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BeeCup: A bio-inspired energy-efficient clustering protocol for mobile learning

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HIGHLIGHTS

- We explore clustering to improve energy efficiency of mobile learning network systems.
- A bio-inspired dynamic clustering protocol called BeeCup is proposed.
- We find a suitable fitness function of artificial bee colony for mobile learning.
- We propose two intelligent clustering maintenance methods to achieve load balance.
- Extensive simulations have been conducted to evaluate the performance of BeeCup.

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ABSTRACT

Mobile devices have become a popular tool for ubiquitous learning in recent years. Multiple mobile users can be connected via ad hoc networks for the purpose of learning. In this context, due to limited battery capacity, energy efficiency of mobile devices becomes a very important factor that remarkably affects the user experience of mobile learning. Based on the artificial bee colony (ABC) algorithm, we propose a new clustering protocol, namely BeeCup, to save the energy of mobile devices while guaranteeing the quality of learning. The BeeCup protocol takes advantage of biologically-inspired computation, with focus on improving the energy efficiency of mobile devices. It first estimates the number of cluster heads (CHs) adaptively according to the network scale, and then selects the CHs by employing the ABC algorithm. In case some CHs consume energy excessively, clusters will be dynamically updated to keep energy consumption balanced within the whole network. Simulation results demonstrate the effectiveness and superiority of the proposed protocol.

1. Introduction

The ubiquitous deployment of wireless technologies has revolutionized the method of knowledge acquisition. Nowadays, learning is no longer limited to a classroom with a teacher in front. Mobile learning (m-*learning*), which facilitates education through wireless networks, provides learners with an opportunity to access abundant teaching materials and educational services using hand-held mobile devices, such as smart phones, laptops and so on. According to Gartner, a market research institution, the total number of mobile phones had reached to 1.211 billion in 2010 in the world [1] and the sales volume of smart phones has surpassed desktop machines to become the most prevalent computing platform in 2011 [2]. As the mobile devices are available to more and more people, the trend of the development of m-learning will be inevitable.

M-learning emphasizes its characteristics on "moving in" learning, contextual relevance, and other new features [3,4]. This benefits learners to learn at any time, any place as long as the mobile devices can access the server from the internet. However, the device display, CPU and wireless network interface card drain a lot of energy when displaying and processing the intensive multimedia content [5], which may shorten the study time and significantly decrease the quality of learning. Accordingly, how to save the energy and provide the learners with a long and persistent acceptable quality of learning experience becomes a great challenge.

It has been realized that the approach which is likely to effectively provide an energy-efficient [6,7] and load balancing [8] solution is by using the hierarchical structure, which is also called clustering. Clustering can be extremely effective in one-to-many, many-to-one, one-to-any, or one-to-all (broadcast) communication. For example, in one-to-many communication, the teacher

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only needs to transmit the multimedia streaming or other teaching files to the Cluster Heads (CHs) that have more residual energy and less mobility. Then the CHs dispatch the teaching resources to their Regular Nodes (RNs) within the communication range of the clusters, and the RNs only need to communicate with their CHs and consequently can omit the long distance communication with the server. In this way, the clustering structure can effectively save the mobile devices' energy.

However, the existing clustering protocols cannot be directly applied to the mobile learning because some protocols (e.g. [9,10]) cannot determine the number of clusters adaptively according to the varying network environments. Some of them do not consider the maximal cluster size which may overpass the upper limit of the communication methods [11]. Some clustering protocols may create many single-node clusters which have to communicate with the server node directly, thus consuming a lot of energy.

In this paper we design a new energy-efficient clustering protocol (called BeeCup) for m-learning applications over ad hoc networks. The BeeCup protocol takes advantage of bio-inspired computation. It firstly estimates how many clusters are suitable for the current m-learning network, and then selects some mobile devices as CHs taking into account several factors affecting the energy consumption as well as learning quality in practice. By introducing the clustering into m-learning scene, only the devices which are selected as CHs will communicate with the server directly using long-distance communication protocol, e.g. WLAN. Other users who want to download resources or submit the feedback only need to communicate with their CHs which are near and hence low-power communication methods can be employed. This can substantially save the mobile devices' energy, thus prolonging the learning time and enhancing the learning experience.

In order to select the most suitable mobile devices to serve as CHs while considering factors that remarkably affect the energy consumption, we need to model the clustering in m-learning. It has been shown in many papers that the collective behavior of social insects has many attractive features [12]. Inspired by the food foraging behavior of bees [13], Karaboga et al. [9] proposed the bio-inspired artificial bee colony (ABC) algorithm for solving complex optimization problems. ABC is a population-based metaheuristic approach which has very good convergence rate and robustness, and has been applied in many fields such as numerical function optimization [14], clustering [9] and so on. Here we will use the ABC algorithm to estimate the number of clusters for the current mobile learning scene, and to optimize the fitness function which covers the factors that have a close connection with the energy consumption of mobile devices such as their residual energy, real-time mobility and so on. In our previous work [15], we proposed the EBABC protocol, a clustering protocol for the ad-hoc sensor networks. In this paper, we substantially extend our previous work [15]. For instance, we will improve the process of CH number estimation by using a new structure of solution for ABC, thus making this process faster. We also propose two flexible clustering maintenance methods.

The major contributions of this paper can be summarized as follows:

(1) We introduce the clustering protocol into mobile learning to prolong the network lifetime by saving mobile devices' energy, and to enhance the quality of experience as well as learning effects. The proposed BeeCup protocol explores bio-inspired computation to adaptively determine the most proper number of clusters instead of assigning one manually.
(2) We find a suitable fitness function for the scene of mobile learning considering factors affecting the energy consumption and learning quality. We also propose two intelligent clustering maintenance methods to adjust the clusters dynamically to achieve load balance among the networked mobile devices during system runtime.
(3) We conduct extensive simulations to evaluate the performance of the proposed BeeCup protocol under different scenarios, as compared against three existing well-known protocols. Results are presented to show the effectiveness and superiority of the BeeCup protocol.

The rest of this paper is organized as follows. Section 2 briefly surveys related work. Section 3 outlines the problem statement and enumerates our assumptions. Section 4 presents the BeeCup protocol and the maintenance mechanisms. Section 5 shows their effectiveness via simulations, and compares it to other clustering techniques. Finally, Section 6 gives concluding remarks.

2. Related work

Many previous studies have investigated techniques to reduce energy consumption in m-learning, with focus on the following aspects: saving energy by personalizing the multimedia content [5,16], saving energy at the playing stage [17,18], using an optimized transport method during the transmission of teaching resource [19–21] and so on.

The BAAMLS system [5] varied the parameters of a multimedia clip such as the encoding technique and video resolution based on the mobile device's battery and its behavior when the residual energy was not sufficient for playing the requested media content. This decreases power consumed by the mobile device to retrieve, decode and display the multimedia content while maintaining a good perceived quality and prolongs the time of learning. In BaSeAMy [16], the remaining battery level and video stream duration as well as the packet loss rate were assessed to dynamically adjust the bit-rate of the stream and display brightness which could save energy, bring a good quality of learning experience and prolong the network lifetime. However, the above systems may affect the learners' quality of experience with a lower resolution or low bit-rate of stream.

Displays have been known as one of the major power consumers in mobile systems and different display technologies have different energy consumption profiles [17]. Effective control of the display is very important for energy saving during mobile learning. Cheng et al. [22] proposed an algorithm for Liquid Crystal Display (LCD) screen devices to adapt the backlight of the screen while also adjusting the intensity level of each pixel in the video frame to compensate for the degradation of video quality. The GreenVis scheme proposed in [18] builds a multi-objective optimization approach based on the Organic Light-Emitting Diode (OLED) power model to find energy-saving sequential color schemes and reduce power consumption on an OLED display.

Some works focus on the optimization of the communication protocols, such as CoolSpots [21] and SwitchR [20] used the Bluetooth as a communication method when the data rate did not reach the Bluetooth limit. Bluetooth was also used to wake up the WLAN channel when necessary. Nevertheless, these methods did not consider the whole network condition and could not prolong the network lifetime by cooperation.

None of the above works take the network structure into consideration. It is realized that a hierarchical structure is likely to provide a scalable and energy-efficient solution. Many clustering algorithms have been proposed for the purpose of energy efficiency. In WSNCABC [9], distance and the residual energy of the cluster heads were considered for clustering using the ABC algorithm. However, it did not consider the coverage of the CHs which may leave many single-node clusters. The negative impacts of single-node cluster on the network performance have been shown in [23]. The CONET protocol [11] reformed clusters according to each node's bandwidth requirement, energy use, and application type, using Bluetooth as an intra-communication method and WiFi