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Adaptive resource discovery in mobile cloud computing

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ABSTRACT

Mobile cloud computing (MCC) is aimed at integrating mobile devices with cloud computing. It is one of the most important concepts that have emerged in the last few years. Mobile devices, in the traditional agent-client architecture of MCC, only utilize resources in the cloud to enhance their functionalities. However, modern mobile devices have many more resources than before. As a result, researchers have begun to consider the possibility of mobile devices themselves sharing resources. This is called the cooperation-based architecture of MCC. Resource discovery is one of the most important issues that need to be solved to achieve this goal. Most of the existing work on resource discovery has adopted a fixed choice of centralized or flooding strategies. Many improved versions of energy-efficient methods based on both strategies have been proposed by researchers due to the limited battery life of mobile devices. This paper proposes a novel adaptive method of resource discovery from a different point of view to distinguish it from existing work. The proposed method automatically transforms between centralized and flooding strategies to save energy according to different network environments. Theoretical models of both energy consumption and the quality of response information are presented in this paper. A heuristic algorithm was also designed to implement the new adaptive method of resource discovery. The results from simulations demonstrated the effectiveness of the strategy and the efficiency of the proposed heuristic method.

1. Introduction

Cloud computing, which is aimed at providing infrastructures, platforms and software as services has been introduced and implemented in the last few years. It is widely recognized as the next generation of computing architecture. Wireless communication technologies have simultaneously been extensively developed. Different kinds of wireless networks like the third generation of mobile telecommunications technology (3G), Bluetooth, wireless local area networks (WLANs) and worldwide interoperability for microwave access (WIMAX) have become available in our daily lives. Users can choose different networks according to different requirements. The network connectivity and data throughput of mobile devices have been greatly improved. Therefore, the integration of mobile devices with cloud computing has attracted a great deal of attention from both industrial and academic communities because of its potential value. Mobile cloud computing (MCC) has been widely accepted as one of the most important solutions to this issue.

MCC can be roughly divided into two different architectures: agent-client based and cooperation-based [1]. The cloud (data center), in the agent-client based architecture, provides overall resource management for mobile devices. Mobile devices use resources in the cloud to enhance their functionalities and improve their processing abilities (e.g., data storage and processing speed). However, along with the development of hardware and software technologies, modern mobile devices like smart phones and tablets have many more resources than before, e.g., computing, communication, sensor and software-application resources [2]. As a result, two shortcomings in the agent-client based architecture have emerged: (1) available resources in the mobile devices themselves are not utilized efficiently and (2) long delays are caused by the long distance between the cloud and mobile devices. To solve these problems, cooperation-based MCC views the mobile devices and other fixed wireless devices (e.g., wireless routers and sensors) as part of the cloud. Available resources in these devices could be shared among themselves through wireless communication. Delays could also be reduced by devices benefiting from high throughput short-range communication and location proximity. The traditional cloud (data center) in the cooperation-based architecture plays a role as a scheduler in the collaboration by wireless devices. Of course, according to different contexts, the data center

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can also provide resources to mobile devices as it does in the agent-client based architecture. Due to its huge potential benefits, cooperation-based architecture has become the most interesting research area in MCC [3] [4]. This new architecture of MCC has also been defined as "Fog Computing" in [3]. However, to achieve cooperative resource sharing among wireless devices, it is quite important to find how available resources in nearby devices are discovered. This paper introduces an energy-efficient method of adaptive resource discovery to solve this problem. (see Fig. 1).

Much research on resource discovery has been published [5–15]. However, most of the existing work has adopted a fixed strategy for resource discovery and failed to adapt this strategy based on different network resource statuses, e.g., the degree of resource scarcity and the pattern of resource requirements (to differentiate it from "Network Status", which mainly refers to network traffic and bandwidth, Network Resource Status (NRS) is used in this paper to represent the characteristics of resource distribution and usage in the network). Apart from that, more resources consume more energy. Battery capacity also becomes a bottleneck in wireless applications. Consequently, more and more research [9,10,14,15] has aimed at providing energy-efficient solutions to resource discovery. However, there are two main problems in their research: (1) most of them have saved energy through sacrificing other important quality metrics like the accuracy and coverage of response information without formal quantitative analysis and (2) they have only taken into consideration resource discovery and energy consumption in homogeneous networks like 3G cellular or ad hoc WLANs alone. Obviously, energy consumption in heterogeneous networks is more realistic and more important for modern society.

This paper proposes an energy-efficient method of resource discovery that automatically transforms between centralized and flooding strategies according to different NRSs. The three main contributions of this paper are: (1) According to the best of our knowledge, this is the first proposal that has introduced an adaptive solution to resource discovery based on strategy transformations and the first work that has taken into consideration resource discovery in heterogeneous wireless networks. (2) We also established theoretical models of energy efficiency and quality of response information. (3) A heuristic algorithm was designed to implement the proposal and it was proved to be energy-efficient through extensive simulations.

In the rest of this paper, Section 2 introduces our system model. Our analysis of the proposed method of adaptive resource discovery is presented in Section 3. The heuristic algorithm is introduced in Section 4. An extension of the proposed method is presented in Section 5. Section 6 explains how we evaluated the adaptive method through extensive simulations. Related work is discussed in Section 7. Conclusions are drawn and future work is discussed in the last section.

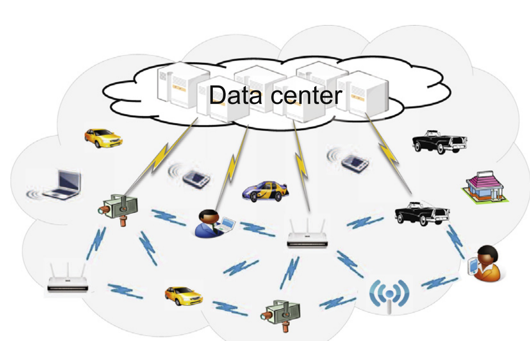

Fig. 1. Architecture for cooperation-based MCC.

2. System model

We assumed that mobile nodes were in heterogeneous wireless networks including both 3G cellular and ad hoc WLANs in this paper. Fig. 2 outlines the scenario. There is a central base station in the 3G cellular network that is able to communicate with all nodes in the area. We called it the central resource broker (CRB) in the background of resource sharing. Apart from that, every node can communicate with nearby nodes through a ad hoc WLAN. The assumed communication abilities are common in current smart phones and other devices. Nodes are assumed to be uniformly distributed throughout the area ([16] provides some application scenarios using this assumption. The effect of node mobility, which may violate this assumption, has been left for future work). Nodes either maintain a resource directory in the CRB through a widely-covered 3G network (a centralized mode) or flood resource requests in the area through a short-range ad hoc WLAN (a flooding mode) to discover resources.

Different resource discovery modes consume different amounts of energy. We tried to minimize energy consumption through transformations between the two modes according to different NRSs. Time is divided into consecutive time slots in our model. We define x_i as an indicator that specifies whether a centralized or flooding mode is selected in time slot i:

$$x_i = \begin{cases} 1 & \text{centralized mode is selected} \\ 0 & \text{flooding mode is selected.} \end{cases} \qquad (1)$$

Accordingly, $E_i(x_i)$ is defined as the energy consumed in time slot i based on different values of x_i. Without loss of generality, the period from time slot 1 to time slot Q is considered. The optimization problem is defined as the selection of an Q-dimensional vector comprised of x_i that minimizes the energy consumed by all 2^Q candidates, while keeping the expected value of resource information availability (RIA is a quality metric of response information defined in Section 3.2) no less than a threshold R_{thresh}. R_{thresh} is a real value in [0,1].

$$\text{objective}: \min \sum_{i=1}^{Q} E_i(x_i)$$

$$\text{subject to}:$$

$$x_i = 0 \text{ or } 1$$

$$E[RIA] \geqslant R_{thresh}$$

3. Proposed method of adaptive resource discovery

3.1. General description

As described in Section 2, nodes can discover available resources through both 3G cellular and ad hoc WLANs. There are two modes in the proposed method:

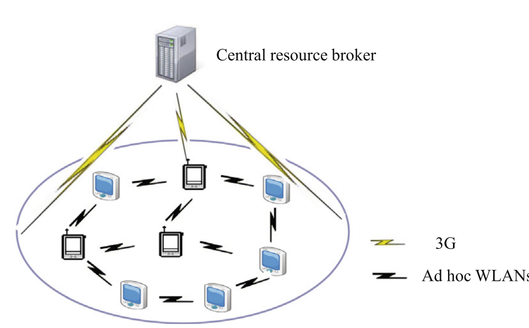

Fig. 2. System architecture.