ACADÉMIE DES TECHNOLOGIES

POUR UN PROGRÈS RAISONNÉ CHOISI PARTAGÉ

Energy Consumption By ICT: Facts, Measurements and Trends

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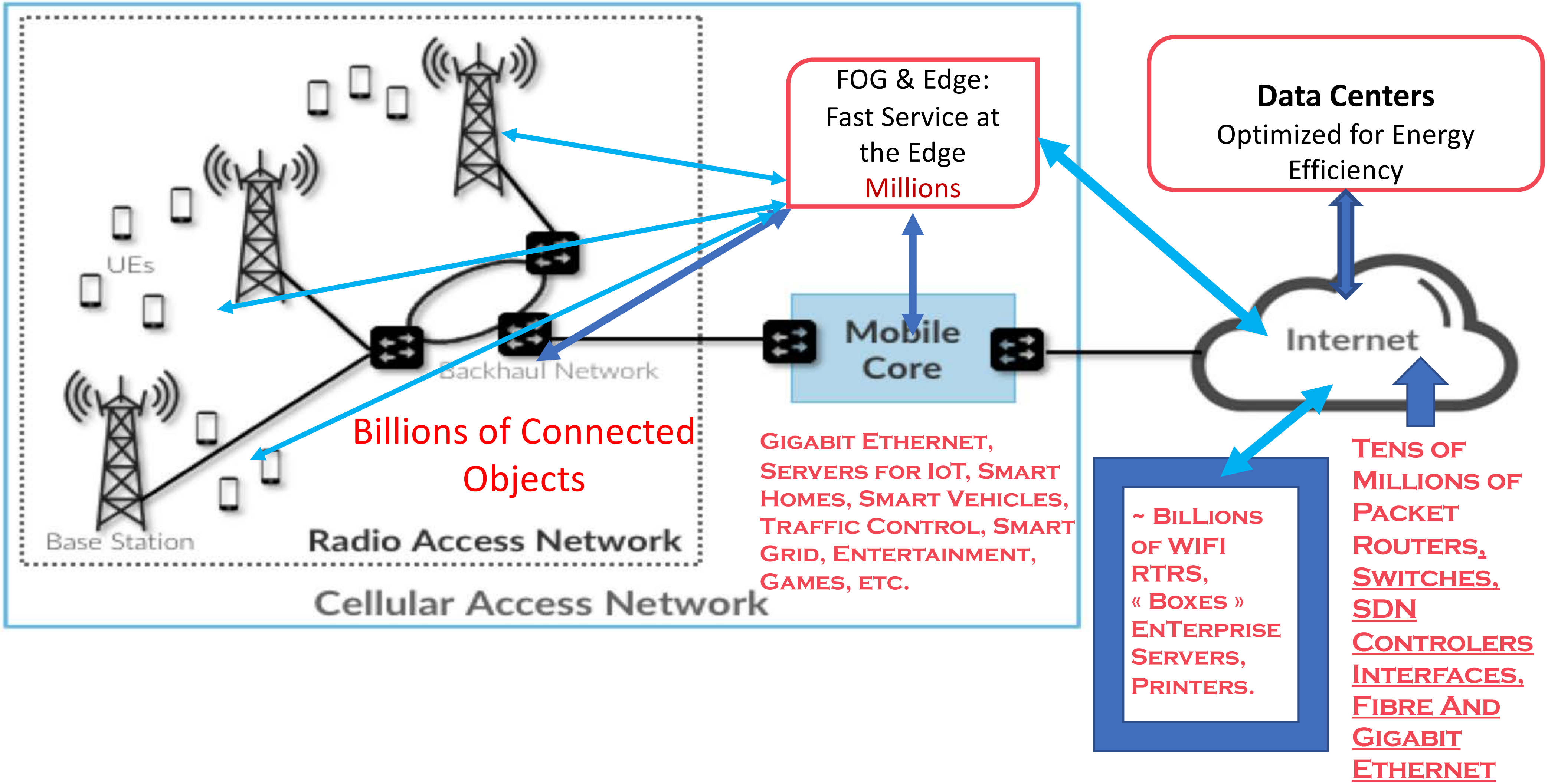
Worldwide ICT Architecture



Worldwide ICT Electricity Consumption

8 TO 9% OF TOTAL

Figures From 2019 ~8.5%

WORLDWIDE ELECTRICITY	~23500	TWH
DATA CENTRES	~ 200	TWH
NETWORKS: INTERNET & RAN	~ 250	TWH
END USERS	~ 550	TWH
MANUFACTURING OF ICT	~1000	TWH
ICT Electricity Consumption	~ 2000	TWH

Worldwide ICT Electricity Consumption
8 TO 9% OF TOTAL

Figures From 2019 ~8.5 %

WORLDWIDE ELECTRICITY/Yr	~23,500	TWH
ICT Electricity Consumption	~ 2000/Yr	TWH

Decommissioning ???

Extraction of Materials, Rare Earths Etc ???

ICT Electricity Over a 4 Yr EQPT Life-Time:

20% for Manufacturing & 80% For Usage

Worldwide ICT Electricity Trends 2007 to 2019

2019: ~8.5 % Of Total Energy WORLDWIDE ELECTRICITY/Yr ~23,500 TWH ICT Consumption ~ 2000 TWH
Electricity ~38% Of Total Energy Related Emission

D8.1: Overview of ICT energy consumption

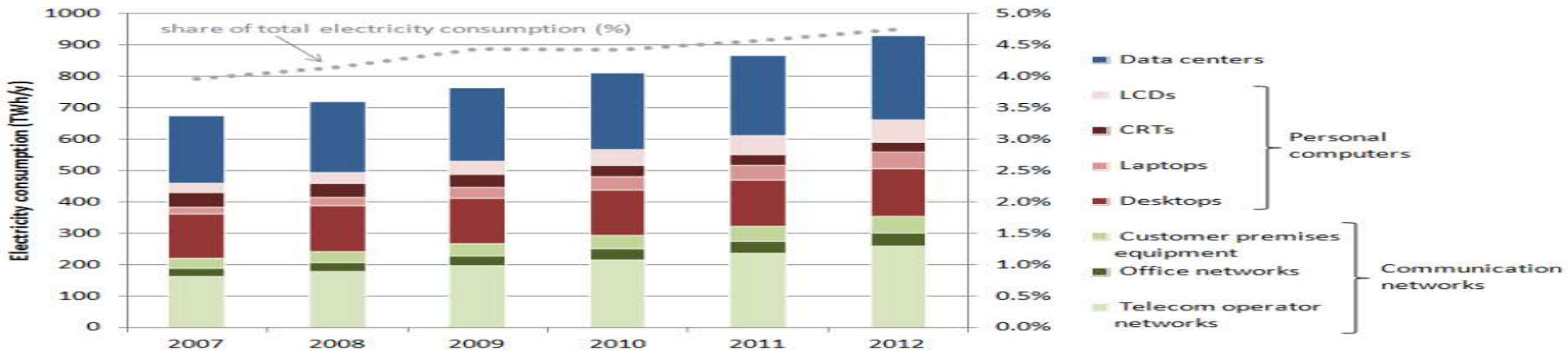


Figure 3-1: Worldwide use phase electricity consumption of communication networks, personal computers and data centers. Their combined share in the total worldwide electricity consumption has grown from about 4% in 2007 to 4.7% in 2012.

ICT Production & Usage ~ 3.23 % Energy Related Emissions
Decommissioning ??? Extraction of Materials, Rare Earths Etc ???

Worldwide ICT Electricity Trends 2007 to 2019

2019: ~8.5 % Of Total Energy WORLDWIDE ELECTRICITY/Yr ~23,500 TWH ICT Consumption ~ 2000 TWH
2010: Worldwide Electricity Consumption 18.443 TWH ICT Consumption ~ 800 TWH (4%)

2010 -> 2019

ICT Electricity Usage Increased 25%

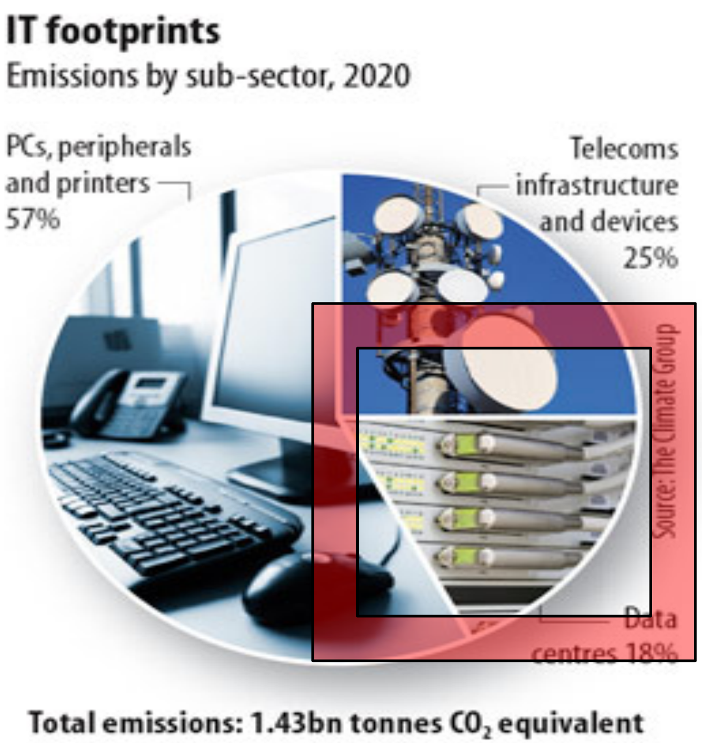
Change in Electricity For ICT Manufacturing Over The Same Period?

WORLDWIDE ICT ELECTRICITY PREDICTIONS 2012

2019: ~8.5 % OF TOTAL ENERGY WORLDWIDE ELECTRICITY/YR ~23,500 TWH ICT CONSUMPTION ~ 2000 TWH
2010: WORLDWIDE ELECTRICITY CONSUMPTION 18.443 TWH ICT CONSUMPTION ~ 800 TWH (4%)

Wrong:
Growth 4%
2020 ICT Carbon
➔
1.43 BTONNES CO_2

2007 ICT =
0.83 BTONNES CO_2
~ Aviation = 2%
Wrong:



2019 : ACTUAL
AVG Growth by
2.7 % Per Year

2019:
~ 1 BTONNES CO_2

2007 ICT =
0.83 BTONNES CO_2
~ Aviation = 2%

2010 -> 2019 ICT ELECTRICITY USAGE INCREASED 25%
CHANGE IN ICT ELECTRICITY FOR MANUFACTURING OVER THE SAME PERIOD?

Impact Of 5G: GSMA Report

GSMA is a global member-led organisation representing the mobile industry. Its members work towards common goals, around priority industry topics such as 5G, IoT, Roaming, AI, Security and SIM Technology.

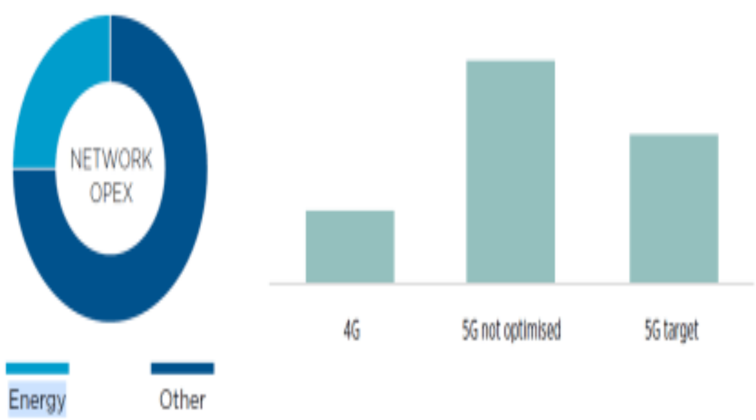
ON OPEX of 22%, Electricity is roughly 25%

Optimized 5G May Consume Roughly 100% More Electricity than 4G

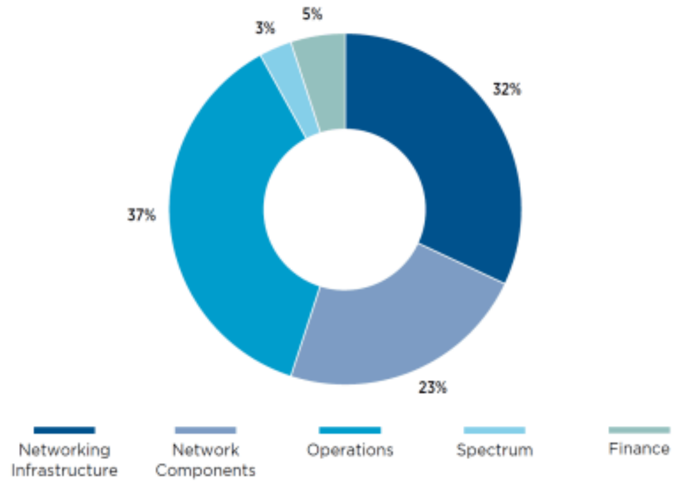
https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

« Huawei estimates that energy consumption will fall initially until around 2021 (MDPI report). However as 5G data traffic (and network deployments) increase, so does energy usage .. at a rate of 5% p.a. from 2022 until 2025 ... contingent on a breakthrough in efficient 5G technologies, a delay of which could see global energy usage increasing by an additional incremental 30% »

PROJECTED IMPACT OF ENERGY OPTIMISATION IN 5G NETWORKS (SOURCE: ORANGE)



TOTAL COST OF OWNERSHIP, BASED ON THE GSMA'S NETWORK ECONOMICS MODEL ESTIMATE FOR A HYPOTHETICAL OPERATOR IN A MOSTLY DEVELOPED MARKET



How Can We Moderate The Electricity Consumption of Ict?

- Measure The Consumption → Massive Data+ Massive Data Transfers and Computation + More Data Centers
- Optimum Replacement Policies for Equipment → What Happens to Old Equipment?
- Dynamic Management of QoS + Energy → Complexity + Risks of Failures
- Dynamic Sleep → Reduced Performance (Delay, Loss of Data) and Energy To « go to sleep » and « Wake Up » + « Denial Of Sleep Attacks »

Zero Traffic is Rare: Hard to Go To Sleep ..

A. Gallal et al. (2016), "Power Consumption of Packet Processing Engines and Interfaces of Edge Router: Measurements and Modeling," The Twelfth International Conference on Networking and Services (ICNS) 2016.

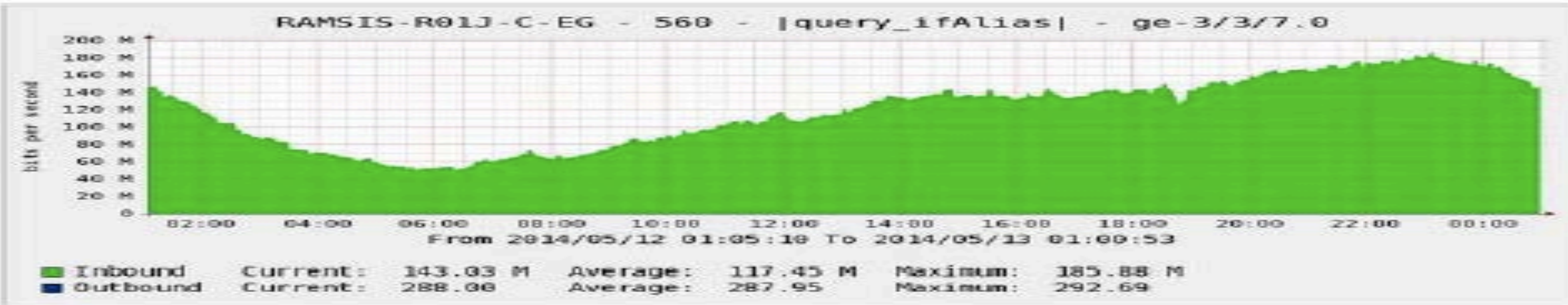


Figure 3. (a) Daily traffic profile of core TE Data network router peering with Vodafone.

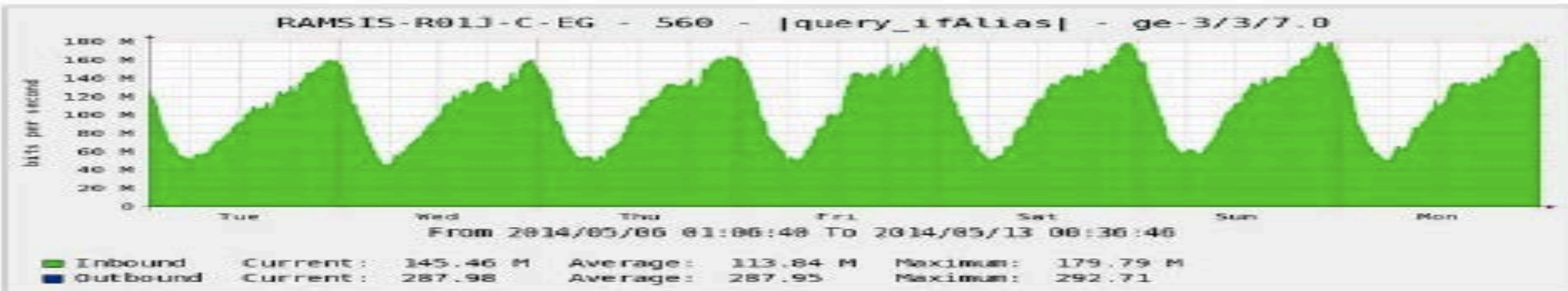
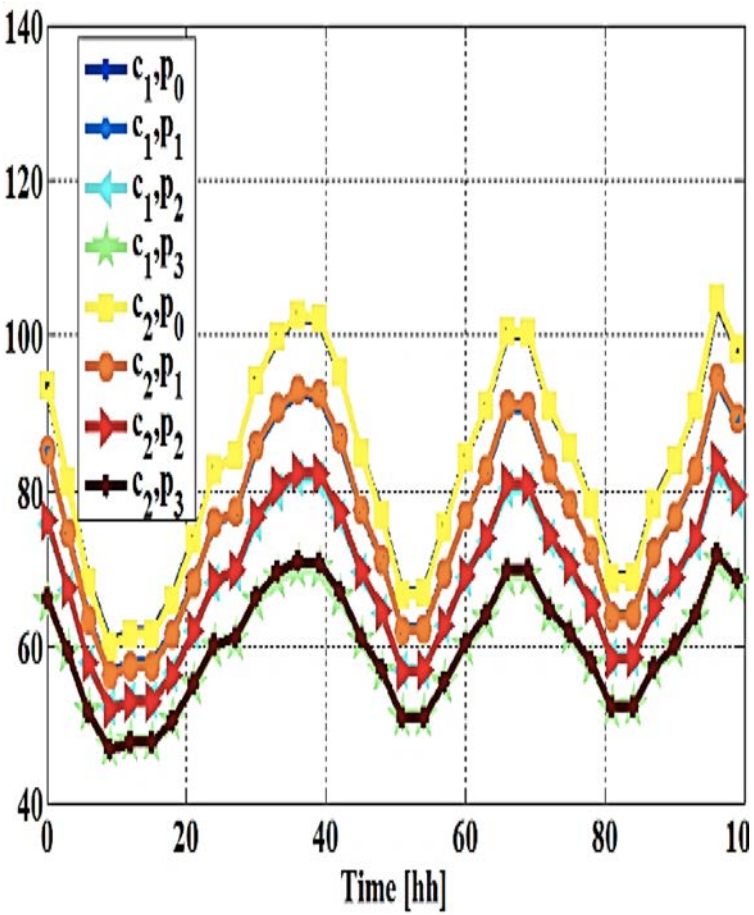
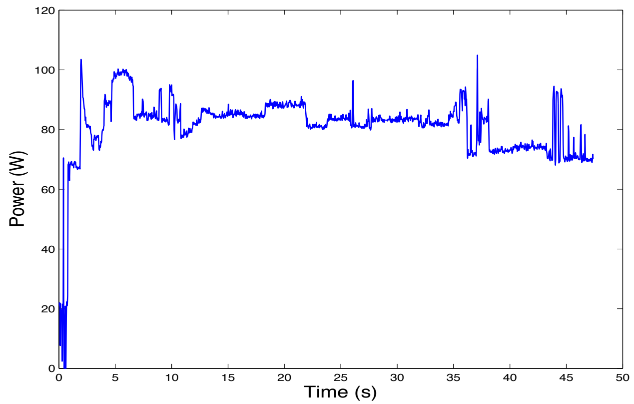


Figure 3. (b) Weekly traffic profile of core TE Data network router peering with Vodafone.

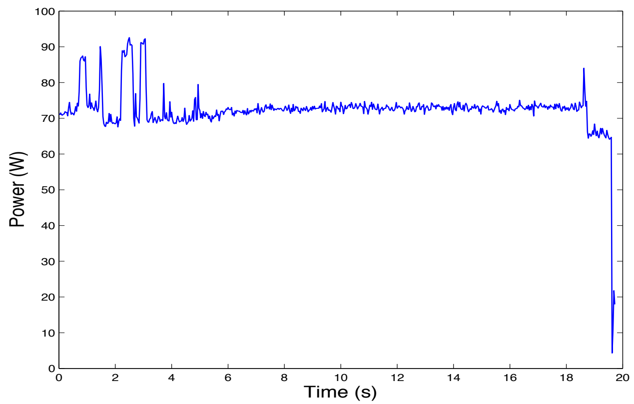
Sleep Mode is Expensive!! !!

Many « PACKETS » are Lost

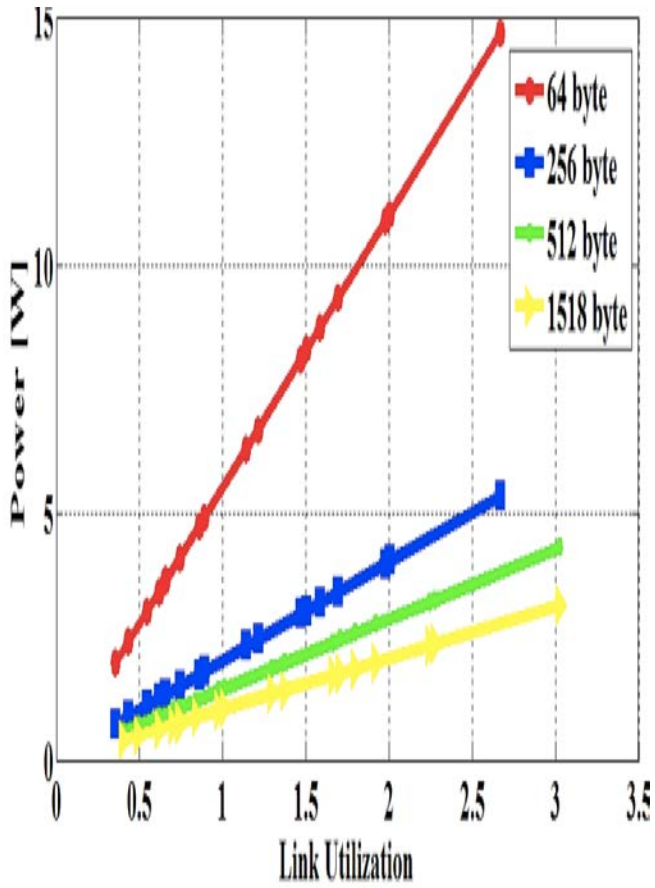




(a) System resuming



(b) System hibernating



When You Go To Sleep You Lose Packets!!

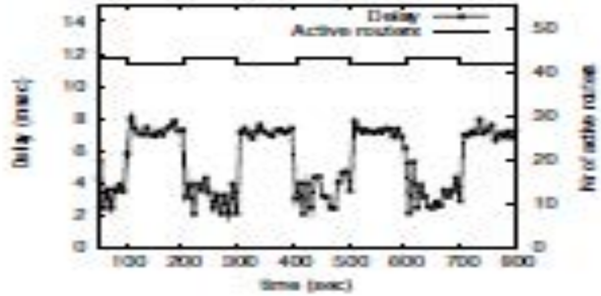


Fig. 5. Delay – second experiment

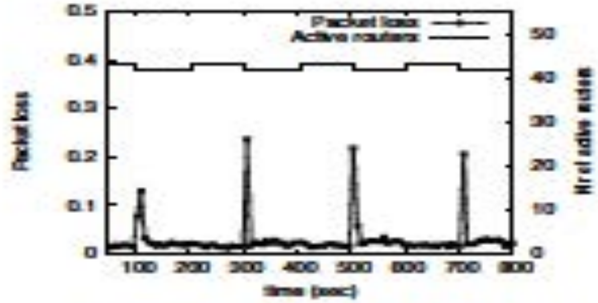
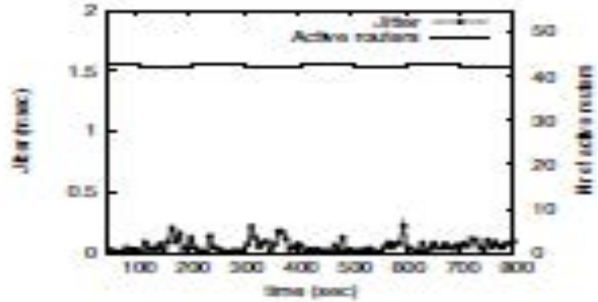
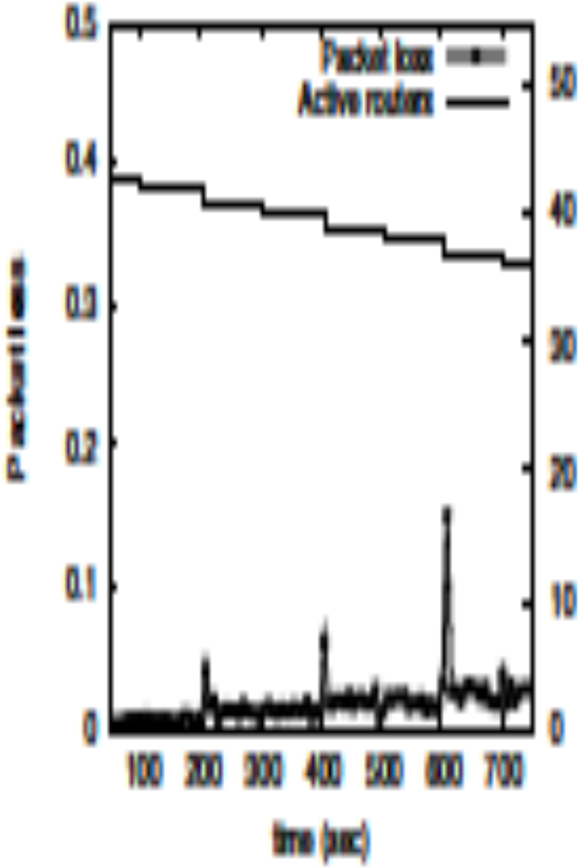


Fig. 6. Packet loss – second experiment





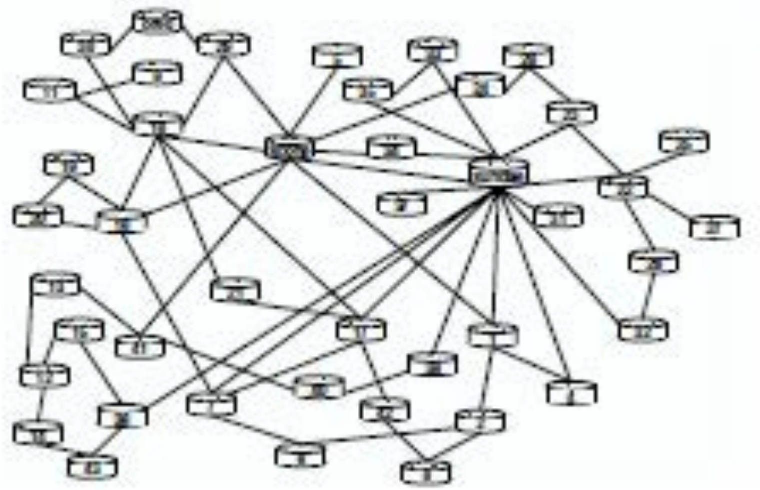
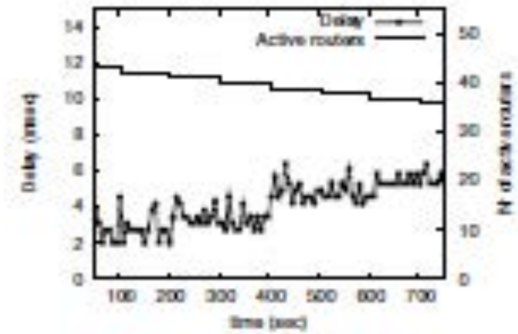


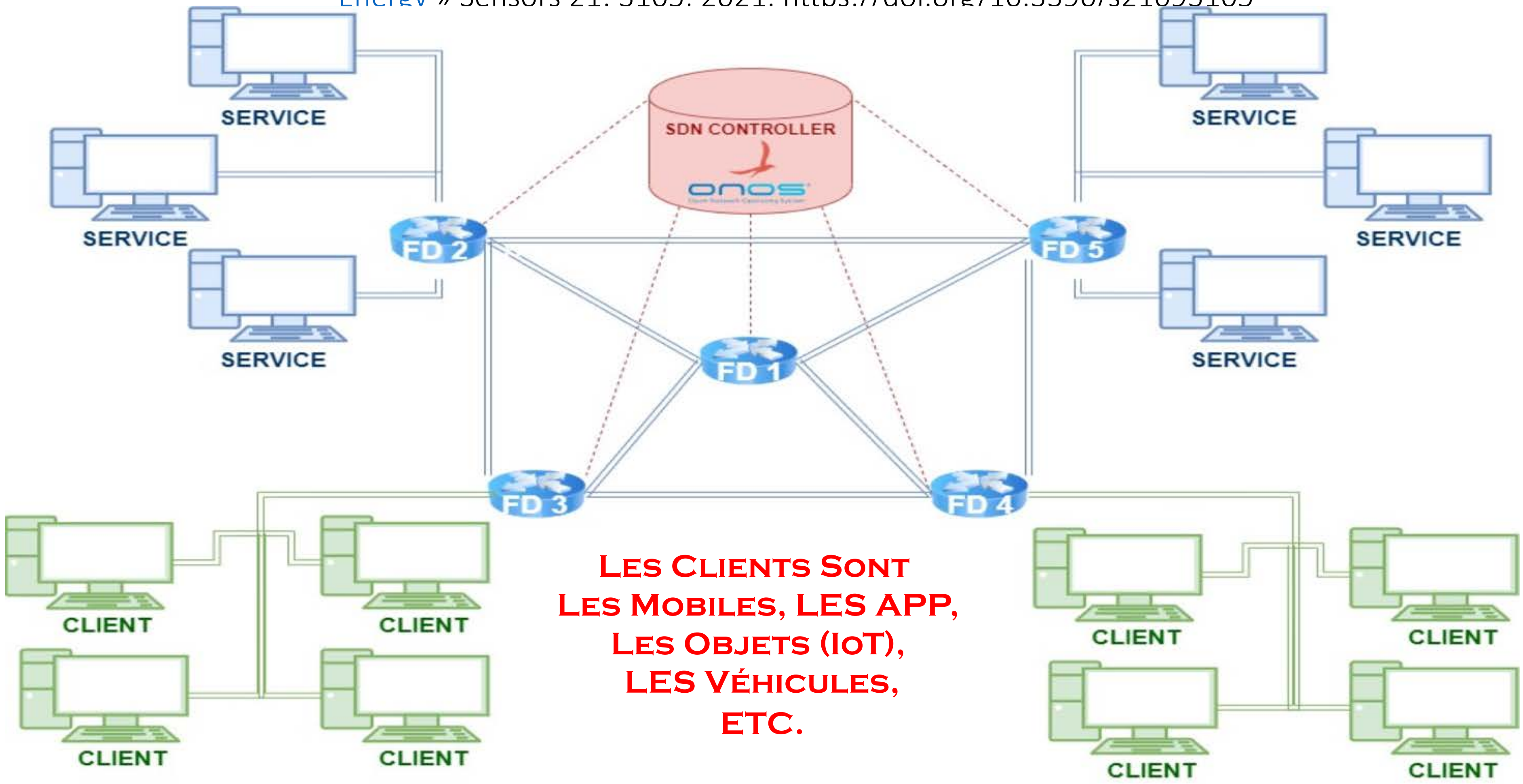
Fig. 1. Topology of the test-bed in use



E. Gelenbe and S. Silvestri, ``Optimisation of Power Consumption in Wired Packet Networks,'' Proc. QShine'09, 22 (12), 717-728, LNICST, Springer Verlag.

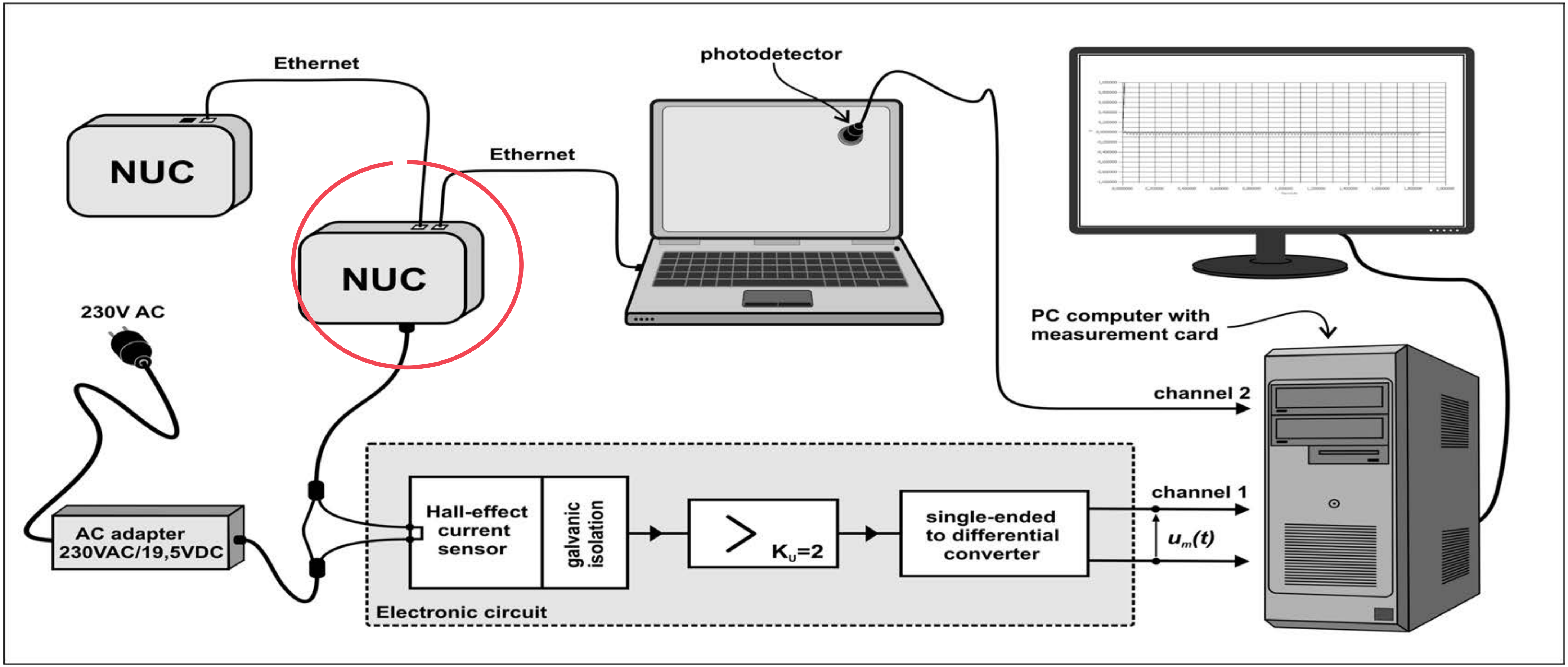
Measure & Optimize The Edge: Distributed SDN Network [SDN Switch = Intel NUC, Server = Intel NUC]

P. Fröhlich, E. Gelenbe, J. Fiołka, J. Checinski, M. Nowak, Z. Filus, « Smart SDN Management of Fog Services to Optimize QoS and Energy » Sensors 21: 3105, 2021. https://doi.org/10.3390/s21093105

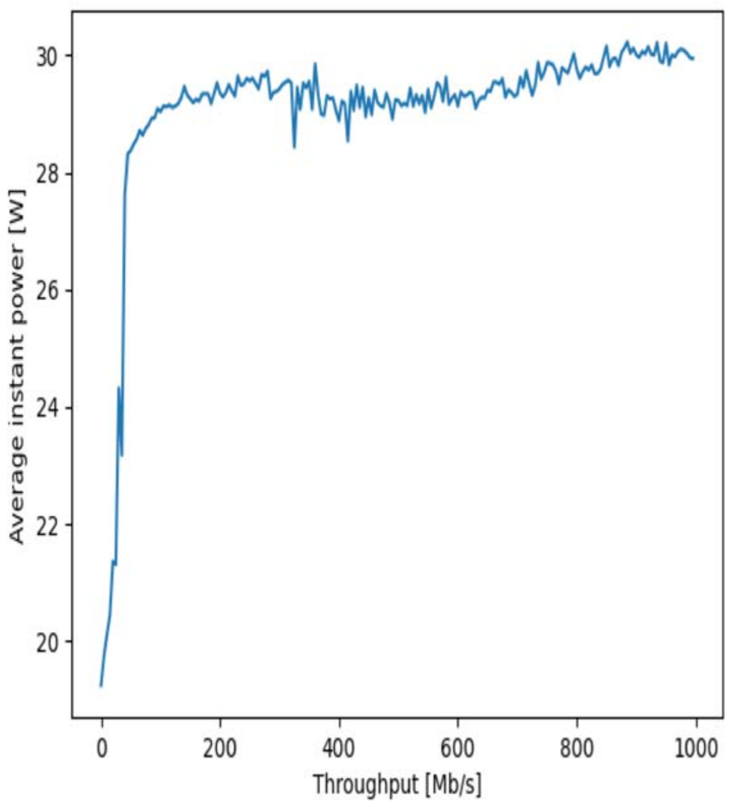


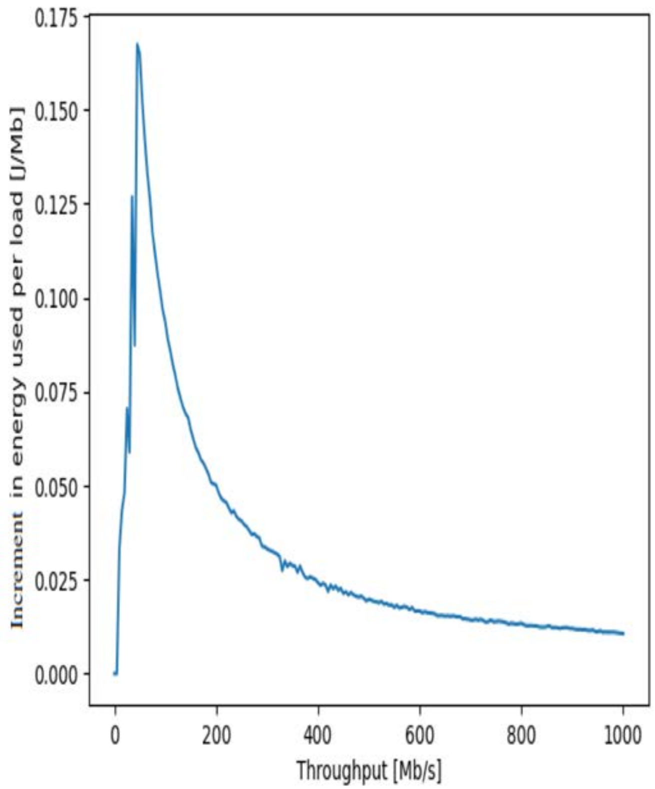
Les Clients Sont Les Mobiles, LES APP, Les Objets (IoT), LES Véhicules, ETC.

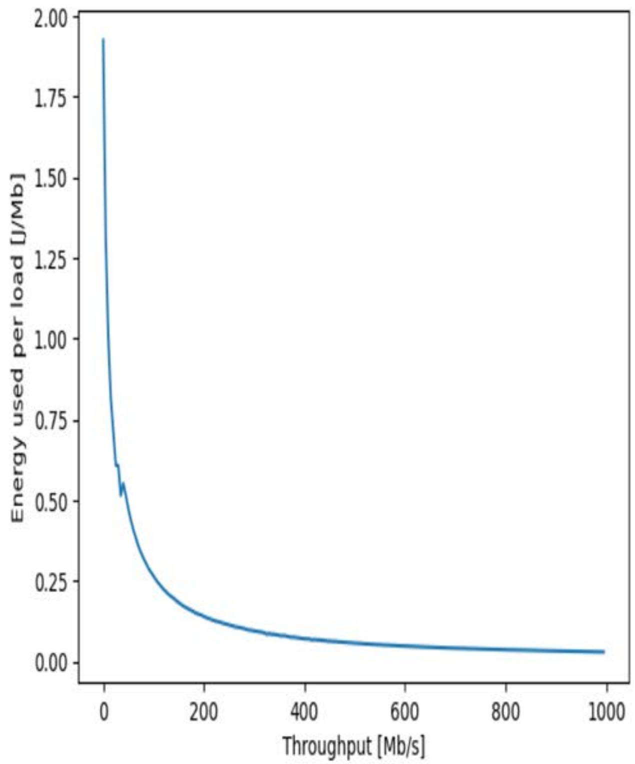
Measuring Energy Consumption is Non-Trivial



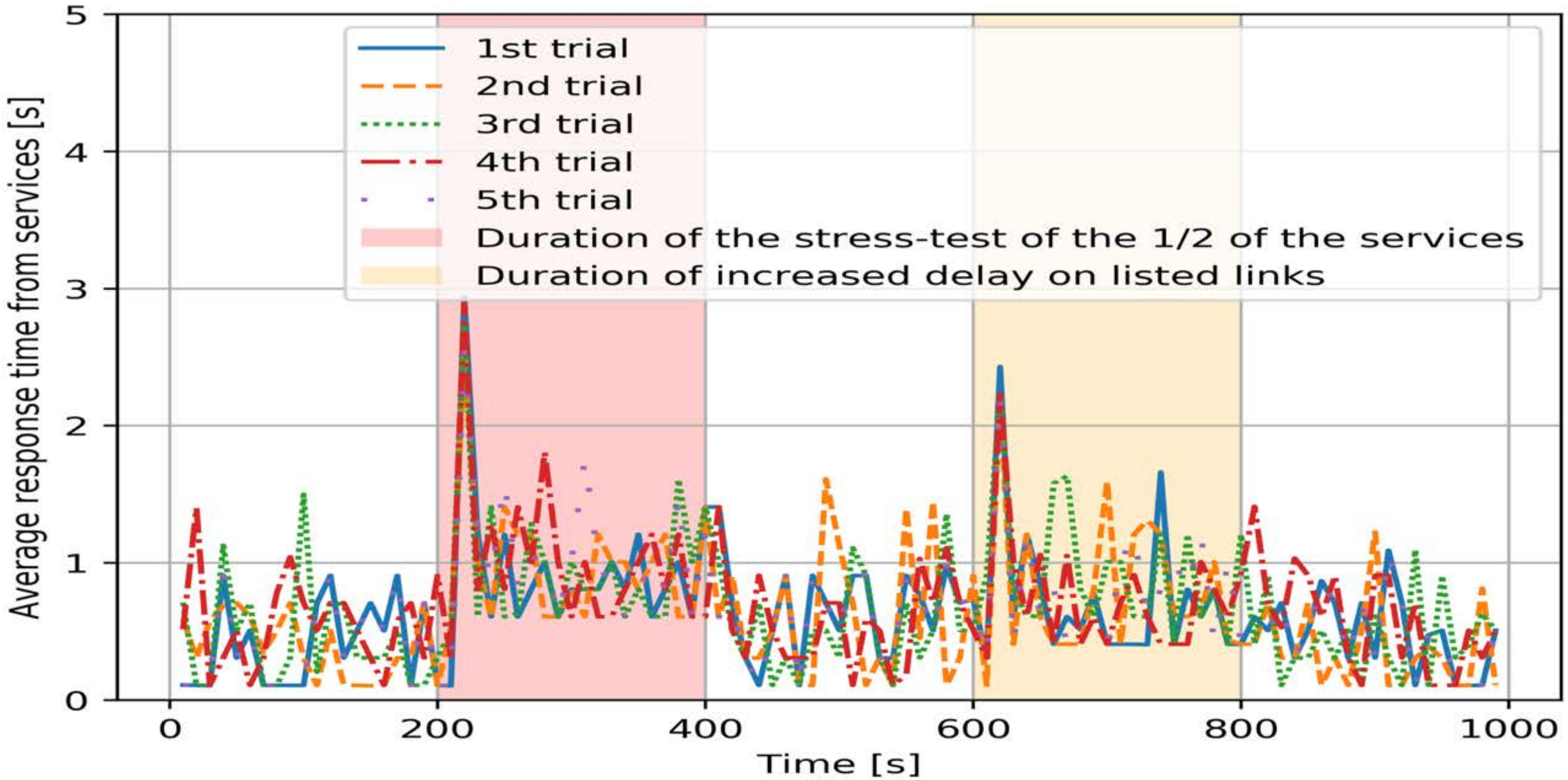
The NUC's Energy Consumption Characteristics



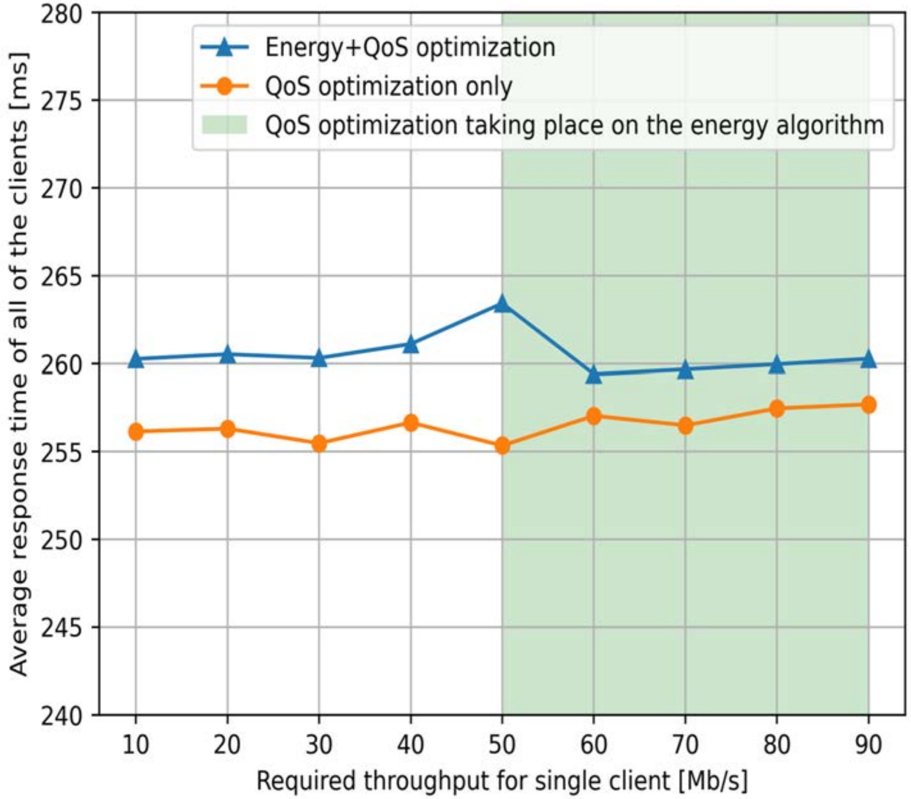


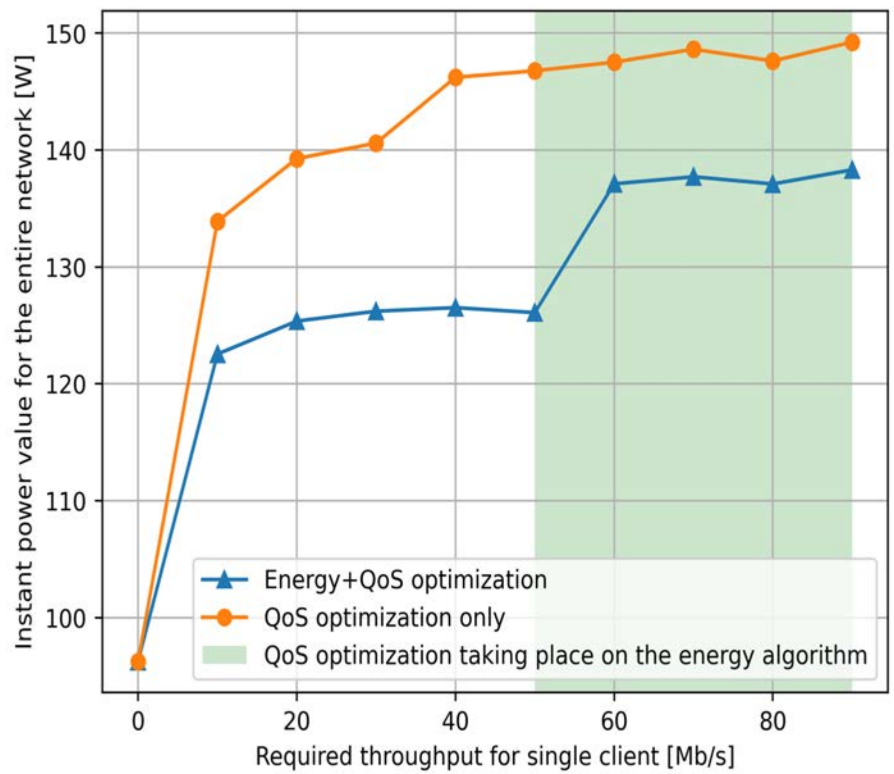


Random Behaviour Of The System As a Function of Load



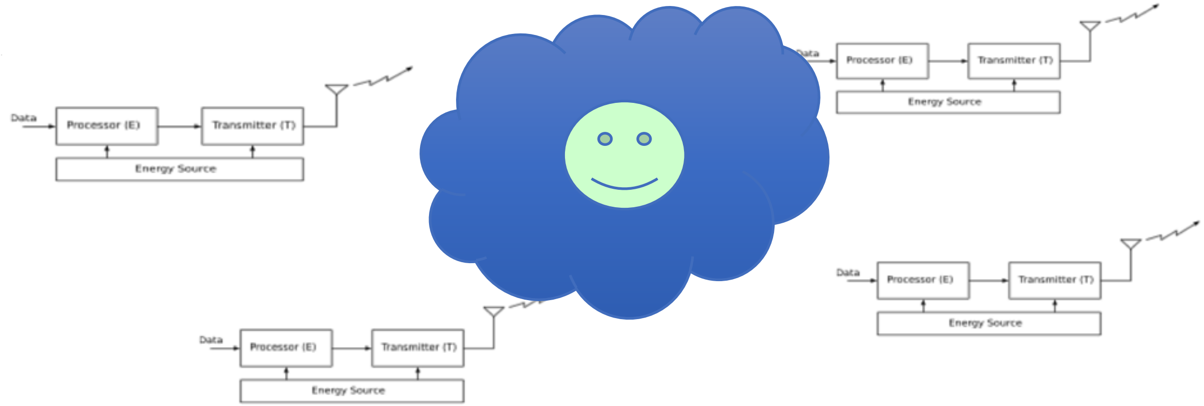
Adaptation with Reinforcement Learning Reduces Power Consumption by 15% At A Cost of 2% in the Average Response Time





Conventional Problem: Optimum Power to Minimse Energy Consumed per Successfully Received Data Packet

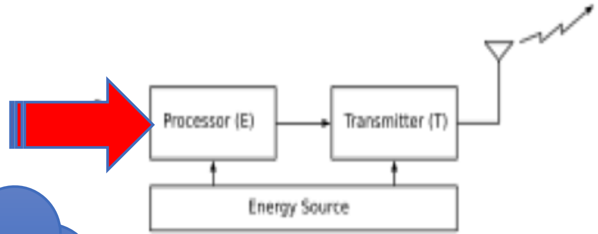
- Cooperating (Wireless) Transmitters
- Choose the *Individual transmission power* to Minimize the *Energy Consumed per Correctly Received Packet*

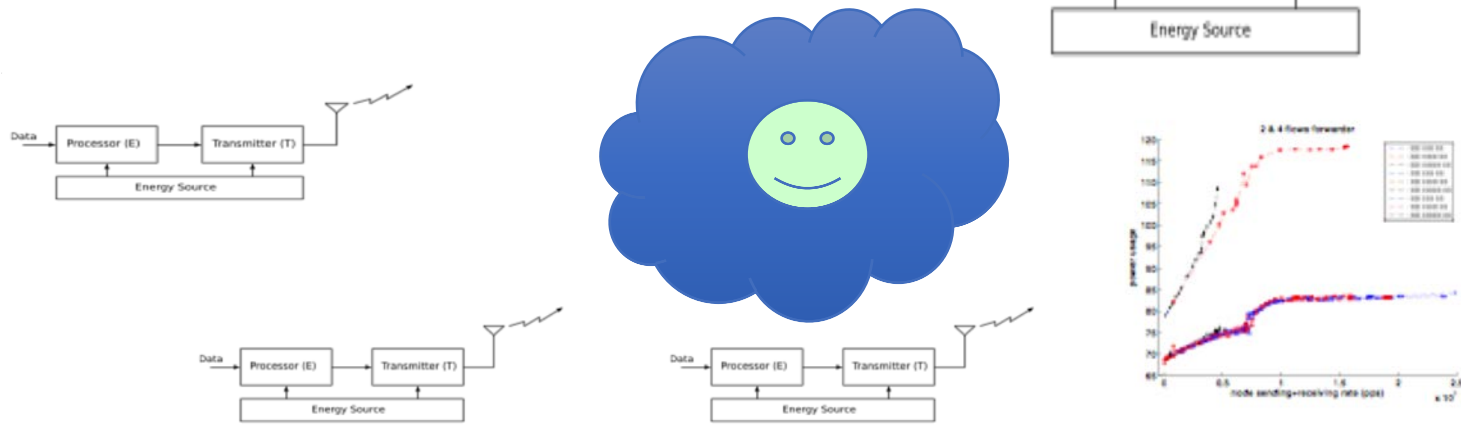


Power Level, Interference and Errors

- Identical Wireless Transmitters
- Transmit *D* packets at rate *v: Transmission Time D/v*
- Power Consumption *P(v)* → *Energy per Packet P(v)/v*

$P_{Electronics} + P_{Transm} + P_{Packet\ Queue}$



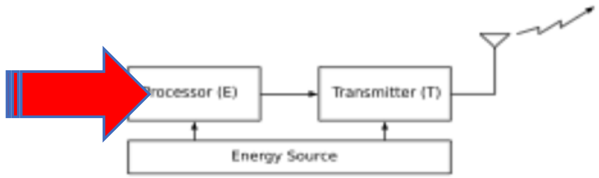


Energy Efficiency vs Power

- Error Probability $\sim 1 - f\left(\frac{rP_T}{B(noise) + Interference}\right)$
- Effective Transmission Time $T_{\text{eff}} = \frac{D}{v.f(\gamma)}, \quad \gamma = \frac{rP_T}{B+I}$
- Efficiency: Number of Effectively Transmitted Packets per Energy Unit (NOT Power Unit)

$$\bar{D}(P_T) = \frac{D}{(P_E + P_T)T_{eff}} = v\frac{f\left(\frac{rP_T}{B+I}\right)}{(P_E + P_T)}$$

$P_{\text{Electronics}} + P_{\text{Transm}} + P_{\text{Packet Queue}}$



Identical Users with n-bit packets

- Error Probability

$$\sim\ 1 - f(x),\ f(x) = [1 - Q(\sqrt{x})]^n, \quad x = \frac{rP_T}{B + \alpha P_T}$$

- Energy Efficiency – Number of Packets Correctly transmitted per Unit of Energy

$$\bar{D}(P_T) = \frac{D}{(P_E + P_T)T_{eff}} = v\frac{f(\frac{rP_T}{B + \alpha P_T})}{(P_E + P_T)}$$

When $I = a\ P_T$, the optimum P_T that Maximizes Energy Efficiency will satisfy

$$\frac{\partial f(x)}{\partial x} = \frac{(B + \alpha P_T)^2}{rB(P_E + P_T)}.f(x),\ \text{where } x = \frac{rP_T}{B + \alpha P_T}$$

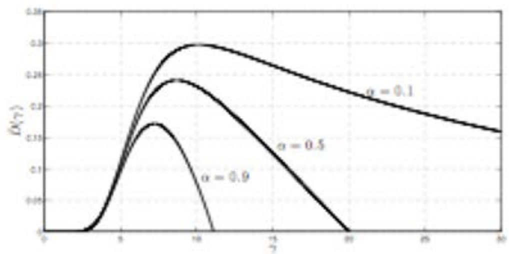


Fig. 4. Optimal transmission power with scaled interference power for varying levels of interference ($\alpha = 0.1, 0.5, 0.9$). Data is transmitted in an uncoded fashion using BPSK modulation with packet length $n = 100$, processing power $P_E = 2$, channel gain $r = 1$ and noise variance $B = 1$.

Servers: Simple Composite Cost C_{Job} for Delay and Energy

- Composite Cost Function:

a.[Average Response Time per Job]

+ b.[Average Energy Consumption per Job]

$$
\begin{aligned}
C_{job} &= \frac{aE[S]}{1-\lambda E[S]} + bJ_{job} \\
&= \frac{aE[S]}{1-\lambda E[S]} + \frac{bA}{\lambda} + bBE[S]
\end{aligned}
$$

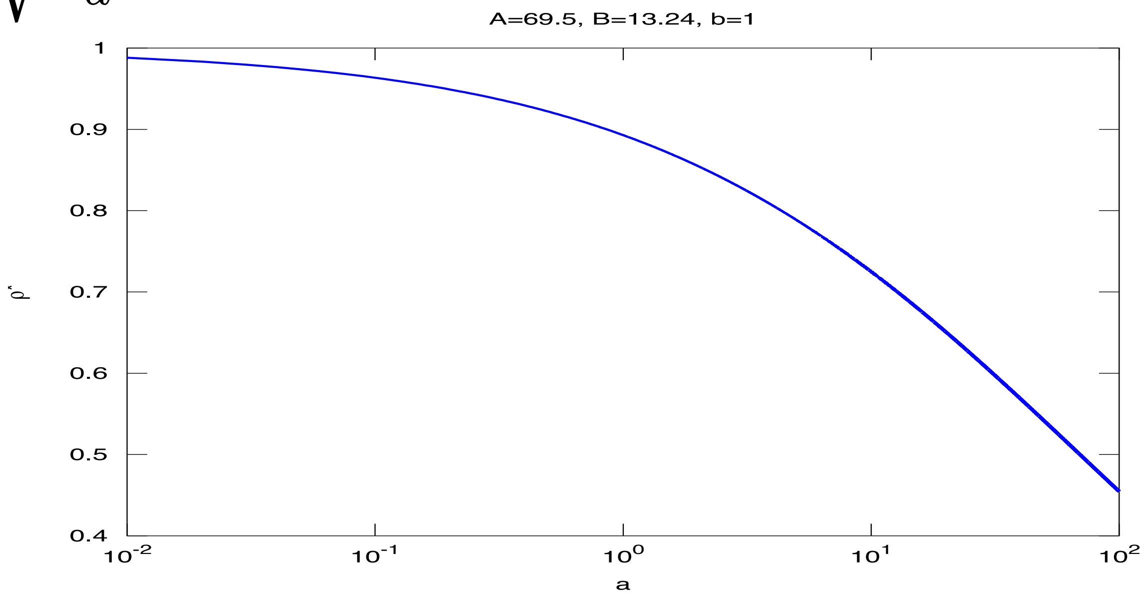
Optimisation of the Load

Optimum Load that Minimises the Composite Cost

$$\rho^* = \frac{\sqrt{\frac{bA}{a}}}{1 + \sqrt{\frac{bA}{a}}}$$

We can also see that ρ^* is an increasing function of ratio bA/a. In particular id we call $x = bA/a$ we have:

$$\frac{\partial \rho^*}{\partial x} = \frac{1}{2\sqrt{x}[1+\sqrt{x}]^2}$$

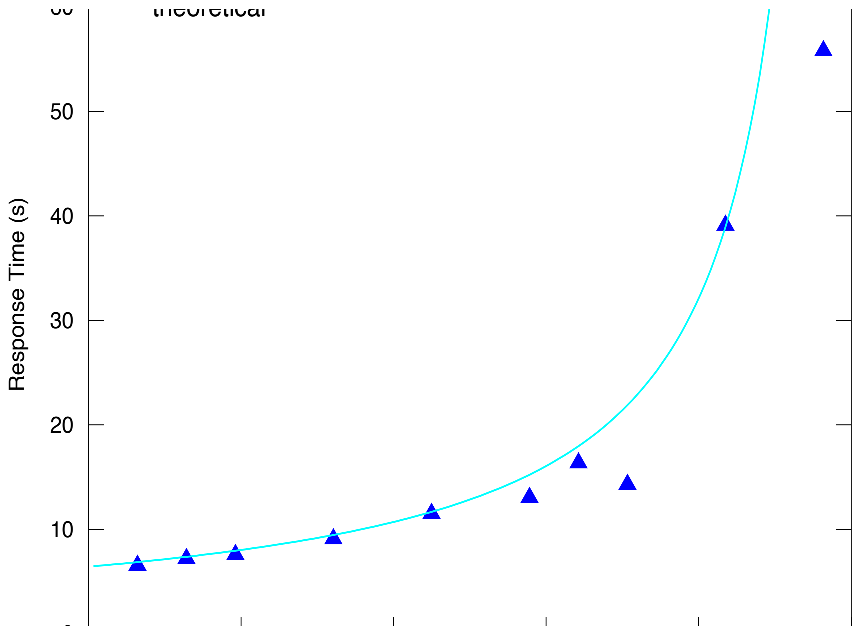


Measurements

To validate the energy-QoS metric and optimum load model, we conducted a series of experiments using jobs executing on a server class system having a quad-core Intel Xeon 3430 (8M cache, 2.4 GHz), 2 GB RAM, single 150 GB SATA hard drive, and 2 on-board Gigabit Ethernet interfaces. The system runs Linux (Ubuntu) with CPU throttling enabled with the *ondemand governor*, which dynamically adjust the cores' frequency depending on load. A client machine is attached to the server through a fast Ethernet switch to generate the workload, and the client machine also measures the system's power consumption [].

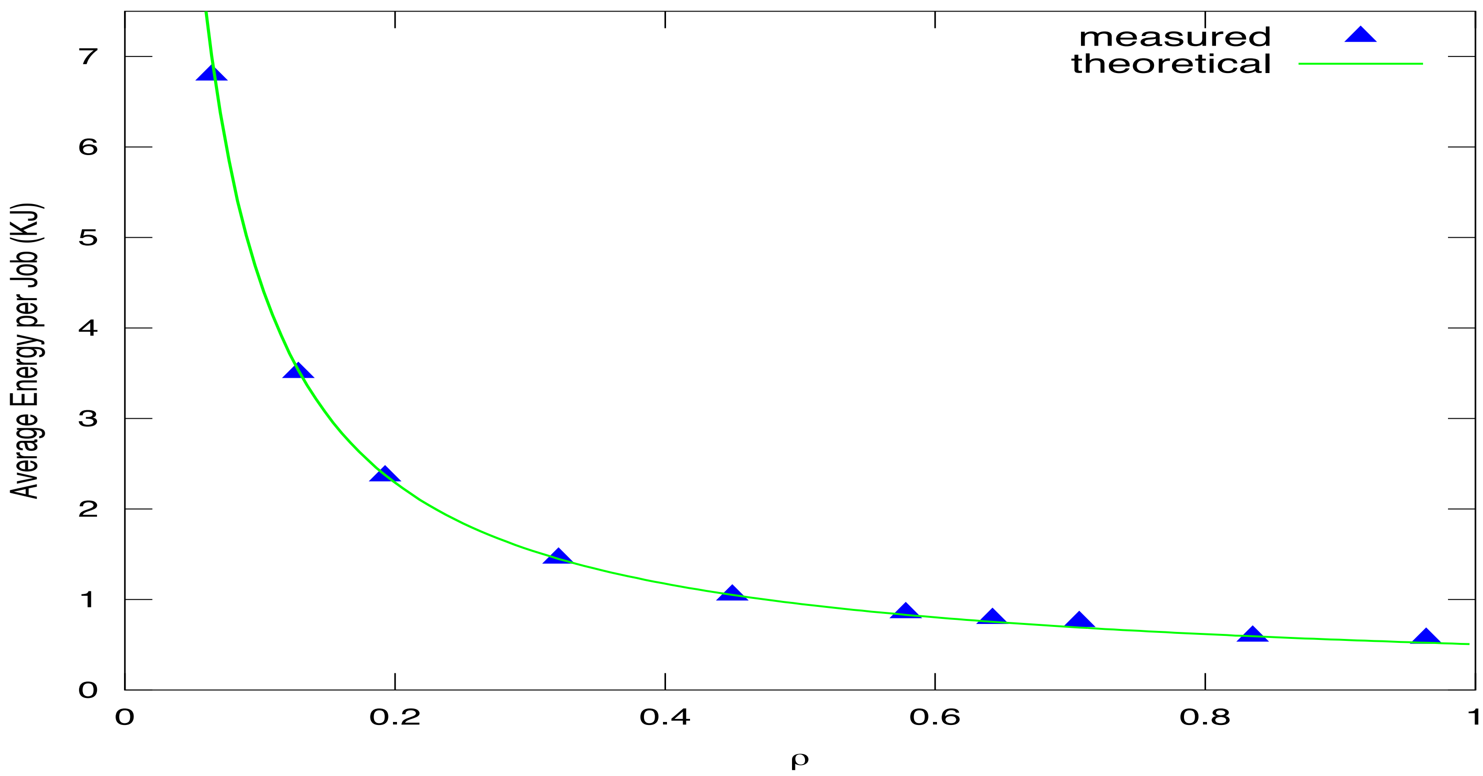
We measured power consumption when it is idle, i.e. when it has no external jobs to execute, to be $A = 69.5$ Watts, which corresponds to the value of A in equation (4).

Then we measured the average energy consumed by a single job from observations obtained from serving a large number of jobs (1000), the average power consumption and the total running time of the experiment. The value of B was measured to be 13.24 Watts per job on average. The measured value of J_{job} and the calculated results from (4) we the experimentally estimated values of A and B are shown

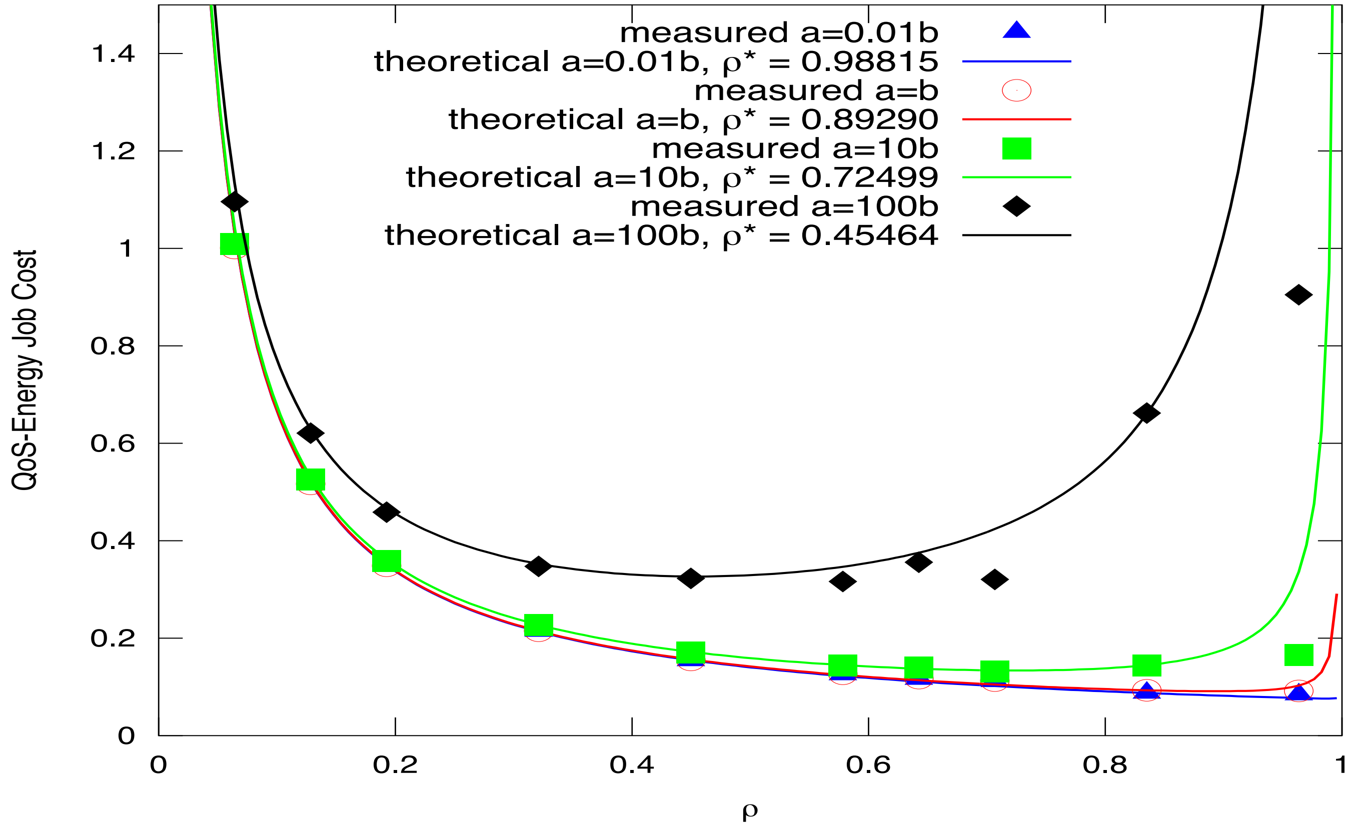


Validation

- Average Energy Consumption per Job vs Load



Theory versus Experimental Data



CONCLUSIONS

ICT Systems are Complex and Highly Interconnected

ICT is Becoming More Energy Efficient
As it becomes more complex (5G, 6G) it Can Consume more Energy

And The Presence of ICT is Growing

New Applications Such as Crypto-Currencies and BlockChain are Highly Energy-Vorous

In 2020: BitCoin ~ Electricity Consumption of the Netherlands

CONCLUSIONS

ICT Consumes A Significant Portion of Electricity and Has Significant Environmental Impact – Both Good and Bad

Understanding the QoS and Energy Characteristics Is a Scientific Problem That Requires Careful Analysis and Experimentation

Adaptive Management Schemes Must Be Used To Reduce ICT Energy Consumption and Environmental Impact

Many Thanks for Your Attention