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Femtocaching in video content delivery: Assignment of video clips to serve dynamic mobile users

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ABSTRACT

Online video streaming has been experiencing great popularity in recent years, and an increasing number of video contents are now delivered via wireless networks, which brings an overwhelming burden towards mobile operators. Femtocells are introduced to improve the area spectral efficiency of wireless video delivery via short link transmission. The backhaul pressure in the presence of dense deployment of femtocells can be reduced by the technologies of femtocaching. In this paper, video clip selection and video clip assignment problems are considered for femtocaching. On one hand, since mobile users always pursue the video clips that are highly popular and can be played smoothly, it is important to ensure the satisfaction of mobile users. On the other hand, the assignment of multiple video clips among multiple femto-caches is also significant as the capacity of each cache is limited. To model the video selection dynamics of mobile users, an evolutionary game is introduced and two algorithms are proposed to result in an evolutionary stable strategies, which correspond to the balance of video popularity and video quality. For the video assignment problem, the auction-based algorithms are proposed with low complexity to approximate the social optimality with the limited caching capacities. As a consequence, all femtocells and mobile video users are satisfied with their utilities respectively.

1. Introduction

The recent decade has witnessed the boom of wireless multimedia, especially the soaring requests for video. Cisco's investigation [1] reveals that mobile video traffic exceeded 50% of global mobile data traffic for the first time at the end of 2012. It is also estimated that video traffic would increase 14-fold between 2013 and 2018, accounting for over two-thirds of the world's mobile data traffic by 2018.

A number of new technologies have emerged to deal with such huge data requirements. In particular, femtocell is one of the promising approaches [2]. Femtocell is a practical application of short-range transmission, which is able to provide wireless terminals with better service quality by taking advantage of the proximity between transmitters and receivers. Femtocell also enhances the spectrum efficiency by effective spectrum reuse, and reduces the operation expenditure of macrocell. In terms of hybrid access [3], femtocells are able to serve both femtocell users and macrocell users.

On the other hand, triggered by video providers such as YouTube, Netflix and Hulu, video contents are requested at an unprecedented level. Different from typical voice and data services, video service has its own distinctive characteristics. Firstly, based on content reuse, scores of people could get access to the same video, whereas they would never share their private phone calls or text messages. Secondly, lots of resources have to be allocated for video traffic because the file size of video is always large, especially when High Definition videos are becoming increasingly popular at this moment. Thirdly, mobile users constantly expect that the video could play smoothly without too much buffering time or distortion, *i.e.*, with high video quality. If a certain video has low playback quality due to either buffering time or distortion, there would be a great possibility that the user switches to another one. Lastly, different video contents have different *popularity*. For instance, people obviously prefer a hot movie to an old documentary, and therefore

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they are more likely to get access to the former one. In this sense, popularity could be used as a label to distinguish different video contents.

Although femtocell networks can provide a better quality for video delivery, the dense deployment of femtocells will increase the backhaul burden since the real-time wireless video traffic requires more bandwidth than data and voice services. As a useful approach, femtocaching [4] has been proposed in order to facilitate femtocells in providing video contents. With some storage capacity to store video contents, femtocells are able to serve mobile users in a more efficient way. To be more explicit, a femto base station could download some video clips in advance and then save these video clips in its own cache. When mobile users request such video contents, the femtocell does not need to obtain video contents via backhaul once again. Instead, it could take the video out from its cache and then send it to multiple users requesting it. The most significant advantage is that the femtocaching replaces repeated backhaul communication, and the video quality could be improved due to the femtocells' short-range communication. In addition, the wireless communication resources of macrocell are also saved.

As a consequence, it is reasonable to motivate femtocells to serve macrocell users with video requests. However, it is also non-trivial to consider several limitations of femtocell. An important point is the storage capacity of the cache, as a femto base station is apparently not able to store too many video clips. In the meantime, because femtocells have to guarantee the service of femtocell users as the prerequisite in hybrid access, extra resources such as bandwidth are needed for femtocells to serve macrocell users.

In this paper, we consider a situation where the cache of femtocell is used to store video contents. Within a certain range of area, there are multiple femtocells which might use their caches to serve macrocell video users (MVUs). We assume that the femtocell charges each MVU that obtains the video. Intuitively, femtocells look for the most popular video contents and thereby attract more MVUs. However, in order to avoid slowdown or even breakdown caused by the massive requests from MVUs, every femtocell needs to control the number of accessed MVUs. As we would elaborate in Section 4.1 that greater video popularity leads to lower video quality, every femtocell is thereby able to control the number of accessed MVUs by adjusting the video quality it provides.

Considering the relationship between the high popularity and low quality of video delivery, every MVU needs to choose video clip carefully to acquire a satisfying utility as well. From this perspective, we use evolutionary game [5] to depict the interactions among the MVUs. On this line, replicator dynamics based on deterministic model is proposed to investigate the evolution of MVUs.

Moreover, since each femtocell could store only a limited amount of video contents, how to assign miscellaneous kinds of video contents to each femtocell and thereby maximize the revenue of all femtocells is also a significant problem. We apply auction algorithm [6] as an effective solution to derive an efficient video assignment policy, taking the advantage of low computational complexity as well as low memory requirement.

The main contributions of our work are as follows:

- We apply popularity as a kind of label to distinguish videos and associate it with video quality to describe the utility of MVU, which mimics video clip selection process in practice.
- Different from previous works that mainly investigate the video delivery, we also take into consideration the behaviors of MVUs and femtocells, which better depicts practical video services.
- We introduce evolutionary game to model the dynamics of MVUs, and derive the video clip assignment policy based on auction algorithms for femtocells. The algorithms perform well in terms of fast convergence.

The remainder of this paper is organized as follows. In Section 2, we review several previous works. Then the system model is elaborated in Section 3, while the problem is formulated in Section 4. We model the evolution of MVUs using replicator dynamics in Section 5, and then obtain the optimal bandwidth for femtocells in Section 6. Auction-based video clip assignment policy is investigated in Section 7. Section 8 presents some simulation results, and we finally conclude our work in Section 9.

2. Literature review

Caching is a heated topic in recent years, especially in delivering video to mobile users. For example, in [7] proxy caching is utilized to improve the quality of streaming, while in [8] mobile switching centers could locate video contents closer to users with the help of cache servers. Caching is also of great benefit in small-cell network, as [9] discusses the impact of cache in transmission scheduling and congestion control. Some interesting issues about collaborative caching in video streaming are investigated in papers such as [10,11]. In addition, caching and coding are jointly considered in [12]. Femtocaching has been proposed as well. In [4], femtocaching helps lead a novel way to increase area spectral efficiency of video transmission in cellular networks.

Video popularity has sparked off scores of researches as well. Among those early papers covering video popularity models, [13] investigates a lot in pre-acquired data and hierarchical servers. Meanwhile, some recent works include [14] studying video streaming in terms of an energy-spectrum-aware scheduling scheme, and [15] discussing video popularity associated with video quality using evolutionary game. Additionally, [16] sheds light upon the way for building the next-generation video cloud.

However, aiming at improving the system performance, most of the prior works mainly focus on caching and video delivery, without paying much attention to wireless service providers or mobile users. To our knowledge, video service and business problems have been addressed in few papers such as [17,18]. In effect, participants' behavior needs to be taken into account as well, in that they all rationally care for their own utilities. In this sense, we build our system model based on interactions among all sides of participants, thus demonstrating a more realistic situation.

Evolutionary game is a useful tool to model the behavior of human beings in the society [19]. In an evolutionary game, all of the players are grouped into a population. Each player independently chooses a certain strategy, while observing the utility of other players in the same group. In this case, a player tends to switch to the video clip which provides a higher utility. The solution to evolutionary game is the evolutionary equilibrium where there is no change in proportion of players choosing the different strategies [20]. From the perspective of evolutionary game, a spectrum trading problem with multiple sellers and multiple buyer is effectively solved in [20], while [21] derives a wireless multicast policy.

Auction is an effective approach to efficiently allocate resources, especially when the seller has no knowledge about the value of the resource in advance. It mimics a competitive bidding process in which unassigned players raise their prices and bid for objects simultaneously. For instance, in [22] the optimal assignment of the clients to the available access points in 60 GHz millimeter-wave wireless access networks [23] is proposed, and [24] pinpoints several auction-based resource allocation algorithms for uplink OFDMA cellular networks.

3. System model

Illustrated in Fig. 1, we consider a downlink model with N femtocells within a certain range of area, and the femtocells are