Cyber Physical Systems based on Cloud Computing and Internet of Things for energy efficiency

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ABSTRACT

Cyber Physical Systems (CPS) and energy efficiency play a major role in the context of industry expansion. Management practices for improving efficiency in the field of energy consumption became a priority of many major industries who are inefficient in terms of exploitation costs. The effort of adopting energy management means in an organization is quite challenging due to the lack of resources and expertise. One major problem consists in the lack of knowledge for energy management and practices. This paper aims to present authors' concept in creating a Cyber Physical Energy System (CPES) that will change organizations' way of consuming energy, by making them aware of their use. The presented concept will consider the security of the whole system and the easy integration with the existing electric network infrastructure.

Keywords: Cyber Physical Systems, Energy Efficiency, Cloud Computing, Internet of Things.

1. INTRODUCTION

Over the years, while researchers developed and used different methods and tools for analyzing, modeling and control physical processes, computer science allowed them to simulate processes using Cyber Physical Systems [1]. One of the existing general definitions of a Cyber Physical System (CPS) can be stated as: A Cyber Physical System is a firmly integrated engineered system consisting of electronics, computing, communication and control sub-systems. Cyber Physical Systems have a number of potential applications that include: advanced automotive, avionics, energy conservation, environmental control, healthcare, instrumentation, process control, traffic control and safety, as well as transportation.

According to the results of recent studies released by Transelectrica, in the first six months of 2015, electricity consumption decreased by 4.9% compared to the same period in 2014, reaching 23.55 TWh. Production in the first quarter was higher by 1.6% compared to the same period last year, more than a third is produced in conventional power plants. They have produced 12.04 TWh, with a decrease of almost 10% of the total energy generated in January-June 2014. A significant contribution to overall output growth rebounded wind farms, which in the first half produced 3.04 TWh, with almost 26 % more than in January-June 2014 [2]. Tools that provide energy consumption awareness entail significant changes in the energy behaviour of individual. An increase in consumers' knowledge will motivate them to be more energy efficient. Since many interrelated factors are involved in their level of knowledge, it is difficult to determine their individual influence, but factors such as electricity metering and information campaigns prove to bring significant positive results in consumer behavior [3].

This paper presents the main opportunities avaialable in the field of energy efficiency within buildings and what authors' concept of a Cyber-Physical Energy System looks like. The rest of the paper is organized as follows: Section II reviews the related work, Section III details the cyber physical system for energy efficiency conceptual model, followed by Section V that concludes the paper and presents future work.

2. RELATED WORK

On the Romanian and European market there are a couple of companies that deal with the automatization and modernization of houses to provide means for a proper energy management.

WINS [4] (Wireless Integrated Network Sensors) is a monitoring and controlling technology that combines micro-sensors and low-power signal processing, computation and low-cost wireless networking in a compact system which can be employed in different fields of interest. The compact and low-cost design allows WINS to be embedded and distributed at a lower cost than the one of a regular wireline sensors and actuator system. On an energetic scale, WINS devices can equip power plants, appliances and energy systems to enhance reliability, reduction in energy usage and improvements in quality of service.

Wiser [5] is an energy management system that integrates an application with sensors and electronic devices to control the energy usage and efficiency in buildings. The system has access to real-time home's energy output information, and the user can program, manage, monitor and control what he/she pays each month in utility bills, saving energy costs.

Dexcell Energy Manager [6], provided by DEXMA, can be accessed from the Web, which is also available in trial version. The system provides a utility bill tracker, reports, alerts and energy patterns for its users. The service is oriented to big energy consumers, has a partnership with DEXMA Energy Academy and is based in different protocols and manufactures, making it easier to integrate with other products and services.

Engage [7] is a web portal from Efergy, developed for a better management of energy usage. The user can monitor and manage in real-time from anywhere, helping to save money and to reduce his/her carbon footprint. The platform is oriented to the user, so it displays any type of data available to the client, and is still in beta version.

Cisco Energy Manager Suite [8] platform by Cisco includes software and services that helps to manage and measure the energy use of all devices connected across the perimeter. Mainly focused in school, offices, data centers environments, etc., it is designed to cut the energy consume, providing data about energy costs and wastes in devices.

ZigBee Smart Energy [9] is a public profile that defines a technology platform for monitoring and actively managing energy consumption at the end-user level. This profile identifies eight device types that work cooperatively to report energy consumption by individual users and allow utilities to manage peak loads directly, increasing efficiency, and ultimately allowing consumers to adopt more sensible energy usage habits.

EMOSS [10] is a Building Energy Management Open Source Software platform that is engineered to improve sensing and control of equipment in small- and medium-sized commercial buildings. BEMOSS aims to optimize electricity usage to reduce energy consumption and help implement demand response (DR) programs. This opens up demand side ancillary services markets and creates opportunities for building owner/operators.

3. CYBER PHYSICAL SYSTEM FOR ENERGY EFFICIENCY – CONCEPTUAL MODEL

This sections presents the conceptual architecture of a cyber physical system as perceived by the authors. Energy systems became one application area of Cyber Physical System that gained more and more interest from researchers as energy efficiency became a requirement. Most energy systems require the management of both physical and cyber variables and present a large-scale distributed architecture. These systems needs to be adapted to face new challenges by exhibiting flexibility, scalability, efficiency, effectiveness, sustainability, reliability and security. Such performance can be achieved by systematically embedding cyber technologies with capabilities as monitoring, communication and controlling. These capabilities rely on smart meters, sensors and actuators. Due to the fact that installing advances sensors and actuators is often not enough because the systems flood with data and create bottlenecks, system designers need to focus on novel architectural models and schemes of control. In general, the main features of a CPE include:

- Reliability, security and autonomy – Due to its scale and complexity, such a CPES must be robust, secure and reliable to system failures and changes in the environment. The CPES should also be adaptable to unexpected conditions and system failures by the means of predefined problem resolutions, thus ensuring autonomy. To achieve a high level of automation, control loops need to be closed.

- Comprehensive integration – CPES need to be closely integrated. They are the integration of computation and physical processes which relies on embedded real time systems and network communication infrastructures.

- Constrains – Due to the fact that every component of the system uses embedded software to communicate to other components, the proper functioning of the system depends on computing power, resource allocation, network bandwidth etc. Within a CPES, the components are characterized by a certain granularity of time and spatiality, thus these systems are constrained by spatiality (components are distributed, thus making them dependent of localization services and network signal) and real time (time critical applications where the components interact to one another to achieve a task in a specific time frame). The network communication constraints, such as time delays, can degrade CPES' performance and cause instability.

The criteria that formed the basis for the concept were represented by an extremely low power consumption, the high scalability and remotely controllable features. Within buildings, smart sensing and control systems are designed to ensure occupant comfort and operational efficiency. Electricity consumers in buildings can be optimized to increase the overall energy efficiency and productivity. On a high level of abstraction, the system architecture is based on four main components, as presented in Fig. 1.

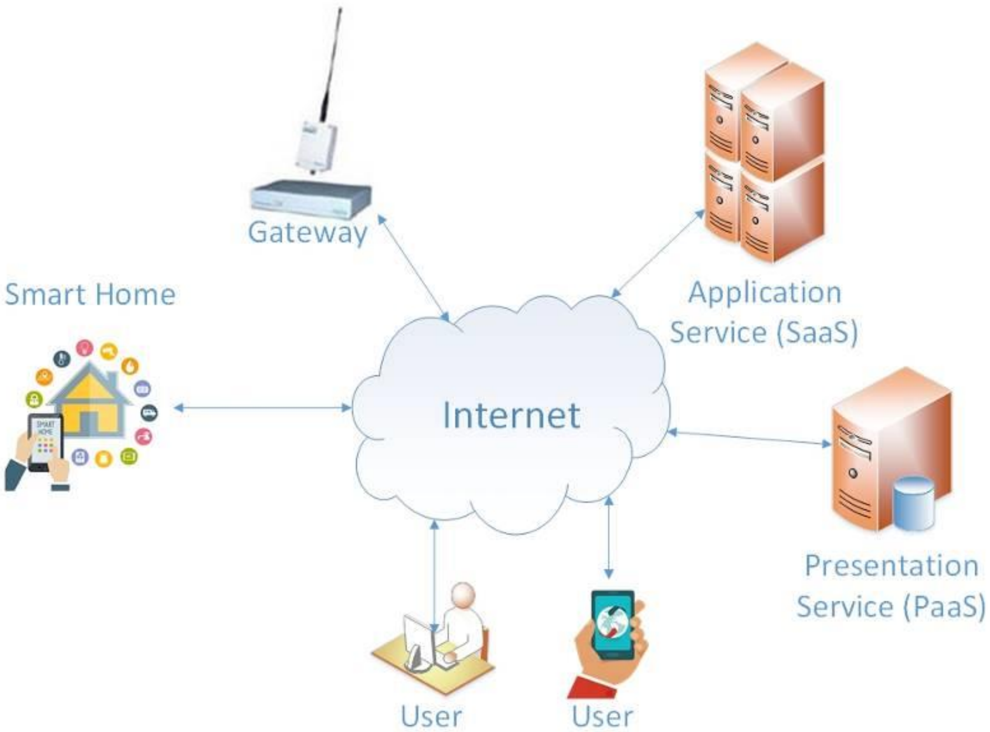

Figure 1. Conceptual Cyber Physical System Architecture

For data collection, the cyber physical system uses a wide variety of Smart Home sensors capable of measuring environmental parameters (temperature, moist, pressure, fluid level, light intensity, air quality etc.) or the amount of energy consumed in building. These information will be further used by the system to make operational decisions, thus increasing the level of comfort and reducing energy costs. In Fig. 1 presented above, the Gateway is the base station which receives sensor data and temporarily stores it. The SaaS and PaaS components are responsible for data collection from Gateways and make it available to the user for viewing or for special analysis. All the processing take place on the server, which is responsible for downloading data from the Gateway, storing data into the database, starting and stopping extensions and respond to user queries. These components should allow the CPS to benefit from capabilities as data collection, activity prediction and wireless communication between network devices and multimedia technologies, all connected in a modular architecture. Cloud Computing can provide humanized services for appliances and allow smart home nodes to form peer-to-peer networks. Energy monitoring systems based on Internet of Things rely on sensor networks and computer information processing to provide a information acquisition and processing platform suitable for existing and new constructions.

The areas of applicability of a cyber physical energy system relate to:

A) Modeling Energy Systems

The power system modeling is executed by using standard models based on differential algebraic equations (DAE) which are usually simplified and divided by time span of the studied phenomena. CPAs can provide a platform for developing simulation, analysis and design tools. The basic modeling approach relies on the representation of each component as a cyber-physical module based on both physical and cyber signals, internal dynamics, sensing and actuation and also on the integration of modular components based on network constraints.

B) Energy Efficiency

In the area of energy efficiency within ICT companies, researchers are studying CPES capable of reducing the power consumption of computers, servers and wireless devices. The main focus of their research was to improve system stability, reduce cooling costs and extend battery lifetime of portable devices, thus increasing the overall reliability of modern systems. Cyber Physical Systems can play a major role in sensor networks where components require mobility and an efficient use of battery life. In WSN (Wireless Sensor Networks), a large number of sensor nodes continually generate measurements that should be received by other nodes such as actuators in a regular fashion. Meanwhile, energy-efficiency is also important in WSN. Motivated by these, can be developed scheduling policies which are energy efficient and simultaneously maintain "regular" deliveries of packets. A tradeoff parameter is introduced to balance these two conflicting objectives. A Markov Decision Process (MDP) model can be employed where the state of each client is the time-since-last-delivery of its packet, and reduce it into an equivalent finite-state MDP problem. Although this equivalent problem can be solved by standard dynamic programming techniques, it suffers from a high-computational complexity. Thus we further pose the problem as a restless multi-armed bandit problem and employ the low-complexity Whittle Index policy.

C) Energy Resource Management

Energy conservation is a major concern of Cyber Physical Systems. Resource management is of paramount importance for QoS provision because the resource budgets need to be guaranteed in order to achieve certain QoS levels. This is particularly true for communication systems where computing, communication and energy resources are inherently limited. Generally speaking, a higher level of QoS corresponds to a need of more resources. For example, CPU time, memory size, bandwidth and/or energy. Resource management is challenging, because of the ever-increasing complexity of CPS, highly dynamic feature of the networks, and changing and unpredictable environments. To overcome these challenges, self-management technologies are needed. This implies that the system needs to address resource management issues in an autonomous manner. With respect to changes in resource availability, resource manager will automatically adapt resource usage in a way that the resulting overall QoS is optimized. This has to be conducted in an efficient way. Since the resources are limited, the overhead of resource management should be minimized.

D) Energy Control

A Cyber Physical Energy System requires the development of special controllers which address dynamic phenomena describing a wide variety of behaviors. Some major topics of interest in the field of energy control address topics as decentralized load frequency control, on-line closed loop voltage control, small-signal stability controller and other stability controls.

4. CONCLUSION

In these challenging times of turbulent energy costs, economic recession and global climate change, a Cyber Physical Energy System provides many opportunities to greatly improve national energy efficiency and conservation, also reducing the emissions of greenhouse gases.

In this paper, the CPES concept is introduced as well as its main features which are meant to address actual challenges in the area of energy efficiency. As mentioned in the introduction, CPS are designed and used for a wide variety of domains, also providing an increasingly significant impact in ensuring a proper management of energy.

The main research areas that CPES address are: modeling energy systems, energy efficiency, energy resource management and energy control. Closed loop voltage control, small-signal stabilization and decentralized load frequency control are just a few future directions for research and development in the area of CPES. A Cyber Physical Energy System should be reliable, secure and autonomous and should provide a comprehensive integration.

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