From Energy-Efficient Networking to ZEN*

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1 Summary

Energy-efficiency has become a hot topic in networking research. Several large international research projects have been activated in recent years on this subject. Examples are GreenTouch [1], conceived at Alcatel Lucent Bell Labs, TREND, EARTH, ECONET, C2POWER, CHRON, STRONGEST, Fit4Green, COST IC 804 [2,3,4,5,6,7,8,9], all funded by the European Commission through its 7th Framework Programme, and many national research projects, such as COOL SILICON in Germany and EFFICIENT in Italy. In addition, most equipment manufacturers feature their own internal research projects on this topic, such as GREAT in Huawei. The objective of all these research efforts consists in the reduction of the energy consumption of data networks, but their targets vary, from the 20% saving in today's networks quite realistically claimed by TREND, to the reduction by a factor 1000 in future networks somewhat optimistically foreseen by GreenTouch.

In spite of all this interest in energy-efficient networking research, in reality, the power consumed by actual networks keeps growing at an alarming pace. While this is a significant concern for network operators in developed countries, because of the impact that energy costs have on the growth of OPEX, and of the consequent reduction of margins and profits, the energy-greedy attitude of today's networks, coupled with the lack of reliable power sources, remains one of the main obstacles (if not *the* obstacle) for the widespread diffusion of data networks in some developing countries.

This is the reason why we advocate the need for a paradigm shift in energy-efficient networking research, toward what we call Zero Electricity Networking (ZEN).

The ZEN concept is based on network elements (such as routers, base stations, etc.) that are not connected to a power grid, but can acquire limited amounts of energy from (probably intermittent) local generators exploiting renewable sources (solar, wind, etc.). During periods of sufficient energy production by the generator associated with a network element, energy is used to operate it, in a mode which is carefully chosen to balance performance and power consumption,

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and any energy surplus is stored in a battery, so that the element can operate also in periods of low or no production, as long as energy is available, but it is forced to switch off when the battery is depleted. Typically, we can expect that some periodicity exists in the possibility of energy production at network elements, for example because of the day/night variation in solar energy production (similar periodicities also exist in traffic demands, and we can expect the correlation to be significant). This means that (most of) network elements may be fully operational only for fractions of time, until energy lasts, or that they must choose operation modes which correspond to less-than-desired capacity, but are compatible with the available energy.

Research on ZEN can build upon many studies performed under similar constraints, but with different objectives, in the field of ad hoc networks, sensor networks, and wireless mesh networks [10,11,12,13,14,15,16], as well as in delay tolerant networks, or in military networks, where the activity of network elements cannot be given for granted at all times [17,18,19,20,21,22,23].

The viability of the ZEN approach must be investigated under realistic assumptions as regards the quantity of energy that is necessary at network nodes, that can be obtained from renewable sources at limited cost, and that can be stored in reasonable size/cost batteries. The investigation must also consider realistic traffic patterns, and performance or QoS/QoE (Quality of Service / Quality of Experience) requirements, consistent with the needs of a network operator (this is a major difference with respect to research performed in ad hoc and sensor networks or in delay tolerant networks, and is also one of the main challenges in ZEN).

The assessment of the feasibility of the ZEN approach requires multidisciplinary research, including competences in energy generation and storage, in low-power networking systems and equipment, in energy-efficient distributed and adaptive algorithms, and, of course, in networking. The ZEN concept has the possibility of opening new opportunities for the development of modern data networks in regions where energy grids are inexistent, or unreliable, or temporarily unavailable (because of both structural problems, and exceptional events, such as earthquakes, wars, or terrorism), or simply where energy is too expensive for operators to provide services at reasonable cost (a risk that may be faced also by developed countries in the not-so-distant future).

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