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GREEN TECHNOLOGIES IN WIRELESS NETWORKING: MAJOR ISSUES

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ABSTRACT

We briefly discuss three issues related to the relevance and the possible impact of research in the field of green networking, with special attention to the wireless case in this paper. In this context energy efficiency is needed most.

KEYWORDS: Green Technology, Networking, Wireless Networking, Energy, Health, ICT, ITU, OPEX, Energy Savings

INTRODUCTION

The energy consumption of ICT is extremely critical in some areas, where the lack of access to reliable and unrestricted power sources constitutes a significant obstacle for the development of ubiquitous ICT infrastructures. These facts have generated a keen interest of researchers in both fields of ICT for energy efficiency and energy-efficient ICT.

Moreover, Different radiations from electrical devices are harmful for people health. For this matter lowering the radiations is a major issue. While the possible relevance and impact of effective ICT solutions for the optimization of the energy consumption is unquestionable, because they target the most energy-greedy sectors, the significance of research efforts in the field of energy-efficient ICT in general, and energy-efficient networking in particular, is not obvious, in spite of the growing number of research initiatives and projects in this field.

SOME DATA ABOUT ICT AND ENERGY

The interplays between the ICT and energy fields are becoming stronger and stronger. On the one hand, ICT is expected to play a key role in reducing the energy consumption is several fields, and in particular in those where most energy is spent, such as transport, buildings, and manufacturing. On the other hand, ICT is emerging as a greedy energy consumer, with a very high growth rate.

As regards the first aspect, a recent study of the ICT-ENSURE Project [1] estimated that ICT can be instrumental for a 26% reduction of the energy consumed in the transport sector, a 5-15% reduction of the energy used by buildings, and a 25-30% reduction of the energy required in manufacturing. These savings add up to 17-22% of the total energy that is consumed in all sectors [2]. Moreover, ICT is expected to significantly improve the energy generation, transport and utilization through the novel concept of Smart Grid.

This very positive role of ICT on energy consumption also carries an energy cost, since the widespread use of ICT implies the activation of a progressively larger number of equipment, which are today estimated by the Global Action Plan to consume a fraction varying from 2 to 10% of the world power [3]. About one third of this is due to networking. Similar estimates were also obtained by other agencies, such as the Fraunhofer Institute, and ITU. While the fraction of energy consumed by ICT today is not very high, it is expected to grow rapidly, possibly doubling over the next decade [4].

In addition, the energy consumption of ICT is extremely critical in some areas, where the lack of access to reliable and unrestricted power sources constitutes a significant obstacle for the development of ubiquitous ICT infrastructures. These facts have generated a keen interest of researchers in both fields of ICT for energy efficiency and energy-efficient ICT. While the possible relevance and impact of effective ICT solutions for the optimization of the energy consumption is unquestionable, because they target the most energy-greedy sectors, the significance of research efforts in the field of energy-efficient ICT in general, and energy-efficient networking in particular, is not obvious, in spite of the growing number of research initiatives and projects in this field. Among them, we mention the Green Touch initiative launched by the Alcatel-Lucent Bell Labs [5], and several research projects funded by the European Commission within its 7th Framework Programme, most notably the TREND Network of Excellence [6] coordinated by Fabio Neri, professor at Politecnicodi Torino in Italy, who passed away in the days of writing this manuscript. This paper is dedicated to him with great affection.

Energy-efficient networking targets the reduction of energy consumption costs, with focus on the energy needed to operate a network. The research that accounts also for the energy con-sumed for the production, deployment and end-of-life disposal of the devices is usually referred to as green networking.

While the two terms, energy-efficient and green networking, are sometimes used in an interchangeable way, most of the research efforts are today devoted to energy efficiency, often motivated by the urgent need to reduce networks operational costs that, for big players such as operators, service providers, or companies that make massive use of networking, are becoming a significant fraction of operational expenditures (OPEX).

In this paper we discuss some issues related to the relevance and the possible impact of research in the field of energy-efficient networking.

THREE QUESTIONS

Energy efficiency has not been part of the network design and analysis problems for almost a century, following the seminal works of A.K.Erlang; it came into the picture with the need to guarantee long connection times for battery-operated network elements in cellular, ad-hoc and sensor networks. More recently, the seminal paper by Gupta and Singh at Sigcomm 2003 [7] posed the problem of energy savings in the Internet, and opened the field of energy-efficient networking, which is experiencing a burst of activity in this period, with new conferences, and journal special issues, popping up almost every day.

Researchers are looking at a number of different issues in energy-efficient networking, but which of these are most relevant is not clear. This brings forward the first question that 2011 The 10th IFIP Annual Mediterranean Ad Hoc Networking Workshop 978-14577-0900-5/11/$26.00 ©2011 IEEE 41 we will try to answer in this paper: **Which type of networks can yield the most significant energy savings?**

Several different paths can be followed to achieve energy efficiency; the most commonly considered being the development of more energy-efficient hardware, the introduction of energy-proportional equipment (which is given this name because energy consumption should be close to being proportional to traffic load), and the adoption of sleep modes for network elements.

While more energy-efficient hardware is surely necessary and welcome, the issue of energy proportionality comes from the fact that for today’s equipment it is common to exhibit a power consumption that is almost independent on the traffic load (80-90% of the energy is spent as soon as the equipment is turned on; the rest depends on traffic). This means that turning on some equipment to serve a very small amount of traffic can be quite inefficient from the point of view of energy. For this reason, several studies have considered the possibility of turning on and off portions of the network elements, depending on the traffic load. These operating modes aiming at energy efficiency are called low-power or sleep modes. Their rationale is that by switching off some network component in periods of low traffic, provided that the desired level of QoS (quality of service) can be offered with alternate components, allows a reduction of the energy consumption. Clearly, the need for sleep modes is maximum when the power consumption of network elements is independent of load, and diminishes with the equipment energy proportionality. The second question that we will address is the following: **Will energy-efficient networking be based only on more energy-proportional equipment, or do we need network-level solutions, e.g., sleep modes?**

Finally, assuming we know which networks offer the highest potential for energy saving, and that sleep modes are neces-sary (Ooops! We just gave away our opinion on the second question...), the problem of the network energy management becomes crucial, and adequate algorithms must be devised to tackle it. Our third (and last) question thus is: **What can be the role for distributed and self-organizing approaches in network energy management?**

IN OUR HUMBLE OPINION

A. Base Stations and Hot Spots If we look at fixed networks, we can see that the majority of energy is spent in the network periphery, although the most energy-greedy equipment is in the network core. Indeed, while a core router typically absorbs a power of the order of 10 kW, a router in the feeder network requires about 1 kW, and a home gateway absorbs a fraction of a kW, considering the number of units as a multiplier, we find that well over half of the total energy consumed by the network is spent in the periphery. This means that the largest part of the energy cost is distributed over a very high number of users, each of which has limited motivation in energy saving, since its share of the cost is very small (much smaller than the cost the user pays for connectivity).

On the contrary, if we look at cellular networks, we see that the portion of the network that is in the hands of the operator (from the core network to the base stations) absorbs practically all of the energy that is necessary for the network operation. Indeed, we, as users, are in charge only of the energy to power our smart phones and laptops, whose energy consumption is carefully optimized to achieve long battery operation. In cellular networks, the operator is thus a cost aggregator for most of the energy (some estimates say up to 90%), and is strongly motivated to introduce energy-efficient approaches in the network in order to bring down its OPEX, specially in these times when costs and revenues are getting closer.

If we now look in more detail into the network of a cellular operator, we see that the energy share to power base stations is largely predominant. Indeed, considering that the number of base stations worldwide is of the order of 5 millions, and that each consumes about 1 kW on average, we obtain an overall power consumption of about 5 GW. Instead, assuming that networks comprise around 10 thousand core routers, which consume about 10 kW each, we get a power requirement of just about 0.1 GW.

The conclusion that we can draw from the observations above is that base stations are the most interesting candidates for the adoption of energy-efficient approaches in the present networking scenario. This conclusion is consistent with both the industrial efforts to bring to the market more energy-efficient base stations, and the many papers on energy-efficient cellular networks that have been recently published (e.g., see [8], [9], [10], [11], [12]).

Similar considerations can also be made for the case of access points in wireless LANs, but in this case the energy consumed by each one of these is much less than for a base station, and the private nature of the network distributes the energy cost among many different parties. The only case that comes close to cellular networks is represented by dense corporate WLANs, which can comprise tens of thousands of access points, so that an efficient management of the energy consumed by the network becomes interesting (e.g., see [13], [14]).

The Need for Sleep Modes

In order to discuss the relative merits of energy-proportional equipment and of sleep modes, we consider a very simple and idealized cellular network setting, which is however sufficient, in our opinion, to grasp the key message. The energy consumption of a UMTS or LTE base station (BS), or a WiFi access point (AP), as a percentage of the maximum, can be expressed as:

$$E(\rho) = E_F + \rho E_V \quad \text{………………………………..………………… (1)}$$

Where ρ is the traffic load of the BS, and varies in[0,1](the BS capacity corresponds to load 1);EF is the percentage energy consumption that is necessary to power on the BS, regardless of the traffic load; EV is the percentage of the BS energy consumption that is proportional to the traffic load

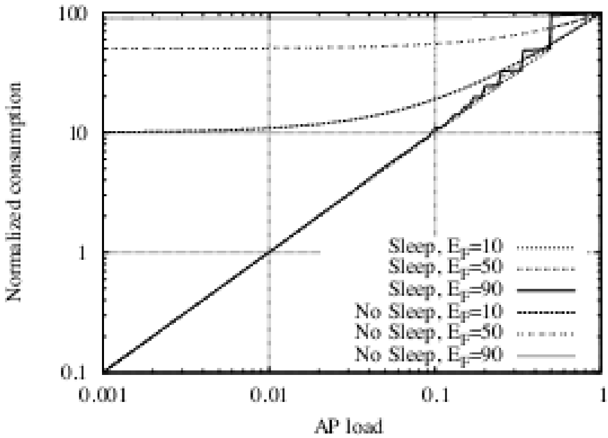

Figure 1: Effects of the Use of Sleep Modes

Consider a very simple and idealised scenario, where all cells are identical, traffic is the same in all cells, and if any fraction of BSs is put to sleep, the other BSs can provide coverage and absorb the traffic. If we rely just on the energy proportionality of BSs, due to the uniform setting we are considering, the average energy consumption per BS is the same as in (1), since all BSs consume the same energy. If we can power off BSs as soon as some other BS is capable of carrying the traffic of the BSs that are put to sleep, the average energy consumption per BS in our network becomes:

$$E_S(\rho) = \frac{E_F + k\rho E_V}{k} \qquad \frac{1}{k+1} < \frac{\rho}{100} < \frac{1}{k} \quad \text{…………………………………………… (2)}$$

Indeed, if the fraction of load in a cell is less than 1/k , then just one BS out of k is capable of carrying the traffic, and the other k−1can be put to sleep. Assuming that sleeping BSs consume a negligible amount of energy, the only one that remains powered on consumes the energy resulting from the traffic of kBSs, but its consumption averages over the kBSs.

Present BS and AP equipment is such that around 80 to 90% of the energy consumption is spent as soon as the BS or AP is turned on (so that EF = 90andEV= 10orEF= 80 and EV= 20are representative of today’s technology). Manufacturers are working to develop more energy-proportional hardware, so that in the near future we may expect products with EF =EV= 50. It may be possible to also achieve EF= 10andEV= 90 in the long term, but we claim that this will not eliminate the need for sleep modes.

Indeed, if we plot (See Figure 1) the behavior of E(ρ) from (1), and of ES (ρ) from (2) versus ρ for variable values of EF and EV, we see that energy savings for the two cases are identical for traffic loads between 0.5 and 1, but the savings obtained with sleep modes become much larger than those possible with only energy-proportional equipment when the traffic load becomes a small percentage of the peak, as is normally the case due to daily fluctuations in user location and activity patterns. Moreover, we see that different levels of energy proportionality only have an impact for high traffic loads. When traffic is very low, the effectiveness of sleep modes dominates over the amount of energy proportionality of the equipment.

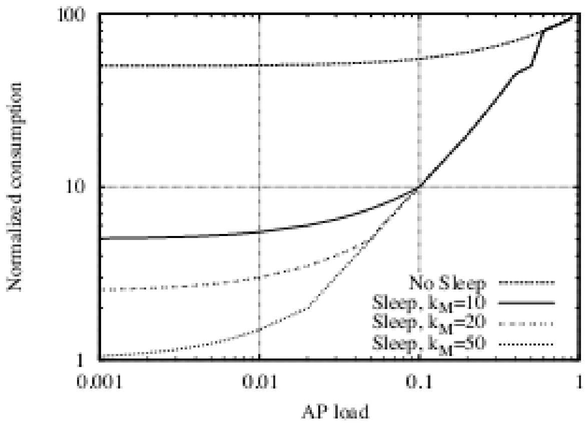

Figure 2: Effect of the use of Sleep Modeswhen no More Than k_M- 1 BSs out of K_m Can be Put to Sleep, with k_M=10, 20, 50; E_F=50

We can thus conclude that energy proportionality is important, specially to cope with small fluctuations in the traffic load, but sleep modes are a must, also with energy proportional equipment, in order to exploit large traffic load fluctuations.

Of course, should it become possible to obtain perfect energy proportionality of the networking equipment (EF= 0 and EV= 100), sleep modes would not be necessary, but probably the implementation of sleep modes poses less problems than achieving perfect energy proportionality.

The results in Figure 1 are based on the assumption that any fraction of BSs can be put to sleep, and that for any fraction of sleeping BSs, the BSs that remain awake can provide coverage and absorb the traffic. In practice, this can be true for fairly large values of kin (2), for those service areas where the need for high capacity is addressed by cell densification, so that a few large cells cover the area, and many small cells provide the necessary capacity. In other areas, where cell density is lower, reaching very large values for k may be a problem. For this reason, in Figure 2 we plot curves similar to those in Figure 1, imposing a limit on the maximum value of k, namely kM. As expected, we see in the figure that curves flatten when the maximum benefit due to the possible sleep modes is reached, i.e., when 1 BS out of kMis powered. Nevertheless, the gain achieved with sleep modes with respect to only using energy proportional equipment is still quite relevant.

Centralized vs Distributed Algorithms

The introduction of low-power modes for base stations of cellular networks brings about the need for effective energy management algorithms. Indeed, before putting BSs to sleep, it is necessary to monitor the traffic load variations in time and space, and identify which BSs can be powered down, and which other BSs can absorb the traffic of the sleeping BSs. In order to do this, it is necessary to be able to identify the optimum set of BSs to power down for a given traffic level and spatial distribution, and to devise a centralized or distributed algorithm to implement the power-down.

Similarly, starting from a low-power configuration in which a number of BSs is in sleep mode, when the traffic load grows, it is necessary to identify the BSs that have to wake up, according to a new optimal network configuration for the new traffic distribution, and to implement an algorithm for the BS power-up.

This requires first of all the ability to identify the optimal network configuration in terms of powered-up and powered-down BSs, where optimal refers to a minimum energy consumption for a given QoS constraint. This problem is similar to network dimensioning, but only refers to the activation/deactivation of BSs within the available network configuration, which is dimensioned for peak traffic load in each spatial area.

Once the optimal network configuration is known, the implementation of a centralized algorithm is in principle simple, except for the fact that the information about traffic load and its variations is intrinsically distributed among BSs. This means that implementing a centralized energy management algorithm requires the collection of information from the BSs to the energy manager, and the subsequent distribution of the new configuration to al BSs (much like in, e.g., a centralized routing algorithm) [15].

Given the intrinsically distributed nature of the traffic load information, distributed algorithms for energy management seem a natural choice, but in this case the distributed optimization of the network configuration seems tricky.

In addition, after the new optimal network configuration has been identified as a variation of the present configuration, the management of transients for those users and those data flows that need to migrate from a BS that must be powered down to another, must be handled in terms of handovers and QoS (e.g., see [11]).

Finally, either for normal situations, or as a special case to handle users in particular locations, that cannot receive the desired QoS with limited energy otherwise, the possibility of relaying should be considered. Relaying means exploiting an intermediate node to support the transfer of information of a given user toward a BS. Relaying nodes can be either specialized networking equipment, or just end user equipment. In the former case the relay has functions of support to BSs. In the latter case, the behavior that, at least in some peripheral part of the network, approaches that of ad-hoc networks, is intrinsically started and handled by distributed algorithms, and exploits self-organizing features of end nodes.

CONCLUSIONS

In this short paper we tried to briefly address three questions concerning research in the field of energy-efficient networking. Our opinion is that, at least in a first stage, economic motivations will mainly stimulate research in the field of cellular networks; while equipment manufacturers are working at the development of energy-efficient network components (particularly base stations), an important task of academic research is to devise algorithms to dynamically activate the portions of the network that are necessary for the provision of services to end users with the desired QoS. These algorithms are today often called sleep modes for base stations, and they raise a number of problems, from the identification of the optimum subset of elements to activate in a network for a given instantaneous traffic pattern, to the distributed choice of the base stations to switch off, and of those to switch on, according to variations of traffic, to the management of transients due to base stations switch-off, and much more. This opens the way to a whole new field, which can be called network energy management; in this area, both centralized and distributed approaches will be necessary, with the latter being probably more interesting in the longer term.

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