Ad Hoc Networks 000 (2016) 1–13

Contents lists available at ScienceDirect

Ad Hoc Networks

journal homepage: www.elsevier.com/locate/adhoc

PMC^{2}O: Mobile cloudlet networking and performance analysis based on computation offloading

Hao Jin, Shidong Yan*, Chenglin Zhao, Dong Liang

The Key Laboratory of Universal Wireless Communications for Ministry of Education, Beijing University of Posts and Telecommunications, Beijing 100876, China

ARTICLE INFO

Article history:
Received 29 April 2016
Revised 12 November 2016
Accepted 12 November 2016
Available online xxx

Keywords:
Hybrid ad hoc network
Networking
Cloudlet
Computation offloading

ABSTRACT

The increase of smart mobile device (SMD) results in explosive growth in mobile traffic and provokes mobile users to leverage more and more compute-intensive applications through SMD. Framework of seamless mobile application execution and networking based on edge computing resources is proved to be one of the promising trends in future mobile Internet. Focusing on networking of Ad hoc cloudlet, this paper proposed a dynamic cloudlet self-networking framework based on component offloading (PMC^{2}O). Taking node mobility into account, dynamic cloudlet behaviour is investigated, and an optimized allocation algorithm called SA-UM is presented to reduce the complexity of resolution space on component allocation algorithm. Proactive Remove decision algorithm based on Node Resource Cooperative Sharing Degree (PRDA-NRCSD) is put forward to improve user experience and optimize the load balancing of a mobile cloudlet.

1. Introduction

In recent years, the number of smart mobile device (SMD) increases substantially and results in explosive growth in mobile traffic, capability of mobile devices such as CPU processing, networking and senoring are also enhanced as well, which provokes mobile users to leverage more and more mobile applications through SMD. Since mobile cloud computing integrates mobile computing, cloud computing, and the wireless technologies to unleash the potentials of these technologies, it has become the main trend for mobile application execution [1]. However, processing capability and battery consumption still remain to be the main intrinsic limitations for compute-intensive applications. Application offloading is proposed, which allow SMDs to migrate entire or part of the application to remote data centers, proximate resource-rich computers, group of nearby mobile computing devices and other heterogeneous computing resources in various locations, and the results are sent back to the mobile device for integration with the rest of the application inside the mobile device after successful application execution [2–5].

The state-of-the-art mobile application execution frameworks and computation offloading have been surveyed in [6,7]. From the view point of framework, solutions can be classified by cloud-based frameworks, cloudlet-based frameworks and hybrid based frameworks. For cloud-based frameworks, since smart mobile devices are usually far from remote data centers, it is difficult for SMDs to get the computing results in time due to latencies of wide area network; meanwhile frequent offloading of computing application brings about great traffic burden to backbone networks.

Cloudlet based framework presented by Satyanarayanan [2] is a feasible solution to improve real-time computing efficiency and reduce traffic burden of backbone network. Cloudlet is a local cloud platform that is deployed on a resource-rich device, such as a WLAN server, or a group of mobile devices. The cloudlet-based solutions can be classified into two types according to the deployment location, namely server-based cloudlet and mobile ad-hoc cloudlet. Along with the standardization of 5G, networking methods based on edge computing resources [11] will become the important paradigm for mobile networks. Framework of seamless mobile application execution and networking provided by hybrid wireless Ad hoc networks, such as cellular networks converged with D2D, Wi-Fi is proved to be one of the promising trends in future mobile Internet. This provides more convenience and meets compute-intensive application demand of mobile users especially in those mobile application scenarios such as opportunistic sensing and information integration [8,9], speech recognition, natural language processing, computer vision and graphics, machine learning, augmented reality, planning [1,2,6,7] and rescue.

Since Satyanarayanan et al. introduced the concept of cloudlet and a VM-based cloudlet architecture, the open challenges in cloudlet based computation offloading mainly include the follow-

* Corresponding author.
E-mail address: ysdysdysdysd123@163.com (S. Yan).

http://dx.doi.org/10.1016/j.adhoc.2016.11.006
1570-8705/

Please cite this article as: H. Jin et al., PMC^{2}O: Mobile cloudlet networking and performance analysis based on computation offloading, Ad Hoc Networks (2016), http://dx.doi.org/10.1016/j.adhoc.2016.11.006

ing aspects: firstly, the investigation on cloudlet behavior is indispensable, including cloudlet sizing, networking capacity depending on the specific applications supported and the effect of user mobility to natural clustering of users in cloudlets. Secondly, self-managing of the cloudlet including networking and resource management policies is required, which meet the demand for real-time interactive response by low-latency and high bandwidth wireless access to the cloudlet [2]. Thirdly, cloudlet optimization is necessary considering intermittent connectivity of mobile users and handoff of cloudlets in order to improve user experience [18,19,20].

Some research issues on Ad hoc based cloudlet have been published recently, which mainly focus on mobile framework of computation offloading including mobile device opportunistic sensing [8], discovery and networking, application partition optimization, offloading decision, optimization on computation offloading allocation among offloading nodes and offloaded nodes, reliability and security of cloudlet.

In the respect of research on cloudlet based framework, some cloudlet based architectures have been presented. A general mobile Ad Hoc cloudlet architecture was proposed by Huerta-Canepa and Lee [3], which monitors the status of the devices in the surroundings by P2P functional module and implements node discovery and distribution of contents by Ad hoc discovery mechanism. A fine-grained dynamic cloudlet approach was proposed in [4] that deploys a component based cloudlet on any device in local area network with suffcient available resources, and a discrete system emulation model analysis of the system was given [13]. Koukoumidis et al. proposed a pocket cloudlet architecture [12], which makes use of the large memory capacity of mobile devices to alleviate the latency and energy consumption in accessing the remote cloud by migrating an application focusing on storage service based on a dynamic VM approach. A programming model and framework called CloudAware is presented as a holistic approach to bond computation offloading and context adaptation in [21]. In [23], an Offloading Framework for Internet of Things is provided by providing implementation details for key capabilities and qualitative evaluation of the framework's capabilities. In [24], a decentralized architecture called Drap is designed which enables handheld devices to communicate with each other and also serve as a middleware between the application level and the OS, including modules of Device Manager, Neighbour Discovery and Heterogeneity. In [25], a component based cyber foraging framework is developed to optimize application-specific metrics by not only offloading but also configuring application components at runtime, and it also enables collaborative scenarios by sharing components between multiple devices.

In the respect of application partition optimization, since partitioning is a technique for composing a mobile application into components [22], application partition optimization is indispensable. Partition algorithm is classfied into static partition and dymanic partition which rely on application developers and strong synchronization between a mobile device and cloud Servers [16,22]. The static partition algorithm is usually adopted. Application partition influences the computation offloading decision. In the scenario of cloudlet based computation offloading, because of mobility of application, offloading granularity ranges from VM, application component,code, application key value data and session etc., and the bandwidth required for each granularity ranges from Gigabytes, Megabytes to Kilobytes. The coarser the granularity is, the more bandwidth is required for offloading. The finer the granularity is, the more overhead and complexity for offloading control becomes.Therefore, offloading granularity is one of the essential factors to affect the optimization strategies of computation offloading decision and performance in cloudlet based framework [12], and it also becomes a challenge to the programming of mobile application. In [22], the application partition and offloading granularity is analyzed from the view point of programming model.

In the view point of optimization on computation offloading allocation and offloading decision, since face recognition and AR are selected as the typical applications in most research issues, From the respect of performance evaluation, performance criteria on Ad hoc cloudlet is similar to that compared to the cloud based framework including latency, bandwidth, response time [22] and computation resource usage. Most of the research papers published focus on the optimization of cloudlet considering network resources and computation offloading, energy consumption of mobile devices and application response time. In [26], both an analytical approach and an experimental approach are adopted to highlight the gain given by mobile-to-mobile opportunistic offloading compared to local execution. Multiple offloading strategies with regards to both computation time and energy consumption are investigated. Energy cost of three modes of computation offloading based on subtask for Ad hoc cloudlet was investigated in [10]. The computation offloading of mobile users is based on greedy mechanism. Marinelli et al. designed a Hyrax-based platform, which employs a mechanism for tolerating node departure to provide cloud computing services on a group of mobile devices and servers [14]. A decentralized computation offloading game is designed to model the offloading decision making problem among mobile users considering both computation and communication cost in homogeneous and heterogeneous wireless access scenarios [15]. In [27], a model and comprehensive analysis are presented for computation offloading between wearable devices and clouds in Wi-Fi and LTE scenarios by NS3 simulator. The performance evaluation criteria are the offloading delay and energy consumption without considering node mobility. In [28], a novel offloading system to design robust offloading decisions for mobile services is presented in cellular network scenarios considering the dependency relations among component services, and it aims to optimize execution time and energy consumption of executing mobile services. A trade-off fault-tolerance mechanism for the offloading system, and an improved genetic algorithm is provided for offloading optimization, and the mobility model is RWP. In [29], Energy Efficient Cooperative Computing is investigated in mobile wireless sensor networks by proposing energy efficient cooperation node selection strategies to offer a trade-off between fairness and energy consumption, the problem was formulated as a joint optimization of computing and networking resources. In [30], a system model to capture the response time of offloaded tasks is introduced, the optimization objective is formulated to minimize the maximum average response time of tasks in cloudlets, and a fast, scalable algorithm is presented and evaluated by experimental simulations. In [31], the cloud-assisted collaborative execution of tasks in general topology to conserve the energy on the mobile device under a delay deadline is considered. Each task can be executed either on the mobile device or on the cloud clone. A directed acyclic graph is used to model the tasks within the application. The collaborative execution is formulated as a delay-constrained workflow scheduling problem on the graph in order to minimize the energy consumption on the mobile device.

From the above investigation on cloudlet based computation offloading, the research issues on cloudlet behavior are limited, especially considering node mobiity. In this paper, we propose a dynamic self-networking cloudlet framework, and based on the above framework, present a novel networking mechanism and an optimized allocation algorithm based on component to improve the performance of the cloudlet. To our knowledge, it is the first attempt to investigate the dynamic self-networking cloudlet considering node mobility.The main contribution of this paper is as follows: (1) a dynamic self-networking cloudlet framework called Penetration based Mobile Cloudlet based on Computation Offloading (PMC^2O) is proposed, which consists of discovery of mobile

Please cite this article as: H. Jin et al., PMC^2O: Mobile cloudlet networking and performance analysis based on computation offloading, Ad Hoc Networks (2016), http://dx.doi.org/10.1016/j.adhoc.2016.11.006