Energy Efficient BitTorrent for Green P2P File Sharing

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Based on Joint work with

Ilaria Giannetti, University of Pisa, Italy

Marco Conti, Andrea Passarella, IIT-CNR, Italy

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Dept. of Computing, Hong Kong Polytechnic University, April 1, 2011

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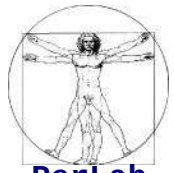

Welcome to...

PerLab

The Pervasive Computing and Networking Laboratory

Home

Perlab is a joint laboratory of the Dept. of Information Engineering at the University of Pisa, Italy, and the Institute for Informatics and Telematics of the Italian National Research Council. Its main purpose is to carry out basic and applied research in the emerging area of Mobile and Pervasive Computing Systems with special emphasis on networking, middleware, security and artificial intelligence.
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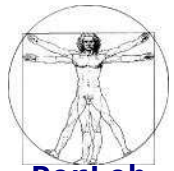
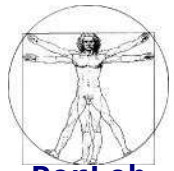
My Research Group



- Giuseppe Anastasi (Associate Professor)
- Mario Di Francesco (Post-doc at UTA)
- Ilaria Giannetti (PhD student)
- Koteswararao Kondepu (PhD student at IMT-Lucca)
- Domenico De Guglielmo (Graduate Student)
- Francesco Restuccia (Graduate Student)
- Francesco Corucci (Graduate Student)

Research Topics



- Wireless Sensor Networks for critical applications
  - IEEE 802.15.4/ZigBee Standards
- WSNs with Mobile Elements (MEs)
  - Adaptive Discovery Strategies
  - Energy-Efficient and Reliable Data Transfer to MEs
- WSANs for Energy-Efficiency in Buildings
  - Monitoring of electricity consumptions
  - Monitoring environmental and context conditions
  - Control of electrical devices
- Green Internet
  - Energy-Efficient P2P File Sharing

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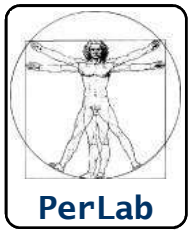


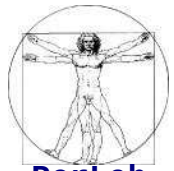
Dept. of Computing, Hong Kong Polytechnic University, April 1, 2011

Acknowledgments

- ICT Action IC0804
  - Energy Efficiency in Large-Scale Distributed Systems
  - Starting date : 23/01/2009
  - End of action : 04/05/2013
  - Additional info at

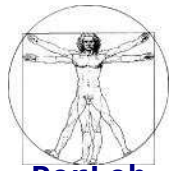
http://www.irit.fr/cost804/

Overview



- Introduction
- Motivations for
  - Energy Efficient Internet
  - Energy Efficient P2P File Sharing
- EE-BitTorrent
- Experimental Analysis
  - Real testbed
- Conclusions

The Energy Problem



- Dramatic increase in the global energy consumption
  - Energy: not renewable and limited resource
  - Environmental pollution and planetary overheating

- Energy consumption of Internet
  - 74TWh/year in US (equivalent to $ 6 billions)
  - 2-3% of the total energy consumption in US
  - About 1/3 of this energy could be saved by simple power management techniques

(Source: Lawrence Berkeley National Laboratory, USA, 2006)

Where Energy is consumed

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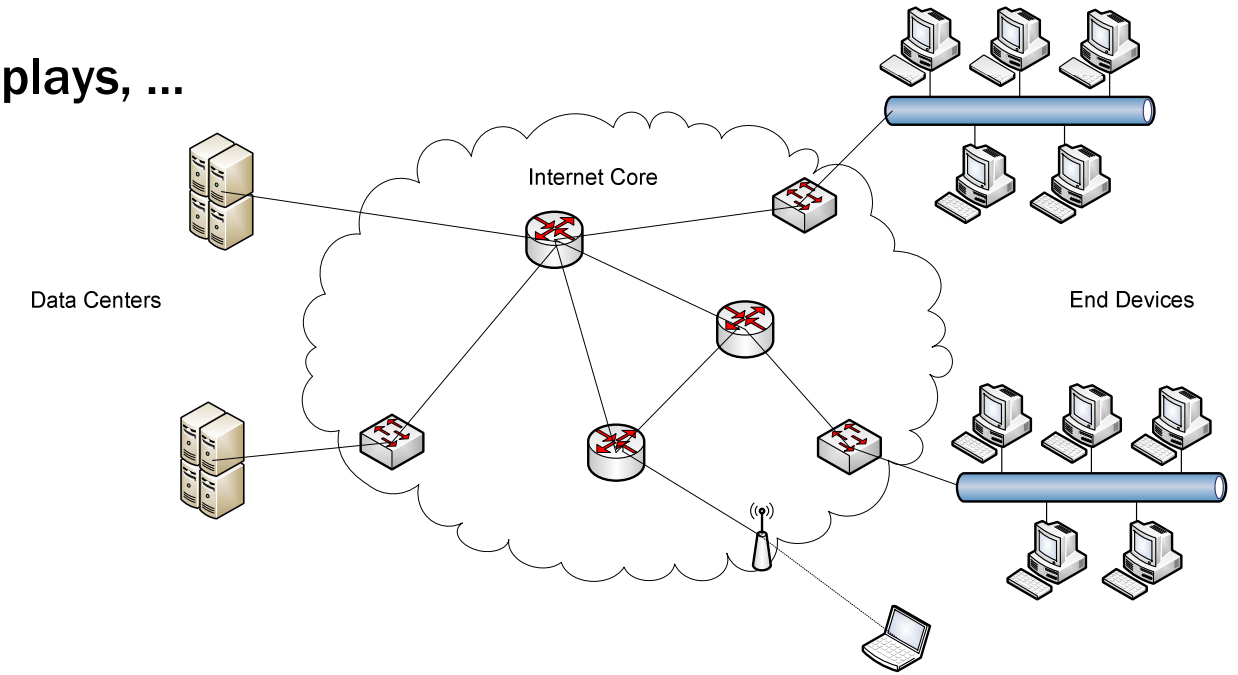
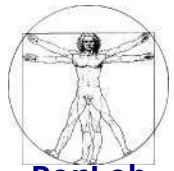
- Internet Core
  - Routers , Switches, Access Points, Links
- Data Centers
  - Servers
- User Devices
  - PCs, Printers, Displays, ...



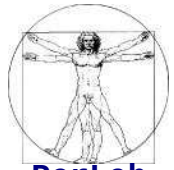
Energy Efficiency in the Internet Core



- **Re-Engineering**
  - More energy-efficient network devices through
    - ⇨ Energy-Efficient Silicon
    - ⇨ Complexity Reduction
- **Dynamic Adaptation**
  - The capacity of network elements id dynamically modulated so as to meet actual traffic loads
    - ⇨ Performance Scaling
    - ⇨ Idle Logic
- **Sleeping/Standby**
  - Unused network/device portions are put in low-power mode

R. Bolla, R. Bruschi, F. Davoli, F. Cucchietti, **Energy Efficiency in the Future Internet: A Survey of Existing Approaches and Trends in Energy-Aware Fixed Network Infrastructures**, *IEEE Communications Surveys and Tutorials*, To appear. Available at http://tnt.reti.dist.unige.it/index.php/en/publications

Edge Devices



- Overall Energy Consumption
  - Data Centers: 2 TWh per year
  - User Devices: 16 TWh per year
    - ⇨ User devices are widespread and very numerous
    - ⇨ User devices are often left powered on even if idle
    - ⇨ People typically do not pay attention to energy issues

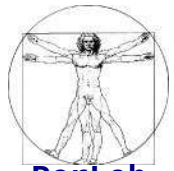
(Source: Lawrence Berkeley National Laboratory, USA, 2006)

Edge devices (cont'd)

- Some statistics about people behavior
  - 43,5% of UK population uses PC at work and
    - ⇨ 18% *never* powers it off
    - ⇨ 16% *sometimes* powers it off
  - Energy wastage corresponding to
    - ⇨ 153 millions of €
    - ⇨ 700.000 tons of CO2
- Motivations for not powering off
  - It is no so important
  - It takes some time and I am always in a hurry
  - I simply forget to power off
  - I don't want to lose my work
  - Nobody else turns PC off , so …
  - ….

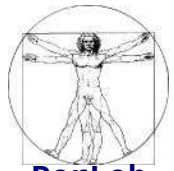
(Source: National Energy Foundation, UK, 2007)

Causes for energy wastes



- PCs left on for
  - ⇨ Laziness, Omissions, …
- PCs intentionally left on for maintaining connectivity
  - ⇨ Remote login
  - ⇨ Automatic software upgrades
- PCs intentionally left on for
  - ⇨ P2P file sharing applications

Possible Solutions

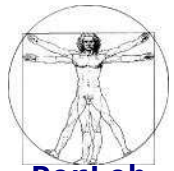


- Centralized Shutdown
  - Already used in data centers and labs
  - No flexibility

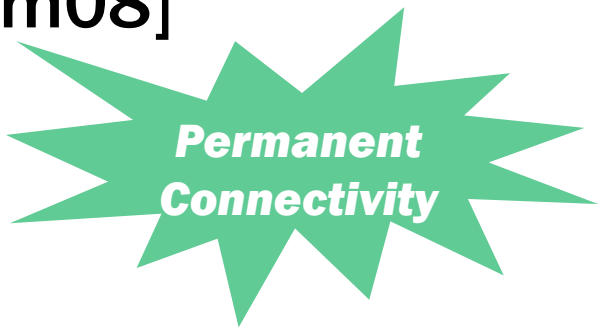
- Power Manager [Chi10]
  - Better flexibility
  - Luca Chiaraviglio, Marco Mellia, PoliSave: Efficient Power Management of Campus PCs, IEEE SoftCOM - 18th *International Conference on Software, Telecommunications and Computer Networks*, Bol, Croatia, September 2010

- Context-aware Power Management [Har05]
  - Uses low-power sensors/devices to predict the user's intention to use/not use the PC
  - [Har05] C. Harris, V. Cahill, Power Management for Stationary Machines in a Pervasive Computing Environment, *Proc. 38th Hawaii International Conference on System Sciences*, 2005.

Possible Solutions



- Network Connectivity Proxy (NCP) [Jim08]
  - Based on proxying + Magic Packet
    - ⇨ Somniloquy [Aga09]
    - ⇨ Sleep Server [Aga10]



- [Jim08] M. Jimeno, K. Christensen, B. Nordman, **A Network Connection Proxy to Enable Hosts to Sleep and Save Energy**, *Proc. IEEE International Performance Computing and Communications Conference*, pp. 101-110, December 2008.
- [Aga09] Y. Agarwal, S. Hodges, J. Scott, R. Chandra, P. Bahl, R. Gupta, **Somniloquy: Augmenting Network Interfaces to Reduce PC Energy Usage**, Proceedings USENIX Symposium on Networked System Design and Implementation (NSDI, 2009), Boston, MA, USA, April 22-24, 2009.
- [Aga10] Y. Agarwal, S. Savage, and R. Gupta, **SleepServer: Energy Savings for Enterprise PCs by Allowing them to Sleep**, Proceedings of the USENIX Annual Technical Conference, June 2010.

- Energy-aware Applications and Protocols

P2P Applications

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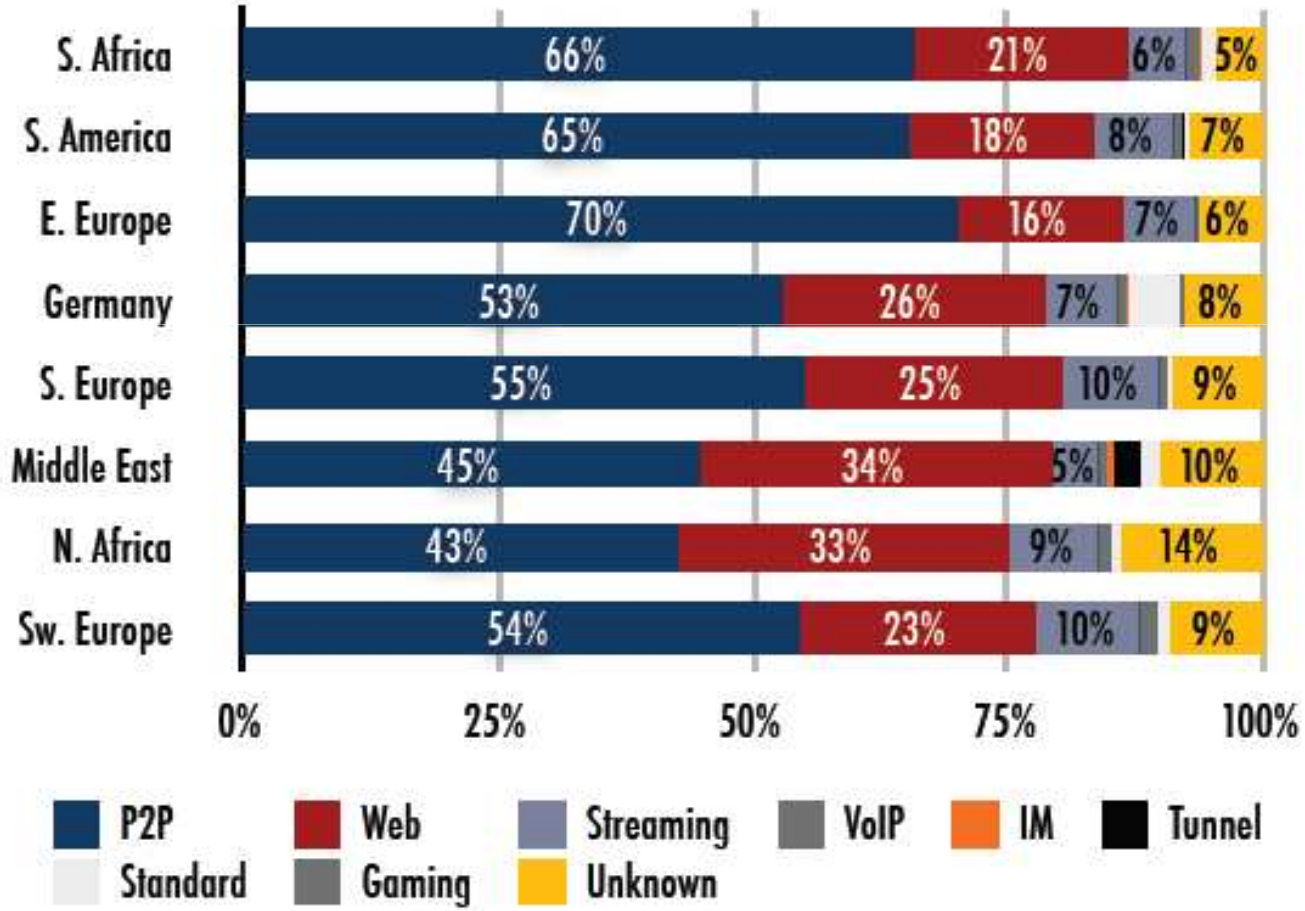
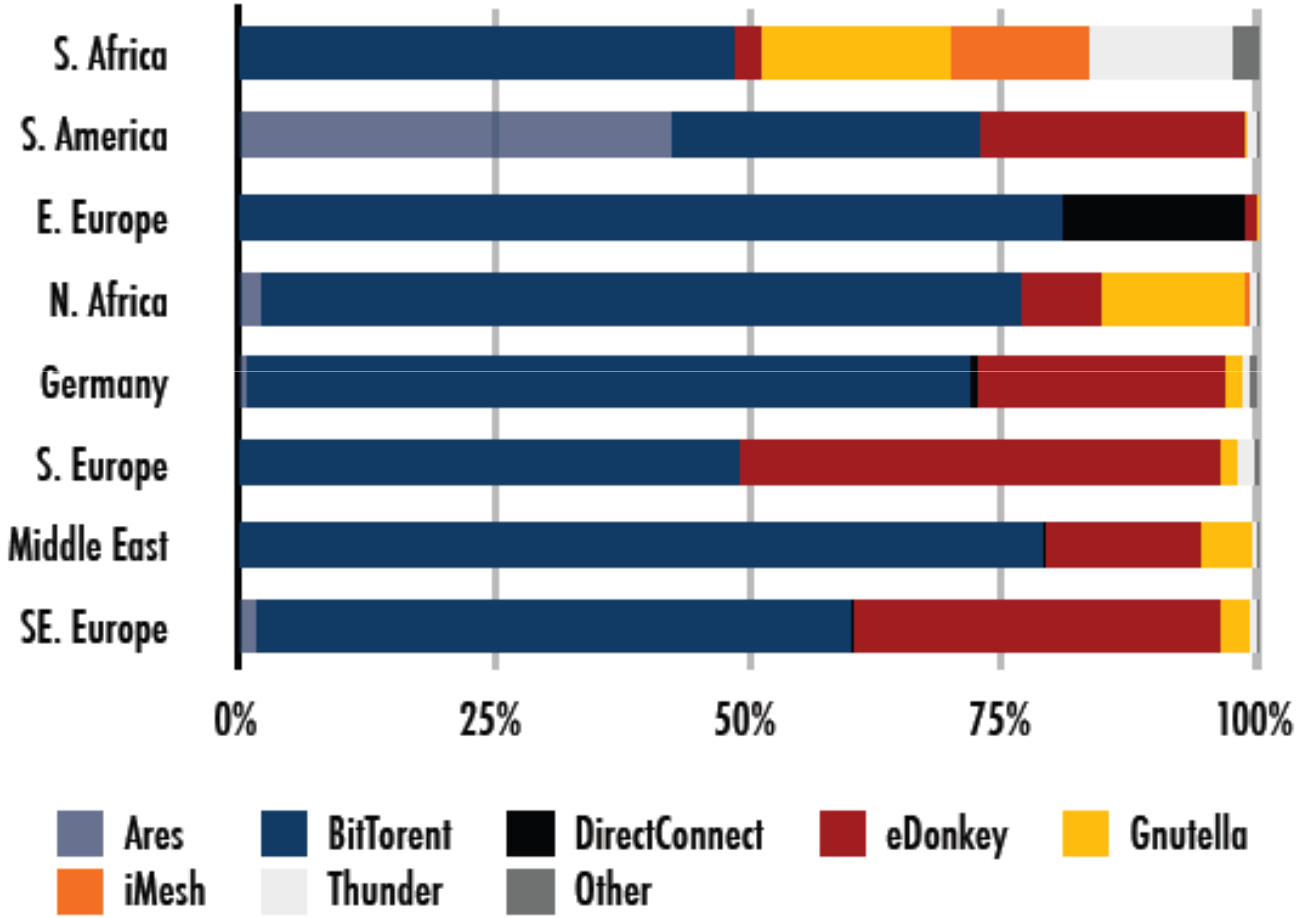
- Require permanent connectivity
- P2P Traffic in Internet



Source: Ipoque 2008 / 2009

P2P Applications (Cont'd)

- P2P Traffic originated by BitTorrent



Source: Ipoque 2008 / 2009

BitTorrent

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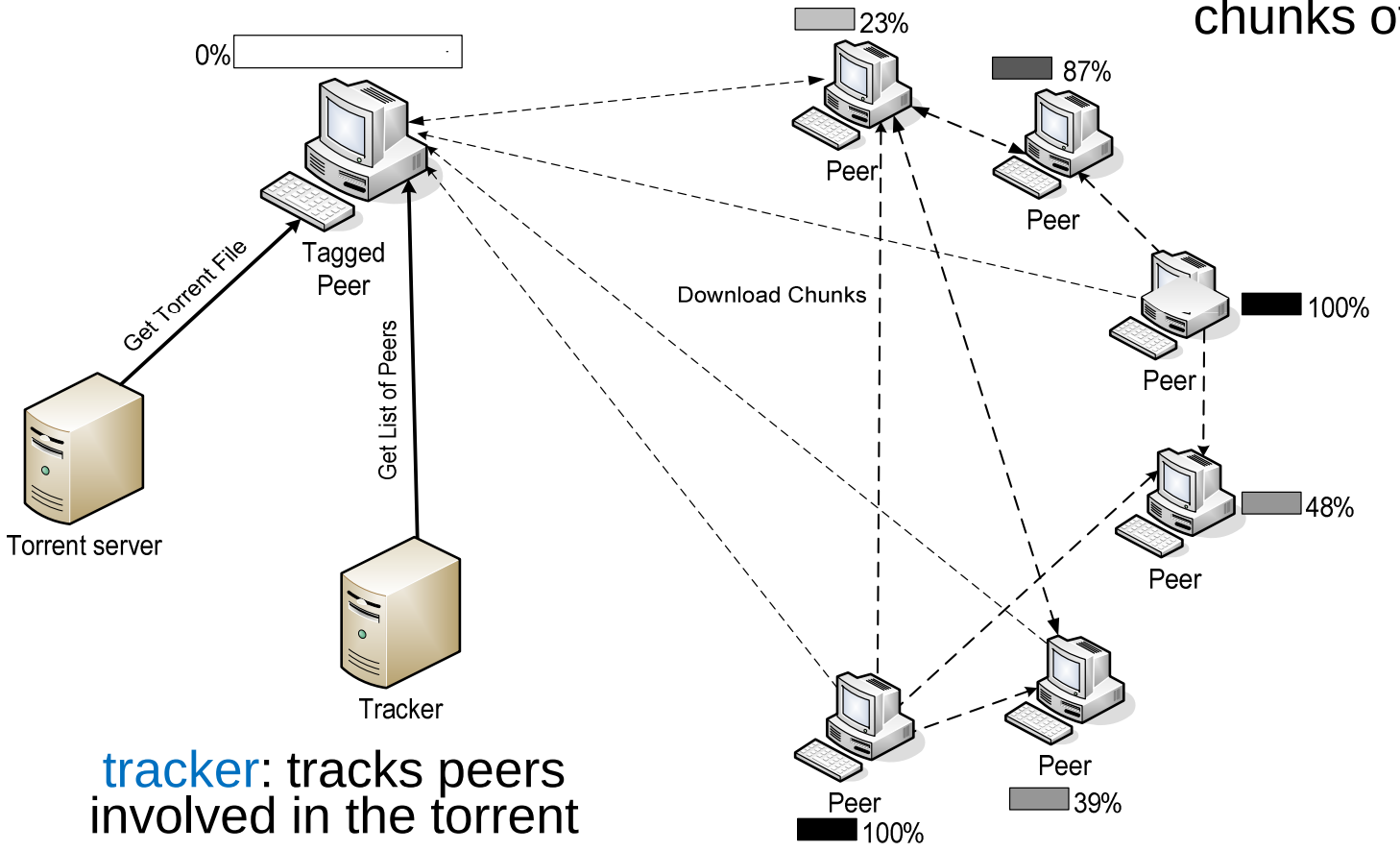
peer: node of the BitTorrent overaly

torrent: group of peers exchanging chunks of a file



tracker: tracks peers involved in the torrent

BitTorrent Protocol

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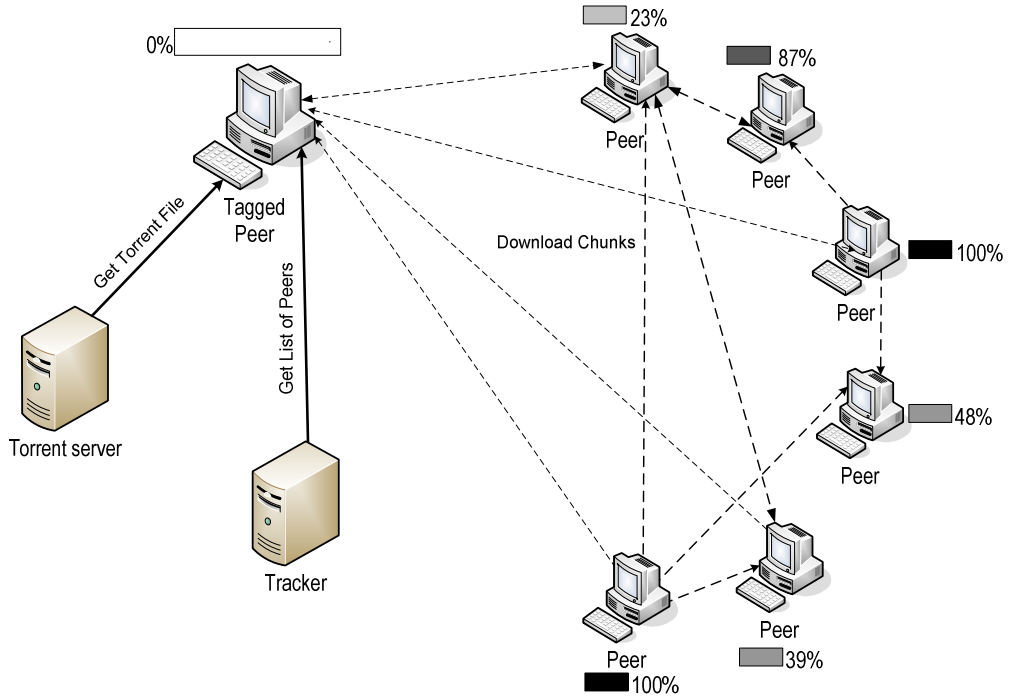
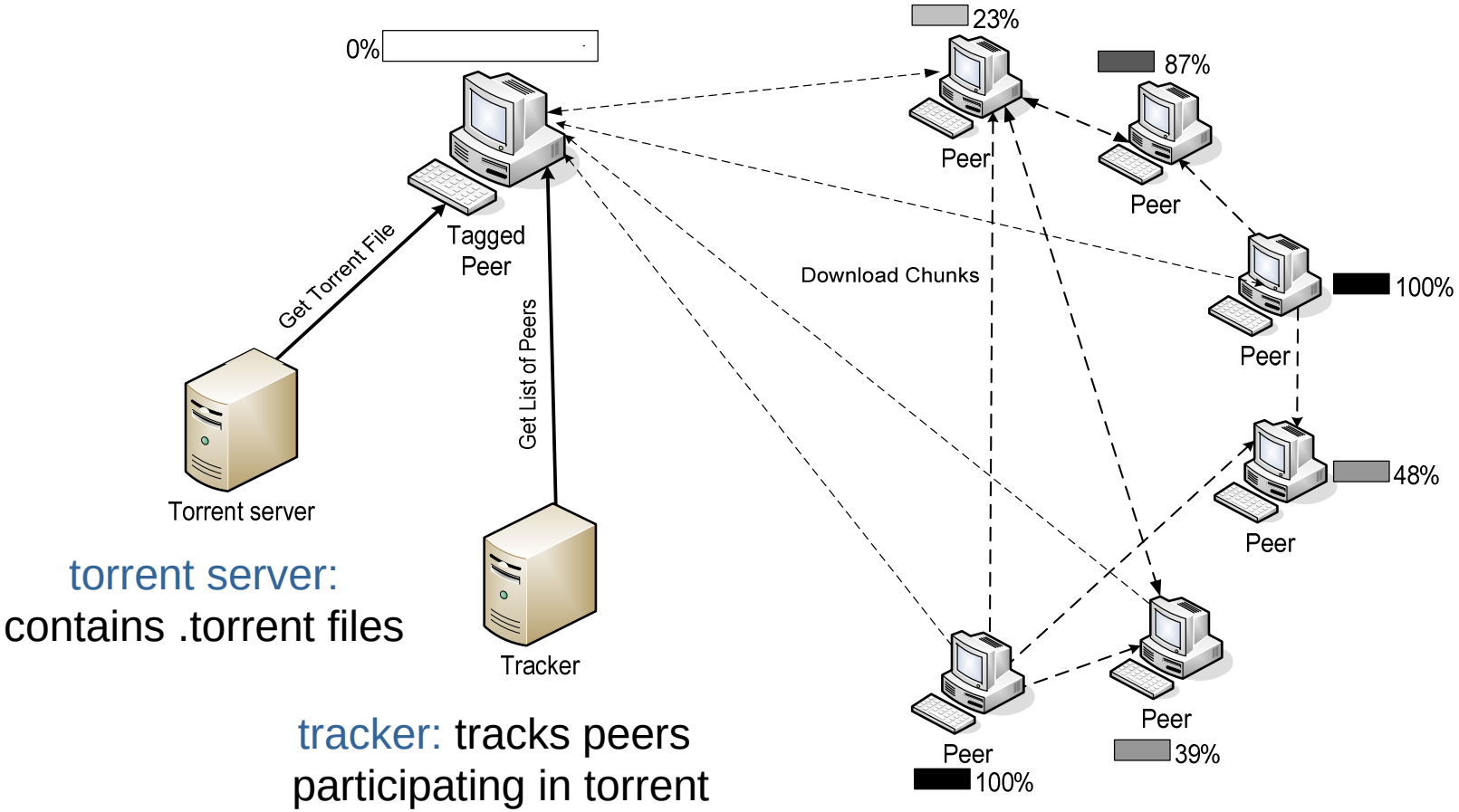
- File divided into 256KB *chunks*.
- Peers download chunks from a multitude of other peers
  - Instead from a single server, as in the traditional C/S approach
- While downloading, peers upload chunks to other peers.
- Once a peer has entire file, it may (selfishly) leave or (altruistically) remain
  - Peers may come and go



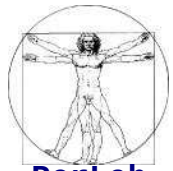
BitTorrent Protocol



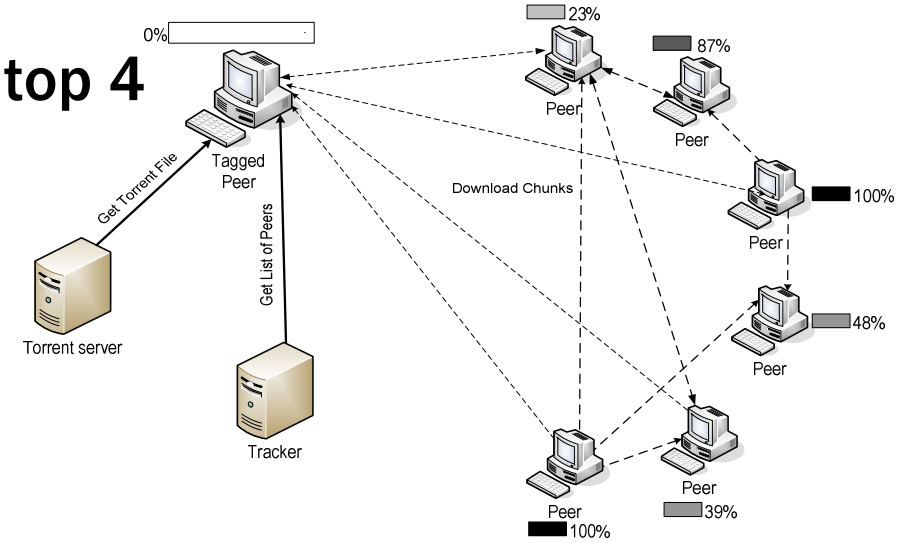
torrent server:
contains .torrent files

tracker: tracks peers participating in torrent

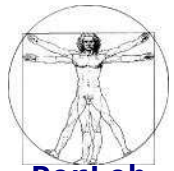
Tit-for-Tat Policy



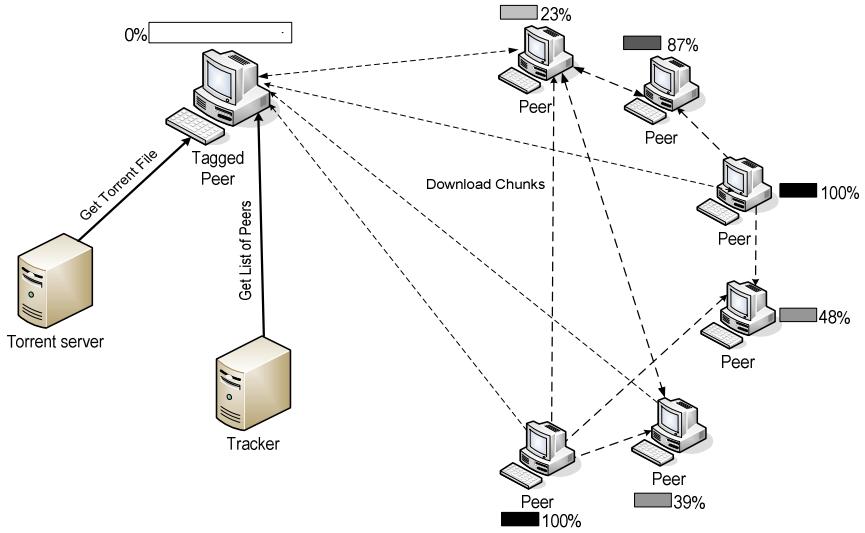
- A peer continuously measures the bit rate achieved by each of its neighbors
- And uploads chunks to the 4 neighbors from which it is achieving the *highest bit rate*
  - re-evaluate top 4 every 10 secs
- Every 30 secs: randomly select another peer, starts sending chunks
  - newly chosen peer may join top 4
  - "optimistically unchoke"



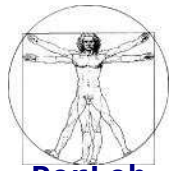
Rarest First Policy



- At any given time, different peers have different file chunks
- Periodically, a peer asks each neighbors for the list of chunks they have.
- And sends requests for missing chunks, giving priority to chunks that are less spread
  - *rarest first*

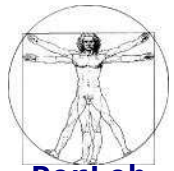


BitTorrent and Energy Efficiency



- BitTorrent is not “energy friendly”
  - BT peers must remain connected during the entire download process
    - ⇨ Powering off a peer stops the download process
  - Coordinated strategies for energy efficiency are unfeasible
    - ⇨ They would be in contrast with the BT design paradigm

BitTorrent and Energy Efficiency



- Energy Efficiency in BitTorrent has not received significant attention so far
  - Most of the proposed optimizations are aimed at improving performance
  - Only indirectly address energy efficiency

- Energy-Efficient Mobile BitTorrent
  - Targeted to mobile devices

I. Kelenyi, A. Ludanyi, J. Nurminen, I. Pusstinen, **Energy-efficient Mobile BitTorrent with Broadband Router Hosted Proxies**, Proc. *IFIP Wireless and Mobile Networking Conference (WMNC 2010)*, Budapest, Hungary, October 13-15, 2010.

I. Kelenyi, A. Ludanyi, J. Nurminen, **BitTorrent on Mobile Phones – Energy Efficiency of a Distributed Proxy Solution**, Proc. *International Green Computing Conference (IGCC 2010)*, Chicago, USA, August 15-18, 2010.

Our Proposal

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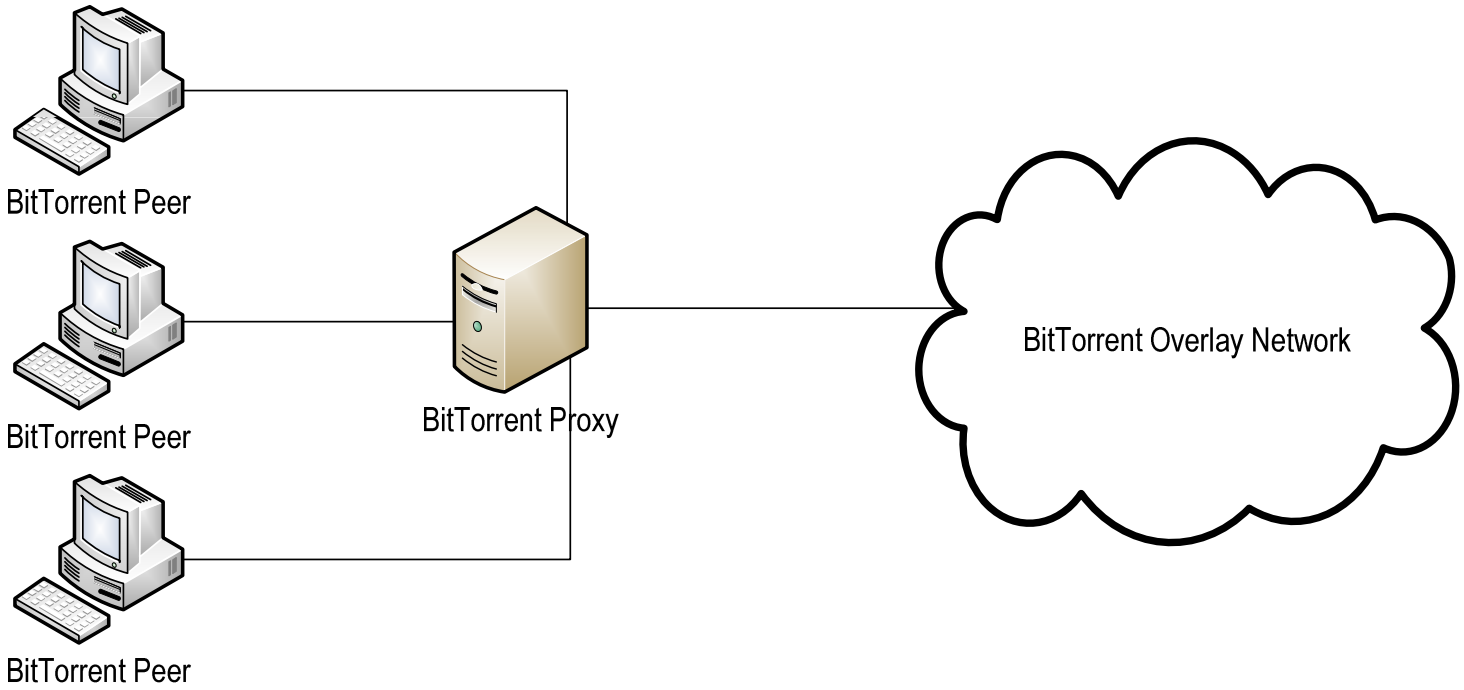
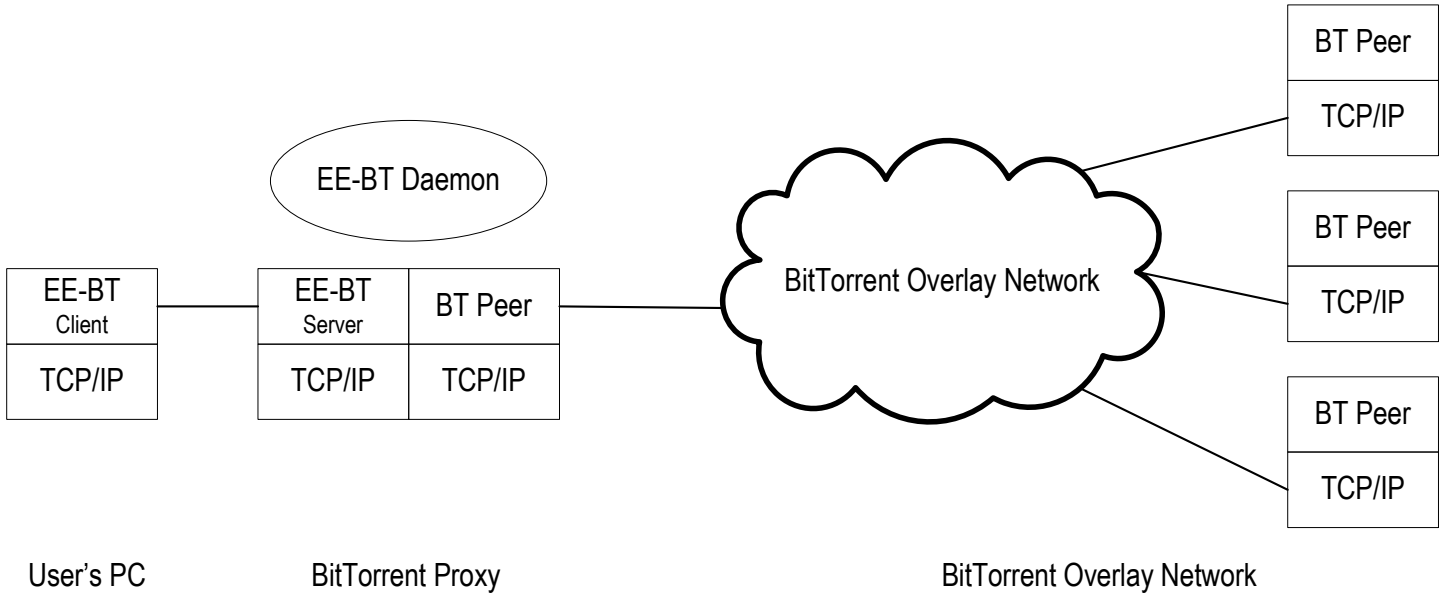
- EE-BitTorrent
  - Proxy-based version of BitTorrent
  - One BT Proxy for a large number of peers (PCs)

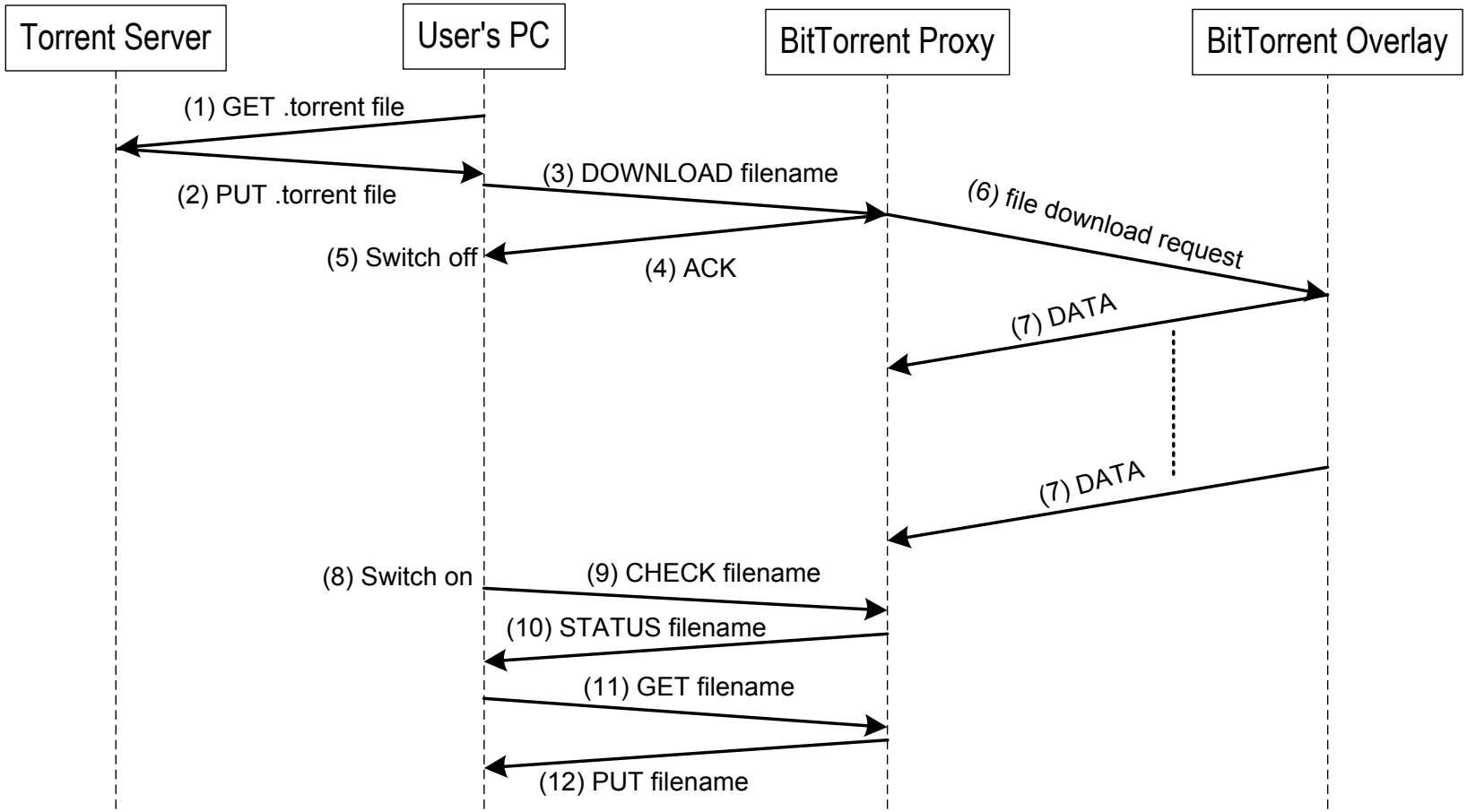


Architecture

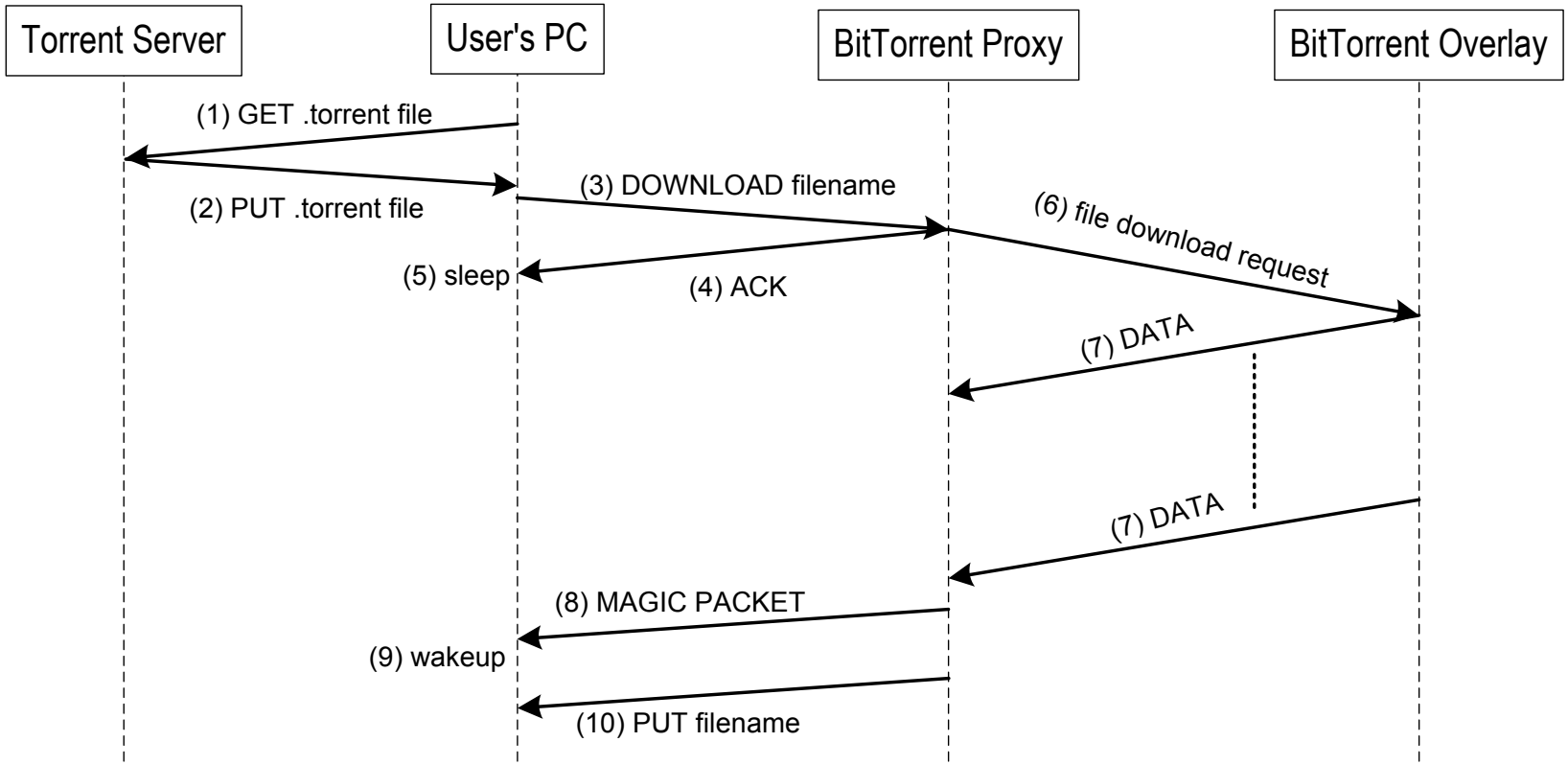


- EE-BitTorrent (EE-BT)
  - Clients and Proxy (clients side)
  - Client/Server scheme
- Traditional BitTorrent (BT Peer)
  - Proxy (P2P Network side)

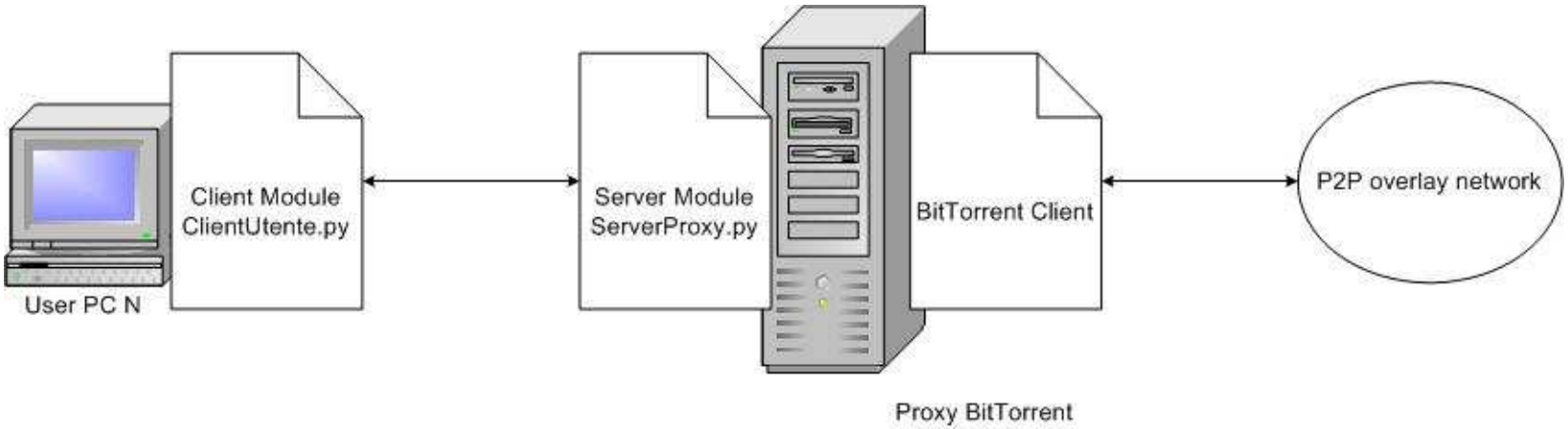
EE-BT Protocol – version 1



EE-BT Protocol – version 2

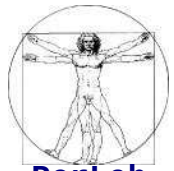


Implementation



- Energy Efficient BitTorrent modules
  - Client – Server scheme
    - Server (Proxy)
    - Client (user PC)
- Programming language: Python
- Libtorrent Rasterbar: library for BitTorrent
- Command-line BitTorrent client

Performance Metrics



- Relative Energy Saving

$$S = 1 - \frac{E_P}{E_L}$$

- Absolute Energy Saving

$$\Delta E = E_L - E_P$$

Performance metrics (cont'd)

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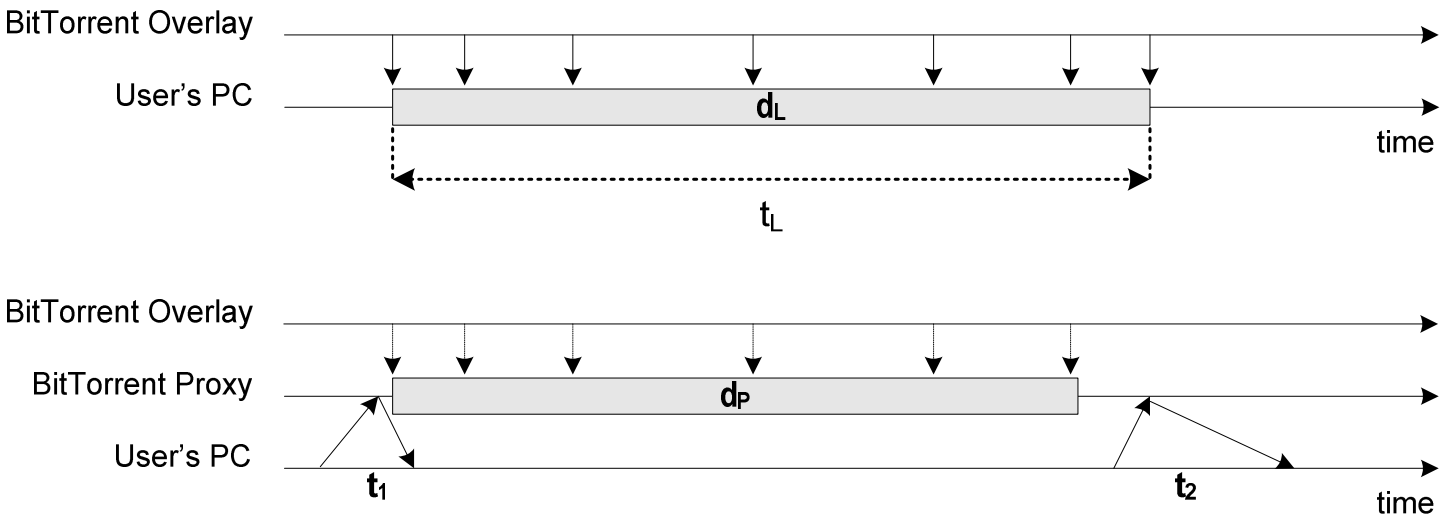
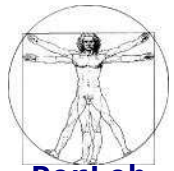
- **Assumption:**
  - **All PCs and proxy have the same power consumption**
    - ⇨ **Energy Consumption proportional to power-on time**



Performance metrics (cont'd)



- **Relative Energy Savings**
  - *The proxy is a multi-server machine*

$$S'(n) = 1 - \frac{\sum_{i=1}^{n} t_1(i) + t_2(i)}{\sum_{i=1}^{n} d_L(i)}$$

  - *The proxy is a dedicated machine*

$$S''(n) = 1 - \frac{d_P^{max} + \sum_{i=1}^{n} t_1(i) + t_2(i)}{\sum_{i=1}^{n} d_L(i)}$$

- **Absolute Energy Savings**
  - *The proxy is a multi-server machine*

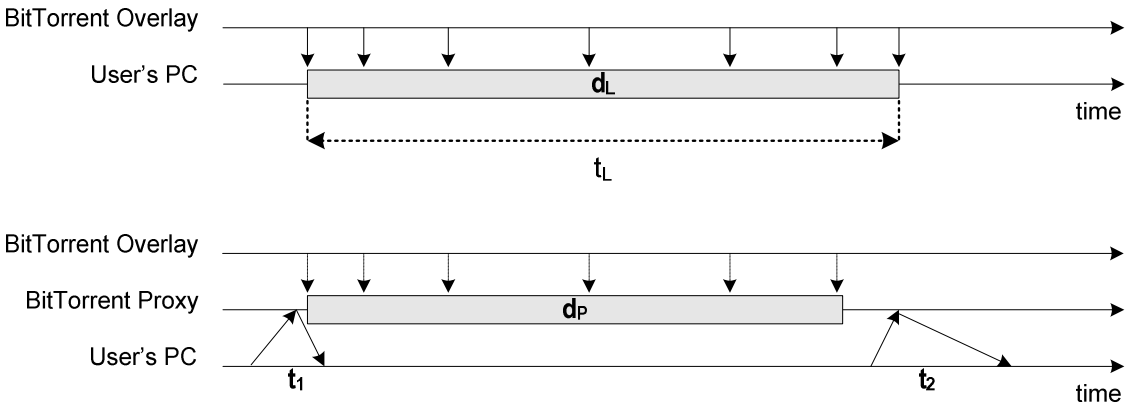
$$\Delta E'(n) = \left(\sum_{i=1}^{n} d_L(i) - \sum_{i=1}^{n} [t_1(i) + t_2(i)] \right) \cdot P_{PC}$$

  - *The proxy is a dedicated machine*

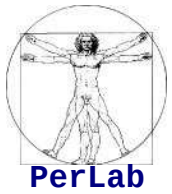
$$\Delta E''(n) = \left(\sum_{i=1}^{n} d_L(i) - \sum_{i=1}^{n} [t_1(i) + t_2(i)] - d_P^{max} \right) \cdot P_{PC}$$

Experimental Testbed

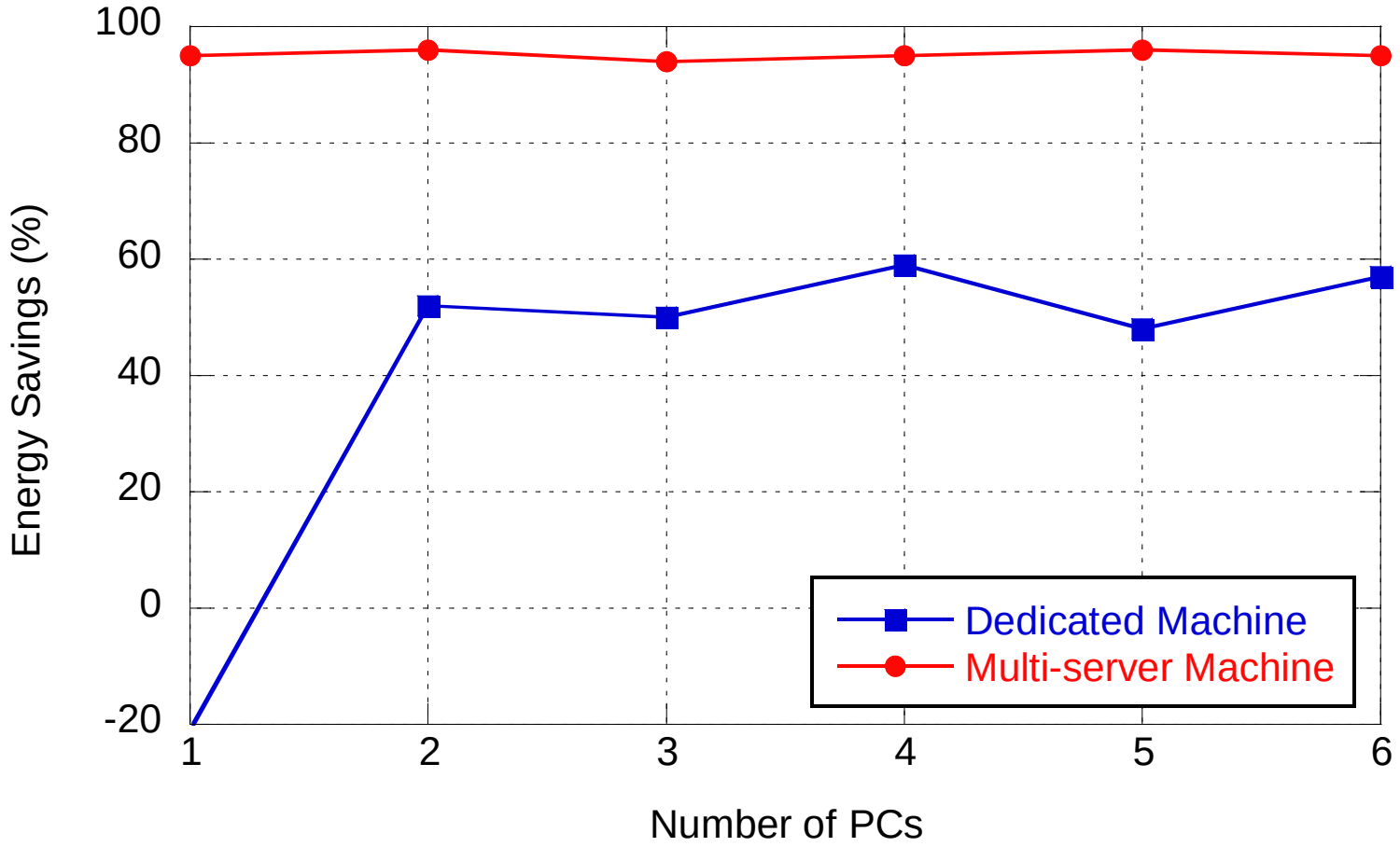
- Two systems:
  - Legacy BitTorrent
  - EE-BitTorrent
- Connectivity:
  - Ethernet LAN
  - 100 Mbps link
- Downloaded files
  - Size: ~4GB [3.95 GB – 4.71 GB]
  - Initial number of seeds: 200 - 800
- Experiments replicated
  - several times per day
  - in different days



Relative Energy Savings



- Multi-server Machine ➔ $S'(n)$
- Dedicated Machine ➔ $S''(n)$



Absolute Energy Savings

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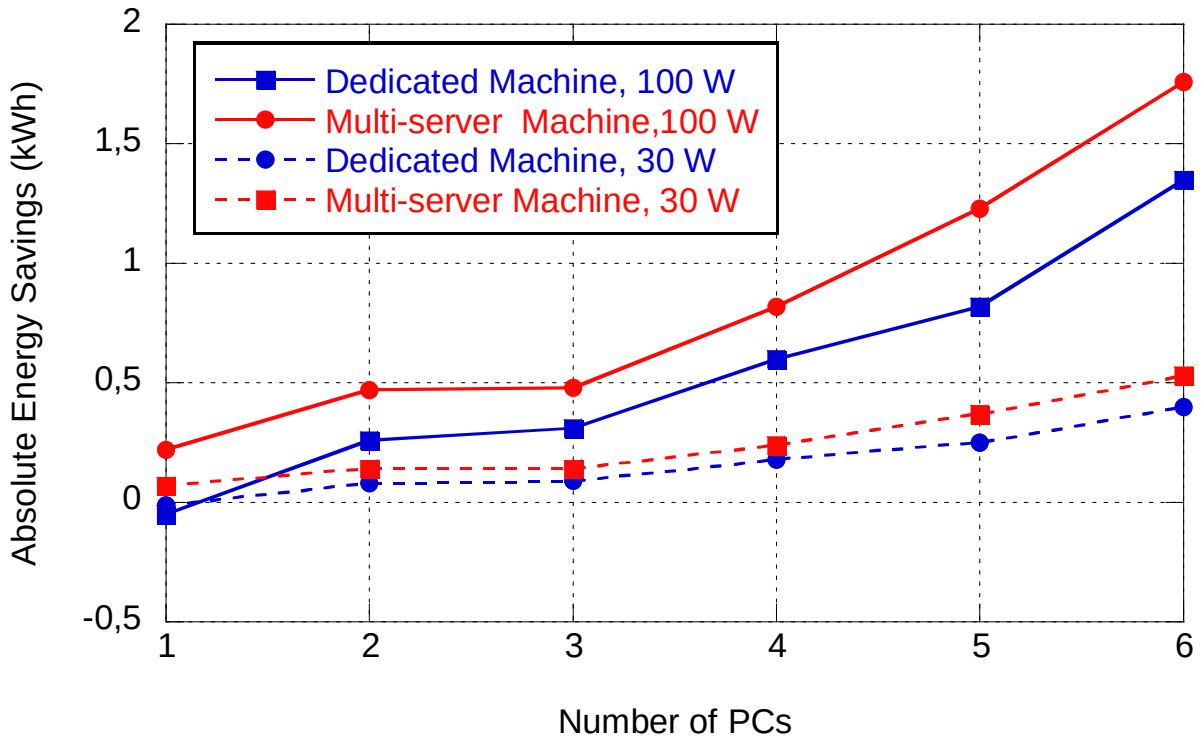
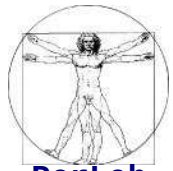
- Assumptions
  - All PC have the same power consumption
  - BT Proxy has the same power consumption of PCc
- Power Values
  - ⇨ 100 W (desktop PC), 30 W (laptop PC)

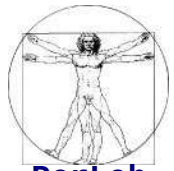


Summary



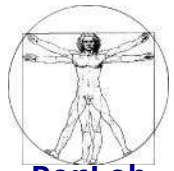
- Departmental scenario
  - PCs and Proxy connected to the same high-speed LAN
- In the analyzed scenario EE-BitTorrent provides a significant reduction in energy consumption
  - When the number of parallel download operations is larger than 1
  - Energy Efficiency increases with the number of parallel download operations
    - ⇨ The energy consumed by the proxy is shared among a larger number of users

Key Question



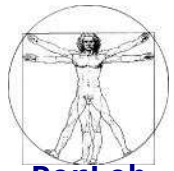
What about users with residential access?

Additional Scenarios



- Residential Access Networks
  - ADSL
    - ⇨ Dowlink rate: up to 8 Mbps
    - ⇨ Uplink rate: up to 512 Mbps
  - UMTS
    - ⇨ Dowlink rate: up to 7.2 Mbps
    - ⇨ Uplink rate: up to 2.0 Mbps

Additional Scenarios



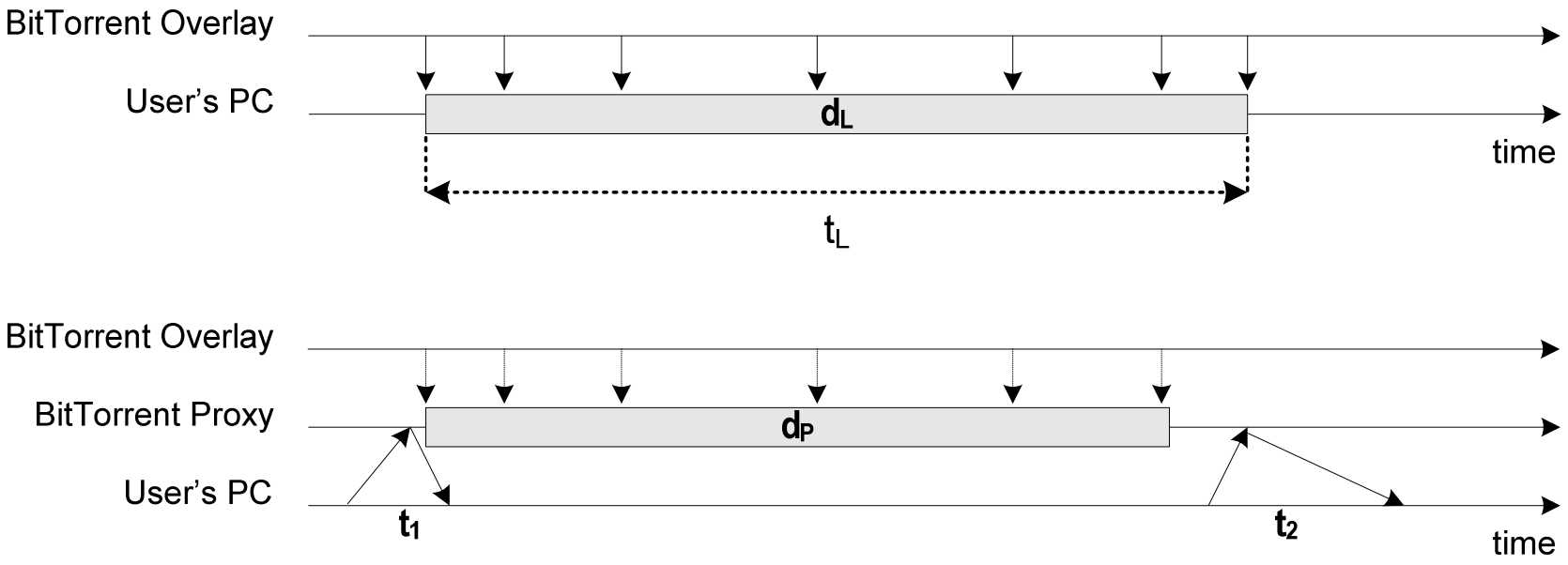
- Single User
  - Legacy BitTorrent
  - Proxy-based BitTorrent

- File Types:
  - 135 MB
    - ⇨ Audio CD (MP3)
  - 350 MB
    - ⇨ Episode of a TV Series (AVI)
  - 4 GB
    - ⇨ Ubuntu 10.10 Distribution (ISO)

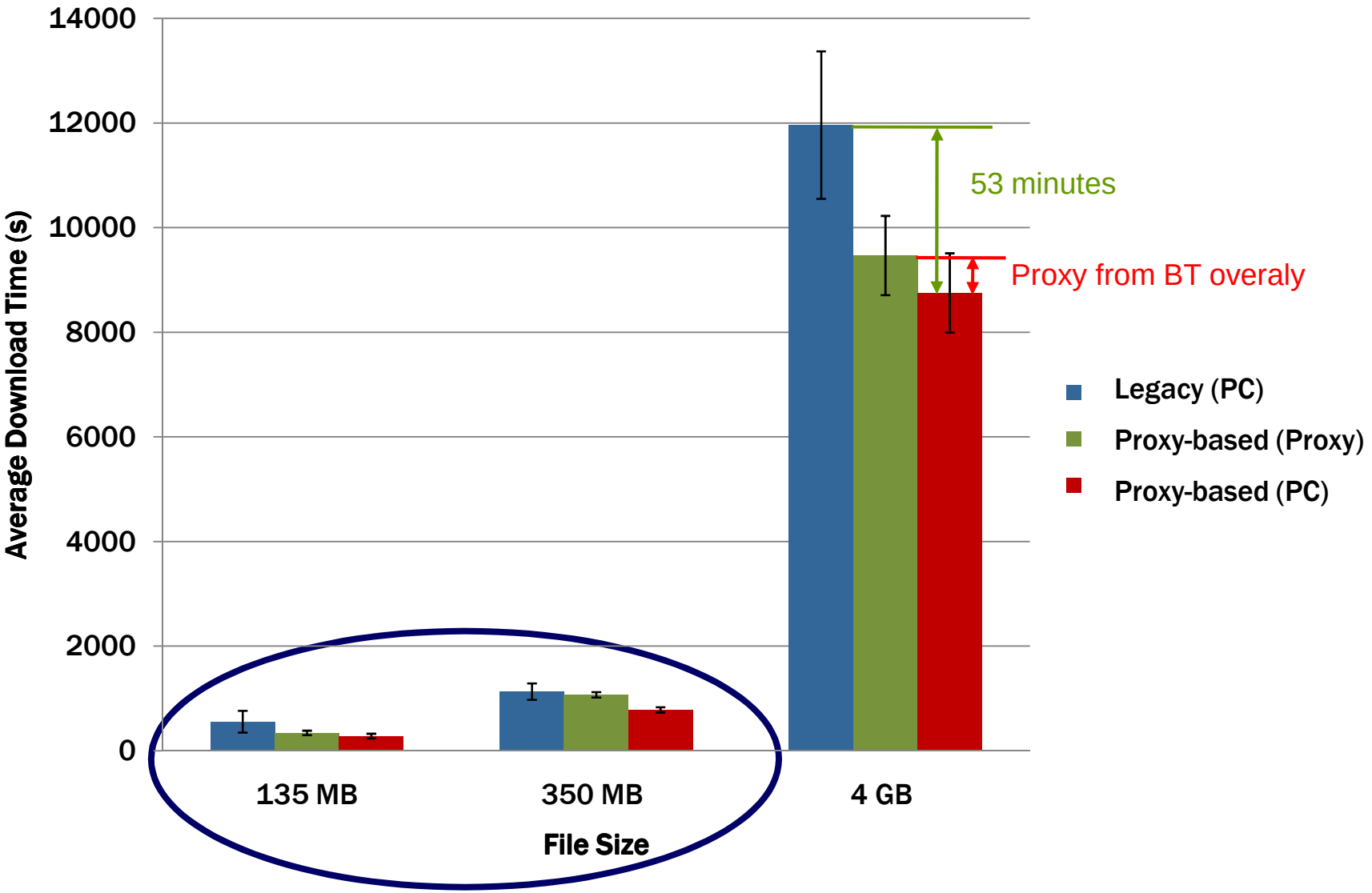
Performance metrics

PerLab

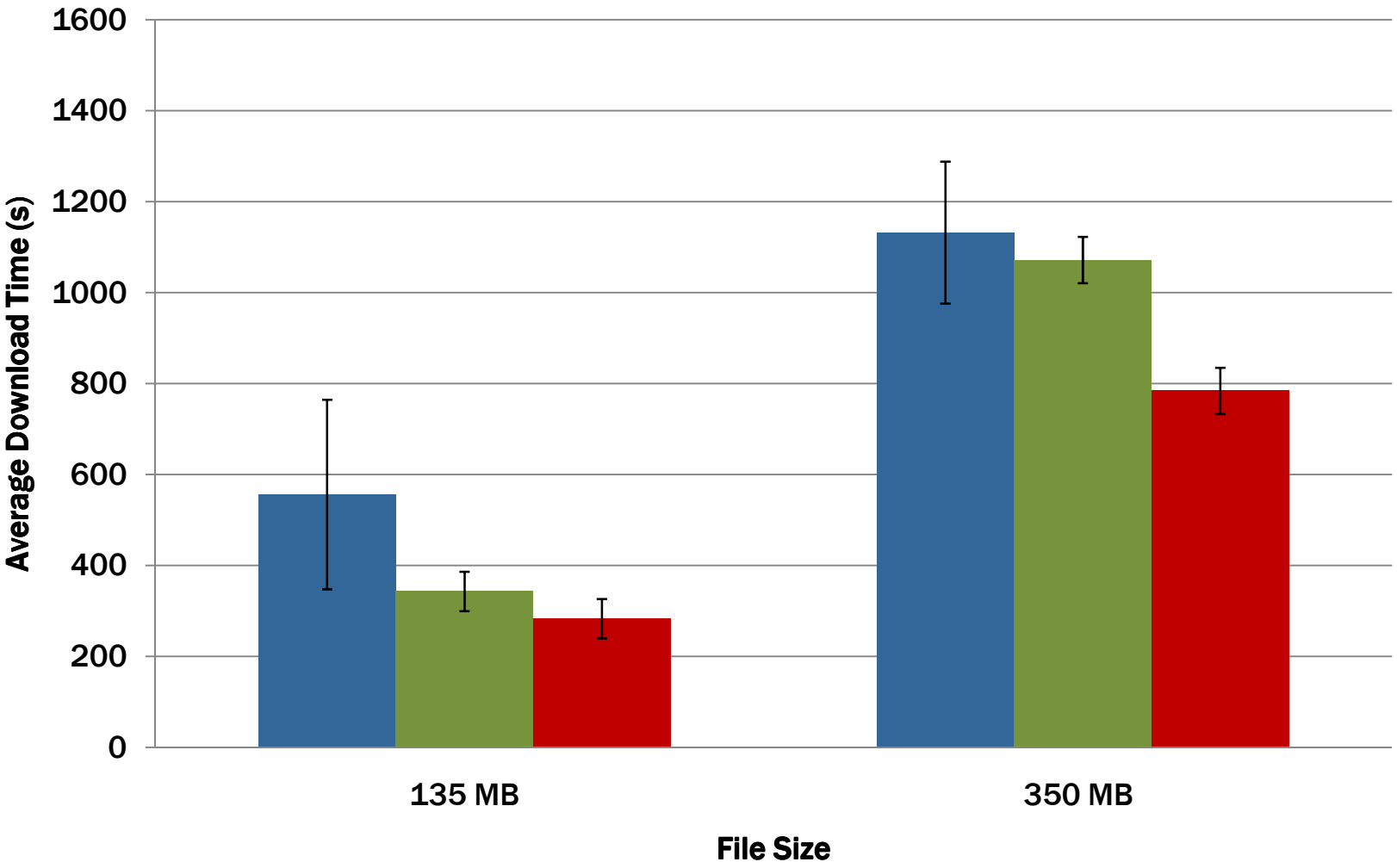
- **Assumption:**
  - **User's PC and Proxy have same power consumption**
    - ⇨ **Energy Consumption proportional to power-on time**



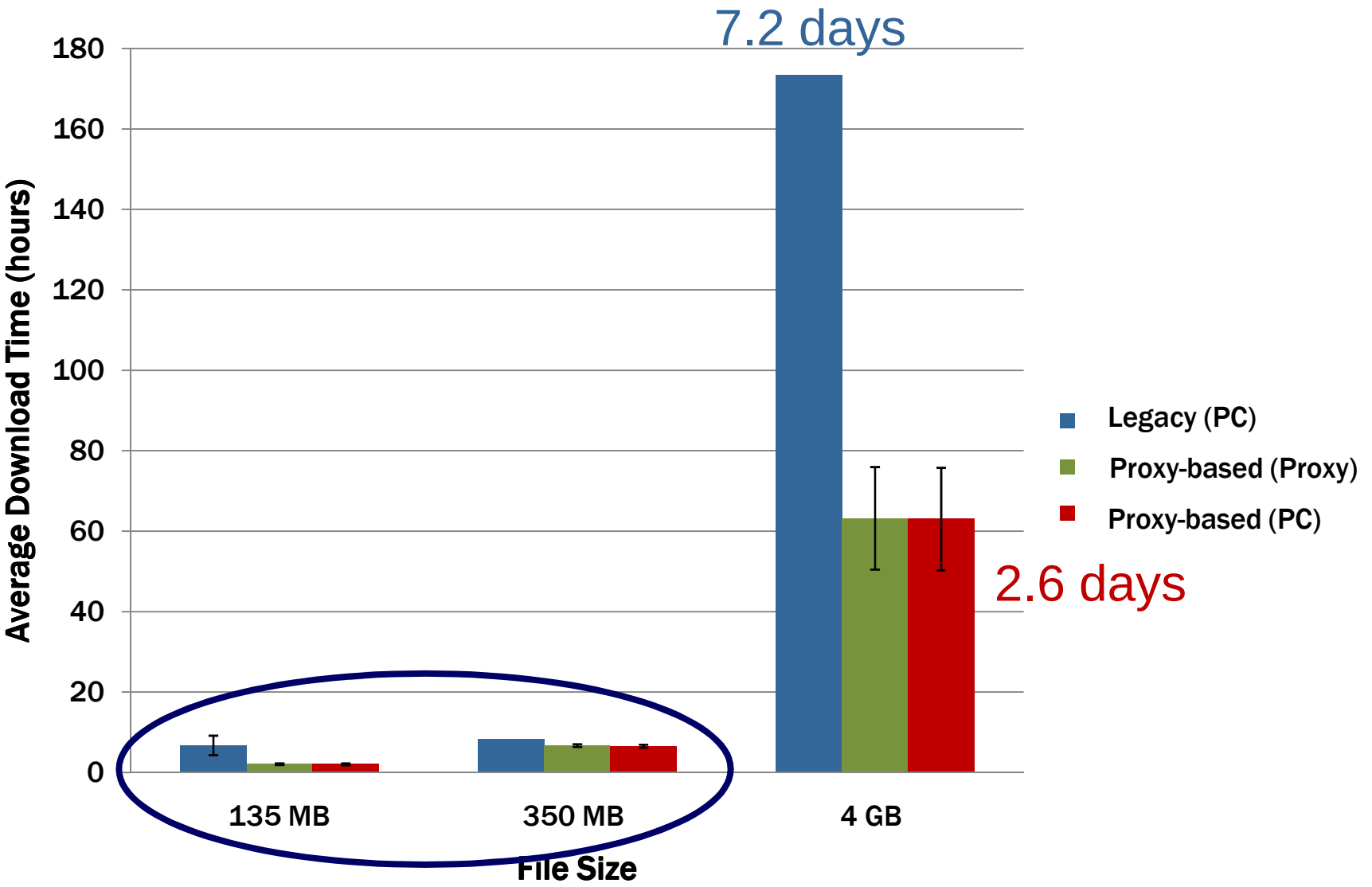
ADSL Access


14000
12000
10000
8000
6000
4000
2000
0
Average Download Time (s)
53 minutes
Proxy from BT overaly
Legacy (PC)
Proxy-based (Proxy)
Proxy-based (PC)
135 MB
350 MB
4 GB
File Size

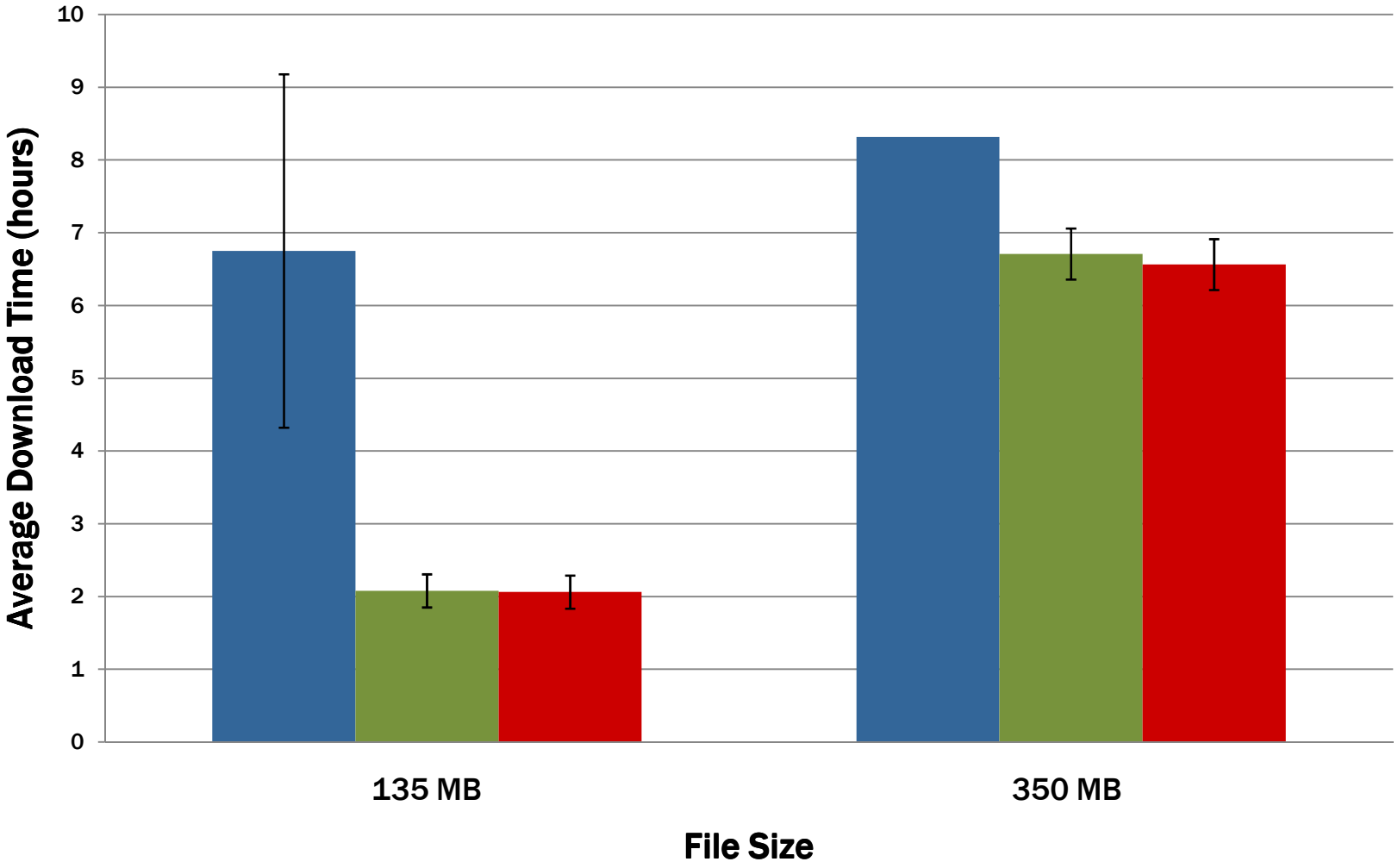
ADSL Access (2)



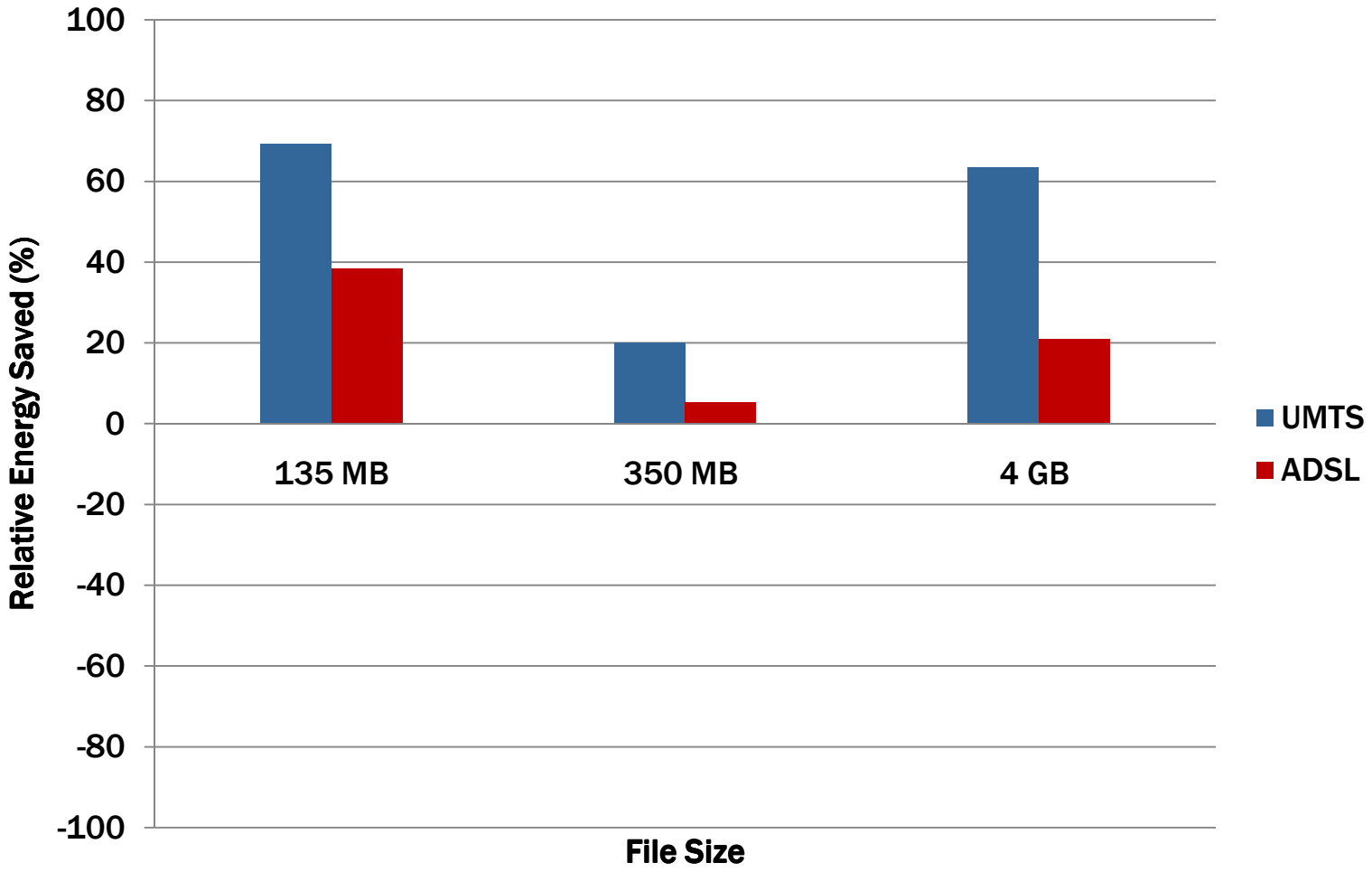
UMTS Access


7.2 days
2.6 days
Average Download Time (hours)
180
160
140
120
100
80
60
40
20
0
135 MB
350 MB
4 GB
File Size
Legacy (PC)
Proxy-based (Proxy)
Proxy-based (PC)

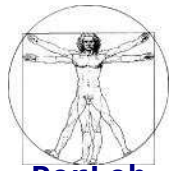
UMTS Access (2)



Relative Energy Saving

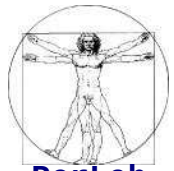


Where to place the BitTorrent Proxy?



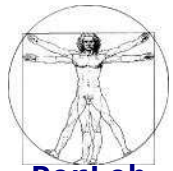
- Departmental Network
  - May be placed on a machine already used for some other services
  - Better access control (in addition to energy efficiency)
- Residential Users
  - Several Options
    - ⇨ Provided (for free) by ISP
    - ⇨ Cloud Proxy leased to users
    - ⇨ Proxy maintained and shared by a group of users (Social Proxy)
  - The proxy should have a high-speed connection
  - The proxy should be as close as possible to users

Conclusions



- Energy Efficient BitTorrent protocol
  - Based on a BitTorrent Proxy
- Implementation
  - Real testbed
- Experimental Analysis
  - EE-BitTorrent provides a significant reduction in energy consumption
  - Both in dept. and residential networks

Reference papers



- G. Anastasi, I. Giannetti, A. Passarella, A BitTorrent Proxy for Green Internet File Sharing: Design and Experimental Evaluation, *Computer Communications*, Vol. 33, N. 7, pp. 794-802, May 2010.

- G. Anastasi, M. Conti, I. Giannetti, A. Passarella, Design and Evaluation of a BitTorrent Proxy for Energy Saving, Proceedings *IEEE Symposium on Computers and Communications (ISCC 2009),* Sousse, Tunisia, July 5-8, 2009.

Thank you for your attention!

Questions?

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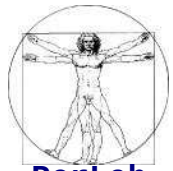
Measurements



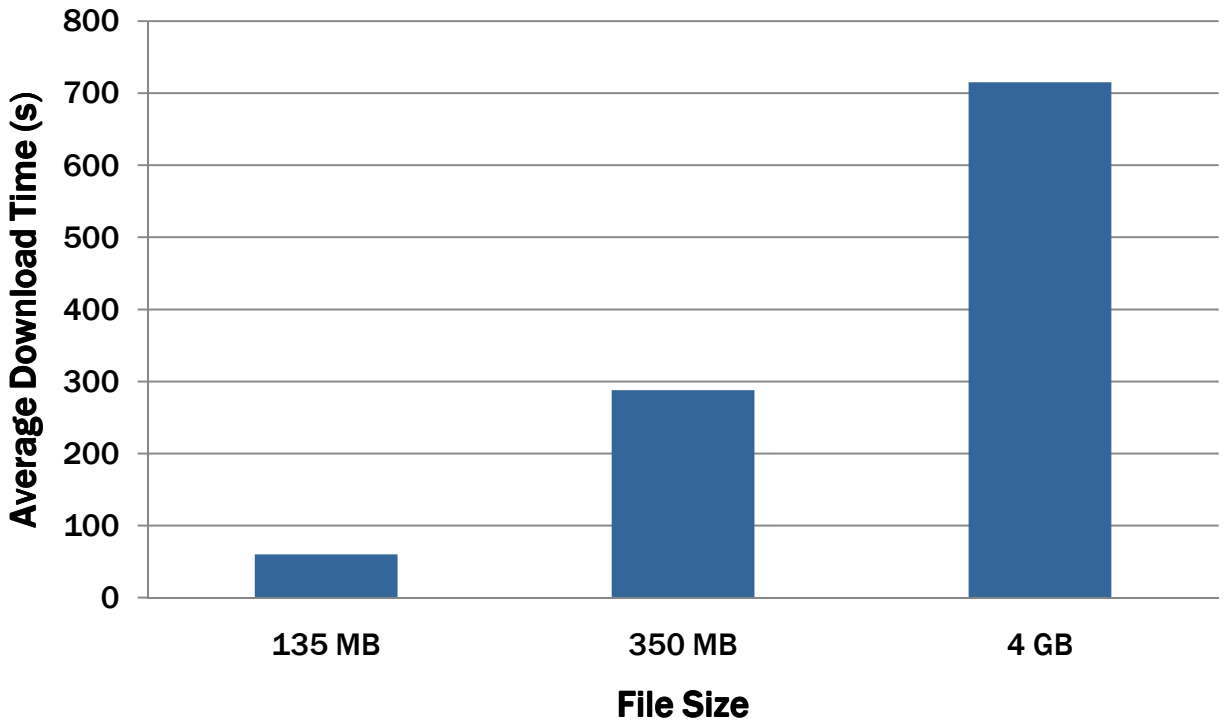
- Avg Delays (sec)

# of PCs	dL Legacy	t1 Proxy-based	t2 Proxy-based	dP_Max Proxy-based
1	8023	0.16	378	9289
2	8928	0.17	379	7597
3	6169	0.16	378	6084
4	7720	0.13	311	7612
5	9262	0.16	378	15012
6	10968	0.16	378	15105

Proxy Performance

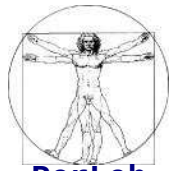
PerLab

- Average Download Time experienced by Proxy



Proxy Average Download Time and Download Rate			
File Size		Download Time (s)	Download Rate (Mbps)
135 MB	(134,05)	60	17,87
350 MB	(350,09)	287,75	9,73
4 GB	(4,06)	715	45,43

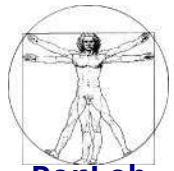
ADSL Access (3)



- Comparison in terms of Bit Rate

File Size	Proxy (Mbps)	Legacy Client (Mbps)	Client from Proxy (Mbps)
135 MB	17.87	1.93	3.79
350 MB	9.73	2.47	3.57
4GB	45.43	2.72	3.71

UMTS Access (3)



- Comparison in terms of Bit Rate

File Size	Proxy (Mbps)	Legacy Client (Mbps)	Client from Proxy (Mbps)
135 MB	17.87	0.044	0.145
350 MB	5.33	0.094	0.119
4GB	45.43	0.052	0.143