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A novel energy-driven computing paradigm for e-health scenarios

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ABSTRACT

A first-rate e-Health system saves lives, provides better patient care, allows complex but useful epidemiologic analysis and saves money. However, there may also be concerns about the costs and complexities associated with e-health implementation, and the need to solve issues about the energy footprint of the high-demanding computing facilities. This paper proposes a novel and evolved computing paradigm that: (i) provides the required computing and sensing resources; (ii) allows the population-wide diffusion; (iii) exploits the storage, communication and computing services provided by the Cloud; (iv) tackles the energy-optimization issue as a first-class requirement, taking it into account during the whole development cycle. The novel computing concept and the multi-layer top-down energy-optimization methodology obtain promising results in a realistic scenario for cardiovascular tracking and analysis, making the *Home Assisted Living* a reality.

1. Introduction

e-Health is a new concept of health management that produces several benefits. First, it reduces sanitary costs by prevention of potential diseases. Besides, it empowers the patients with a new generation of non-invasive, wearable personalized devices to make them more independent, and to provide early signals of health decline and advice for appropriate actions in daily life. Finally, the analysis of the obtained data greatly improves prevention by detecting early patterns of potential diseases; it allows us to evaluate the efficacy of treatments, to understand (through complex processing) the evolution of diseases and the factors that influence them. Biomedical engineers envision "a new system of distributed computing tools that will collect authorized medical data about people and store it securely within a network designed to help deliver quick and efficient care" [1].

In order to obtain such benefits, the target population has to be monitorized 24 h a day, and a Wireless Body Sensor Network (WBSN) is deployed. Thus, the system is composed of a large set of nodes, distributed among the population. Such nodes are non-intrusive and portable, which impose constraints on their energy consumption. Data obtained by the sensors are communicated to the embedded processing elements (PDAs, smartphones, etc.) by means of wireless connections.

Then, the huge set of data must be analyzed with the aim of performing the epidemiologic assessment. Also, diagnosis algorithms have to be implemented to allow early detection of pathologies and to learn the evolution of patients.

Since the target population is large, so it is the number of sensing nodes, and the amount of data to be managed is huge. In order to deal efficiently with such computationally intensive tasks, the use of cloud services is devised. Cloud computing is emerging as the dominant computer platform for scalable online services. Thus, the WBSNs will be connected not only at the node level, but also through the PDA, smartphone, etc. to the Cloud. Part of the data processing and storage will be local to the node, while another part will be communicated and processed in the cloud, depending on the application, on the state of the batteries and on security or privacy requirements of the information. The availability of the aforementioned technologies and the need of a continuous, portable, and non-invasive monitoring of the health information has led us to envision and design a Cloud computing-based real-time health monitoring and analysis framework capable of aiding health-care professionals. This computing environment where the mobile client utilizes mobile network services to communicate with cloud through the Internet is called *Mobile Cloud Computing* (MCC) [2]. Mobile cloud computing can address the problem of scalability by executing mobile applications on resource providers external to the mobile device.

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According to [3], one of the main questions to be answered in MCC is how computation can be offloaded and distributed to the cloud efficiently. The reasons for sharing/offloading work from a mobile device would be: limited computational capability, limited battery power, limited connectivity and to make use of idling processing power.

The focus of this work is proposing a novel multi-layered approach for the energy optimization of MCC technologies, and the validation with a case of study devoted to health monitoring and analysis applications.

1.1. Related work

The use of MCC environments for the automation of personal health-care systems has been recently related in literature [4–6]; however, none of these works have approached the energy efficiency in mobile cloud architectures.

Energy consumption is one of the major concerns for the adoption of population-wide health monitoring systems, but energy efficiency cannot be added as an afterthought. Truly energy-efficient monitoring can only be achieved by considering energy as a first-class requirement, taking it into account during the whole development cycle, from design to implementation. Thus, we propose an architecture driven by energy concerns and aimed at optimizing energy consumption globally.

In the literature, we can find several energy optimization techniques that target the different abstraction levels of the MCC architecture.

At the distributed computing level, the design of WBSN nodes is mainly focused on maximizing the lifetime of the node by reducing the energy consumption, although other performance requirements such as the delay and quality of the delivered data must be kept into account [7]. Energy efficiency in WBSNs has been tackled by proposing efficient MAC layer alternatives [8,9], providing stochastic approaches for traffic handling [10] or enabling compressed sensing signal acquisition/compression algorithms [11].

At the server level, one of the main problems to be solved in order to achieve the performance goal is the so called *power-wall*. Semiconductor manufacturers are reaching the limits of voltage scaling, no longer reducing power consumption in new chips. Thus, power consumption limits the advances in computer technology and is becoming a relevant part on the budget of present data centers. According to [12] power is the second-highest operating cost in 70% of all data centers and data centers are responsible for the emission of tens of millions of metric tons of carbon dioxide annually, more than 2% of the total global emissions. As a result there has been as well a recent research interest in the development of energy efficient data centers.

The researchers have done a massive amount of work [13–20] to provide an energy-aware high-performance computing environment. In these works, different scheduling, resource allocation and work assignment mechanisms are studied to improve the energy profile. Multi-layered approaches like ours, that targets both the node and server levels, are still missing.

Some energy optimization policies have been detected but not successfully proposed mainly due to the fact that they do not consider the global power consumption. In particular, they do not take into account the following:

1. that the agents involved in the problem (wireless nodes, embedded processors, network interfaces, high-performance servers, etc.) are very heterogeneous from the energy point of view. Therefore, the energy cost of performing part of the processing in any of the different abstraction layers, from the node to the data center, should be evaluated;
2. a local optimization in one of the abstraction layers can have a bigger negative impact on the others, so that the global energy of the system is increased. In this way, the relationships between all the computational agents have to be taken into account.

Our proposal develops global energy optimization policies that start from the design of the architecture of the system and take into account the energy relationship between the different abstraction layers.

In our work, we manage the whole set of abstraction levels in MCC to obtain the maximum benefit of the energy-aware policies. Among others, we consider computation offloading from the Cloud to the wireless nodes (and vice versa) as an effective mechanism for energy optimization. Computation offloading in MCC scenarios has been proposed by Kumar and Lu [21] and probed to provide high benefits. However, the authors have not considered realistic scenarios like e-Health and have not proposed a multi-layered optimization approach that combines this technique with other optimization mechanisms.

Some authors have recently followed a similar approach to our multi-layered proposal. For example, [22] described a research work on how to reduce GPS power consumption by offloading certain calculations onto the cloud. However, to the best of our knowledge, this is the first time that a work targets for energy optimization purposes the several constituent layers that enable MCC in e-Health scenarios. Our work provides horizontal and vertical approaches to extend the energy savings that these environments require.

1.2. Contributions

This paper makes the following contributions:

- we define a realistic and current application scenario where the computing and energy saving challenges are exposed;
- we propose a new highly-efficient computational paradigm;
- we demonstrate that the application characteristics must be considered in the computational paradigm since the very beginning of the design process;
- we propose a global strategy for energy efficiency in the computational architecture.

The remainder of this paper is organized as follows: Section 2 describes our envisioned energy efficient computational paradigm, whereas Section 3 details the particular case study. Section 4 describes the models used and Sections 5 and 6 show the different optimizations applied. Section 7 integrates the results obtained so far into a multi-layer approach and describes the new challenges. Finally, the most important conclusions are drawn in Section 8.

2. Devised computer paradigm

As previously described, our envisioned MCC e-Health system is composed of a number of body sensors, wirelessly connected to the cloud through a mobile processing device (as illustrated in Fig. 1). The distributed system spans a network comprised of individual health monitoring systems that connect through the Internet to data center facilities.

To provide adequate energy management, this heterogeneous distributed computing system for health monitoring is tightly coupled with an energy analysis and optimization system, which continuously adapts the amount of processing that is performed in the different layers of the distributed system, and the resources assigned to each task.

It is important to stress the need for a top-down approach, driven by the application context and the energy constraints, in order to reach an optimum solution globally.