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The Green-Game: Striking a Balance between QoS and Energy Saving

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Introduction: ICT for Green

- Information and Communication Technologies (ICT) offer big opportunities to reduce the human footprint:
  - *Videoconferences, telepresence, email, etc.*

Introduction: Green for ICT

• ICT itself represents a strong contribution to the environmental impact of human activities, and with a very high increasing rate:

- *Same footprint of the airplane transports,*
  … but with higher growing rate.

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Remark: our work focusses on "energy aware" ICT
Gas emission is complex to quantify (type of energy, …)
Economical arguments (reduce energy cost)

Green for ICT: A Hot Topic

Many works have been initiated in the last years:
In *Data Centers*, in *Peripherals*, and in *Networks*:

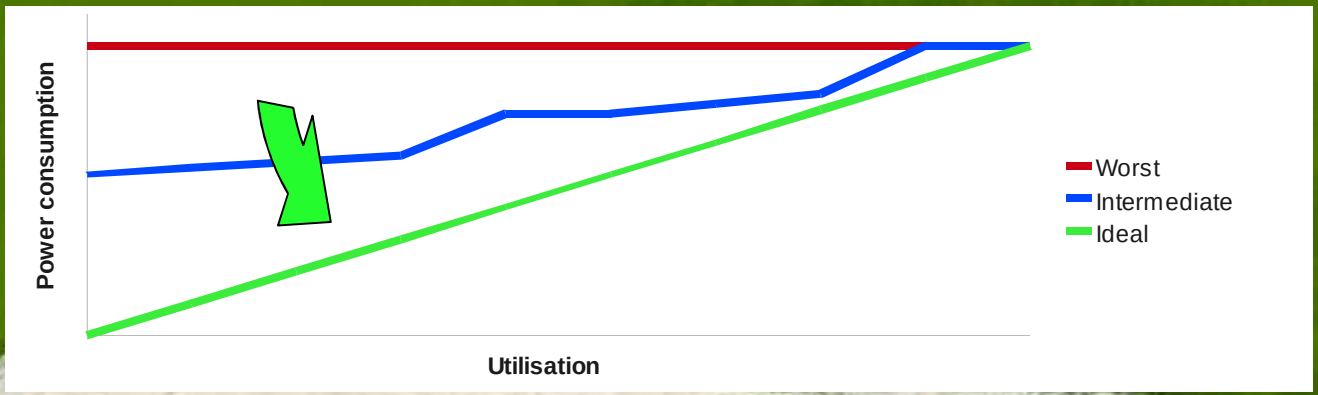
- In *wireless networks*, not completely a "new" subject:
  - Battery constraints in wireless mesh/sensor networks
  - Interferences (power control)
  - Important savings
- In *wired networks*:
  - Still some interesting opportunities
  - Depend on topologies

Energy Saving Opportunities

Facts:

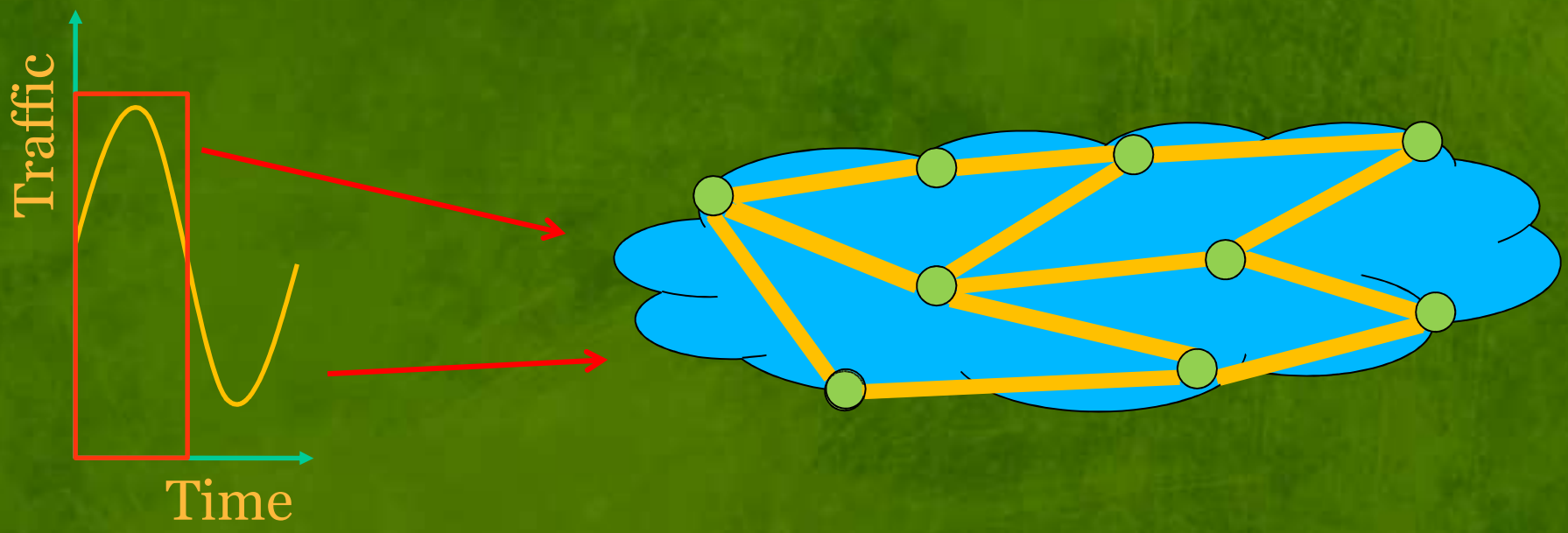
- Network systems and devices are *over-provisioned*
- *Predicable traffic* fluctuations

- Today: energy agnostic equipments
- How to reach proportionality (energy/utilization)



Resource Consolidation

- Already a popular practice in other domains (e.g., Data Centers)



- Traffic aggregation through a proper *weight optimization*.

Resource Consolidation: Open Points

- A solution purely optimizing the energy consumption does not take into account the *system robustness*
- There is no control on which network elements are switched off
- Definition of a *criticality index* for the network devices to drive the resource consolidation process

Definition of a trade off between *Energy-saving* and *robustness*

A Game-Theoretical Approach

- The *basic idea*:
  - Modeling the communication network as a cooperative TU-game
  - Each node is a player
  - Every coalition is a network configuration:
    - Nodes in the coalition -> ON
    - Other nodes -> OFF (or failures)
  - The amount of delivered traffic is the revenue of the coalition

A Game-Theoretical Approach (2)

- The final game is the composition of two games:
  - A *Traffic Game* (A-Priori) over a full-mash network (allows all coalitions, accounts only for the Traffic Requests)
  - A *Topology Game* (A-Posteriori), which is the restriction of the first over the network graph, and accounts for the Topology
  - The two games may be decomposed into several *unanimity games*

The Shapley Ranking

- The *Shapley value* defines a rank among players (on the basis of the amount of traffic that nodes contribute to carry, and of their criticality while composing the coalition)

- Nodes are progressively switched off (if the all traffic requests are still satisfied, with eventual maximum load constraints)

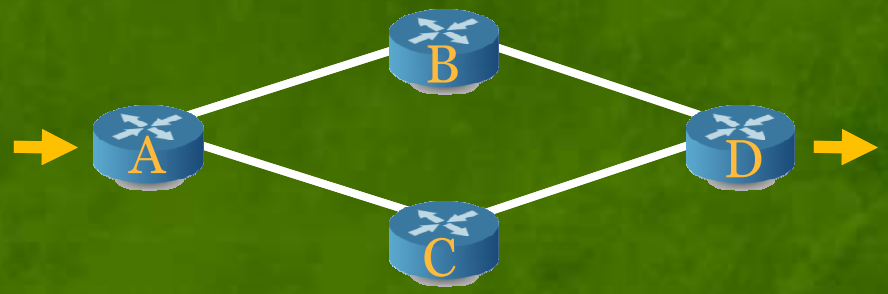
- When to stop?

The Shapley Ranking: Toy Cases

1)

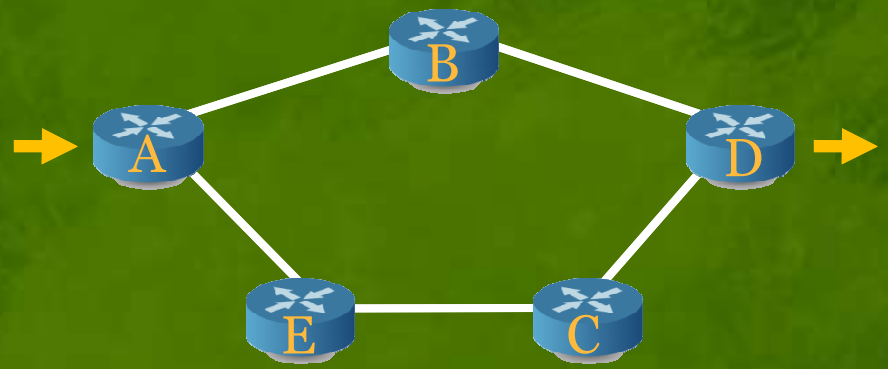
Every node has the same Shapley value

2)



A, D -> 5/12
C, B -> 1/12

3)



A, D -> 23/60
B -> 8/60
C, E -> 3/60

Other Possible Rankings

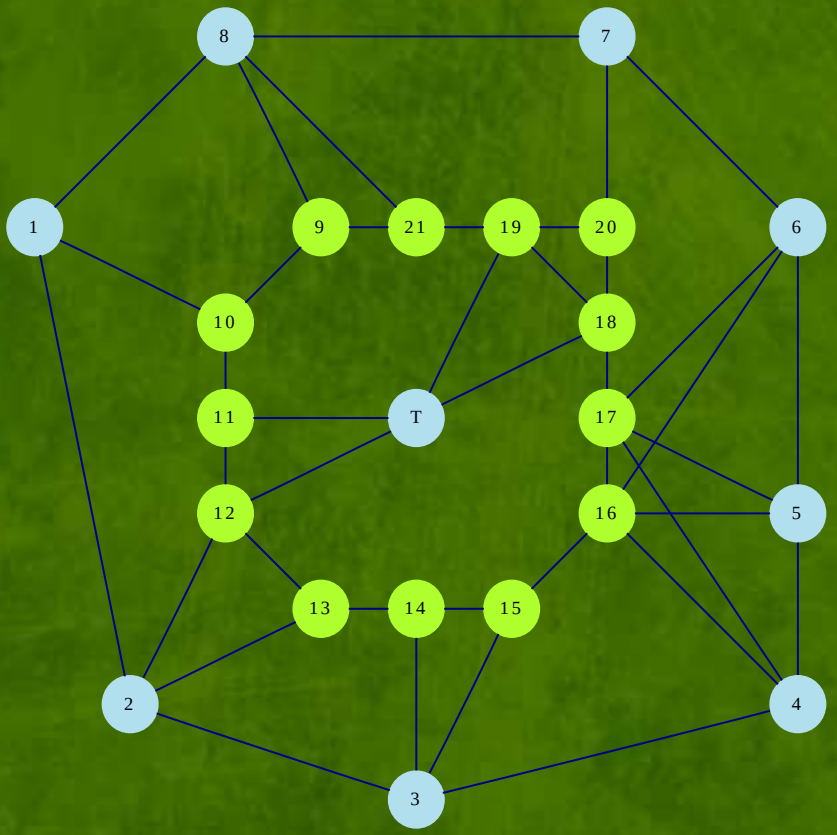
- Other criticality indexes are present in the literature, but all of them only account for the network topology

- The G-Game considering an uniform TM matches quite well these indexes, but there is low correlation when taking into account the Traffic

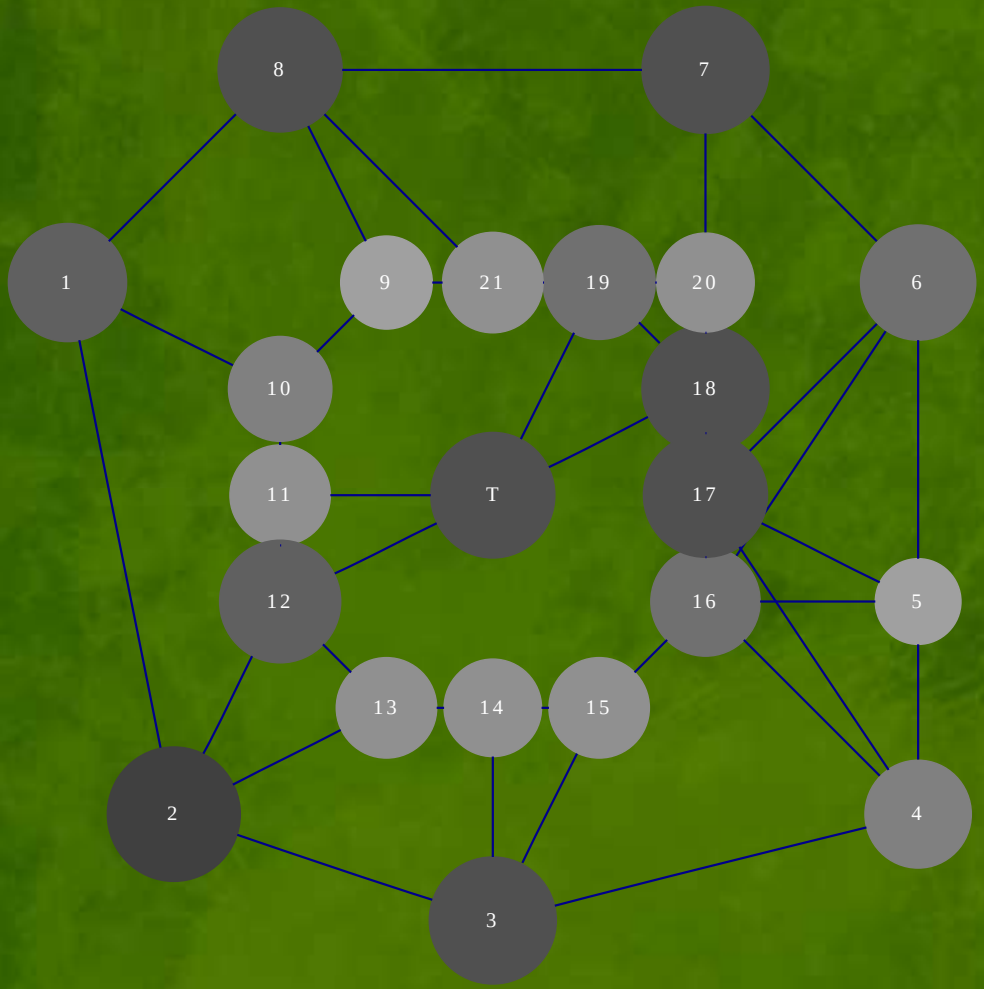
	G-Game (U-TM)	*Betweenness*	*Degree*	*Closeness*	*Eigen*	*G-Game*	*Traffic Load*
G-Game (U-TM)	1						
Betweenness	0.9688	1					
Degree	0.4594	0.5321	1				
Closeness	0.8729	0.9057	0.6216	1			
Eigen	-0.0073	0.0792	0.7335	0.1787	1		
G-Game	0.4085	0.4286	0.2527	0.5132	-0.0220	1	
Traffic Load	0.4251	0.4868	0.4762	0.6046	0.1911	0.5583	1

A Real Case Study: The Network Scenario

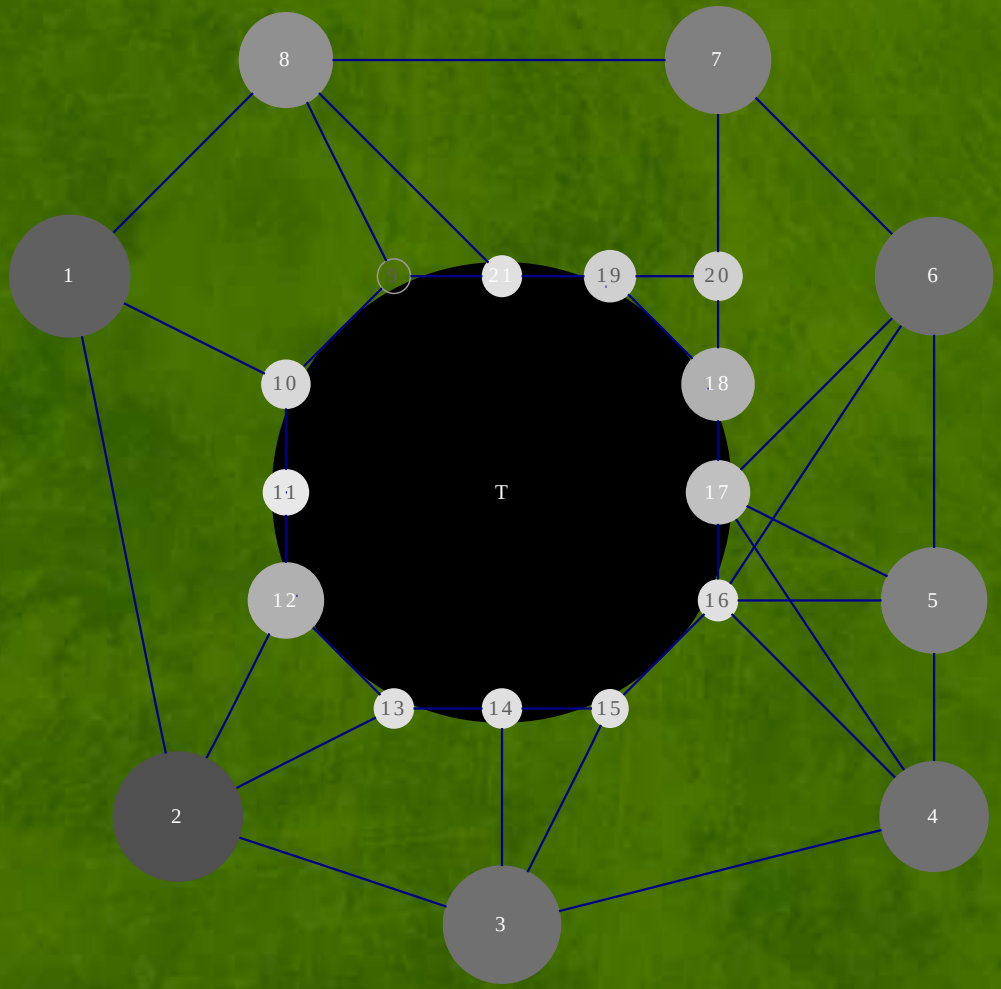
- TIGER2 Network (typical access/metro network)
- *i* *Access* nodes (traffic Sources and Destinations)
- *j* *Core* nodes (only traffic transport)



A Real Case Study: Different Rankings

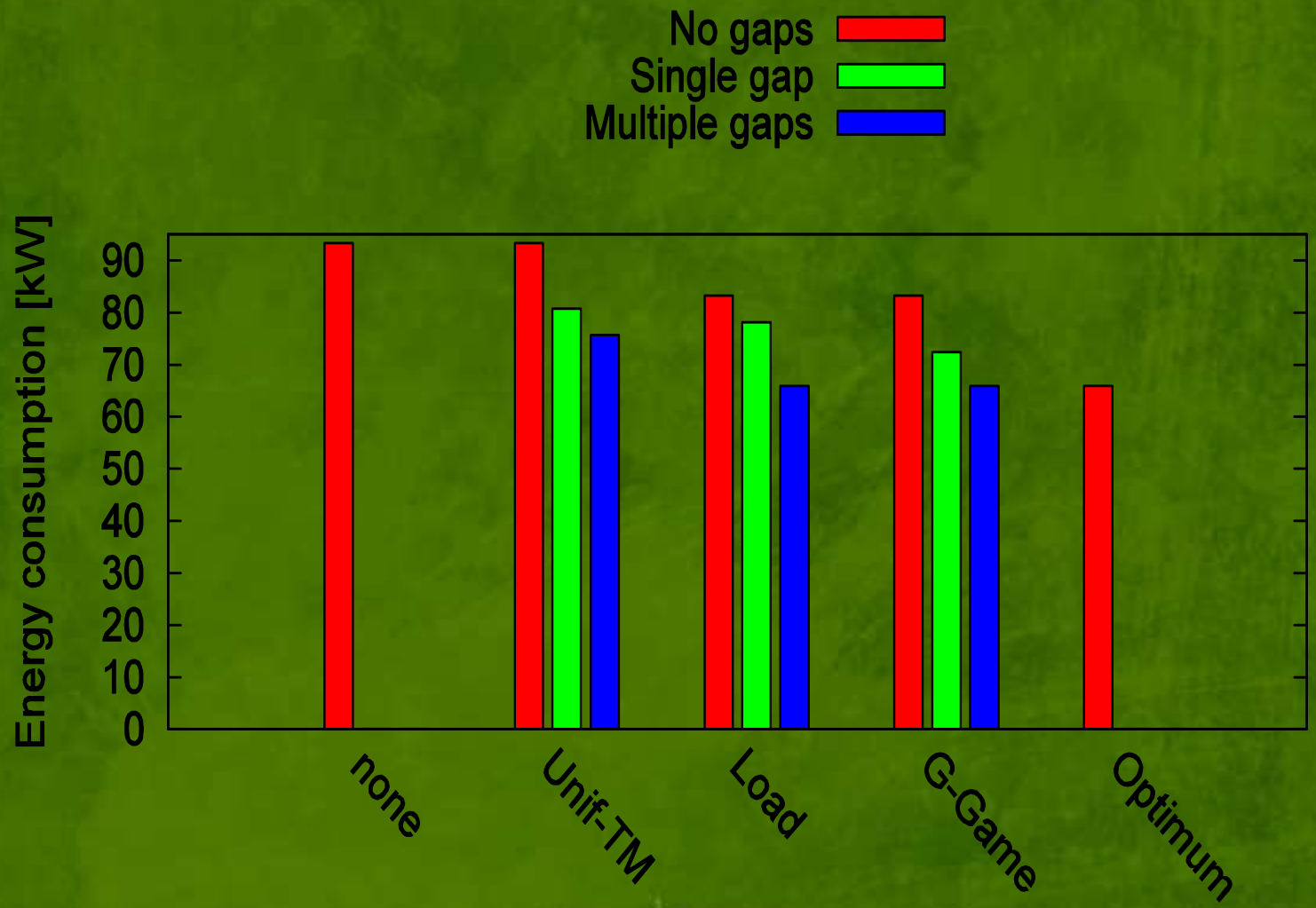


Only Topology



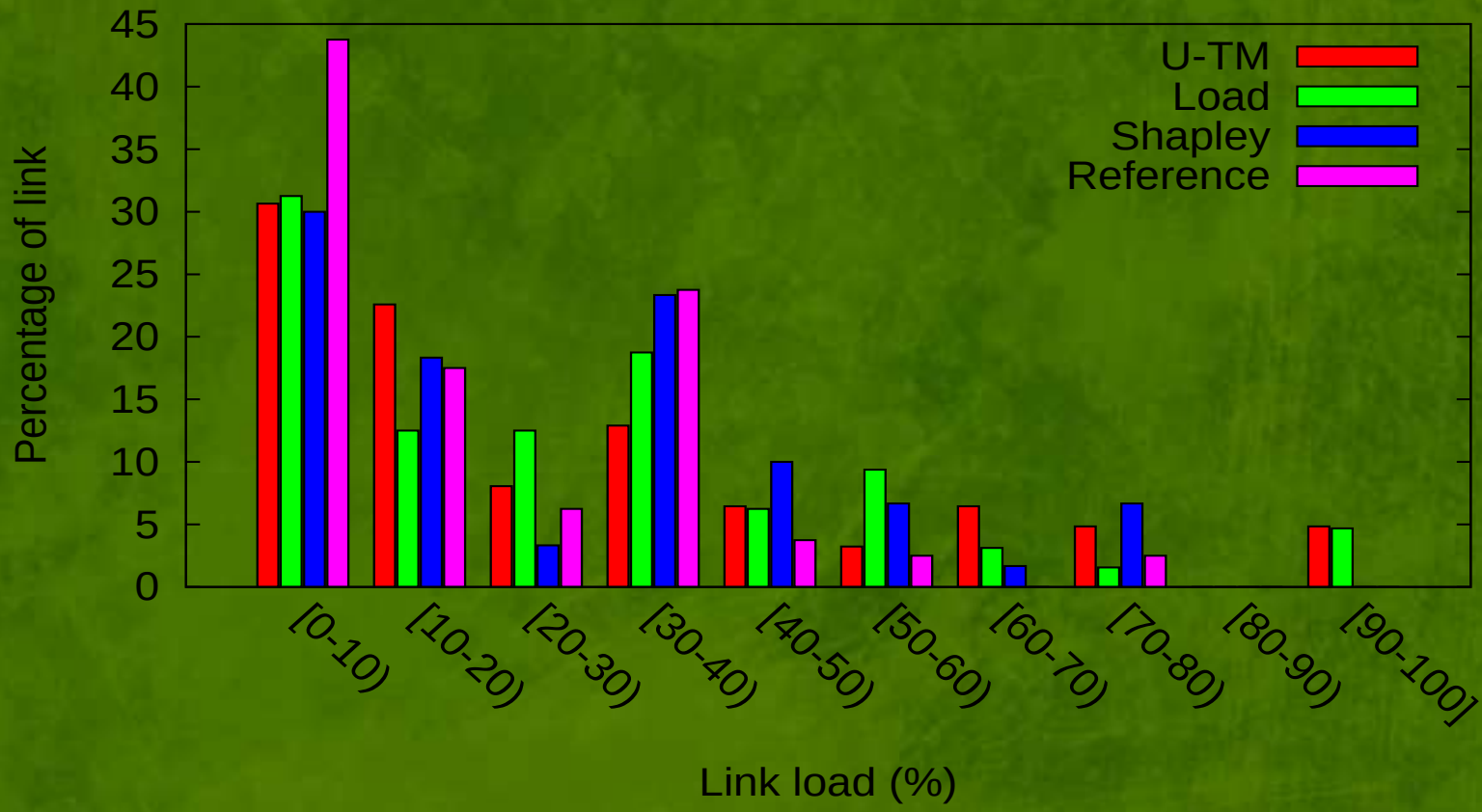
G-Game

A Real Case Study: Results



S	U	L
9	5	9
15	9	15
13	14	8
14	20	7
16	21	5
21	15	4
11	13	21
10	11	20
20	10	2
19	4	3
17	16	1
18	19	6
12	6	14
8	1	11
5	12	10
7	17	19
4	8	16
3	T	13
6	7	12
1	3	17
2	18	18
T	2	T

A Real Case Study: Results (2)



Order	Shapley	U-TM	Load
Energy saving (%)	17.05	13.43	16.27
Weighted avg path length	2.99	3.40	3.25

S	U	L
9	5	9
15	9	15
13	14	8
14	20	7
16	21	5
21	15	4
11	13	21
10	11	20
20	10	2
19	4	3
17	16	1
18	19	6
12	6	14
8	1	11
5	12	10
7	17	19
4	8	16
3	T	13
6	7	12
1	3	17
2	18	18
T	2	T

G-Game: Future Work

- Evaluation of the impact of:
  - different scenarios (topology and TM), to highlight dependences
  - different energy models (e.g. optical transmission, with periodical signal regeneration)
- Evaluation of the effects on the inter-domain routing (hot potato)
- Integration with dynamic routing protocols (IGP Weight Optimization)

Thank you!

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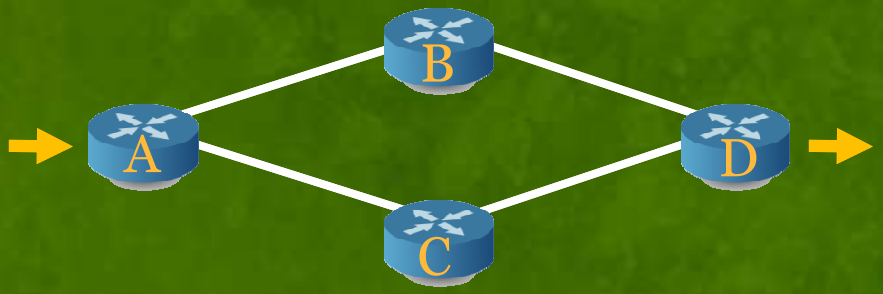
The G-Game: An Example

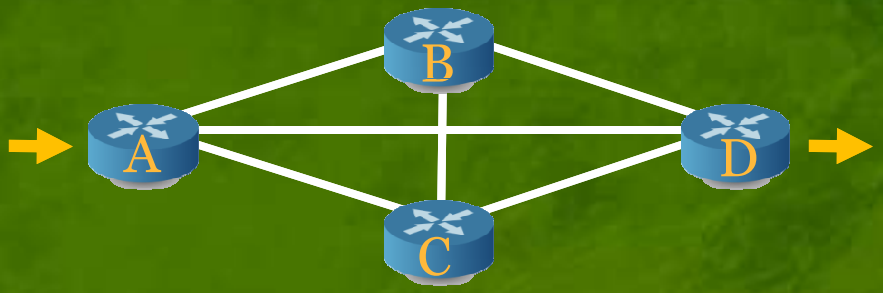
1)



Traffic Request

A -> D: 50Mbps

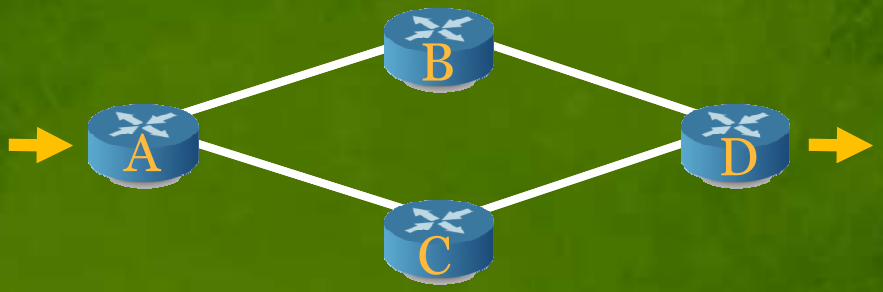
2)



Traffic Game:

$v = u(A, D)$

3)

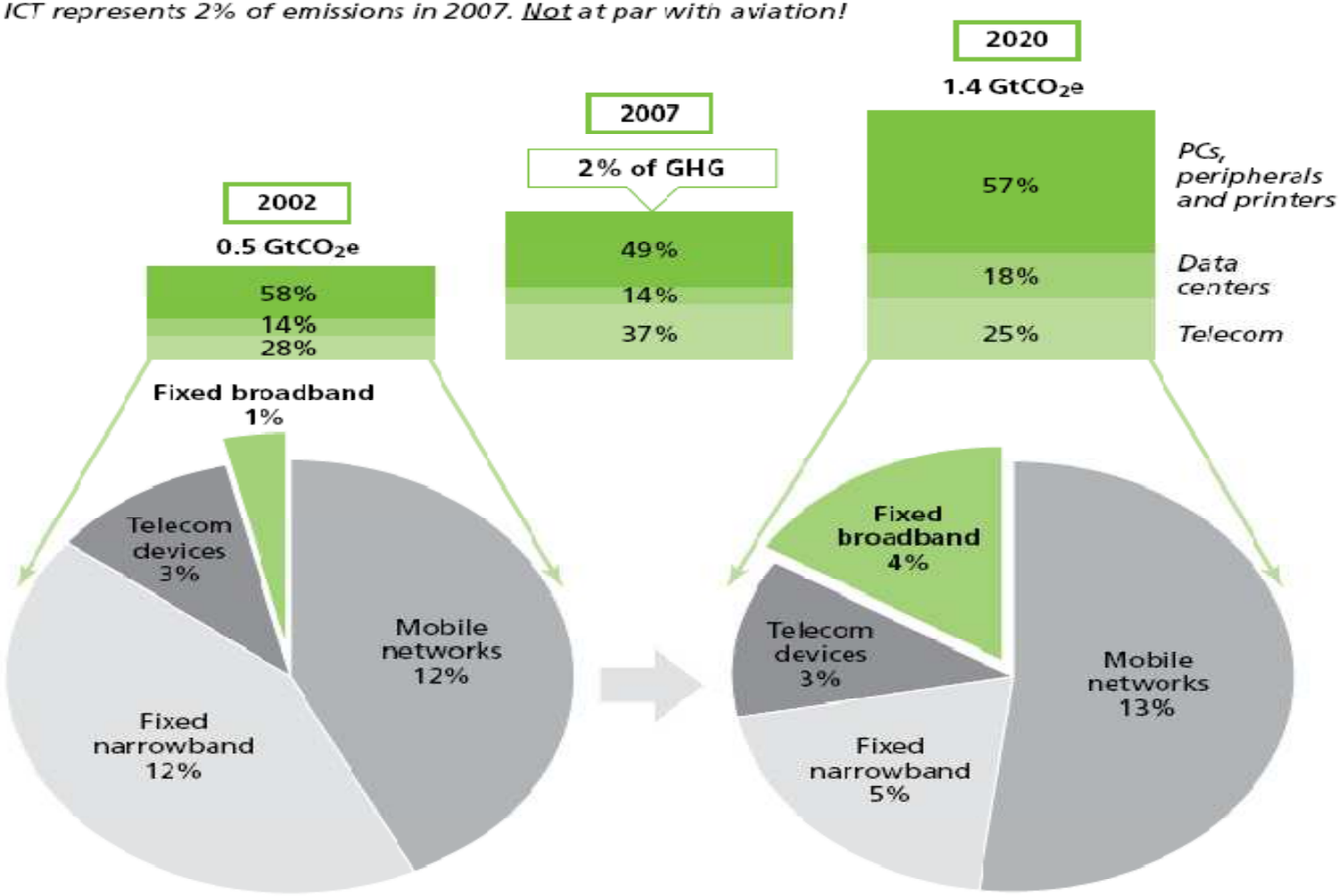


Topology Game:

Minimal connected components containing A, D:

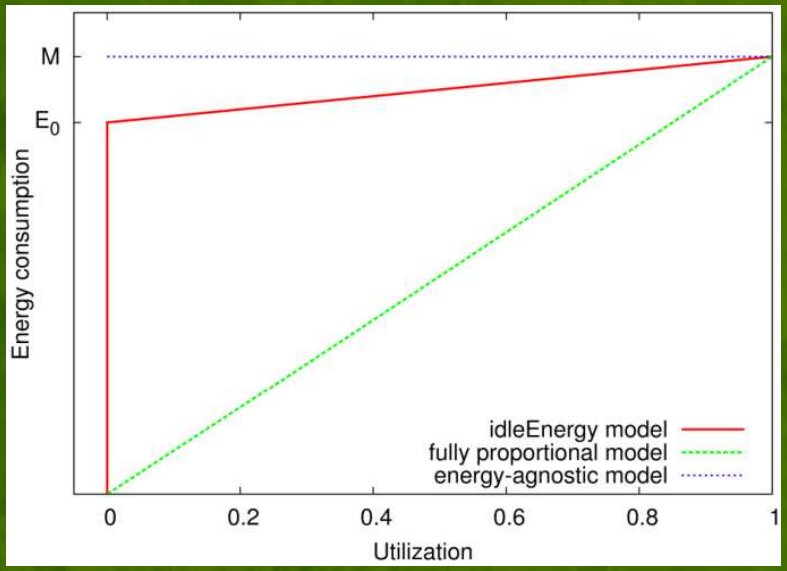
$v^{\Gamma} = u(A,B,D)+u(A,C,D)-u(A,B,C,D)$

Energy Saving Opportunities



EAR: An Optimization Approach

- *Modeling* the device energy consumption as a function of the utilization level



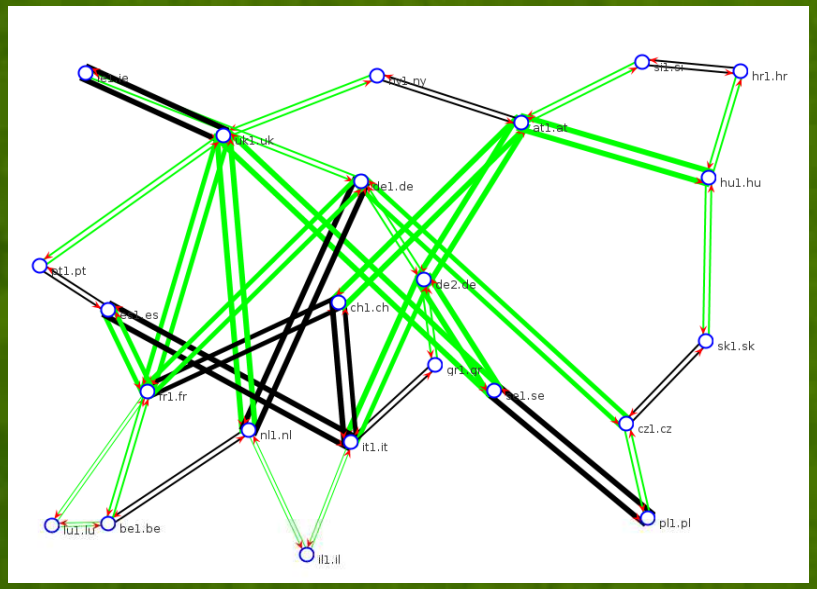
- *ILP formulation* for a minimum-energy routing

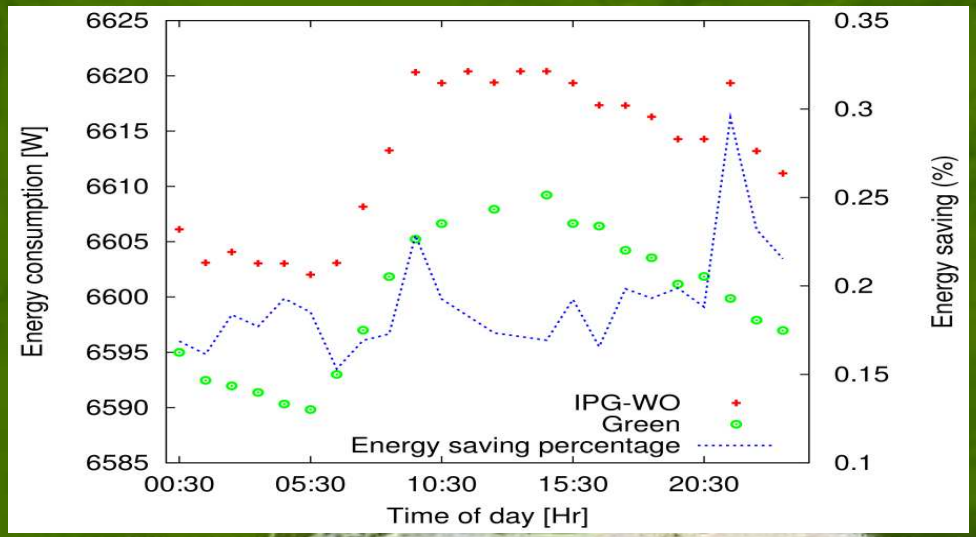
- Evaluation over different network scenarios (i.e., topologies and traffic matrixes)

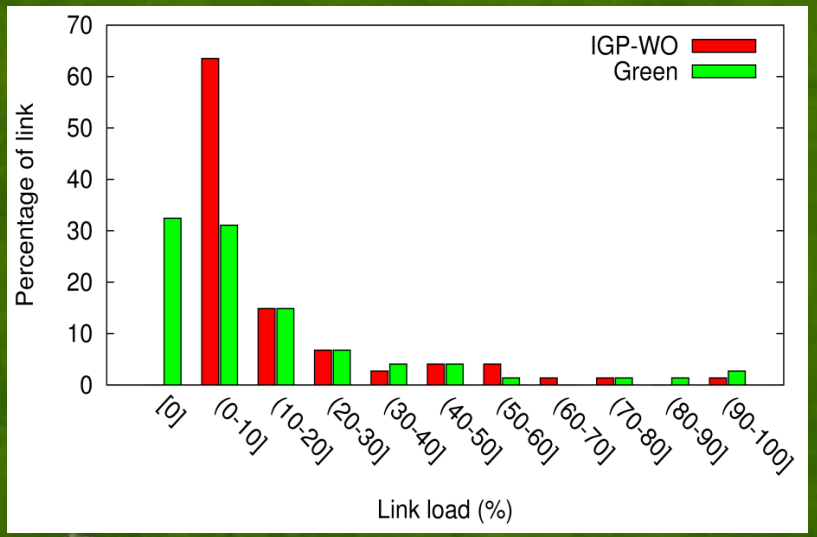
- Accounting for QoS: maximum imposable link load

EAR: Results

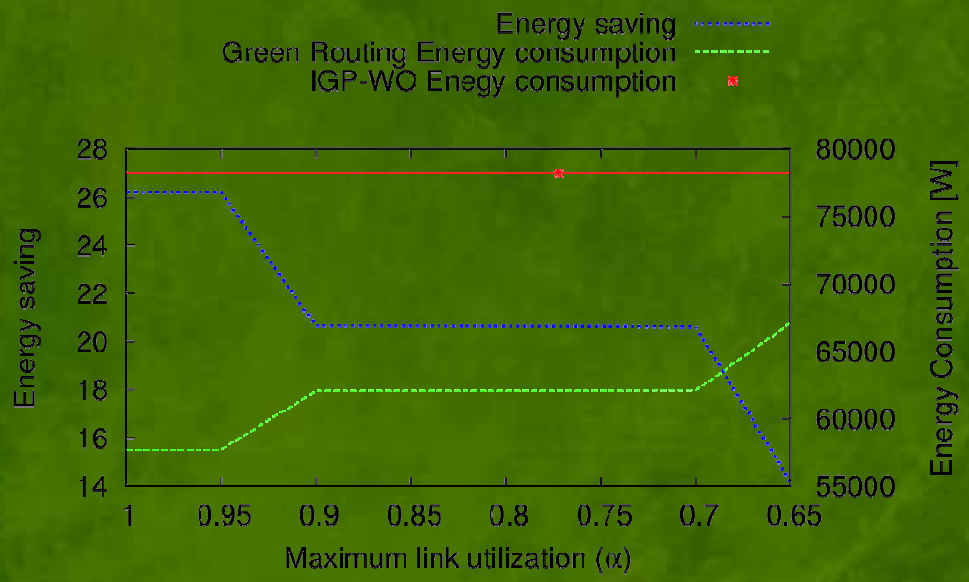
- The solution has been tested over the GEANT2 network with real traffic matrixes
- All nodes generate/receive traffic (unfriendly scenario)

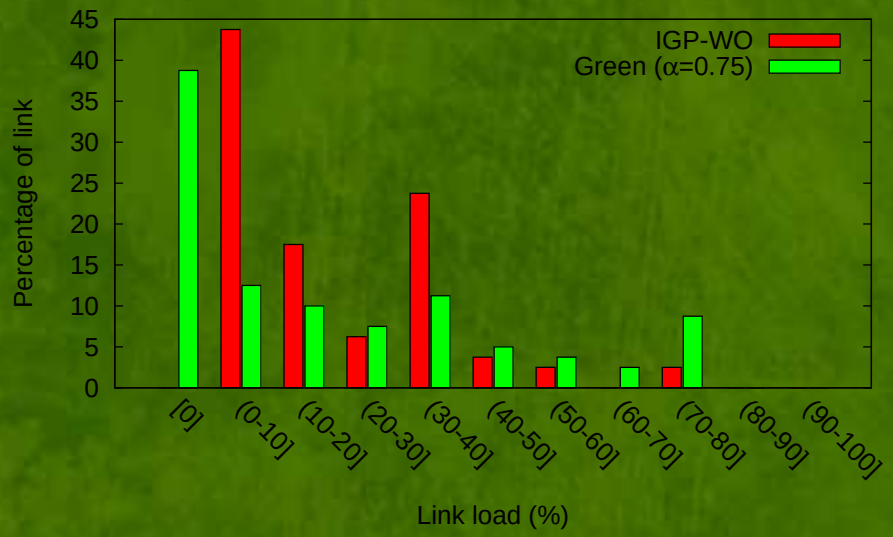






EAR: Results (3)





- The work has been finalized in:

  - A.P. Bianzino, C. Chaudet, F. Larrocca, D. Rossi, J.-L. Rougier, "Energy-Aware Routing: a Reality Check", submitted to *GreenComm3 (GLOBECOM)*, Florida, USA, Dec. 2010.

  - A.P. Bianzino, C. Chaudet, D. Rossi, J.-L. Rougier, "Energy-Awareness in Network Dimensioning: a Fixed Charge Network Flow Formulation", in *ACM SIGCOMM e-Energy'10*, Extended Abstract, Passau, Germany, April 2010.

EAR: What is next?

- Formulation:
  - *Use of approximate solutions*
  - *Comparison with existing heuristics*
- Refinement of the model:
  - *Evaluation of the robustness of the solution*
  - *Considering optical transmission: periodical signal regeneration, thus length dependent energy consumption*
- Result Analysis:
  - *Impact of Topology: Considering a broader set of scenarios (topologies, and TMs)*
  - *Evaluation of the effects on the inter-domain routing*

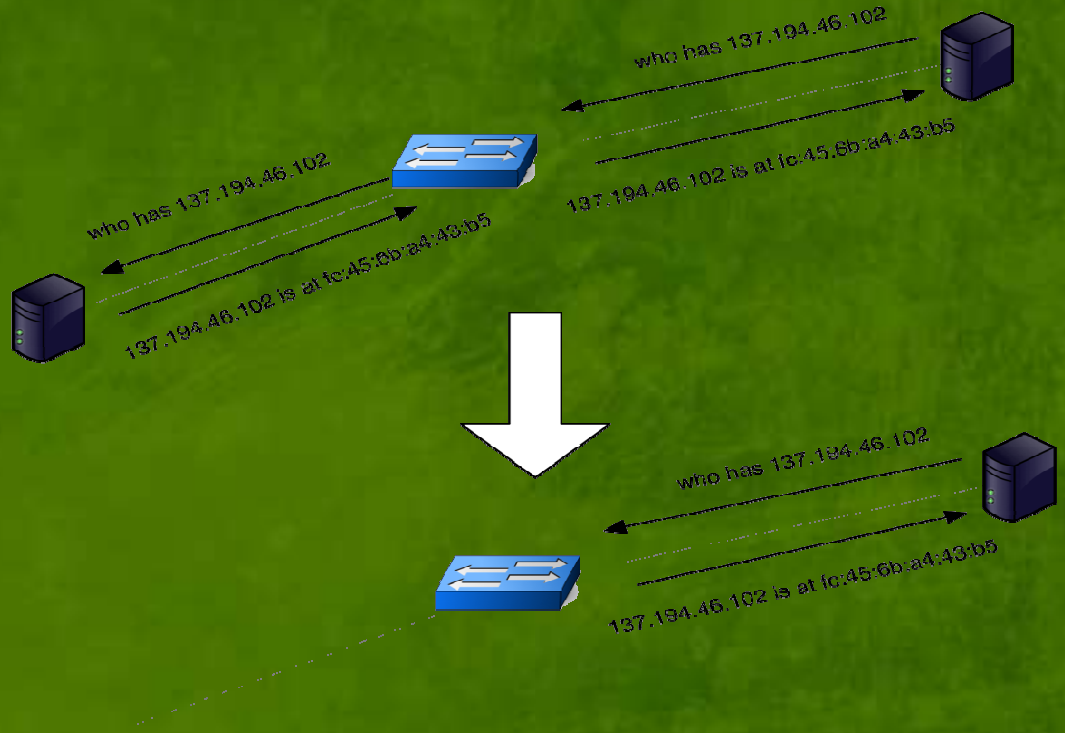
Other Interesting Solutions: ALR

- Automatic adaptation of the link rate to its real utilization

- Different possible algorithms, different possible states/rates
- A comparison is missing
- Evaluation of the interactions with the TCP congestion control
- Evaluation of the effects on the QoS

Other Interesting Solutions: Proxying

- AEx: ARP, BitTorent, …
- Allows terminals to enter into sleep mode



EAR: Further Results (GEANT2)