Energy Saving and Network Performance: a Trade-off Approach

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Introduction

ICT is responsible for a fraction of the world energy consumption ranging between 2% and 10%

Main energy consumers in the ICT field :

- large data centers
- server farms
- telecommunication networks,
  - wired and wireless telephony networks
  - Internet

In Italy, Telecom Italia, consumes more than 2 TWh a year, representing about 1% of the total national energy demand, second only to the Italian railway system

The energy consumption of ICT is expected to grow even further in the future.

Introduction

The attention of the research community and of Telecom operators
only recently started to focus on this theme

Proposed solutions
turn nodes and links off
and re-route traffic to save energy.

TRANSIT NODE/LINK ✓   ~~**NETWORK ACCESS NODE/LINK**~~

The largest fraction of power consumption of an Internet Service Provider (ISP) network is due to access nodes

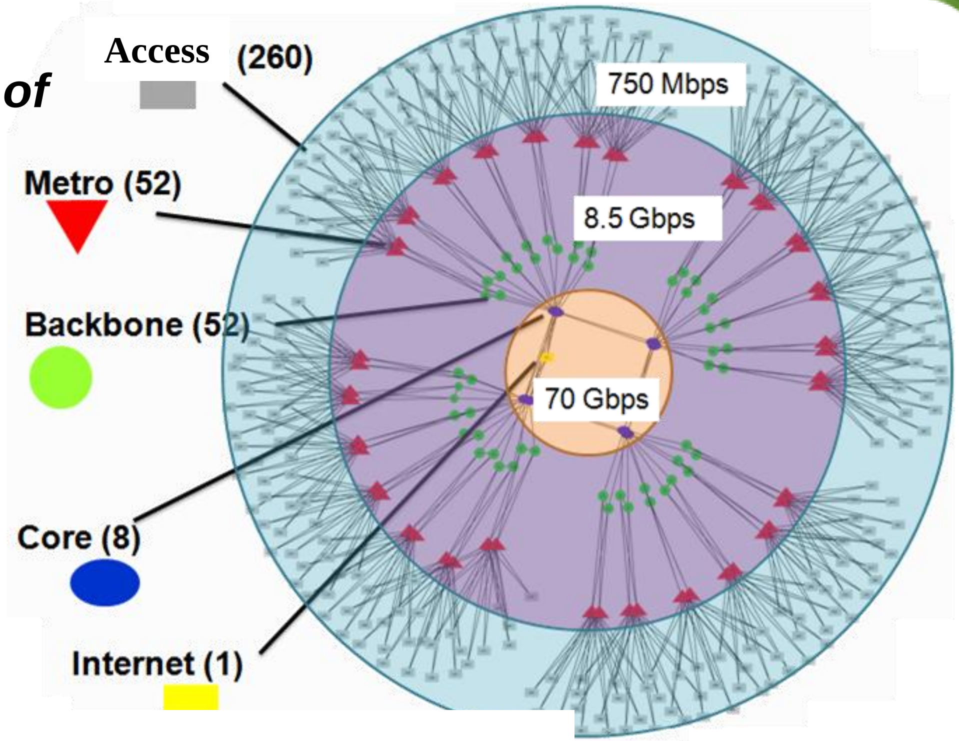
⬇

Solutions to reduce energy consumption without turning nodes off

Introduction

Core/transport and access layers of a network domain: examples of power requirements

To model the energy consumption of routers and links, we consider the specifications of real devices, as provided by the router manufacturers.



Node Type	Power [kW]	Fraction of Total Node Power
Core	10	9.46%
Backbone	3	19.03%
Metro	1	6.32%
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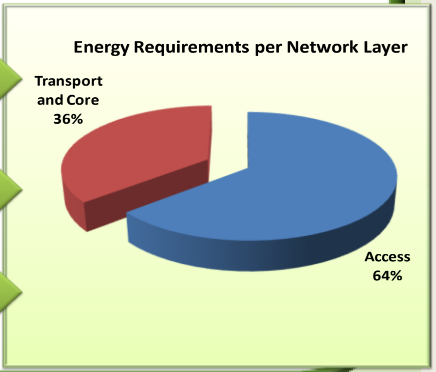
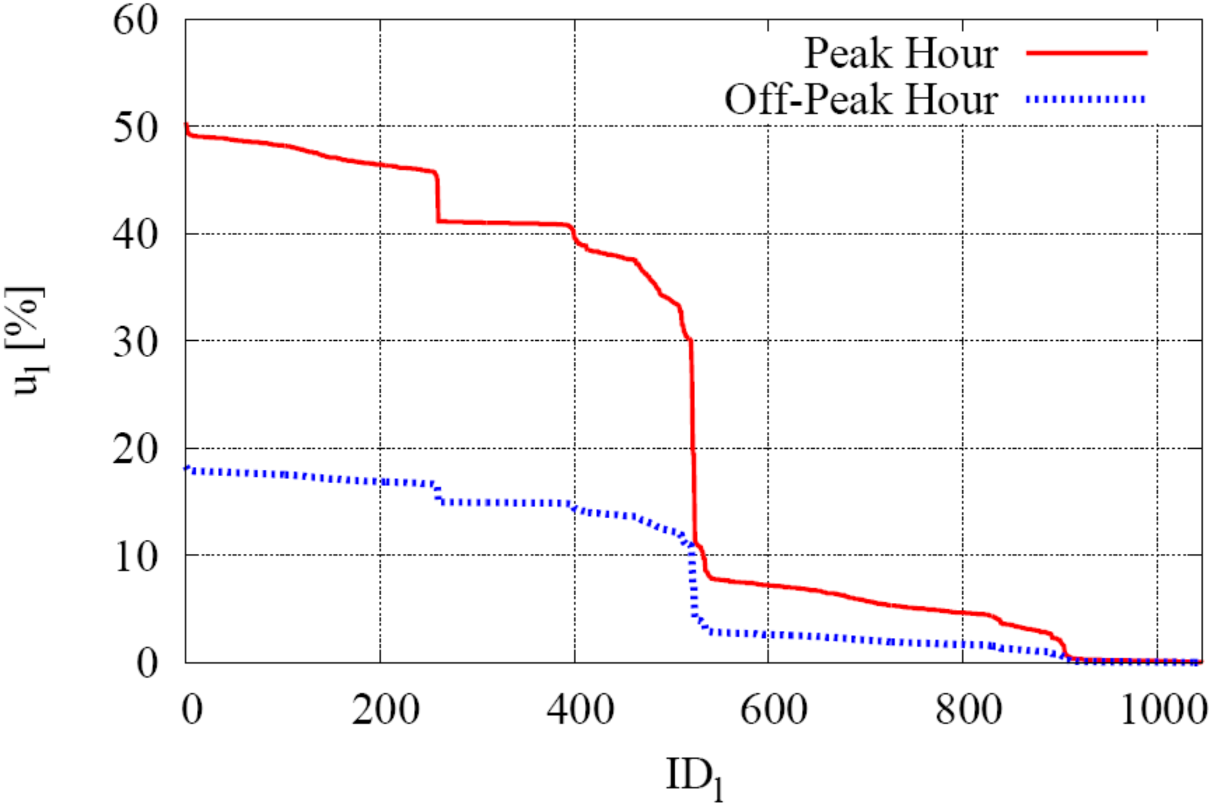


Access Link utilization

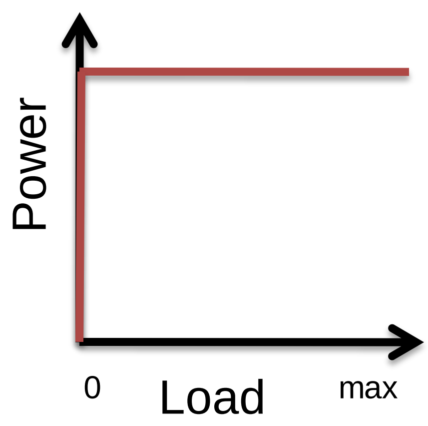


During the peak hour about half of the links are utilized for more than 30%

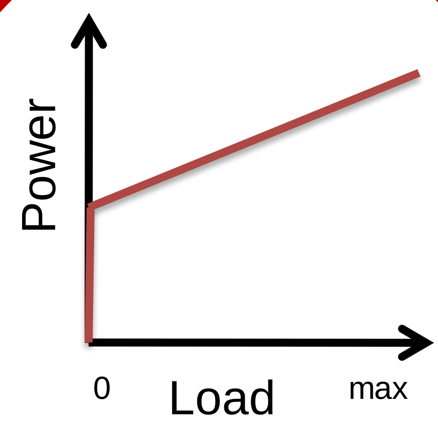
During off-peak time, all links are lightly utilized, never exceeding 20% utilization

Basic idea

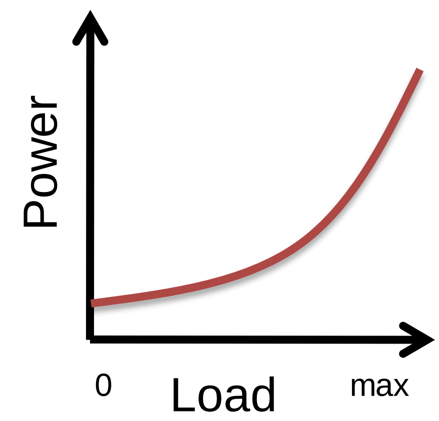
The intuition is to allow network nodes to adapt the switching and transmission capacity to the current traffic demand to save energy and reduce power consumption



On-Off



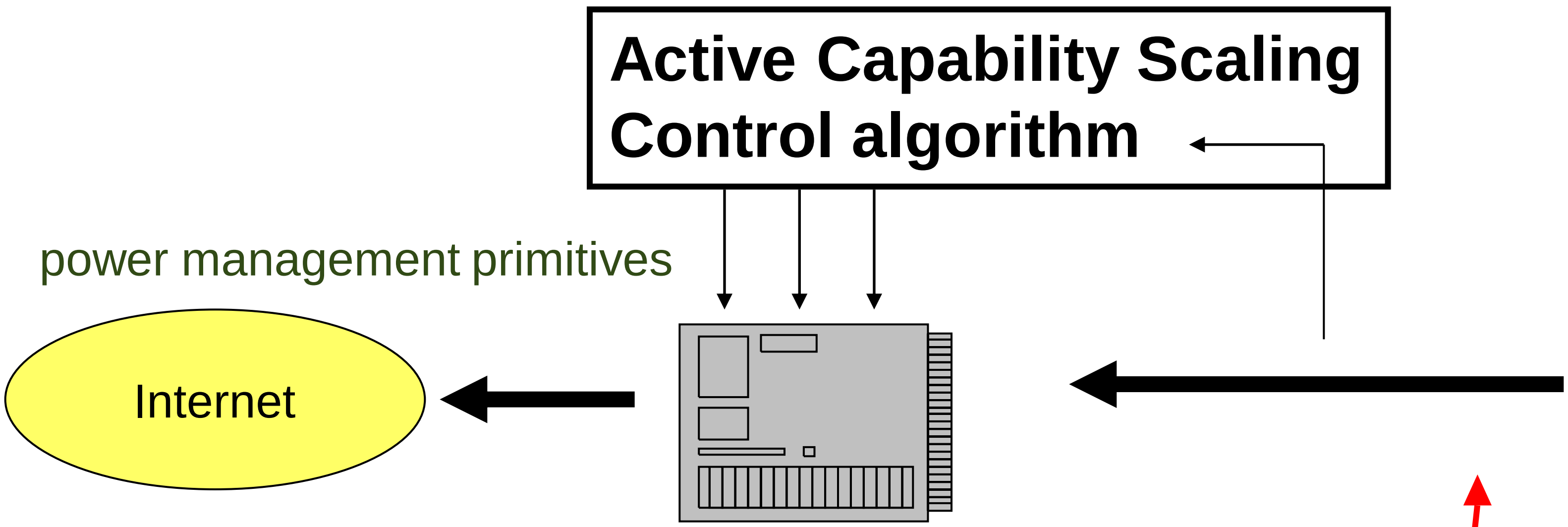
Linear



DVS

The technology to implement variable capacity electronic devices and support capacity scaling is readily available, as for example implemented in modern PCs and mobile devices

Paper target



Determining the minimum amount of capacity each network device has to offer to meet the actual traffic demand.

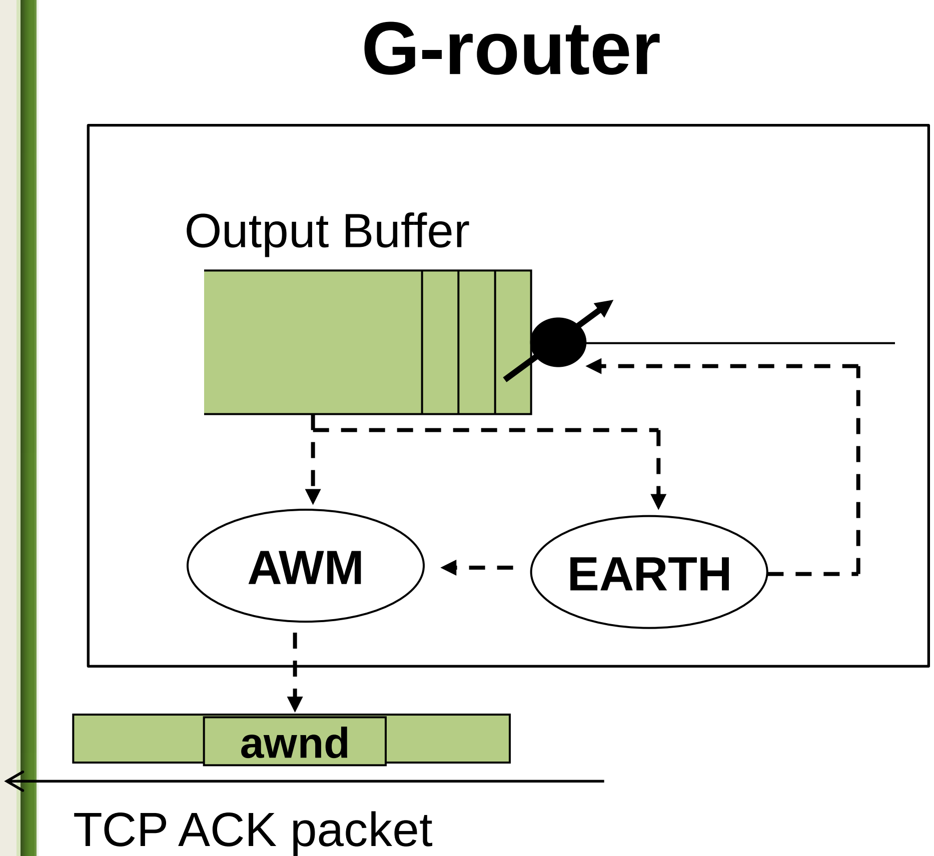
QoS vs Energy trade off: minimum between

Input traffic load

Bottlenecks in the Internet

Capacity Scaling Technique

The Green Router

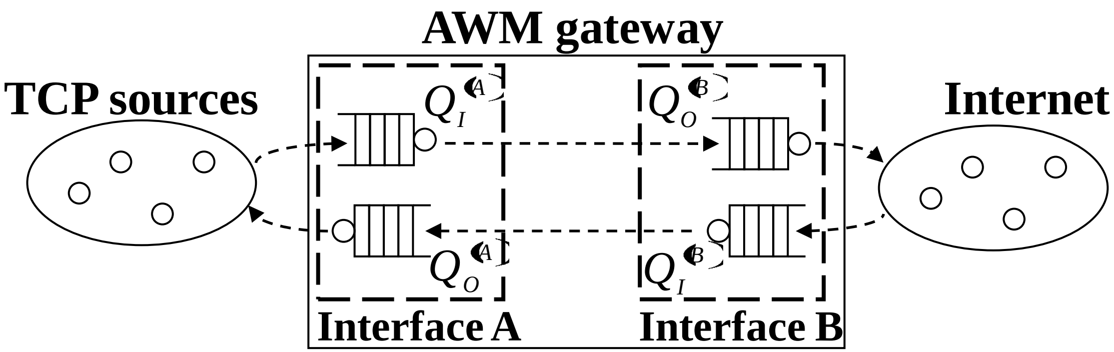


AWM (Active Window Management)*: stabilize the buffer queue length around a *target* value when the access node is the bottleneck

The buffer empties only when the output capacity is higher than the offered load or the access node is not the bottleneck

EART (Energy Aware service Rate Tuner Handling) detects this condition and determines the minimum amount of capacity between the actual traffic demand/the bottleneck capacity in the Internet

The AWM Mechanism



Designed to maximize net utilization with no packet loss *

Estimates the number of bytes that it would receive from TCP source in order to maintain the queue length $Q_O^{(B)}$ in the the buffer close to a target value

Considers the *Advertised Window* field (*awnd*) in the TCP ACK packet queued in the buffer $Q_O^{(A)}$, and changes the *awnd* value with a Suggested Window (*swnd*), if and only if *awnd* > *swnd*

*M. Barbera, A. Lombardo, C. Panarello, G. Schembra, **Queue Stability Analysis and Performance Evaluation of a TCP-Compliant Window Management Mechanism**, to appear on Transaction on Networking

Capacity Scaling Technique

The AWM Mechanism

The value of $swnd_k$ corresponding to the k-th updating event is:

$$swnd_k = \max\left(swnd_{k-1} + DQ_k + DT_k, MTU\right)$$

To avoid the *Silly Window Sindrome*

DQ_k makes a negative contribution to *swnd* when the instantaneous queue length is greater than its previous value, and a positive contribution in the opposite case:

$$DQ_k = \frac{1}{N}\left(q_{k-1} - q_k\right)$$

Estimation of the number of active TCP flows passing through the AWM gateway

DT_k makes a positive contribution when the queue length is less than the target value, and a negative contribution in the opposite case:

$$DT_k = \alpha\left(target - q_k\right)$$

Parameter that control the convergence to the target

Capacity Scaling Technique

The AWM Mechanism

Since the queue length converge to target, at the steady state the derivative of the queue length is zero. As a consequence:

$$\frac{dq(t)}{dt} = \frac{N \cdot W(t)}{R(t)} - C = 0 \Rightarrow N \cdot W(t) = R(t) \cdot C$$

If we assume that the average round trip time does not suffer appreciable variation during the system evolution, the product NW should be costant:

$$N_{k-1} \cdot W(t_{k-1}) = N_k \cdot W(t_k)$$

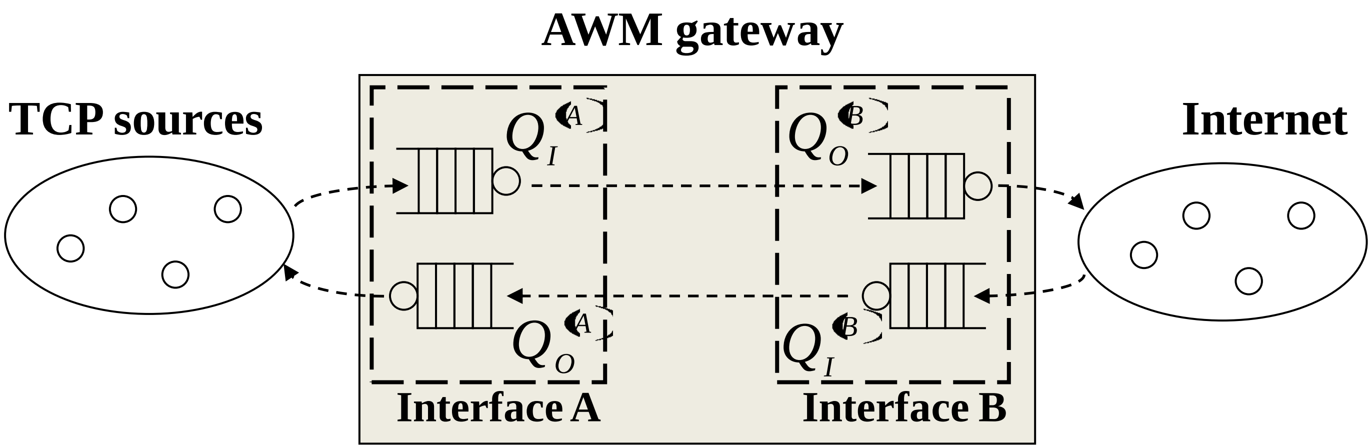
If the AWM algorithm need to change the value of suggested window sent to TCP sources, the reason is that a variation in the number of active sources is occurred. The new value of N is:

$$N_k = \frac{N_{k-1} \cdot W(t_{k-1})}{W(t_k)}$$

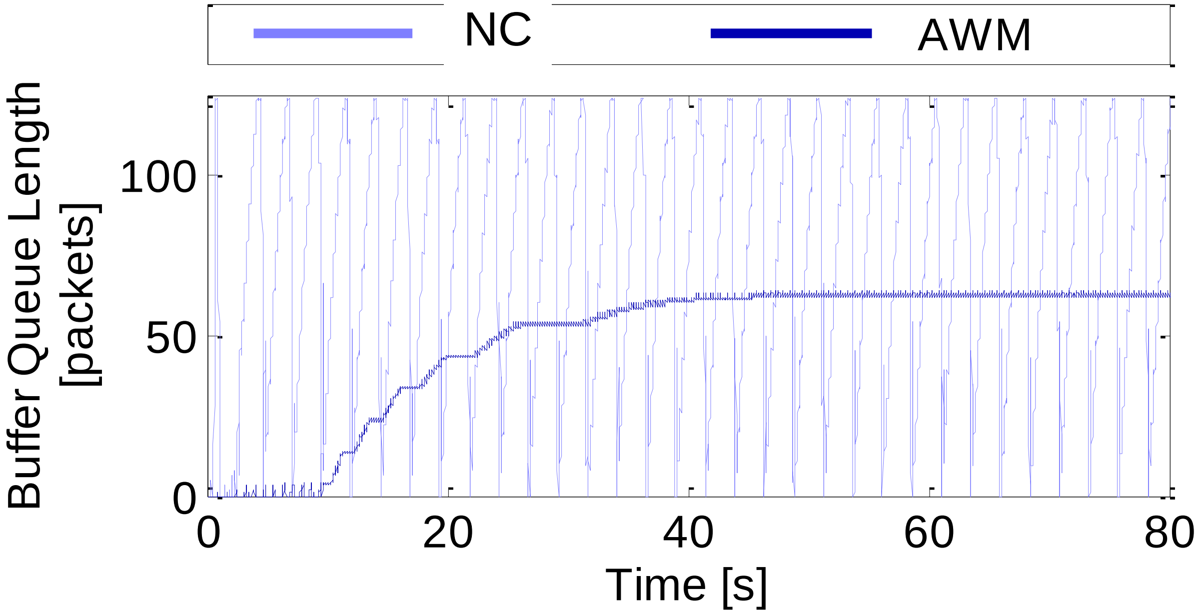
The AWM Mechanism

The AWM gateway updates the *swnd* value on the occurrence of two possible updating events:

- A data packet arrives in the buffer
- A data packet leaves the buffer



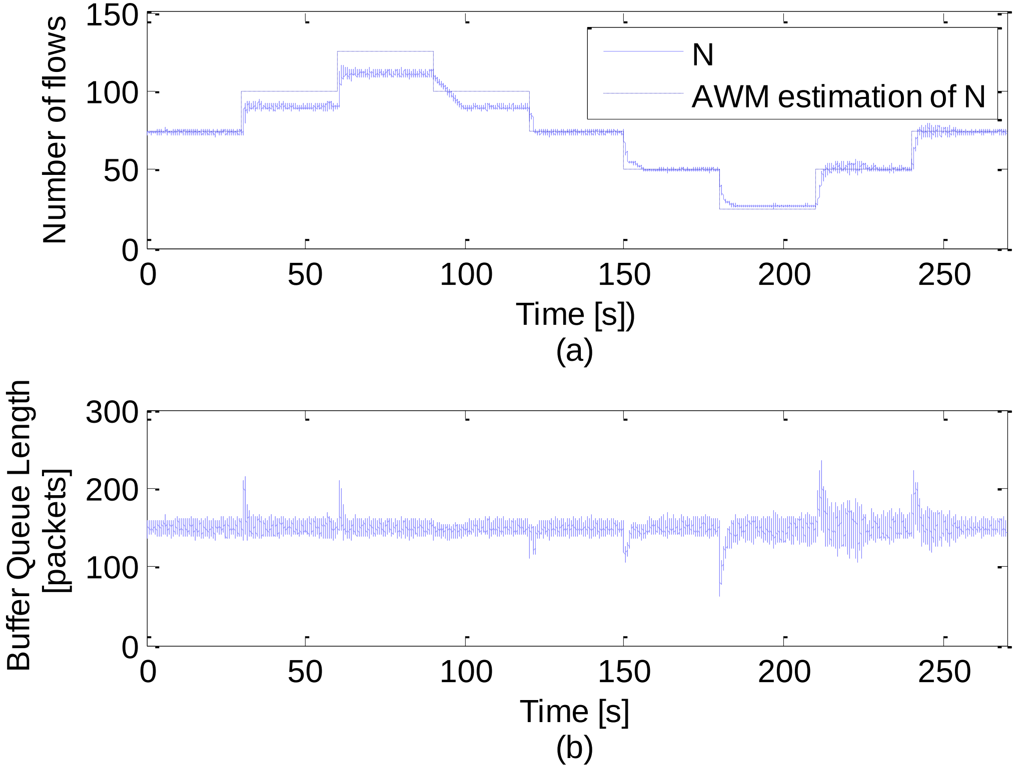
The AWM Mechanism



AWM stabilizes the buffer queue length around the *target* value in the bottleneck node

Capacity Scaling Technique

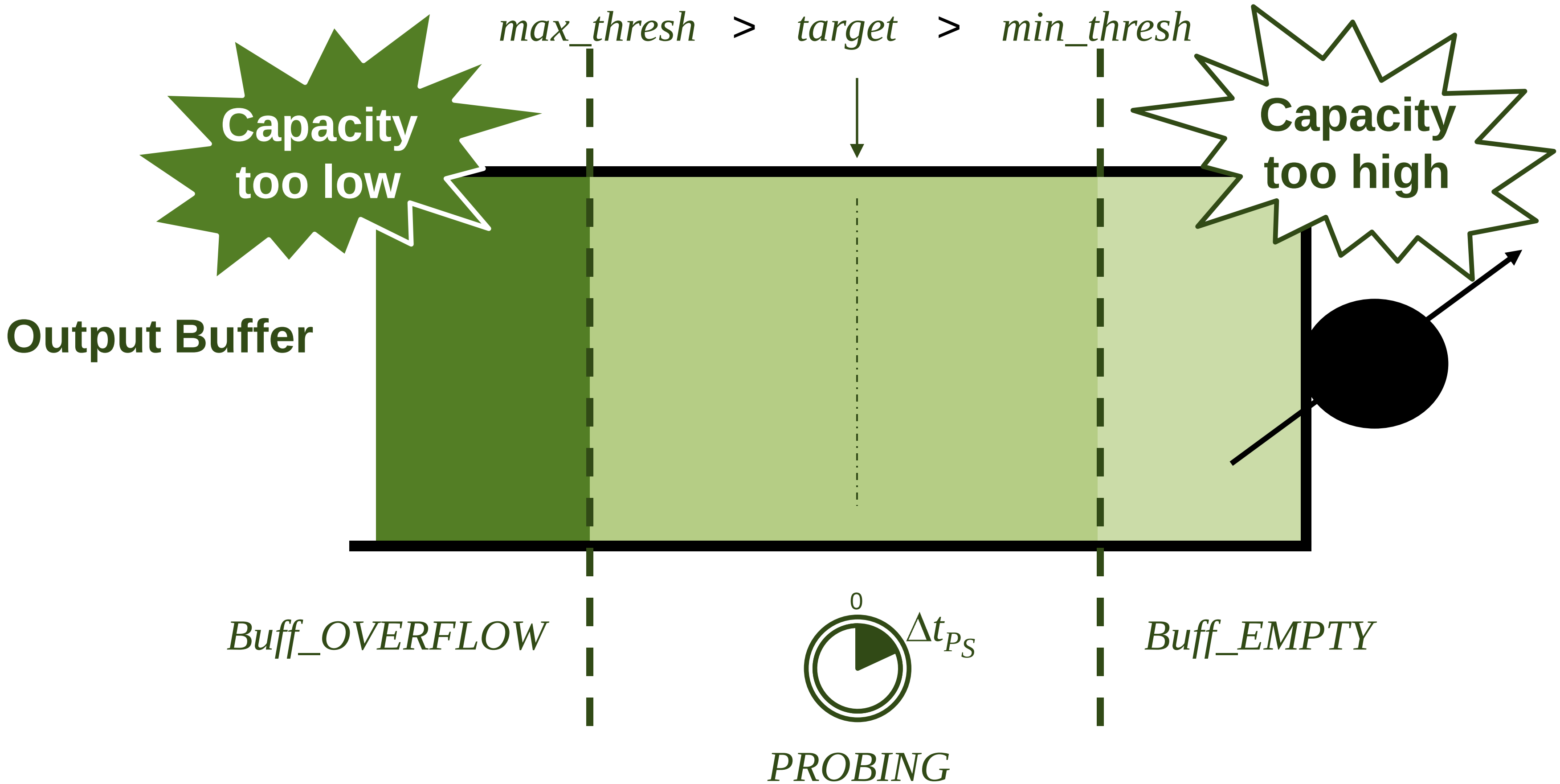
The AWM Mechanism



Estimation of the number of flows

Capacity Scaling Technique

AWM towards EARTH



Capacity Scaling Technique

The EARTH Algorithm

Buff_EMPTY	→	**DECREASE Capacity**	every Δt_E seconds until $q > min\_thresh$
PROBING	→	**INCREASE Capacity**	every Δt_P seconds while $min\_thresh < q < max\_thresh$
Buff_OVERFLOW	→	**INCREASE Capacity**	every Δt_O seconds until $q < max\_thresh$

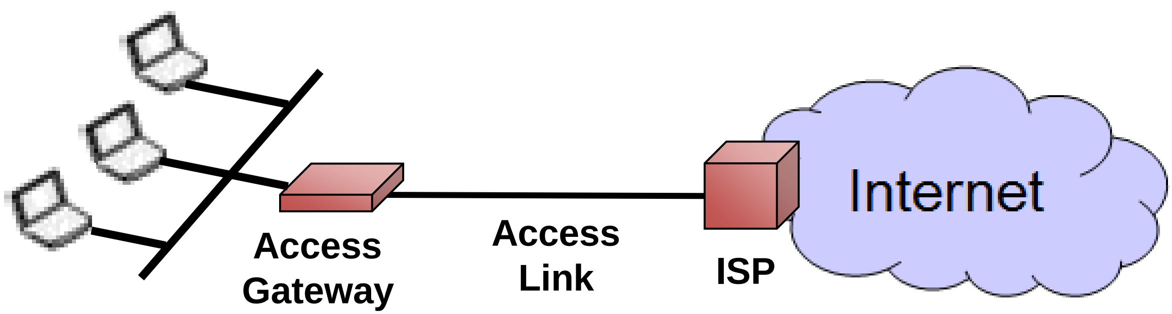
Simulation Results

Network Topology

Round-Trip Propagation Delay: 100ms
MTU length: 1000 bytes
Buffer size: 125 packets
Source down-link rate: 20Mb/s
Source up-link rate: 1Mb/s
Number of Web-like source: Poisson-distributed (average: 5 web file request ps)
Web File size: Pareto-distributed (average: 200 packets and shape: 1.35)
Average Number of FTP-like source: 10

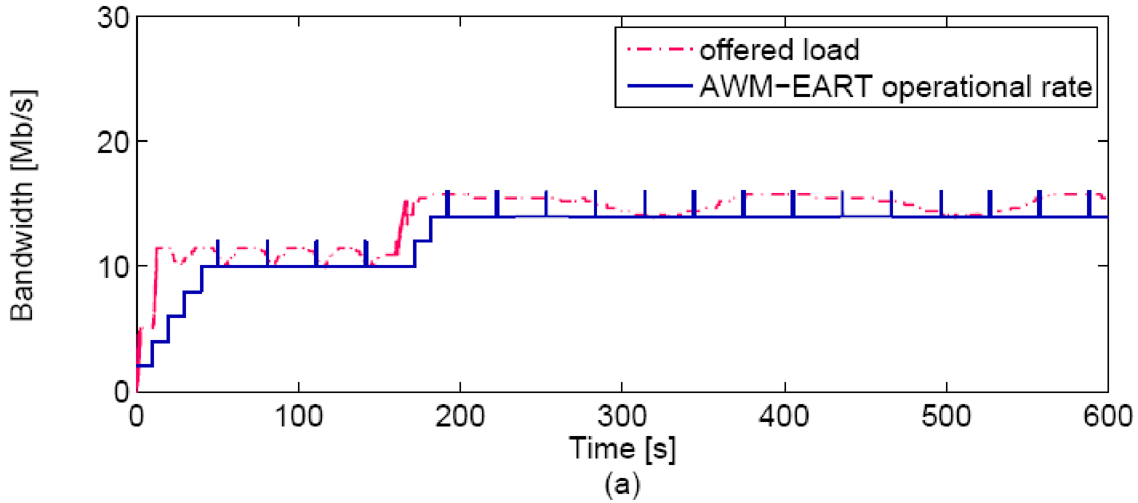
AWM
target: Buffer_size / 2
β: 20kB/s

EARTH
min_thresh: 0
max_thresh: (Buffer size + *target*)/2
ΔtE: 10 seconds
ΔtO: 10 seconds
ΔtPS: 10 seconds
ΔtP: 30 seconds
ΔC: 2Mb/s

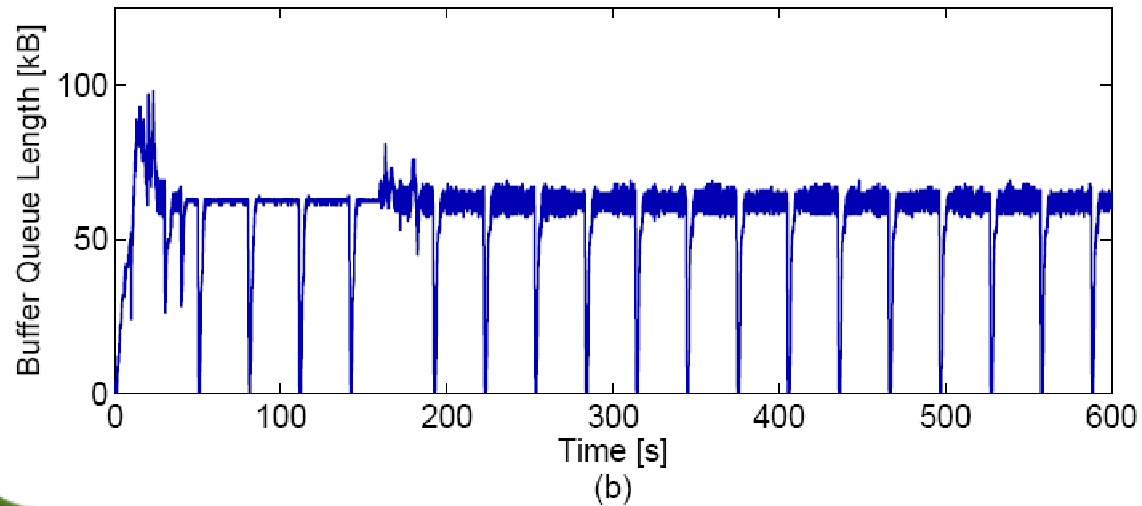


Simulation Results

Case Study 1



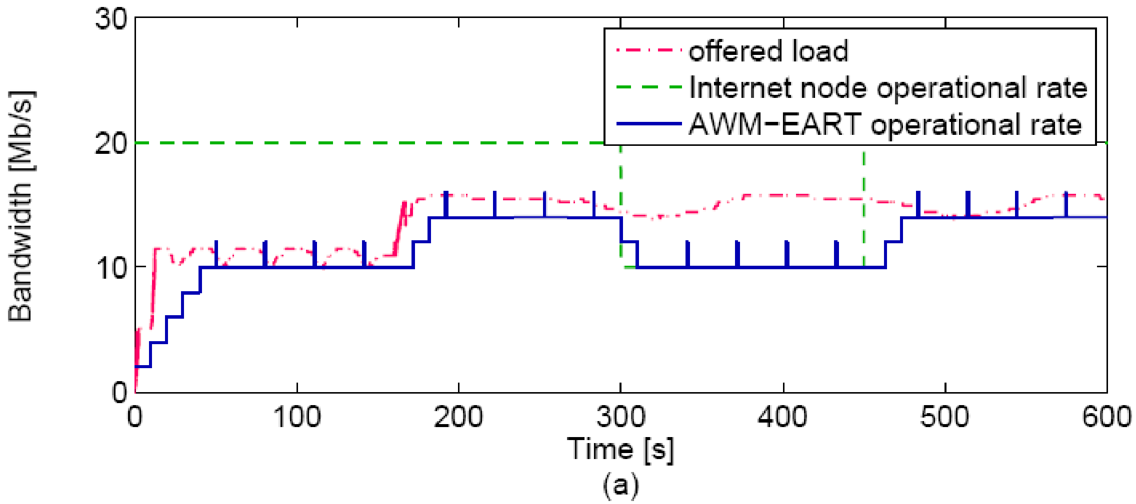
G-router output capacity determined by the EARTH algorithm



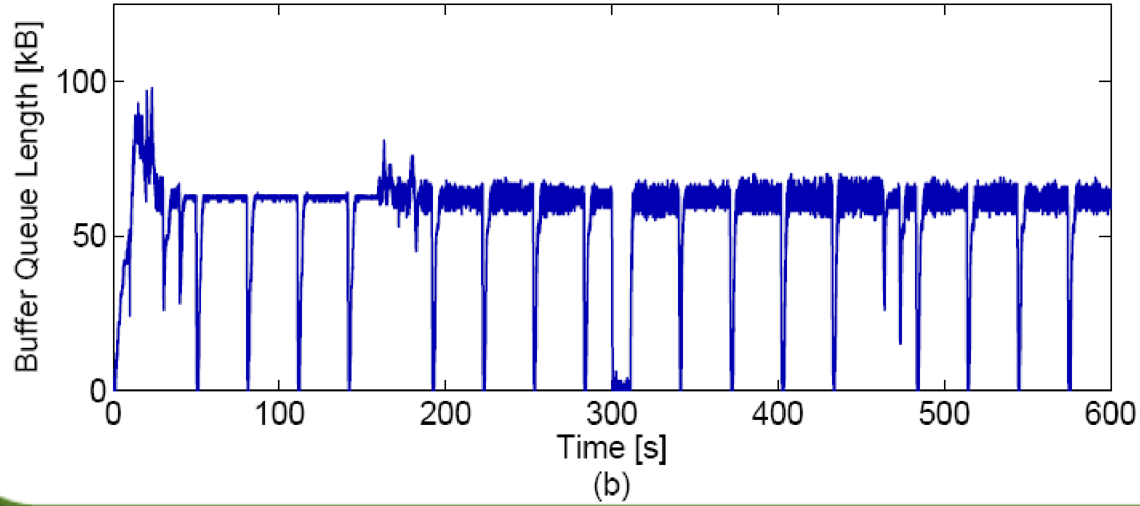
Output Buffer Queue length in the G-router

Simulation Results

Case Study 2



G-router output capacity determined by the EARTH algorithm



Output Buffer Queue length in the G-router

Deploying ACS tech.

Core/transport and access layers of a network domain: examples of power requirements

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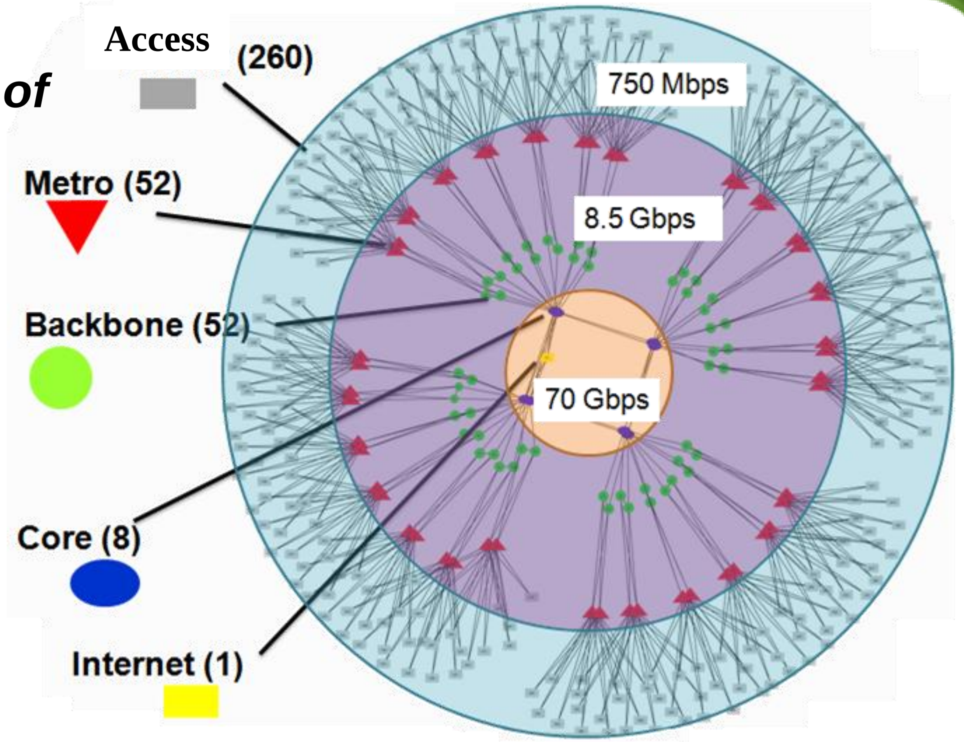

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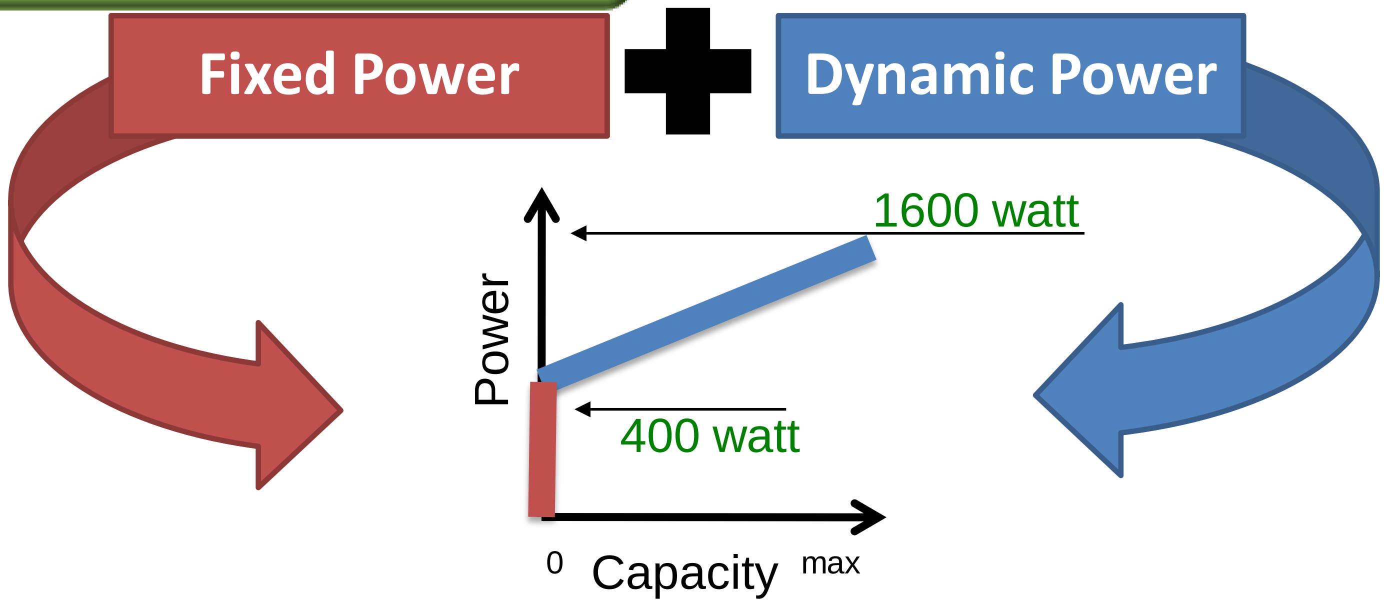
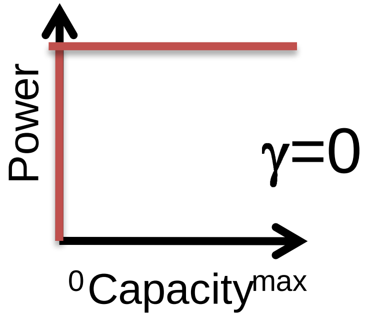
Deploying ACS tech.

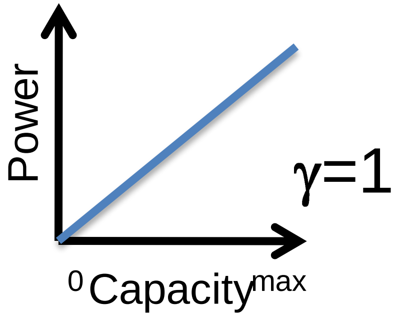
Link Power Model



Total_Power = (1 - γ) · Fixed_Power + γ · Dynamic_Power(Capacity)



γ measures the ACS capability



Deploying ACS tech.

Numerical results

Power Saving variation ζ for different power saving capabilities (γ)

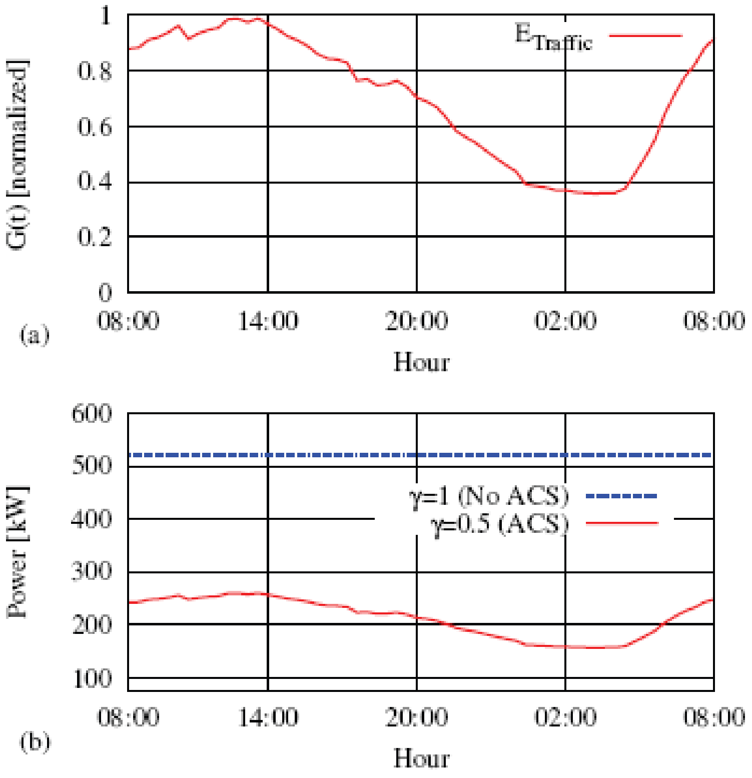


Figure 3: Total traffic daily pattern (top plot), and corresponding power variation when ACS is adopted (bottom plot).

Deploying ACS tech.

Numerical results

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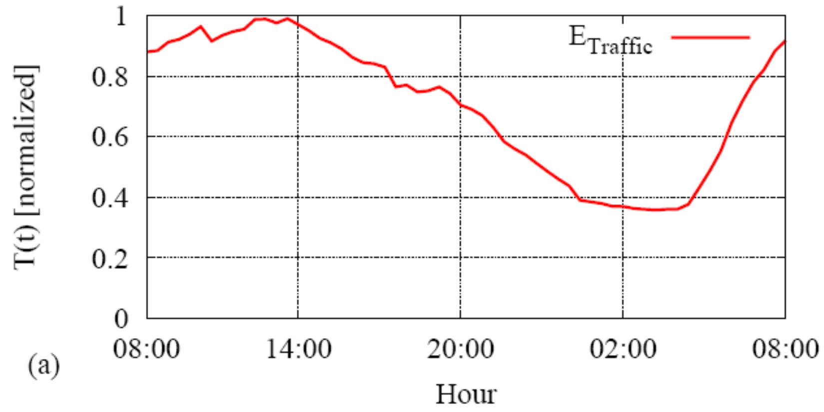

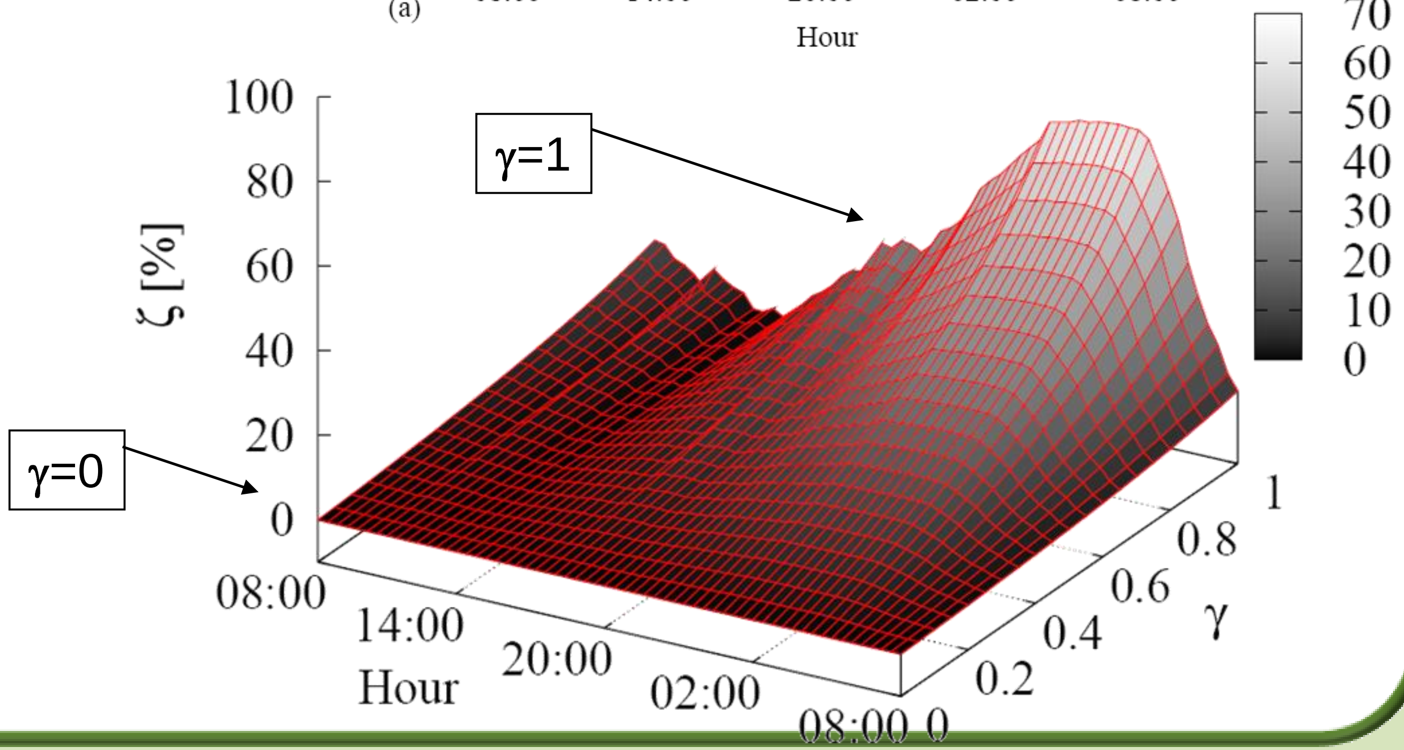

Conclusions

An analytical study over a real ISP topology show that capacity scaling techniques can save up to 60 - 70% of total access network power consumption during off peak hours

The proposed AWM-EARTH mechanism provides for Active Capacity Scaling capability the access nodes of an ISP network

Simulation results have demonstrated that AWM-EARTH is able to adapt the capacity in order to meet the minimum value between the offered load and the forward bottleneck capacity, thus limiting the waste of energy

As a future work we plan to better assess the performance of the AWM-EARTH mechanism considering the impact of design parameters

AWM: Estimation of the number N of TCP flows

Since the queue length converge to target, at the steady state the derivative of the queue length is zero. As a consequence:

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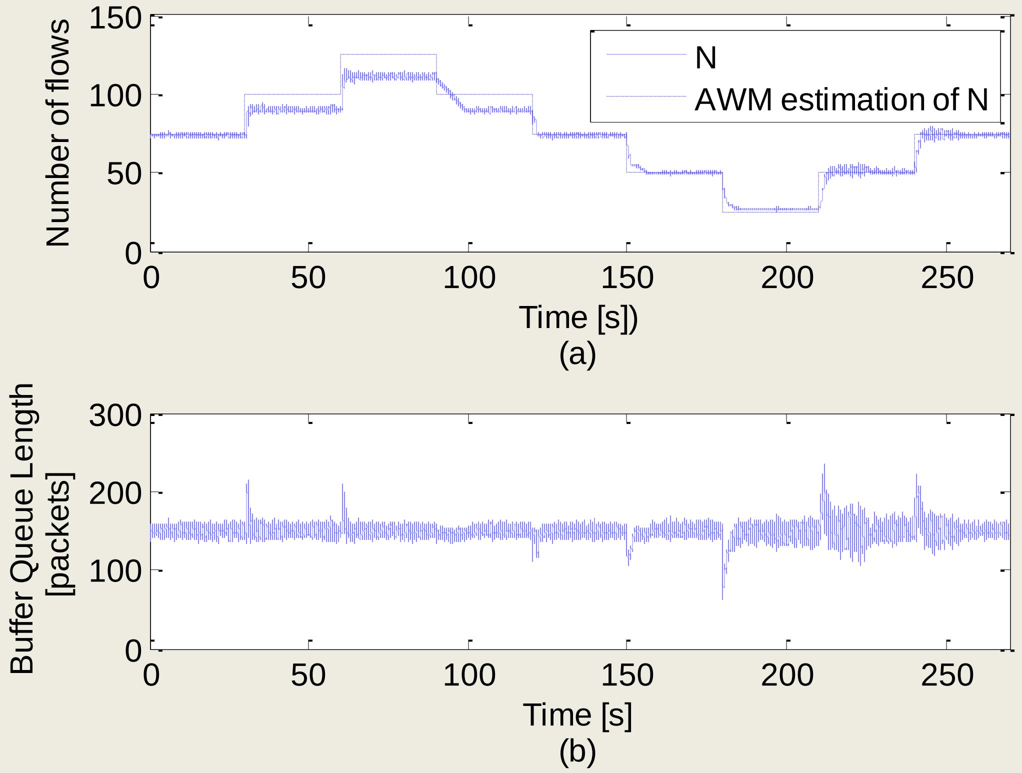
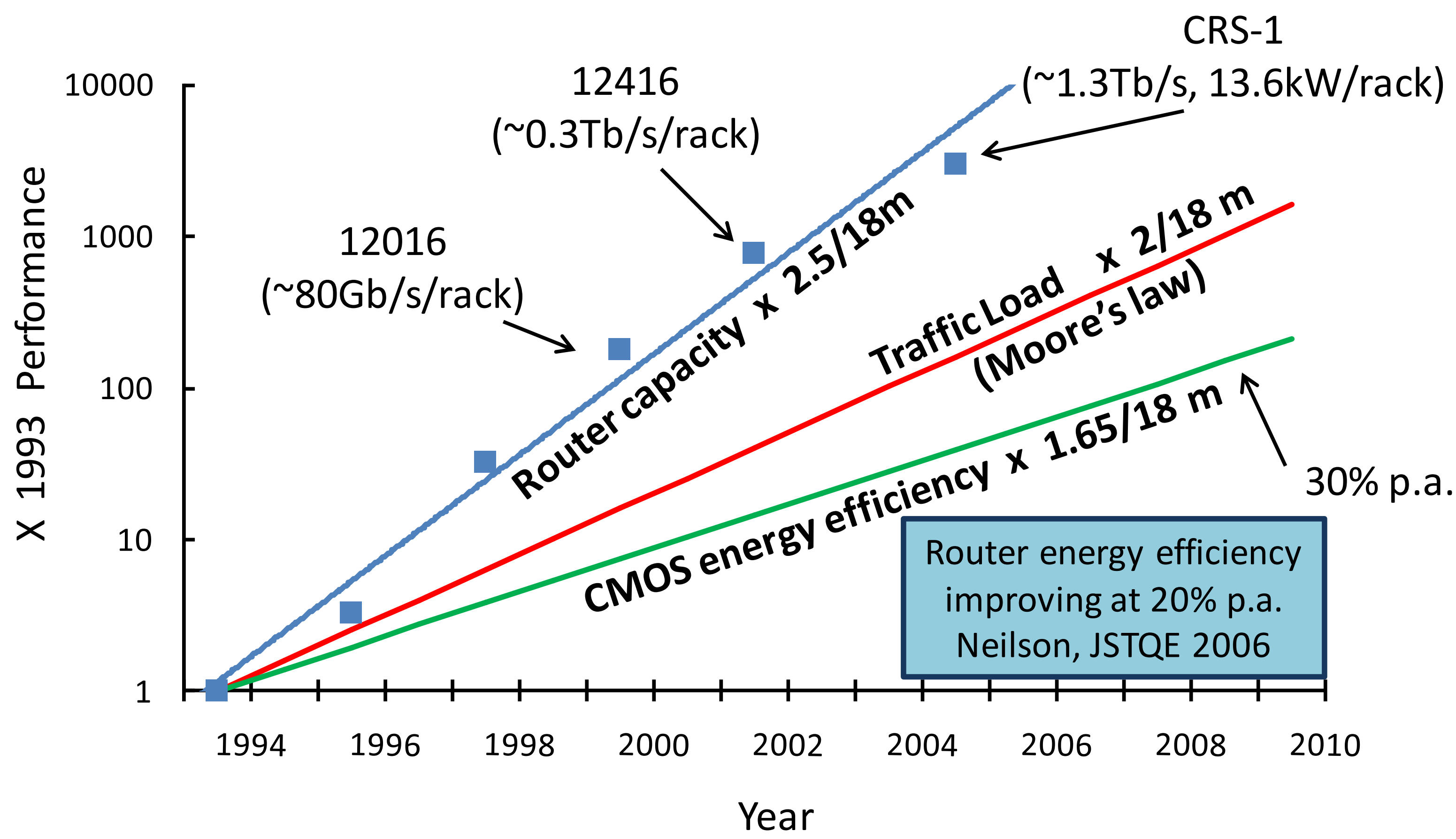
AWM: Model Assessment and Design

Estimation of the number of flows

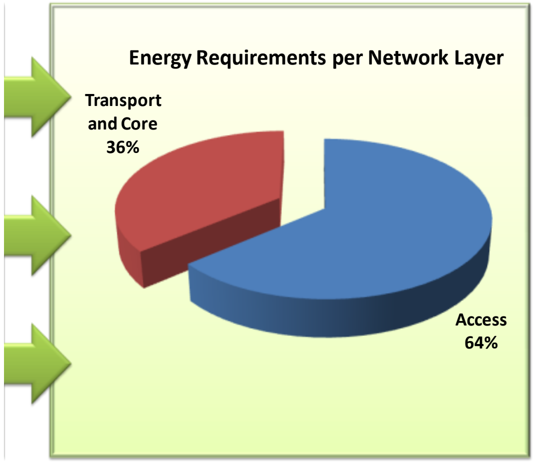


Introduction



Introduction

The largest fraction of power consumption of an Internet Service Provider (ISP) network is due to access nodes



Solutions to reduce energy consumption without turning nodes off