Energy Aware Paradigm for Energy Efficient ICT: a Systemic Approach

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ABSTRACT
Energy is imposing as *the* new constraint in the ICT sector and the problem of energy efficient in ICT has consequently arisen. In this paper we discuss the systemic approach that in our opinion should be taken as reference framework to address the problem and develop and deploy new solutions for achieving energy efficient ICT based systems. Such a paradigm can be useful for both the research community and the industries in designing energy aware algorithms, networking protocols and systems for achieving sustainable growth and prosperity.

General Terms
Algorithms, Management, Design, Economics, Human Factors.

Keywords
Energy efficiency, design, sustainability, renewable energy sources, network devices, data centers.

1. INTRODUCTION
The ICT sector has a growing impact on world power consumption, having consequences on both economic and environmental. ICT industry alone consumes as much energy as the aviation industry and it is responsible for the 2-3% of the world GHGs (Green House Gases) emissions [1]. Thus, the reduction and optimization of energy consumption are arising as ones of the main goals of ICT operators and recent initiatives started to explore energy savings and green energy use in network infrastructure with the dual objective of minimizing energy consumption with its related costs and GHGs emissions. We show the main concepts and challenges for achieving energy efficient ICT focusing on network devices and data centers and present current approaches as well as new ideas for decreasing the carbon footprint and making computing and networking more energy efficient. We envision the future technological innovations and give the open research topics for achieving ICT energy-efficiency towards sustainable (*scalable*) society growth and prosperity.

2. ENERGY EFFICIENT ICT SYSTEMIC APPROACH
Energy efficiency is imposing as a new tight constraint that ICT sector as well as industry and society in general have to cope with. This is essentially due to three reasons: (1) the anthropogenic global warming as consequence of the increasing carbon emissions in the last decades; (2) the unsustainable growing energy requirements for powering and cooling industry devices that are becoming always more and more performing and thus energy hungry and the exponentially increasing number of end-user devices; (3) the mayor costs of energy that are foreseen to increase as the availability of traditional fossil sources becomes scarcer. Increasing energy efficiency alone is not enough and may even lead to increased energy footprint, as a consequence of the unbalanced growth between energy efficiency and the increased demand (cfr. Jevons paradox, Kazzoom-Brookes postulate, rebound effect [2]). For every new solution, both the whole Life Cycle Assessment (LCA) and direct and undirect impacts must be taken into account to assure that the "solution" does not fall into the rebound effect for example in the extraction of the material needed for building the new devices or in their end-of-life disposals. This is a complex task and represents one of the greatest challenges that humanity has to face: not only inverting the global warming trend but also achieve *sustainable* solutions for the decades to come. Here, sustainability represents the key word in order to successfully address all these problems. Every approach to tackle these problems has to be a *systemic* approach, ranging from "high level" policies to "low level" technological improvements cooperating with each other. In this context, ICT is foreseen to play a fundamental role for its intrinsic properties of technological innovations and may act as the drawing factor for other industry sectors as well as for the entire society. For these reasons, the focus of our work is on the ICT industry. Power consumptions of the five ICT subsectors [3] are depicted in Fig. 1. The scope of this work is focused mainly on data centers and network equipment, as they are heterogeneous enough for developing general concepts that may apply also to the other sectors.

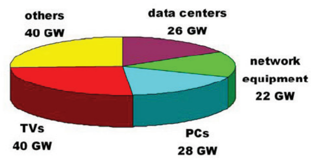

Figure 1: ICT devices power consumption.

In order to assess an analysis of these two sectors, we define the energy aware paradigm (Fig. 2) that we believe should be followed for achieving ICT energy efficiency: it provides the reference framework in which operate to decrease energy consumption and GHG emissions. Not only we report what are the main actors that we believe will drive the developments toward energy efficiency, but also we give a visual clue on how these elements are connected each other, thus helping identifying the relations and consequent co-operations between technological innovations. The paradigm will evolve accordingly as new requirements and technological innovations get into the arena.

3. ENERGY AWARE PARADIGM
3.1 Global view
The energy aware paradigm is depicted as an undirected graph, where a number of elements (nodes) and relations (edges) concur to build the complete framework. The connected elements work together and all the elements collectively contribute to achieve a

systemic coordinated approach. The leftmost part represents higher level elements which *control* the rightmost lower level elements that are part of the global envisioned solution.

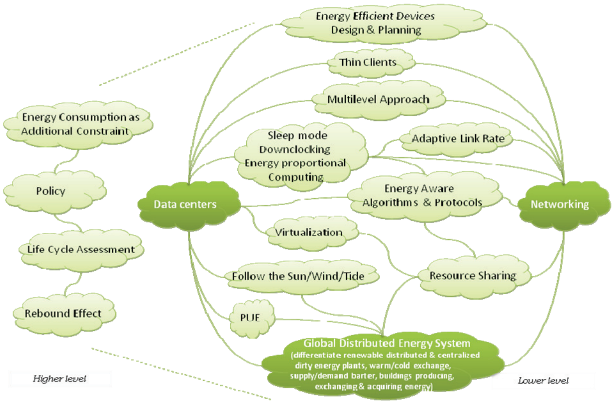

Figure 2. The energy aware ICT paradigm.

3.2 High level practices

Starting from the need to consider the energy consumption as a new constraint, policy should drive the changes both promoting virtuosos practices and discouraging environmental unfriendly approach: cap and trade, carbon offset, carbon taxes and incentives [2] are all viable ways that governments are just starting to explore. In order for any solution to be successful, it is necessary to study its whole life cycle assessment, otherwise it may fall in the rebound effect and get increased energy consumption and concomitant GHGs emissions.

3.3 Low level practices

3.3.1 Energy plants and distributed energy system

Within ICT, we concentrate on data centers and network equipments and on *how* they are powered (energy plants). We differentiate between two types of energy plants: renewable (solar, wind, tide) zero-carbon "green" plants and "dirty" fossil fueled (coal, oil, gas) or nuclear plants that have a non-negative (very high) carbon footprint or severe environmental impact. Nuclear energy is not renewable and, although nuclear plants do not emit considerable amounts of CO_2, they do emit large quantities of water vapor that is the greatest responsible for the green house effect, more than CO_2. Besides, there are several negative effects on the environment: huge amounts of fresh water are drained and warmed up to cool the reactors, dangerous radioactive wastes are produced and high indirect footprint comes from the extraction of the radioactive materials. Green energy plants are inherently likely to be distributed among many sites and this feature should be exploited in order to provide each Internet Service Provider (ISP)/data center with its own green energy source: with an initial CAPEX they will get reduced OPEX costs, reduced GHG emissions and reduced energy dependency (which in the near future will mean *survivability*); besides, they may take advantage of the establishing "green" policies (e.g. cap and trade). We envision an energetic distributed global system, in which energy supply and demand encounter reciprocally and cold and hot flows exchange happens in a barter fashion. A distributed, automatic supply system like the control plane in optical networks (GMPLS) may be deployed for the distribution of electrical energy. The GMPLS routing protocol may be extended to include energy information such as power consumption and the type of energy source currently used by the devices. In this way the system may dynamically acquire or release produced energy in excess as needed. This model can be extended to private houses, business premises, university campus, ISPs, public buildings providing distributed green energy plants (e.g. on their roofs) that may produce, release and acquire electrical energy as well as cold and hot flows from their neighborhood. Today in fact the great need is not for *more* energy, but for *better* energy utilization. Wastes avoidance should be our primary objective. Data centers need to be cooled while office rooms need to be warmed (at least for several months, depending on the latitude). We could for example take advantage of this supply/demand situation by properly exchanging warm and cold flows between data centers and office rooms at 0 €. Industries (e.g. Google) and governments (e.g. Iceland) that will move first will obtain the greatest benefits from this *new* sustainable economy.

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3.3.2 ICT specific solutions

Between data center and network equipment several actions can be considered. A number of good practices and solutions are emerging in literature; they comprise, but not limited to, advanced sleep mode, more energy efficient devices, energy proportional computing, down-clocking, adaptive link rate, data center placement near renewable energy plants, thin clients, virtualization, resource sharing, energy aware algorithms and protocols [4][5][6]. The development of one feature will affect the connected ones thus a systemic approach is envisioned to be indispensable for long term successful solutions.

4. CONCLUSIONS

The presented systemic approach may be taken as reference framework for achieving energy efficient ICT systems. The paradigm can be useful for both the research community and the industries in designing energy aware algorithms, networking protocols and systems in the coming green era.

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