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Joint Cloud and Wireless Networks Operations in Mobile Cloud Computing Environments With Telecom Operator Cloud

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Abstract In mobile cloud computing systems, cloud computing has a significant impact on wireless networks. Cloud computing and wireless networks have traditionally been addressed separately in the literature. In this paper, we jointly study the operations of cloud computing and wireless networks in mobile computing environments, where the objective is to improve the end-to-end performances of cloud mobile media delivered through mobile cloud computing systems. Unlike most existing studies on wireless networks, where only the spectrum efficiency is considered, we consider not only the spectrum efficiency in wireless networks but also the pricing information in the cloud, based on which power allocation and interference management in the wireless networks are performed. We formulate the problems encountered in the operations of mobile cloud computing environments, including determining the price to charge for media services, resource allocation, and interference management, as a Stackelberg game model. Moreover, we extend this game model with multiple players through network virtualization technology, and adopt the replicator dynamics method to solve the evolutionary game between the different groups of small cells. Furthermore, a backward induction method is used to analyze the proposed Stackelberg game. Simulation results are presented to show the effectiveness of the proposed techniques.

I. INTRODUCTION

RECENTLY, cloud computing has drawn a lot of attentions from both academia and industry . It has advantages over traditional computing paradigms, such as avoiding capital investments and operational expenses for end-users. The essential characteristics of cloud computing include on-demand self-service, broadband network access, resource pooling, rapid elasticity, and measured service Furthermore, with recent advances in mobile communication technologies, mobile devices, and mobile applications, more and more end-users access cloud computing systems via mobile devices, such as smart phones. As much, mobile cloud computing is widely considered s a promising computing paradigm with huge marketsIt can bridge the gap between multimedia demands of end-users and the capacity of mobile networks. In traditional mobile computing systems, mobile devices usually have limited computing and storage capabilities. In contrast, utilizing the powerful computing and storage resources available in cloud environments, mobile cloud computing can enable the use of cutting-edge multimedia services. In the cloud, the resources have much higher processing and storage capacities compared to what traditional mobile devices can provide. And thus, the cloud can offer a much richer media experience than current mobile applications There are many promising cloud mobile media (CMM) services based on mobile cloud computing, including media storage and downloading services, audio services, and interactive services (e.g., multi-way video conferencing, advertisements, and mobile multiplayer gaming) . CMM services will not only make the end-users enjoy a richer media experience from a mobile device, but a more important aspect is that CMM services will also offer new opportunities for CMM service providers (SPs) and telecom operators to offer end-users rich media services that can be delivered efficiently such that endusers are satisfied and have a good quality of experience . For telecom operators, CMM services will narrow the increasing gap between the growth in data usage by end-users and revenue earned by SPs. Despite the potential of CMMservices, several research challenges still need to be addressed. These include the following: the availability and accessibility of media services, mobile data integrity, user privacy, energy efficiency, response time, and the quality of service (QoS) over wireless networks [Among these challenges in deploying CMM services, an important one is the response time experienced by end-users, which is highly dependent on the quality and speed of the network Indeed, networking has become a bottleneck, and thus, it has a significant impact on the quality of cloud services. This problem becomes more severe in CMM services due to the scarce network capacity, higher bit error rate, and user mobility in wireless networks .One reason caused the above problem is that cloud computing and communication networks are not jointly designed and optimized

II. SYSTEM DESCRIPTION AND FORMULATION

In this section, we consider a mobile cloud computing system with several third party CMM SPs. The system has a telecom operator cloud that can "mix and interchange" resources offered by different third party CMM SPs, and HWNs contains both macro and small cell base stations. In addition, the problem of joint cloud and wireless networks operations in this system is formulated as a three-stage Stackelberg game.

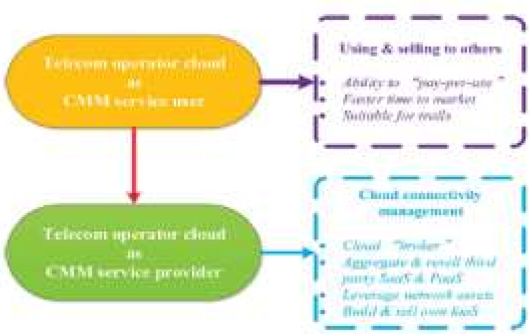

Fig. 1. Telecom operator cloud.

A. Telecom Operator Cloud and Third Party CMM SPs

Future media service will definitely be provided by clouds. The multimedia service may come from different cloud service providers, different network types, different technologies, etc. In this paper, we mainly consider the CMM service model provided by different third party CMM SPs. Different CMM SPs offer rich multi-media services to the end-users, including the streaming media, interactive service, and mobile gaming, etc. In the previous paper, we have discussed that most of the CMM SPs will choose to partner with the telecom operators rather than to pay. In this scenario, telecom operators will pool variety of third party CMM SPs and offer a virtually unlimited selection of customized and diverse services for end-users. Telecom operators are making a stronger push to monetize data traffic through OTT-style services and applications. They also attempt to restrict these traffic-heavy, low-revenue OTT services such as streaming media, but this may have negative impacts on user experiences, even violates the regulationsm sometimes. Operators can play a natural role in the cloud computing, providing the reliable and low-cost connectivity service for any other third party clouds, but this is just an initial step. Some of the pioneers in this area have already explored a new TOC model . On one hand, telecom operators can use the powerful storage and computing capabilities offered by the cloud for network management, such as billing. In this case, telecom operators are cloud users. On the other hand, telecom operators can also be cloud providers as well. For example, the telecom operators can leverage the network assets to aggregate and resell the services of third party clouds. Similar to the cloud computing model, for achieving low-cost media services by using the "pay-per-use" approach, mobile cloud computing can also adopt the utility billing model to require resources and provide Mobile Network as a Service(MNaaS). As shown in Fig. 1, TOC is in an unique position of being as a cloud "broker" between the wireless networks and the third party SPs, and can manage connectivity and offer flexibility in acquiring network resources on-demand and in real-time. There are three major roles, namely, cloud connectivity, delivery of cloud-based capabilities, and leveraging network assets to enhance cloud offerings. This TOC model can align itself in the cloud value chain . Furthermore, MNaaS can use network virtualization technique to make the connectivity much easier, since it allows the operator to set upmultiple channels over the same infrastructure and use whichever network layer is the most appropriate to deliver the required QoS to suit a particular CMM service with the need of end-users. Most scenarios using MNaaS as a delivery model are that virtual networks are on the top of the existing infrastructure to enable the telecom operator integrate its new services without affecting the existing business. Therefore, telecom operators can provide all their network resources, and the other third-party players can focus on the operation of virtual networks leased from the telecom operator cloud to set up their own dynamic pricing schemes. Pricing is an important issue in cloud computing. There are several studies about pricing schemes and algorithms for cloud services .We can group them mainly into two categories, namely static pricing and dynamic pricing. In static pricing schemes, prices cannot be changed in a relatively short period, and the telecom operator cloud does not adapt to real-time congestion conditions, and there is no usage incentives. By contrast, dynamic pricing can adjust the prices in nearly realtime via MNaaS technique in response to the observed network conditions. In mobile cloud environments considered in this research, end-users have the abilities to communicate with TOC in real-time. In addition, end-users can easily control their own usage on the individual devices and applications. Therefore, in this paper, we adopt a dynamic pricing scheme.

B. Heterogeneous Wireless Networks With Small Cells

A promising approach to improve the network performance in terms of capacity and energy efficiency is to use a multi-tier or hierarchical structure with small cells . This architecture represents a novel wireless networking paradigm based on the idea of deploying short-range, low-power, and low-cost base stations, which operate in conjunction with macrocells . Telecom operators have to deploy multiple wireless access networks with different technologies nowadays to meet the growing demands of users in regards to bandwidth and mobility. HWNs is one of the solutions to make the handover between these technologies more transparent for the end-users, and to facilitate a more seamless experience for roaming. One of the key features in HWNs is to always provide the best data service and network connectivity to the end-users via different available wireless access networks when subjected to different interworking scenarios appearing throughout the time of handover and roaming procedures. base station (MBS) and multiple small cell base stations (SBSs). Each SBS is connected to the MBS via a broadband connection such as a cable modem or digital subscriber line (DSL). TheMBS and the small cells have a cognitive capability and can sense the channel state information. There are multiple macrocell users (MUs) and Orthogonal frequency-division multiple access (OFDMA) technology is used. We assume that each small cell serves only one small cell secondary user All the small cells are deploy sparsely to avoid mutual interference. The macrocell and the small cells are considered to be perfectly synchronized and the whole system is operated in a time-slotted manner.

As we consider that the macrocell and the small cell share the spectrum in the mobile network, there will be cross-tier interference between them, which will significantly affect the performance. To guarantee the QoS of end-users and reduce this effect, we introduce an interference price charged by MBS to protect itself from the SSU. According to this price and the channel condition, the small cell will change the sub-bands they access and their transmission power.

C. A Game-Theoretic Approach

In this paper, the problem of joint operations of telecom operator cloud and heterogeneous wireless network is formulated as a three-stage Stackelberg game, The main notations used in this paper are listed in .Each third party CMM SP is a leader that provides a cloud media service price xr to the macrocell and small cells. All the MUs and the SSUs, which are playing the part of followers, decide the amount of media service from the CMM SPs to purchase according to the service price xr in Stage I of the game. We measure the media service in bits per second (bps) to meet the end-user's media demand by guaranteeing performance. In practical networks, there are up to 4 users per small cell. However, they use different channels. So the proposed scheme can be easily extended to the practical case. firstly, the MBS decides as a follower from which CMM SP to buy the media service, then it acts as a leader to offer an interference price y to the small cells to reduce the interference effect. In Stage III, each SBS decides which CMM SP to buy the service from, based upon the service price xr and the interference price y charged by MBS. a) Cloud level game: For the CMM SPs, we assume that each of them is selfish and independent of gaining the revenue as much as possible. Each CMM SP's profit depends on its own resource cost and the service price, as well as the price offered by the other SPs.

V. CONCLUSION AND FUTURE WORK

In this paper, we have studied the issues that arise when jointly considering the operations of cloud and wireless networks in mobile cloud computing environments with the telecom operator cloud. We introduced a system model, which jointly considers the CMM SPs and HWNs with small cells. Multiple CMM SPs offer CMM service prices to the heterogeneous networks. Then the MBS and SBSs adjust the amount of service they procured by performing resource allocation. We formulated the problems of determining a CMM service price, wireless power allocation, and interference management as a three-level Stackelberg game. We also presented an interference price to measure and mitigate the cross-tier interference between the macrocell and small cells. The MBS is allowed to protect its own users by charging the SBSs. At the CMM SP's level, we proposed a homogeneous Bertrand game with asymmetric costs to model the CMM service decisions and used a backward induction method to solve the whole model. Finally, we presented an iteration algorithm to obtain the equilibrium of the Stackelberg

Game. Simulation results have been presented to show that the dynamics of cloud operations have a significant impact on the heterogeneous wireless network, and joint optimization is necessary for the operations of cloud and wireless networks. This is due to unique dynamics tied with cloud, CMM services and wireless networks. By jointly optimizing the operations of clouds and wireless networks, the proposed scheme can significantly improve the performance of the mobile cloud computing systems.

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