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An energy-efficient task scheduling for mobile devices based on cloud assistant

Tundong Liu [a,b], Fufeng Chen [b], Yingran Ma [b], Yi Xie [a,c,*]

[a] *Center for Cloud Computing and Big Data, Xiamen University, China*

[b] *Department of Automation, Xiamen University, China*

[c] *Fujian Key Laboratory of Sensing and Computing for Smart City, School of Information Science and Engineering, Xiamen University, China*

HIGHLIGHTS

- The tasks on mobile devices can be offloaded to the cloud with cloud assistant.
- Propose an energy-efficient scheduling for speeding up executions and saving energy.
- It minimizes the energy consumption under the time constraint of applications.
- The task scheduling problem is reconstructed into a constrained shortest path problem.
- Apply the LARAC method to get an approximate optimal solution.

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ABSTRACT

Mobile cloud computing is an emerging service model to extend the capability and the battery life of mobile devices. Mostly one network application can be decomposed into fine-grained tasks which consist of sequential tasks and parallel tasks. With the assistance of mobile cloud computing, some tasks could be offloaded to the cloud for speeding up executions and saving energy. However, the task offloading results in some additional cost during the communication between cloud and mobile devices. Therefore, this paper proposes an energy-efficient scheduling of tasks, in which the mobile device offloads appropriate tasks to the cloud via a Wi-Fi access point. The scheduling aims to minimize the energy consumption of mobile device for one application under the constraint of total completion time. This task scheduling problem is reconstructed into a constrained shortest path problem and the LARAC method is applied to get the approximate optimal solution. The proposed energy-efficient strategy decreases 81.93% of energy consumption and 25.70% of time at most, compared with the local strategy. Moreover, the applicability and performance of the proposed strategy are verified in different patterns of applications, where the time constraint, the workload ratio between communication and computation are various.

1. Introduction

With the rapid development of wireless technology, mobile devices have been extensively involved in many popular applications which bring great convenience to people. Mobile devices become smart and complete complicated tasks with the support of advanced hardware technologies, such as faster CPU, larger memory storage, bigger screen and higher communication bandwidth. According to the Cisco report [1], traffic from wireless and mobile devices accounted for 46% of IP traffic in 2014. And it will exceed the traffic from wired devices by 2018. However, the development of mobile devices and wireless applications still faces many challenges. One outstanding challenge is the contradiction between the increasing requirements of network applications and the limited resource of mobile devices.

Mobile devices cannot support abundant computation and communication with limited computation capacity and battery storage. The short battery lifetime definitely hinders the development of wireless applications while the breakthrough of battery technology is difficult in a short period [2]. In order to obtain stable and effective network service, mobile devices shall solve the problem of energy optimization. Some researchers [3] studied the design of wireless interfaces and optimized communication proto-

* Corresponding author at: School of Information Science and Engineering, Xiamen University, China.
E-mail address: csyxie@xmu.edu.cn (Y. Xie).

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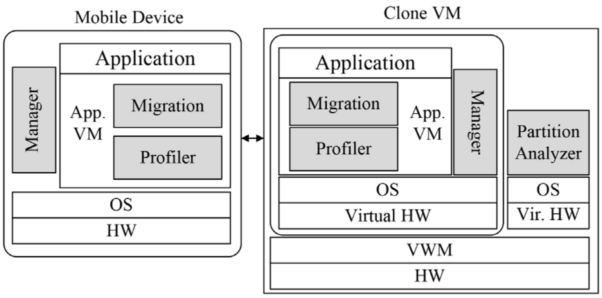

Fig. 1. Implementation of task scheduling.

cols to save the energy of mobile devices. Others [4–6] focused on the system design of mobile devices to save energy during the interactive processes of application programs. These above methods can save energy at the cost of performance.

The emerging cloud computing offers a new approach for mobile devices to extend their capabilities and battery lifetime. Some application tasks can be offloaded to a cloud platform, which may increase the application performance [7] or save the energy consumption of mobile device [8]. As shown in Fig. 1, a clone virtual machine is implemented on the cloud to execute the application of mobile device [9]. The profiler calculates the energy consumption and estimates the processing time of the application on the mobile device and the cloud individually. The manager obtains an energy-efficient task scheduling and the partition analyzer implements this task scheduling by setting the migration and re-integration points of application programs. With the cloud assistant, the use of mobile devices can satisfy the quality of service and improve users' experience. Additionally, the battery lifetime of mobile devices can be extended.

Designing an energy-efficient task scheduling is a critical step in the cloud assistant approach. It decides which tasks shall be executed in the cloud instead of in the mobile device. For example, Shu et al. [10] proposed an optimal time scheduling for a time-limited transmission task from a mobile device to the cloud, where the factors of communication bandwidth and transmission power consumption were considered. Mocanu et al. [11] proposed different task scheduling algorithms to deal with three categories of tasks: data-intensive, computation-intensive and transmission-intensive. A novel solution assumes that a mobile application consists of a sequence of tasks with a linear topology in Zhang's work [12],[1] and the energy-efficient problem is mapped to a directed acyclic graph (DAG), where each task is regarded as one node, and the edge weight between two nodes is denoted as the energy consumption of communication and computation of the prior task. Therefore, the optimal task scheduling using least energy consumption is obtained when the route of shortest path is found. However this analytical solution cannot be applied to general applications or complex network environments. The reason is that Zhang's work only considers sequential tasks and oversimplifies the transmission model of wireless channels.

In this paper, we design an energy-efficient task scheduling for a mobile device when it operates one network application with a time constraint. The mobile device is assumed to access Internet via Wi-Fi access point (AP) because the energy consumed in Wi-Fi communication accounts for a significant proportion of the total in mobile devices [14].[2] The main contributions of this paper are summarized below.

- With the assistance of cloud computing, tasks on mobile devices are offloaded to the cloud for speeding up executions and saving energy, where sequential tasks, parallel tasks and hybrid tasks are all considered.
- The execution of tasks is mapped into a DAG under a Markovian stochastic model of Wi-Fi channel which follows IEEE 802.11 protocol. Therefore, the task scheduling problem is reconstructed into a constrained shortest path problem and the LARAC method is applied to get the approximate optimal solution.
- The energy-efficient scheduling of tasks is obtained to minimize the energy consumption of mobile device for one application under the constraint of total completion time. With cloud assistant, the proposed strategy significantly reduces the energy consumption of mobile device compared with the local strategy, and presents more extensive applicability and better energy efficiency compared with Zhang's work [12].
- The influences of time constraints, communication data volume and computation workload are discussed in detail. To the best of our knowledge, these impact factors have not been comprehensively analyzed before.

The rest of this paper is organized as follows. Section 2 discusses the existing energy-efficient solutions of mobile devices. Section 3 models the network system and formulates the optimal task scheduling problem. The optimal problem is solved in Section 4. The proposed energy-efficient task scheduling is then evaluated and analyzed in Section 5. Finally, we draw a conclusion in Section 6.

2. Related work

The traditional way to save energy in mobile devices is to adjust the operations of components. Some people focused on hardware issues that used a machine learning technique to control the spin down of disk [15], managed a real-time scheduling of processor [16], and designed a dynamic voltage and frequency scaling [17–20]. In order to save energy of mobile devices during communication, some people revised the protocols in different network layers. For example, the QoS packet scheduler [21] and the low-power sleep mode of a wireless network card [22] were proposed in the media access control level. In the network layer, a traffic shaping mechanism [23] was proposed to save energy for all streams without any data loss. Yoo et al. [24] and Xia et al. [25] optimized Transmission Control Protocol (TCP) to increase energy efficiency.

As shown in Table 1, most energy-efficient approaches save energy consumption in mobile devices, but degrade devices' performance to some extent. Cloud assistant adaptively deploys the tasks of one network application in different environments: the servers in cloud and the local devices. With cloud assistant, some applications can save much energy while speeding up the execution of 20 times [9]. In the following, we focus on studying the energy-efficient approaches with cloud assistant.

Many approaches save more energy and extend the capabilities and resources of mobile devices [26] with the assistant of cloud. Various cloud-assisted platforms have been proposed, such as Cloudlet [27] and CloneCloud [9]. In CloneCloud, each mobile device is associated with a system-level clone (i.e., virtual machine, VM) in the cloud infrastructure. This mobile clone can receive data from the mobile device, process the data in the VM, and then send back the result. Therefore a mobile application can be executed on the mobile device (i.e. mobile execution) or on the cloud clone (i.e. cloud execution) seamlessly. It is practicable to save energy and improve performance by offloading computation to the cloud. For example, Shu et al. [10] proposed a transmission bandwidth strategy in 3G/4G and Wi-Fi networks based on

[1] The extended paper [13] further provides a theoretical framework of the optimal scheduling.

[2] More traffic from mobile-connected devices will be offloaded to Wi-Fi devices[1].