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For a Sustainable Future of Communications and Networking

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Editorial For a Sustainable Future of Communications and Networking

IF WE look in the dictionary at the term *sustainability*, we find it to be defined as the quality of being able to continue over a period of time, or, when referred to ecology, the quality of causing little or no damage to the environment to continue for a long time. Sustainability focuses on meeting the needs of the present without compromising the ability of future generations to meet their needs, where needs are related to planet and people, and intersect environmental, economical and social domains. The emergency related to climate changes and unprecedented increase of inequalities is pushing sustainability in the agenda of international and national organizations, a notable example being the United Nation definition of 17 Sustainable Development Goals. By shaping the future, research and innovation play a fundamental role in the processes to achieve these goals, especially in those sectors, like Information and Communication Technologies (ICT) that are drivers of economical growth. Researchers and technicians in all sectors related to information are called to make their part.

The effort to control the growth of ICT is necessary because these technologies combine a pervasive popularity with a disruptive capability to transform all other sectors. The Internet and related technologies are perceived as primary needs; they have reached developing countries much faster than previous technological innovations. Today, 8 in 10 individuals in the developing world own a mobile phone, more than those who access drinkable water and reliable power supply [item 1) in the Appendix]. Pushed by the increase of the popularity of video-services and Machine-to-Machine applications (whose number of connections is expected to reach 15 billion by 2023), the growth of Internet traffic has experienced an increase of a factor 3 in only 5 years and has reached the staggering value of 300 Exabytes carried per month [item 2) in the Appendix].

These numbers correspond to huge resource consumption. Some studies in the last years have estimated that the ICT sector consumes so much electricity to be responsible for about 3.5% of global emissions, an amount that could reach 14% of the total by 2040 [item 3) in the Appendix], or even more [item 4) in the Appendix]. Electricity means not only energy, but also other precious natural resources, like water. Water footprint is not as discussed and known as carbon footprint, but large amounts of water are needed to produce electricity and, in some cases like large data centers, for the cooling systems. According to [item 5) in the Appendix], in U.S., 7.6 liters of water are needed to produce 1 kWh of electricity. Since there is no indication that these consumption growth rates might reduce, and there is evidence of the environmental cost associated to the success and diffusion of these technologies, sustainability issues are becoming urgent.

As reported in [item 6) in the Appendix], all segments of ICT contribute to the consumption for a quite even share. PCs and monitors are responsible for about 40% of the total energy need of the sector; data storage, computing and management reach 23%; the communication infrastructures account for 31%. For what concerns the last two, access networks (composed by a very large number of devices that individually consume relatively little but exhibit a large aggregated total consumption) and data centers (where most of storage and computation needed to implement services is performed), remarkable energy efficiency improvements have been achieved in both fields in the last years. However, the resulting overall trend of consumption is somehow different. In the case of data centers, despite the increased popularity of cloud computing and data-intensive technologies, namely artificial intelligence and machine learning, from 2010 to 2018, the energy consumption growth has been much slower than what was predicted: a growth of a factor 6 of the computing capacity has been achieved by increasing the energy consumption for servers by 25% only; an increase of energy usage by 3 times has allowed to increase storage capacity by a factor 25 [item 7) in the Appendix]. Conversely, at the wireless access, predictions might result to be optimistic. Indeed, despite the efforts to consider energy as a key variable in the design of 5G, the new technology is much more energy demanding than previous solutions, resulting from a combination of network densification and devices, both base stations and terminals, that consume more than in previous technologies. The overall consumption of the 5G might be more than 10 times larger than the 4G [item 8) in the Appendix].

While there is still room for energy efficiency improvements, predicting the long-term limit is difficult, also in light of the possible future deployment of drastically different technologies such as quantum computing, with a potential for huge energy demand. The medium-term predictions, however, are undoubtedly calling for urgent solutions that include new design paradigms and innovative approaches. Some directions in which research should multiply efforts can be identified.

First, the adoption of clean energy procurement should be accelerated acting on the financial side, through direct incentives

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and taxes, as well as on investment in solutions to make technologies greener. For a greener technology, instead of considering the design of power supply and information technology systems as separate tasks, energy consumption and generation should be systematically combined. Fundamental performance indicators like energy consumption and efficiency should be enriched with descriptors that take into account also the kind of energy that is being used (green or brown) and its marginal cost (a unit of energy under a peak demand for electricity or critical working condition of a smart grid has not the same cost and impact of a unit of energy in a temporary over-production period, just to make an example). These descriptors should be integrated in the internal mechanisms of information systems, whenever a decision is made, whatever the decision is: a resource allocation, a task scheduling, the setting of quality parameters, and so on. They should become features of machine-learning algorithms that predict network conditions and optimize its working mode. By embedding energy descriptors in the state variables of the system operation, joint energy and system operation optimizations become possible. Similarly to the flexibility and degrees of freedom provided to data networks by packet-switched paradigm over circuit-switched one, embedding energy into information and communication system operation has the potential to achieve a real flexible and parsimonious use of energy. This, in its turn, can facilitate the adoption of distributed energy sources that generate in an intermittent way: a key element of the smart grids.

Second, the presence of competing companies running their communication infrastructures induces a waste of resources that can be only partially compensated by an adaptive resource allocation and activation on demand. The coexistence of multiple networks and infrastructures, each sized following the principle of peak demand dimensioning, multiplies the waste due to resource over-provisioning and this could be improved by new economical models that include infrastructure sharing. A sort of cross-technology and cross-operation approach to the optimization of the use of the infrastructures would be very beneficial to reduce inefficiencies.

Third, policy making and regulations can also induce sustainable attitudes of the users. For example, regulations about the end-of-life of devices are needed. The use of electronic devices, in particular terminals such as laptops and smartphones, undergoes an extremely fast turn-over and this turns into an extremely profitable market. However, the environmental cost of dismissal is not properly included in the cost of the devices. In [item 9) in the Appendix], it is estimated that more than 40 Mtons of e-waste are generated per year, corresponding to more than 6 kg per person, and only 20% of this waste is properly recycled or disposed, with harmful effects on the environment. New circular economy models are possible, they should be studied, proposed and promoted.

In another direction of investigation and research, undesired and unneeded information delivery, associated to uncontrolled advertisement and spamming, corresponds to a considerable fraction of the total amount of information that is daily carried by the networks. In addition, a lot of users' data are collected, often without users being aware and consenting it, so that it is estimated that less than 60% of the traffic is actually generated by humans. A friendly and transparent control on data gathering will have to be enforced in the next years for security and privacy purposes. This will offer the opportunity to reduce also undesired and unneeded, but costly, information delivery with an indirect positive effect on limiting the traffic growth.

Finally, users can effectively contribute to make ICT more sustainable by adopting proper behaviors as consumers of communication services. For people to become aware of ICT sustainability issues, information and knowledge must be shared. An open data collection campaign, incentivized and promoted by policy makers, is needed. This data is the basis for deriving ecological footprints of services and products, and consumption models. Footprints, models, certifications can guide consumers' choices with a direct effect of consumption reduction. In addition, an energy-aware users' behavior can give a competitive advantage on the market to solutions that are parsimonious in the use of resources, sparkling a virtuous circle in which service providers design more sustainable solutions.

To tackle the challenges of a sustainable future of information and communication technologies, the research community has to increase its efforts, exploiting all the great wealth of knowledge acquired over the years in terms of methodological tools, including complementary approaches that go from stochastic modeling and teletraffic theory, to data-driven engineering. Beyond the borders of disciplinary knowledge, the research community is called to elaborate an holistic long-term view that combines the technological perspective with the environmental, economical, social and political ones.

MICHELA MEO
Department of Electronics and Telecommunications
Politecnico di Torino
10129 Turin, Italy
(e-mail: michela.meo@polito.it)

APPENDIX
RELATED WORK

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Michela Meo is a Professor of Telecommunication Engineering with the Politecnico di Torino. Her research interests include green networking, energy-efficient mobile networks and data centers, Internet traffic classification and characterization, and machine learning for video quality of experience. She edited a book *Green Communications* (Wiley) and several special issues of international journals. She chairs the International Advisory Council of the International Teletraffic Conference. She is a Senior Editor of IEEE TRANSACTIONS ON GREEN COMMUNICATIONS and was an Associate Editor of ACM/IEEE TRANSACTIONS OF NETWORKING, Green Series of IEEE JOURNAL ON SELECTED AREAS OF COMMUNICATIONS NETWORKING and IEEE COMMUNICATION SURVEYS AND TUTORIALS. In the role of General or Technical Chair, she has lead the organization of several conferences, including ITC, ACM e-Energy, Infocom Miniconference, ICC simposia, and ISCC. She was the Deputy Rector of the Politecnico di Torino from March 2017 to March 2018.