Observing Energy in Software Distributed Ecosystems

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***Abstract*—The major transformations in our societies and industries are opening the way for the expansion of distributed computing through cyber-physical systems. These systems include sensing, computation, control and networking capabilities between the physical and the cyber worlds. However, measuring and monitoring their energy consumption is challenging, as these ecosystems are inherently heterogeneous: from the large selection of hardware components, devices and architectures, to the important variability in software versions and configurations, and to the various human actors involved. Monitoring such systems with their heterogenous nature requires building approaches and models to measure energy at various granularity levels (from hardware to software source code), and provide these measurements to the various actors (developers, end users). We present our vision on the major transformations and challenges towards modeling energy of connected devices, hardware components, software, and source code.**

***Index Terms*—Energy consumption, Cyber-physical systems, Software ecosystems, Distributed systems**

I. Context

Recent studies indicate an acceleration of earth's warmth and an alarming increase in temperatures, with recent scenarios describing an increase of up to 7% by 2100 [1]. The major reason for climate change is human activity, and, in particular, CO_2 emissions due to fossil fuel and related energy sources [2]. Earth's resource depletion is also another problem that is also due to human activities, such as extracting mineral resources, water drainage or deforestation.

Information and Communication Technologies' (ICT) greenhouse gas emissions (GHGE) could exceed 14% of global GHGE by 2040 from around 1-1.6% in 2007 [3]. ICT account in 2020 for up to 7% of global electricity consumption and is expected to continue rising [4]. ICT also account in 2015 for 4% of European CO_2 emissions, and up to 10% of the total European's electricity consumption [5].

Human societies today live in the information age where economies and social activities are shifting towards information technology (IT). Energy demands and consumption in information systems, ranging from computers and servers to devices in Internet of Things (IoT) and data centers, have grown subsequently in the last decade [6], [7]. Our societies completed a transition toward full digital storage of information in the early 2000s [8].

Today, people and businesses are more equipped with digital and technological devices and appliances. These devices are nowadays connected together and with distant servers (cloud computing), with complex software controling each devices and the collective of devices, thus transforming our equipment into smart devices and smart systems. This advent of devices and software in every aspect of our lives is a key element in major social changes, such as the fourth industrial revolution (Industry 4.0). Therefore, these smart environments open opportunities for energy management of those devices and appliances, as the energy consumption of appliances has doubled in 20 years, according to the French environment and energy agency, ADEME [9].

Therefore, with these majors changes and transformations of our societies, along with the rise of ICT's impact, it is a necessity to optimize and reduce their consumption. Optimizing energy first requires observing this energy, whether through measurement, estimation or simulation. However, the challenges are numerous, which we will present some in the next section.

II. Transformations and Challenges

The current landscape of computing of today and the evolution perspectives of the future shed the light on three major transformations, that come with their own set of challenges, and that are essential to incorporate in any green approach.

A. Advent of Cyber-Physical Systems

The large increase in computing devices and smart objects, and their tight integration in our homes, industries and societies, are opening the way to the expansion of **cyber-physical systems** (CPS). CPS integrate computing and software in our everyday lives, through sensing, computation, control and networking with physical connected objects. The latter are expected to rise to 125 billion devices in 2030, or an annual 12% increase [10].

B. Heterogeneous Environments

The spread of smart objects, devices and software frameworks and systems is leading to scattered architectures, software, protocols and hardware designs. We live now, more than ever, in **heterogeneous environments** which are more complex to monitor, understand and optimize. Sustainable approaches that focus on one environment or a subset of devices or operating systems or software, will be less relevant and less effective in driving meaningful energy reductions on the long run.

C. Integrating the Humans

As more people and users are interacting with software, through various devices and services, they are steering the rise in computing energy consumption. User requirements, needs and desires are the main driving force behind the widespread usage of smart devices and applications, and hence, the rise in the environmental costs of the infrastructure of modern software: end user devices, network equipment, and data centers. Therefore, optimizing computing and software energy can only be efficiently achieved by **integrating the humans** in the energy efficiency equation.

III. Conclusion

Our computing landscape is living major transformations. To make this landscape greener, more energy efficient and more environmentally friendly, we need to tackle the challenges through a holistic vision and an approach aiming toward software ecosystems: software because they are the *brain* of hardware and of complex architectures and environments, and ecosystems because we need to holistically address the new landscape of interconnected devices and networks where CPS are everywhere.

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