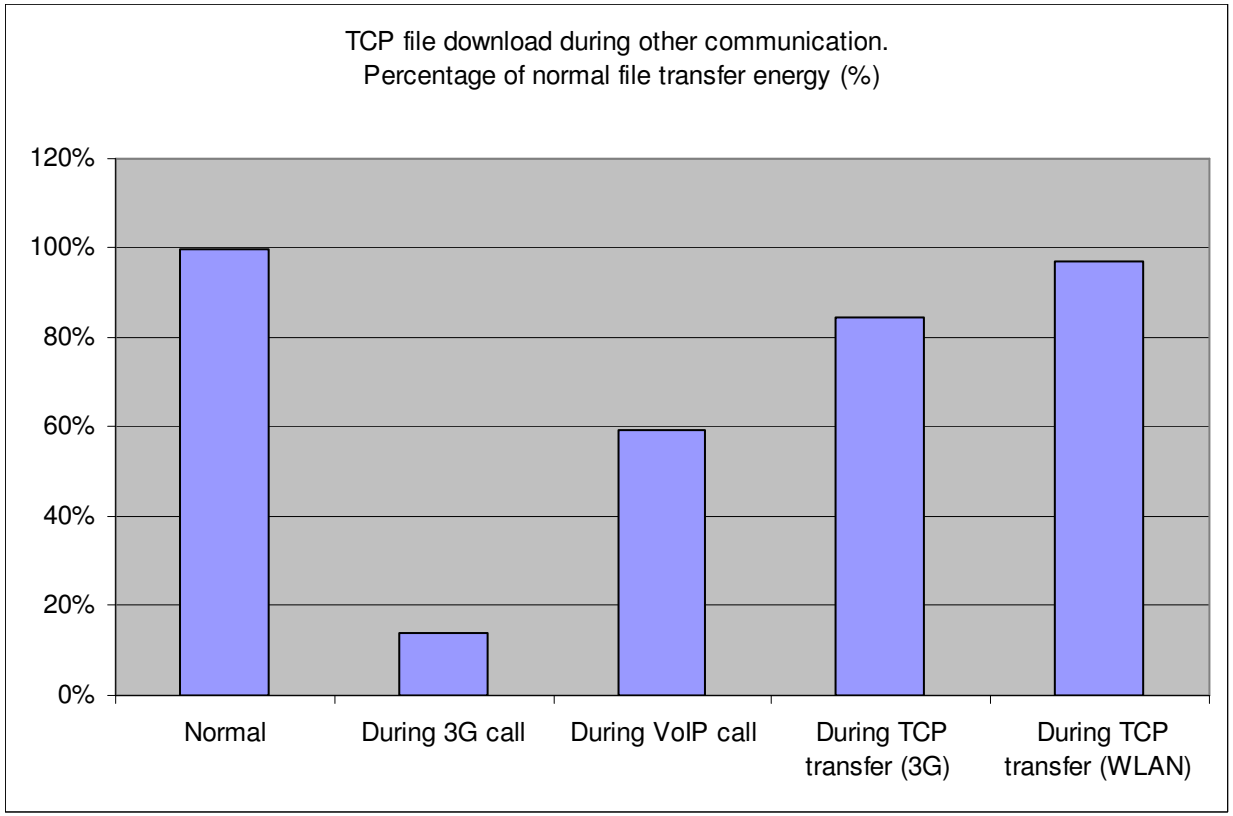
Download requires only

14%

energy when done during voice call



Strategy 1: Synchronize traffic to fill spare capacity Parallel connections

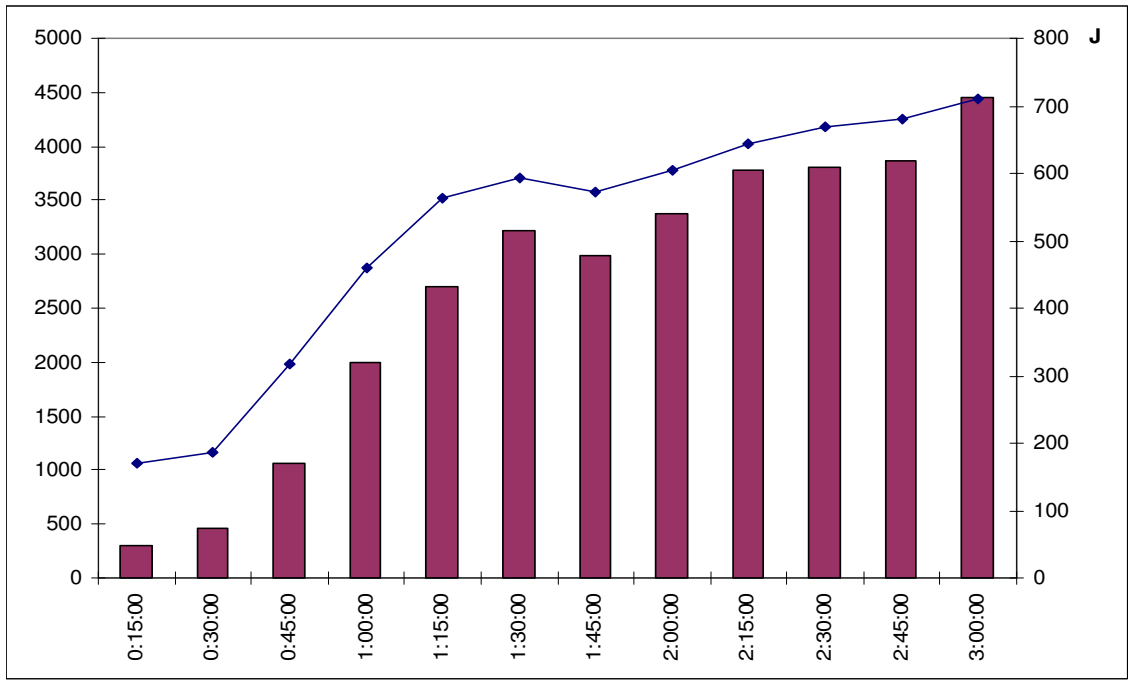


- The benefit is clear in case of voice call and VoIP call. (in case of VoIP call the effect of U-APSD power save mode was not investigated)
- The benefit of parallel TCP is less clear and depends on the relative speeds of the connections and of the independence of the paths of the TCP connections)
- Measured with N95

Nurminen, J.K., "Parallel connections and their effect to battery consumption of a mobile phone," The Second International ICST Conference on MOBILe Wireless MiddleWARE, Operating Systems, and Applications (MOBILWARE 2009), Berlin, Germany, April 2009

Energy-efficient DHT

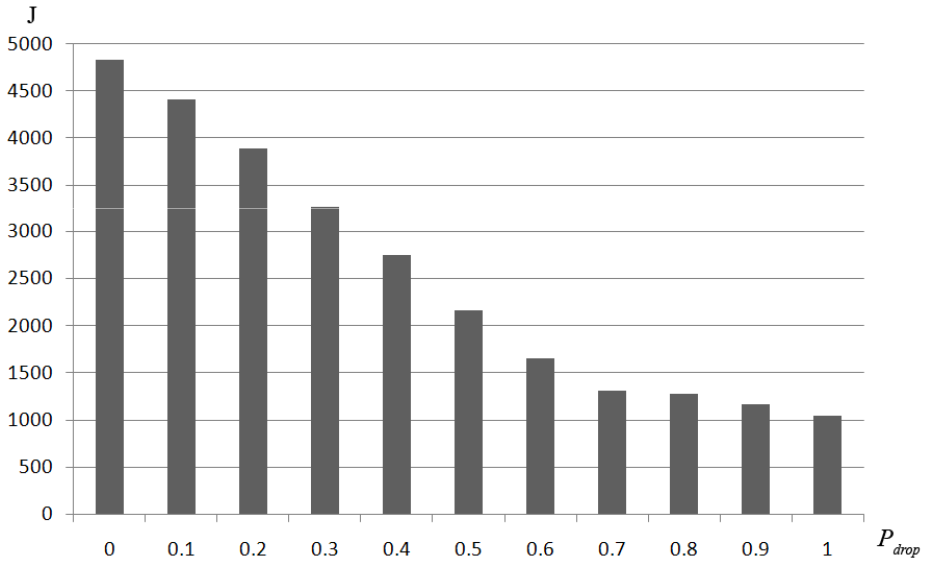
Energy consumption and # of messages in each 15 min interval for a mobile peer in Mainline BitTorrent DHT (Kademlia) over 1 million users



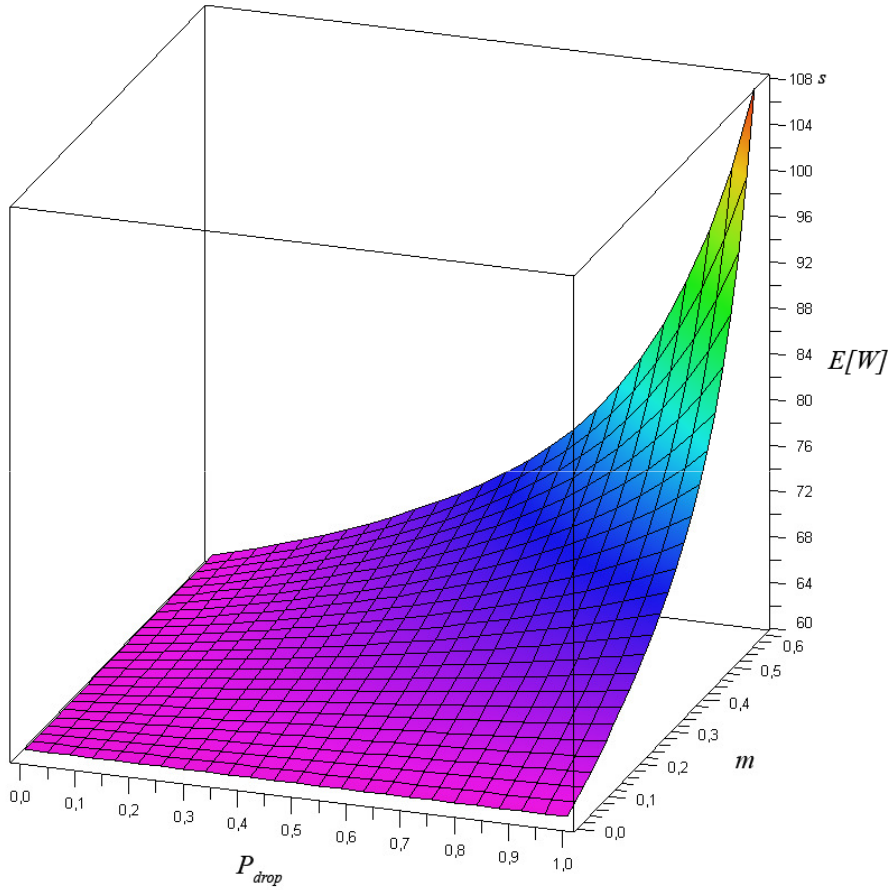
Kelenyi, I. and Nurminen, J.K., "Energy Aspects of Peer Cooperation - Measurements with a Mobile DHT System," IEEE CoCoNet Workshop 2008 Cognitive and Cooperative Wireless Networks collocated with IEEE ICC 2008, Beijing, China, May 2008

Kelenyi, I. and Nurminen, J.K., "Optimizing Energy Consumption of Mobile Nodes in Heterogeneous Kademlia based Distributed Hash Tables," Second International Conference and Exhibition on Next Generation Mobile Applications, Services and Technologies, Cardiff, Wales, UK, September 2008 (to appear)

Strategy: Do less work
Do not reply to each DHT request



Energy as a function of dropping probability



Relationship between dropping probability (P_{drop}), ratio of mobile and normal peers (m), and expected delay E[W]

Utility of participating in P2P community

$$U(C) = b(C) - c(C)$$

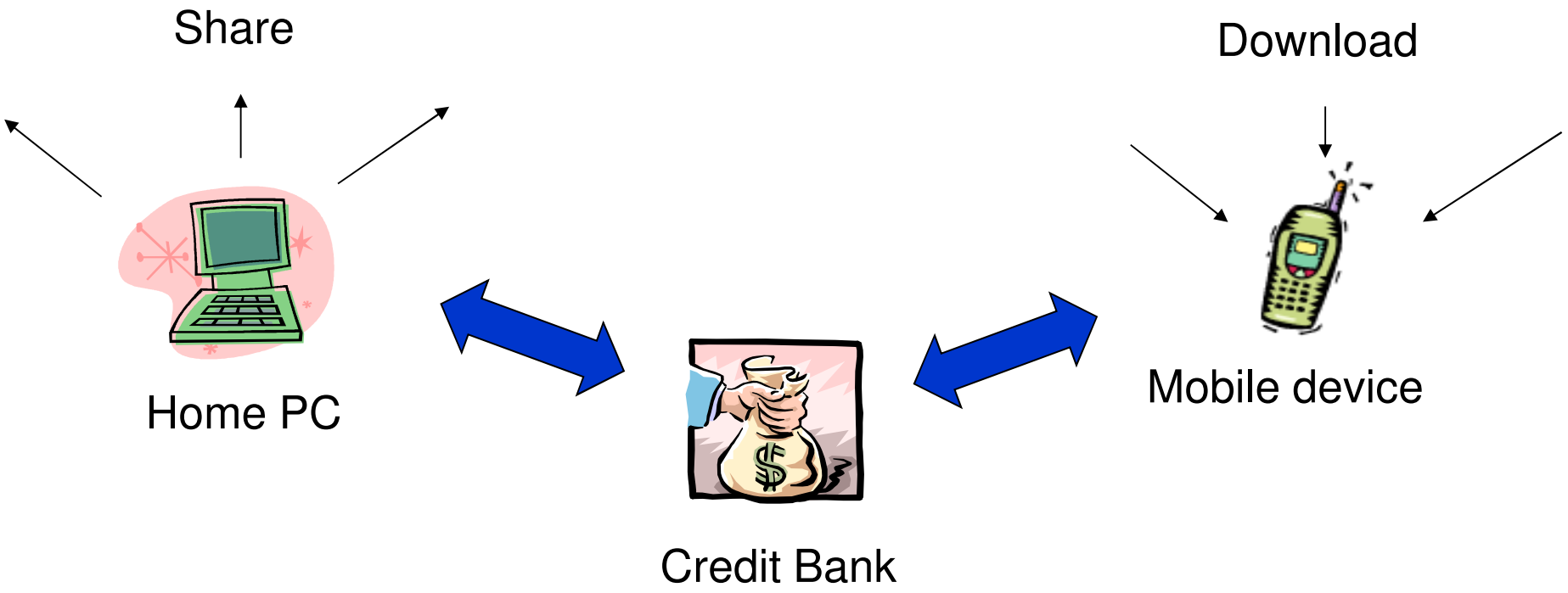
- For PC
- benefit reasonably high
- hardly any cost
- => high utility
- => low threshold to contribute

- For mobile device
- benefit reasonably high
- cost can be quite high
  - Energy
  - Phone bill
- => lower utility, or
- => strong incentive to be selfish

Karonen, O. and Nurminen, J.K., "Cooperation Incentives and Enablers for Wireless Peers in Heterogeneous Networks," IEEE CoCoNet Workshop 2008 Cognitive and Cooperative Wireless Networks collocated with IEEE ICC 2008, Beijing, China, May 2008

Suomalainen, J., Pehrsson, A. and Nurminen, J.K., "A security analysis of a P2P incentive mechanism for mobile devices," 3rd International Conference on Internet and Web Applications and Services (ICIW 2008), Athens, Greece, June 2008

P2P Credit System



- A group of devices shares the same credit account
- Credits earned with one device can be consumed by another device at a later time (in contrast to most existing incentive schemes)

Research questions

- What kind of P2P techniques make sense in mobile networks?
- Dealing with the limitations of mobile devices
- How will handheld use change P2P?
- What new possibilities it allows?
- Legal use cases and business models for mobile P2P