ECOFEN: simulating energy-aware wired networks

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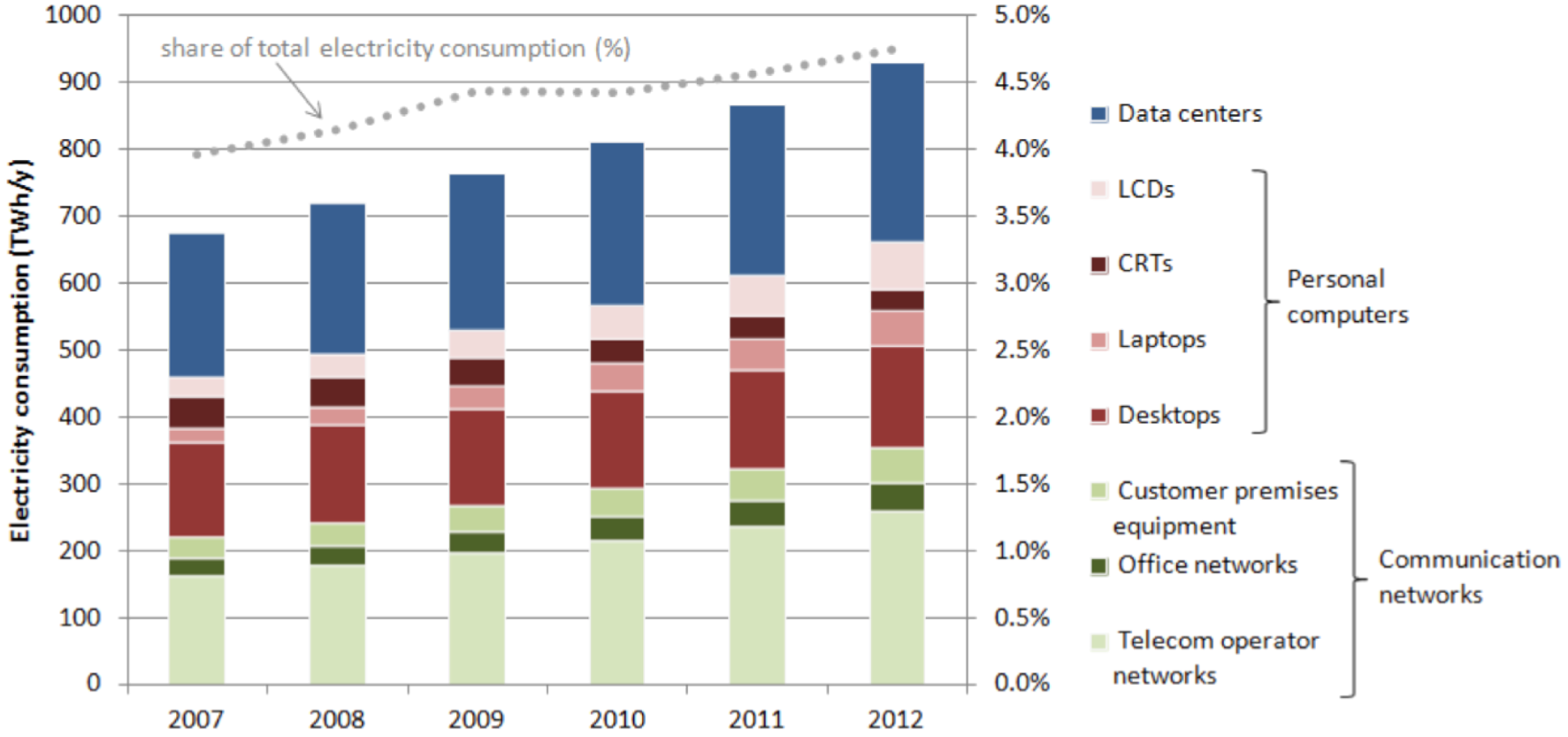
24th May 2016, Dinard, France

Plan

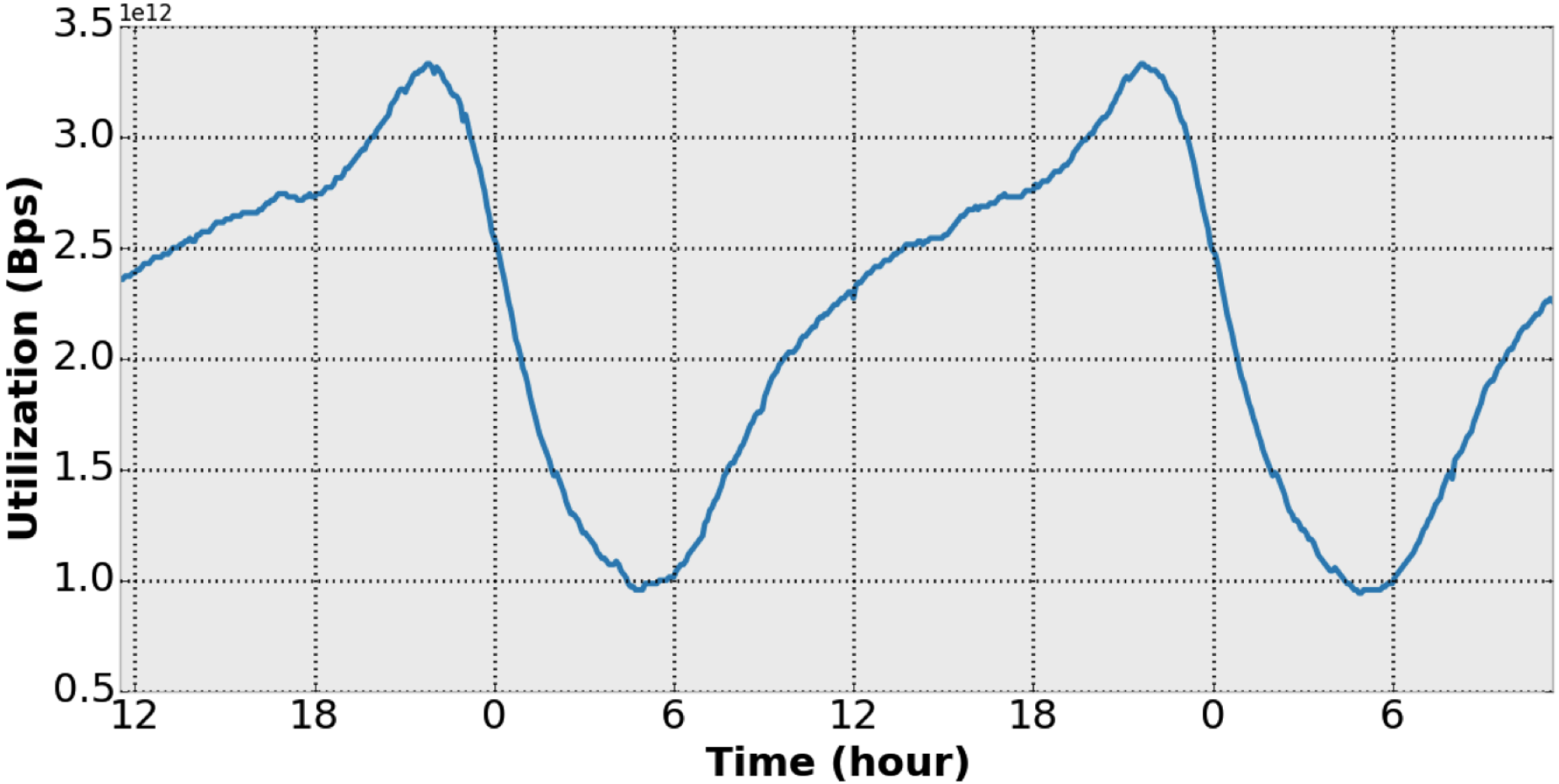
Context: ICT consumed 5% of global energy in 2013[1].



Worldwide use phase electricity consumption of communication networks, personal computers and data centers. Their combined share in the total worldwide electricity consumption has grown from about 4% in 2007 to 4.7% in 2012.

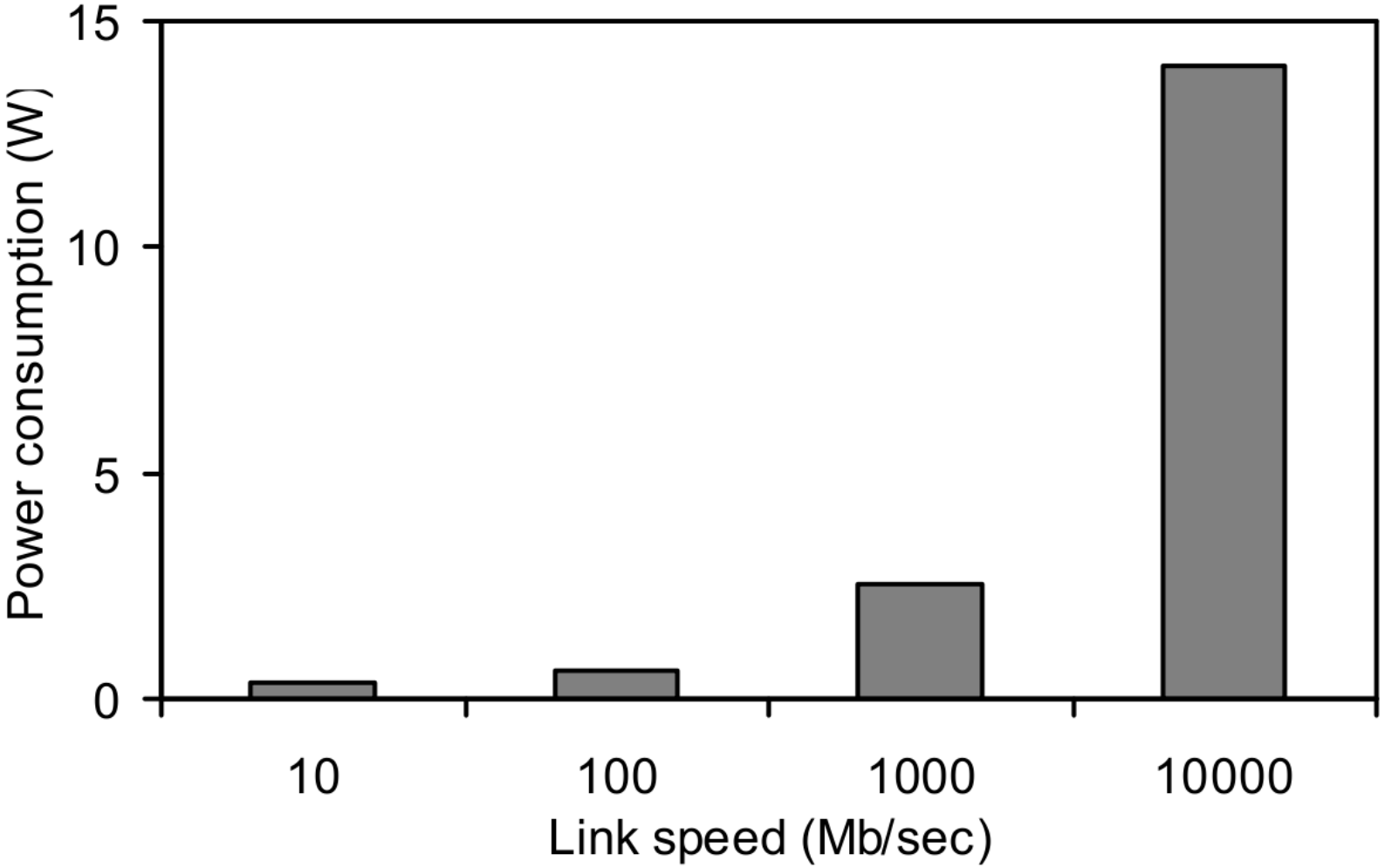
[1] Overview of ICT energy consumption (D8.1) – Report FP7-2888021, European Network of Excellence in Internet Science, February 2013, The EINS Consortium.

Networks are lightly or unevenly utilized.



Daily aggregated traffic on AMS-IX (Amsterdam Internet eXchange Point), July 2015.

Port's consumption depends on datarate.



C. Zhang and K. Sabhanatarajan, "Real-Time Performance Analysis of Adaptive Link Rate", IEEE LCN, 2008.

Plan

Goals of ECOFEN simulator

- Understand end-to-end energy consumption of wired networks
- Plot profile per device or port over time with per packet consumption
- Play with green leverages (low power idle, adaptive link rate, switching on/off ports or entire devices)
- Design new energy-aware algorithms
- Rely on ns3 event-driven packet-level simulator

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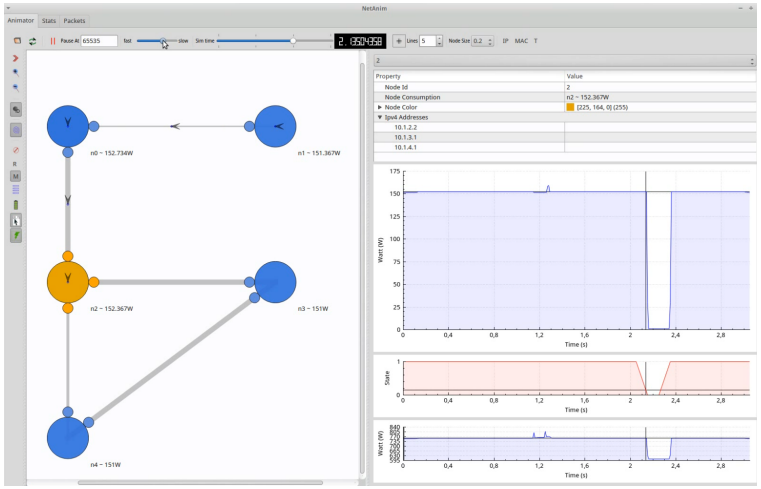
Advanced features

- Implementation of Adaptive Link Rate[2]
- Implementation of Low Power Idle (802.3az, Energy Efficient Ethernet) with packet coalescing[3]
- Visualization tool integrated within NetAnim
- Topology generation integrated within ns3-generator



[2] C. Gunaratne et al. *Reducing the Energy Consumption of Ethernet with an Adaptive Link Rate (ALR)*. IEEE Trans. on Computers, Vol. 57, No. 4, 2008.

[3] K. Christensen et al. *IEEE 802.3az : the road to energy efficient ethernet*. IEEE Comm. Mag., 48(11):50–56, 2010.

Power consumption models

Fixed or static part

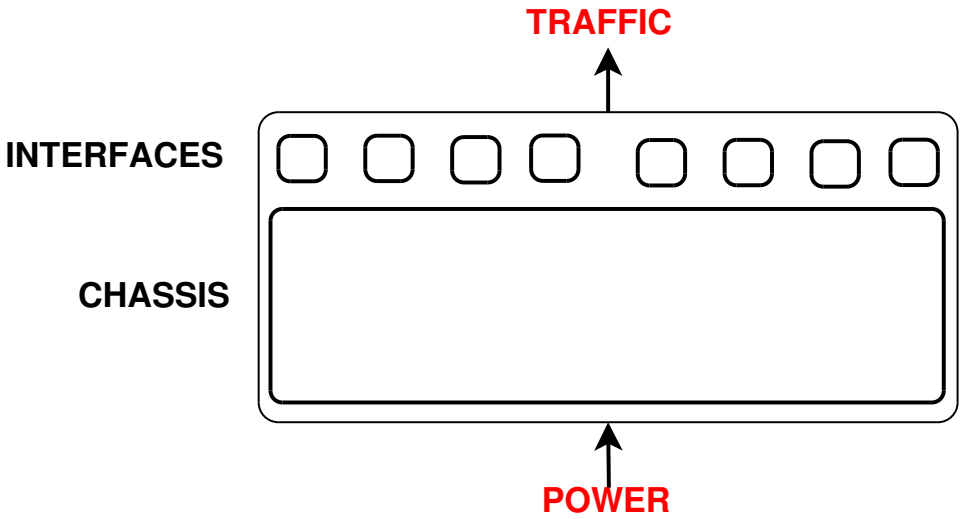
- minimal consumption when it is on but idle
- depends on the type of equipment, the number of plugged linecards, etc.

Variable or dynamic part

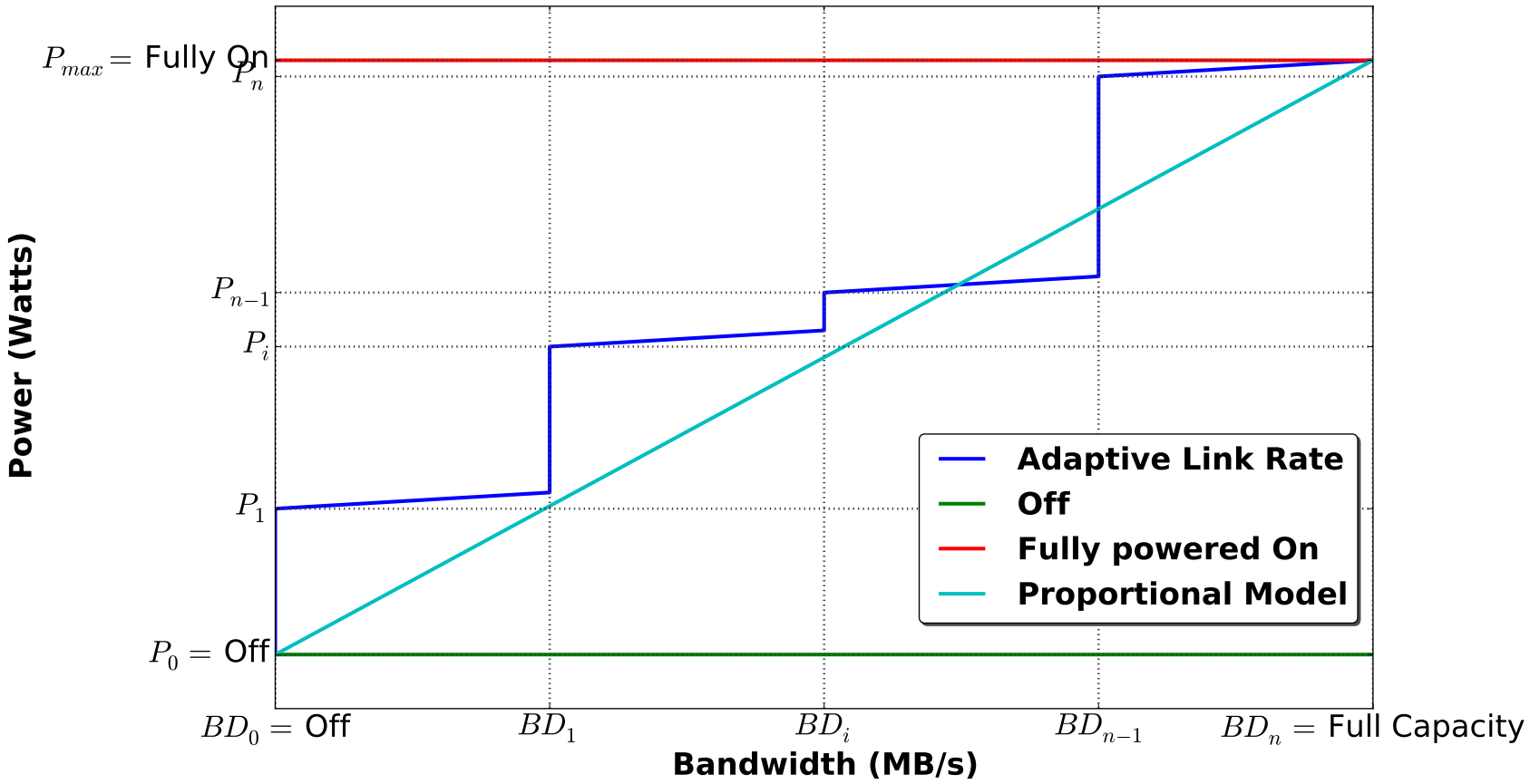
- not constant over time
- depends on the traffic, state of the components (rate adaptation), etc.
  - **Cost per packet**: energy used to process the packet (reading headers, CPU-related cost).
  - **Cost per Byte**: energy used to store the data (into buffers, memory-related cost).

Router consumption model

- Chassis
- Linecards
- Ports
- Rate
- Bandwidth
- Time



Port consumption models

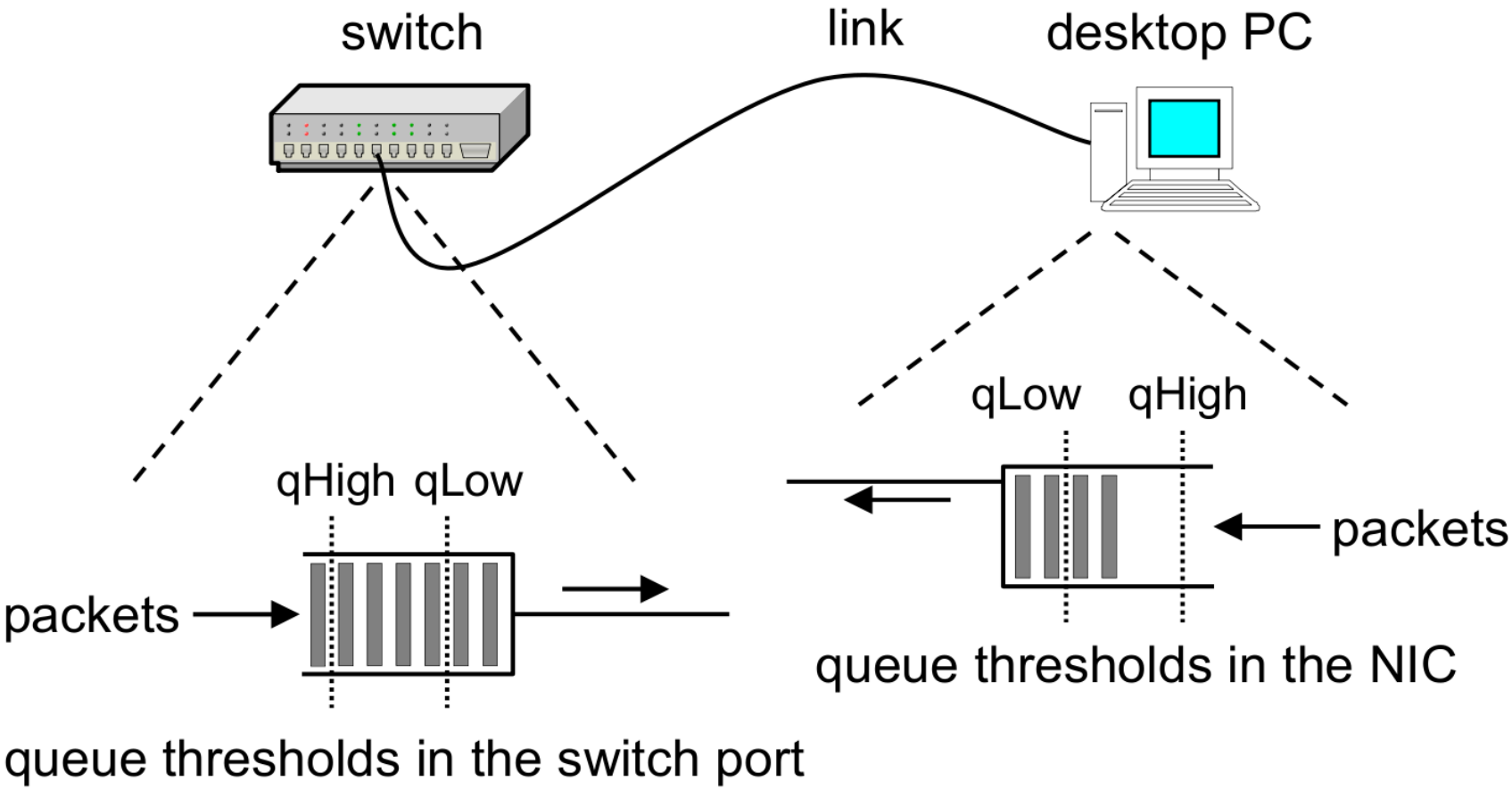


A.-C. Orgerie, L. Lefèvre, I. Guérin-Lassous and D. Lopez Pacheco, ECOFEN: an End-to-end energy Cost mOdel and simulator For Evaluating power consumption in large-scale Networks, SustainIT, 2011.

Plan

Adaptive Link Rate (ALR)

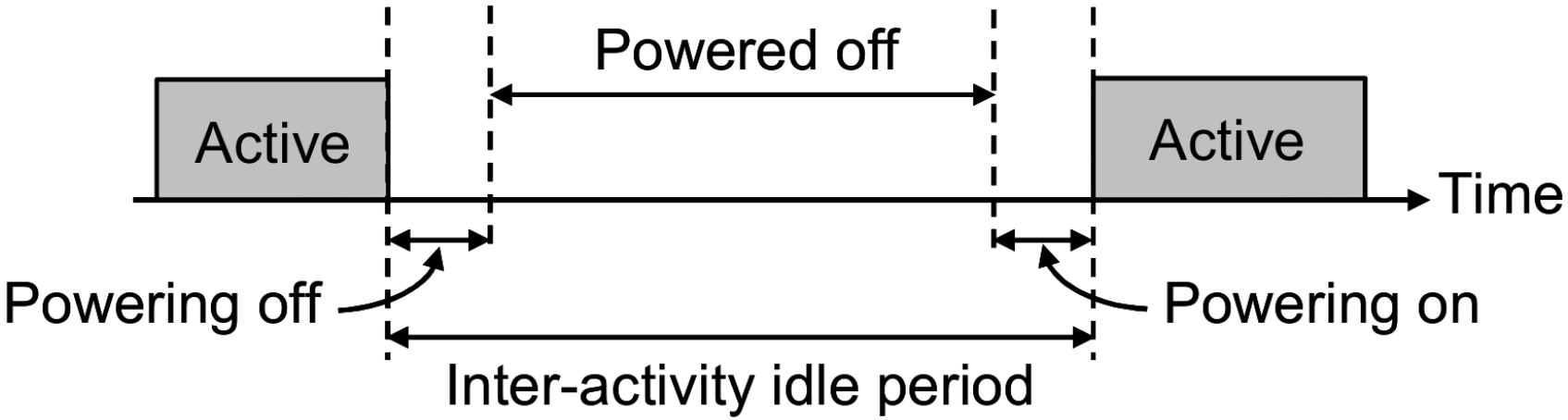
Idea: adjust link rate to the actual traffic to consume less energy.



"Managing Energy Consumption Costs in Desktop PCs and LAN Switches With Proxying, Split TCP Connections, and Scaling of Link Speed ", C. Gunaratne et al., International Journal of Network Management, 2005.

Switching off

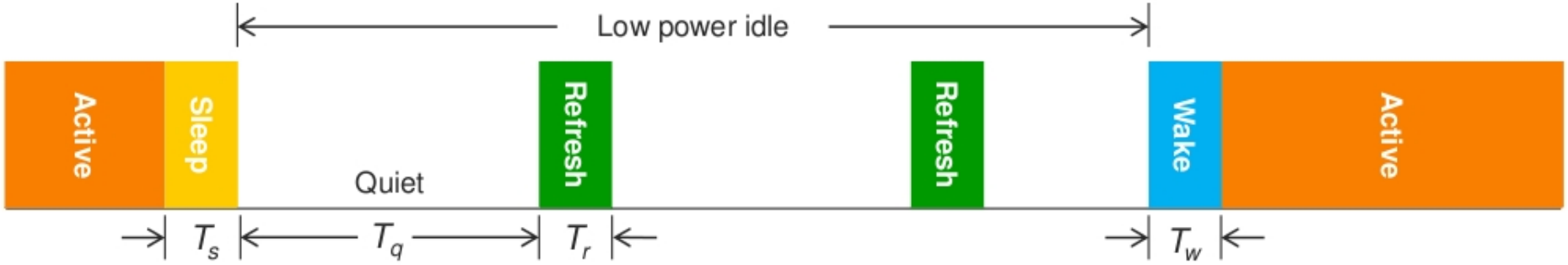
Idea: swith off unused equipment.



"Energy saving and network performance: a trade-off approach" L. Chiaraviglio et al., ACM e-Energy, 2010.

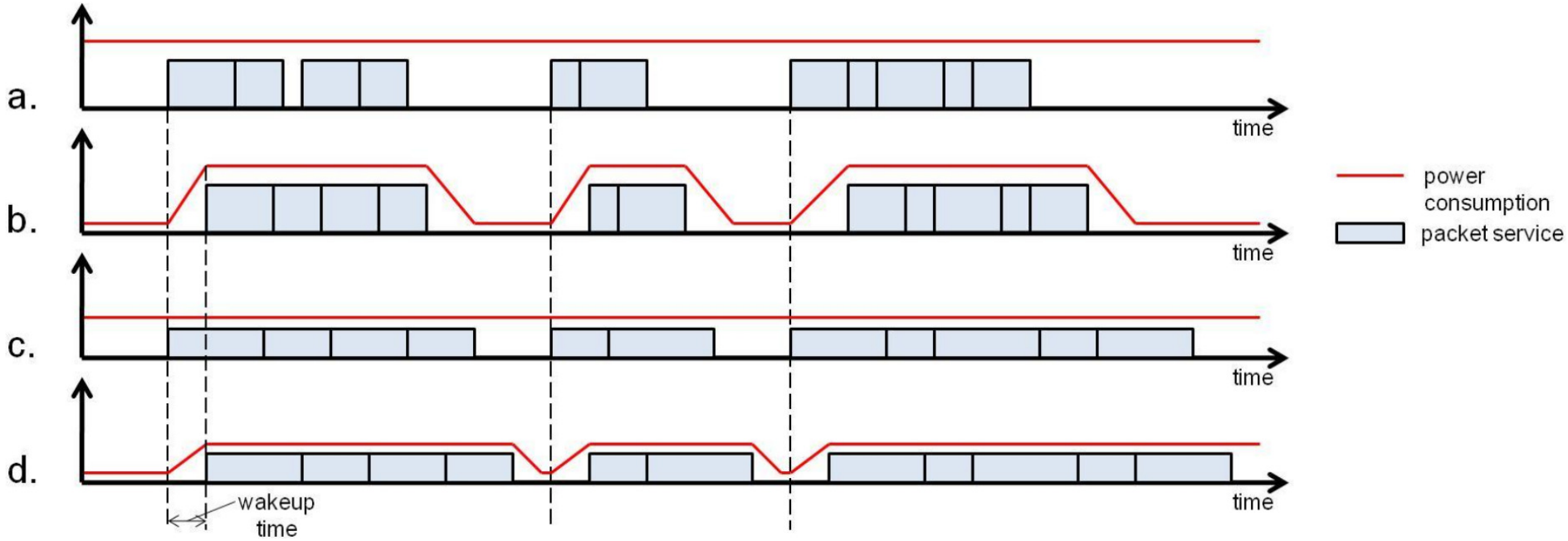
Low power idle (LPI)

Idea: send data as fast as possible, put to low power mode when not unused.



"IEEE 802.3az: The Road to Energy Efficient Ethernet", K. Christensen, P. Reviriego, B. Nordman, M. Bennett, M. Mostowfi, J. Maestro, IEEE Comm. Mag., 2010.

Approaches

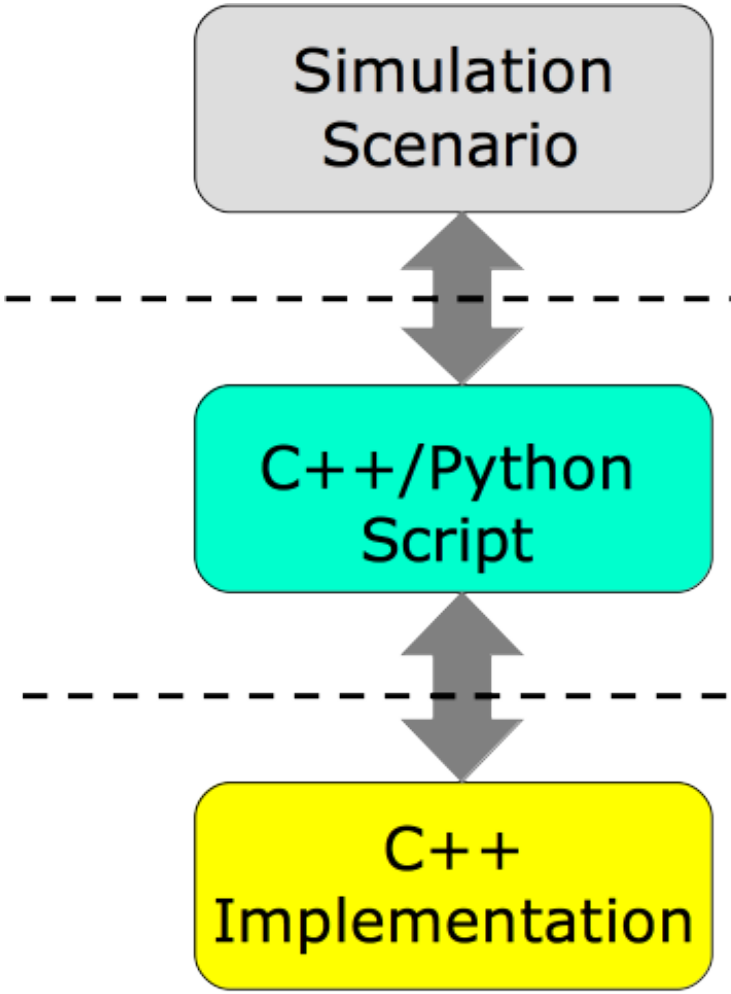


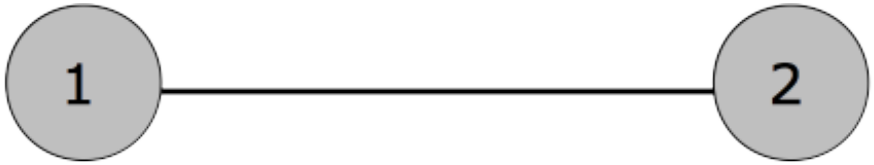
a: normal traffic, b: with on/off, c: with ALR, d: with ALR and on/off.

"Reducing Network Energy Consumption via Sleeping qnd Rate-Adaptation", S. Nedevschi, L. Popa, G. Iannaccone, S. Ratnasamy and D. Wetherall, USENIX Symposium On Networked Systems Design & Implementation (NSDI), 2008.

Plan

ns3 environment





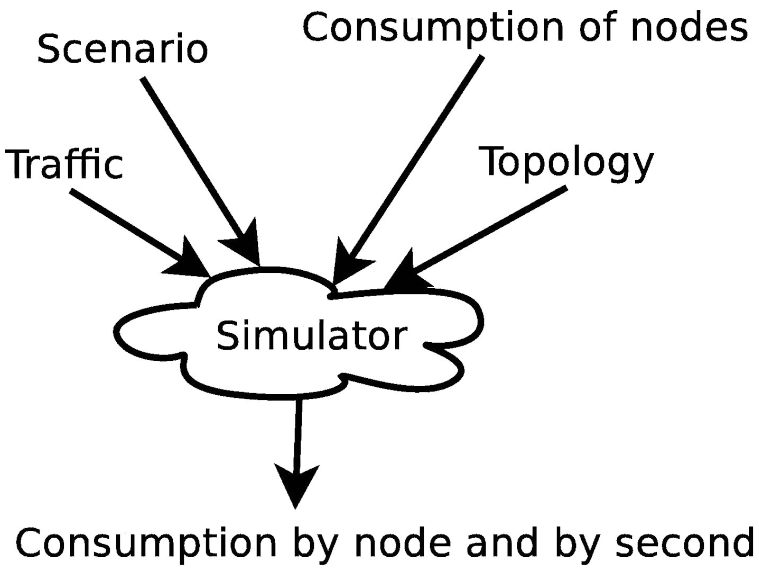

```
NodeContainer nodes;


nodes.Create (2);
```

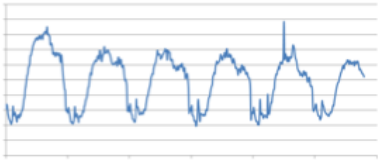
```
class MobileNode : public Node
{
        friend class PositionHandler;
public:
         MobileNode();
                 •
                 •
}
```

Ecofen module

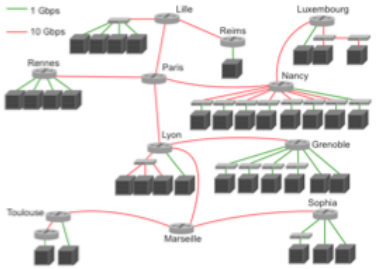
- Traffic: sources, destinations, type of traffic, rate profile, protocols
- Scenario: start and stop of traffic, failures, switch on and off
- Consumption: real values for each kind of equipment
- Topology: link capacities, type of each equipment



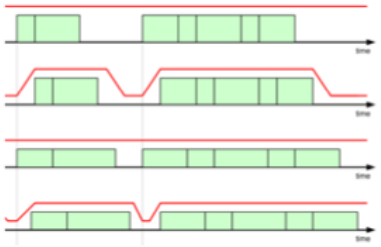
"ECOFEN: an End-to-end energy Cost mOdel and simulator For Evaluating power consumption in large-scale Networks", A.-C. Orgerie, L. Lefèvre, I. Guérin-Lassous and D. Lopez Pacheco, SustainIT: International Workshop on Sustainable Internet and Internet for Sustainability, 2011.



Traffic



Topology

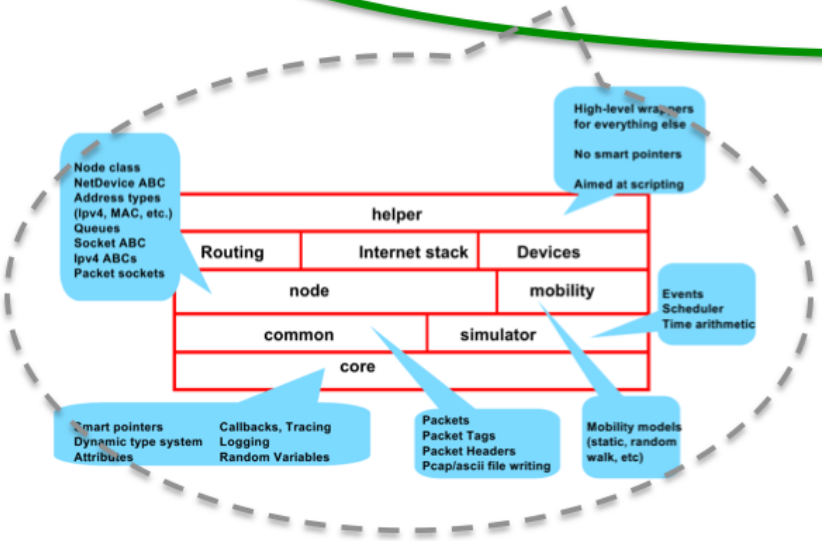


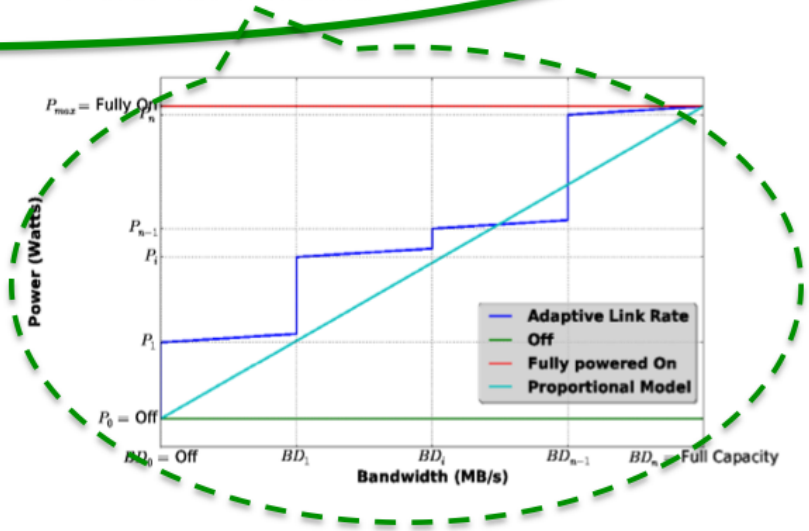
Scenario

Device	State	Value	Unit	Energy model
$NIC_{end\ host}$	On;Idle	6.936	W	basic
	Off	0	W	basic
switch	On;Idle	66	W	basic
	Off	0	W	basic
port	Idle	0.11	W	linear
	ByteEnergy	3.423	nJ	linear
	Idle	0.11	W	linear
	ByteEnergy	3.423	nJ	linear
	Idle	0.11	W	linear
	ByteEnergy	3.423	nJ	linear
	Idle	0.75	W	linear
	ByteEnergy	3.423	nJ	linear

Energy values

ns-3 + ECOFEN





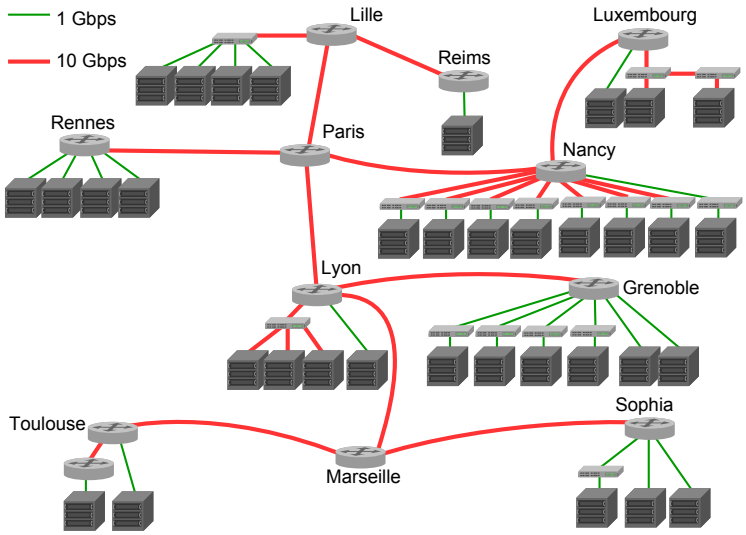
Energy profile over time for all the network devices

Plan

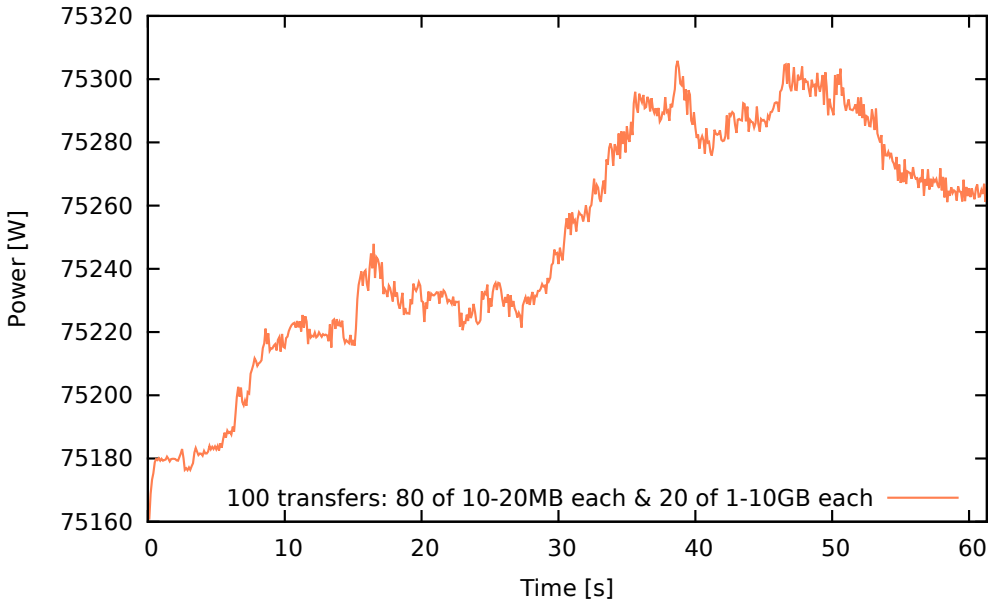
Example of study: Grid'5000 network

Random traffic among Grid'5000 clusters
Elephant and mice workload

Topology



Network energy consumption



"Studying the energy consumption of data transfers in Clouds: the Ecofen approach", B. Cornea, A.-C. Orgerie and L. Lefèvre, IEEE CloudNet, 2014.

Values extracted from the literature

Device	State	Value	Unit	Energy model	Link rate (Gbps)
$NIC_{end\ host}$	On;Idle	1.82	W	basic	1 ; 10
	Off	0.7	W	basic	
switch	On;Idle	150	W	basic	
	Off	0	W	basic	
router	On;Idle	76.4	W	basic	
	Off	0	W	basic	
port[1]	Idle	1.12	W	complete	1
	Off	0	W	complete	
	Send/Recv byte	3.4	nJ	complete	
	Send/Recv packet	197.2	nJ	complete	
	Idle	0.53	W	complete	10
	Off	0	W	complete	
	Send/Recv byte	14	nJ	complete	
	Send/Recv packet	1 504	nJ	complete	

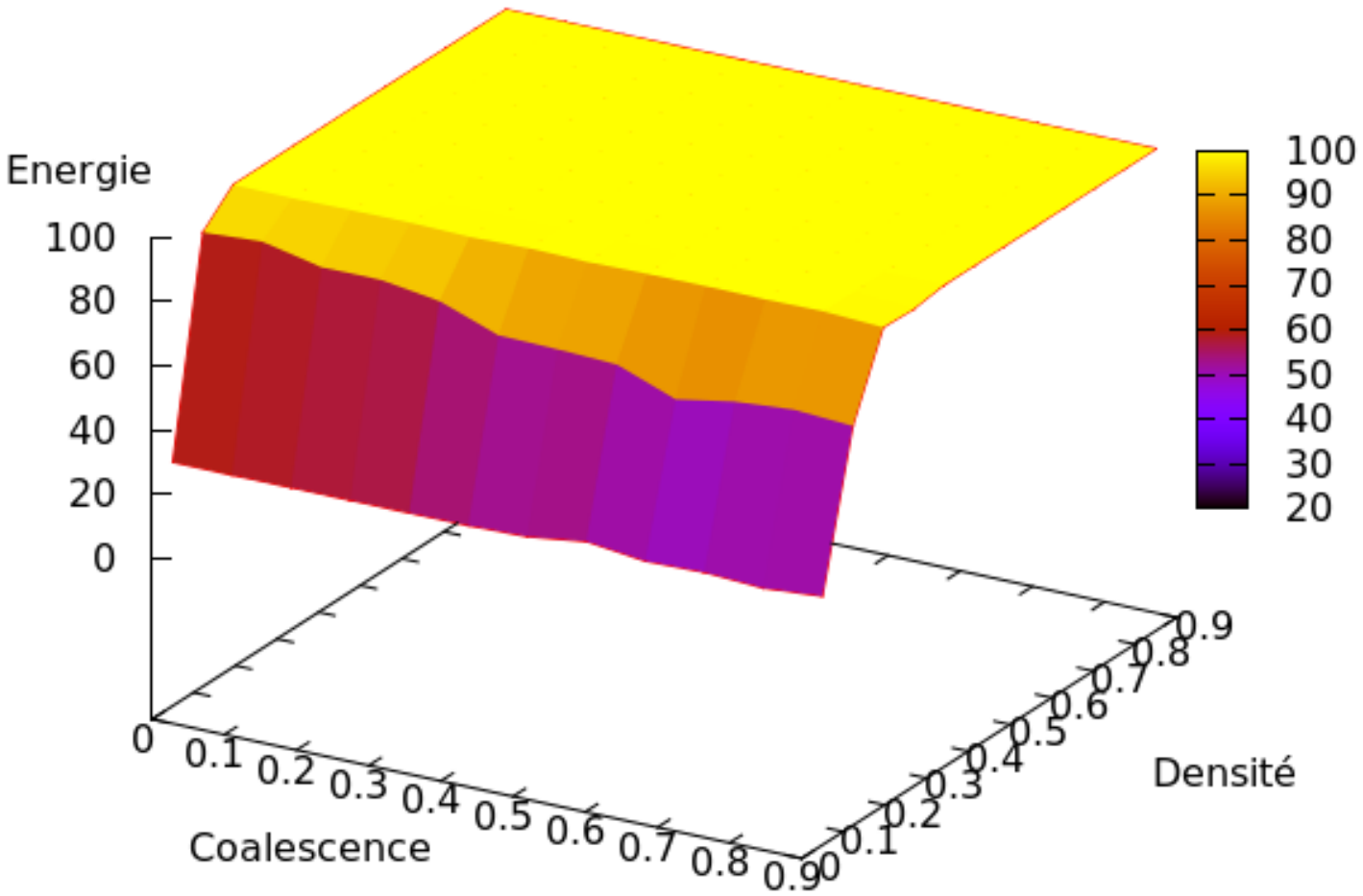
Device	Action	Value	Unit	Energy model	Link rate (Gbps)
$NIC_{end\ host}$	Switch On/Off	$0.91*10^{-3}$	J	complete	1 ; 10
		$0.5*10^{-3}$	s	complete	
switch	Switch On/Off	0.75	J	complete	1 ; 10
		$0.5*10^{-3}$	s	complete	
port[1]	Switch On/Off	$0.56*10^{-3}$	J	complete	1
		$0.5*10^{-3}$	s	complete	

Example of study

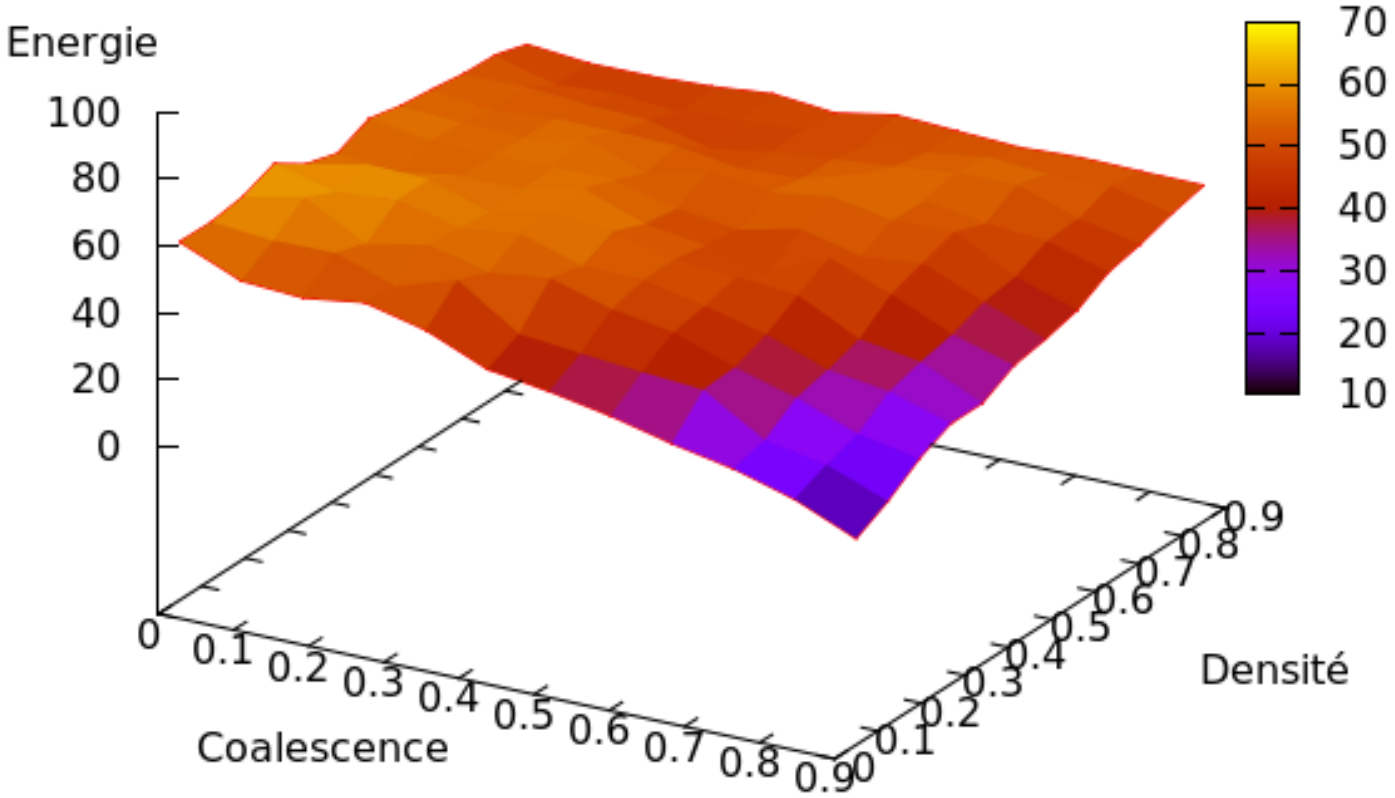
ALR vs. LPI

- Adaptive Link Rate with threshold-based rate switching.
- LPI with coaelescing queue.
- Evaluation of energy consumed by each approach and when combining both.
- Two nodes, varying traffic.
- 2015 Bachelor student thesis.

ALR


Energie
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Coalescence
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Densité
100
90
80
70
60
50
40
30
20

LPI


Energie
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Coalescence
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Densité
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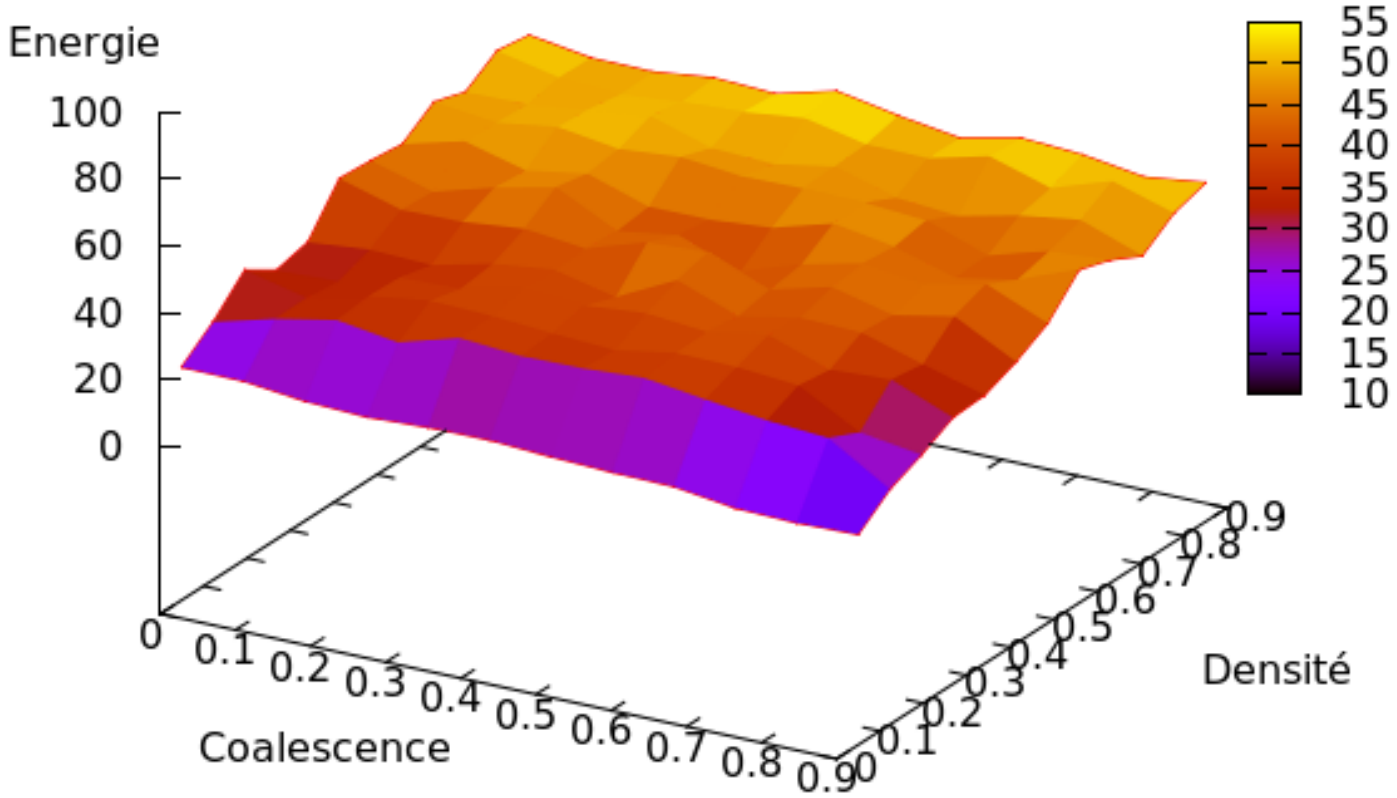
ALR and LPI


Energie
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Coalescence
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Densité
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10

Plan

Today

Now

- Ecofen model and implementation
- Benefits and drawbacks from ns3
- Packet-based simulation
- Evaluation of energy-efficient techniques

Next

- Network virtualization
- Optical equipment
- Flow-based simulation

Contributors

People involved

- Laurent Lefèvre
- Dino Lopez Pacheco
- Timothée Haudebourg
- Guillaume Chapel
- Isabelle Guérin-Lassous

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