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Cellular traffic offloading utilizing set-cover based caching in mobile social networks

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Abstract

To cope with the explosive data demands, offloading cellular traffic through mobile social networks (MSNs) has become a promising approach to alleviate traffic load. Indeed, the repeated data transmission results in a great deal of unnecessary traffic. Existing solutions generally adopt proactive caching and achieve traffic shifting by exploiting opportunistic contacts. The key challenge to maximize the offloading utility needs leveraging the trade-off between the offloaded traffic and the users' delay requirement. Since current caching scheme rarely address this challenge, in this paper, we first quantitatively interpret the offloading revenues on the cellular operator side associated with the scale of caching users, then develop a centralized caching protocol to maximize the offloading revenues, which includes the selective algorithm of caching location based on set-cover, the cached-data dissemination strategy based on multi-path routing and the cache replacement policy based on data popularity. The experimental results on real-world mobility traces show that the proposed caching protocol outperforms existing schemes in offloading scenario.

Keywords traffic offloading, set cover, caching, mobile social networks

1 Introduction

We envision a future in which an era of big data is promoted by the overwhelming growth trend of mobile data traffic. Cisco forecasts that global mobile data traffic will increase nearly 10-fold from 2014 to 2019 and reach over 24.3 EB per month in 2019 (http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/white_paper_c11-520862.html). Such amount of data traffic will raise big penetration to the cellular networks. One straightforward solution to tackle this issue would be deploying base stations to increase cellular capacity, which is expensive with low financial returns. Nevertheless, considering the proximity-based communication ability of mobile devices and the delay-tolerant property of some data items, offloading cellular traffic through MSNs [1] has become a promising approach to alleviate traffic load [2–3]. With proper incentive mechanism [4], some users are willing to wait for a specified delay to download the data item. Thus, traffic offloading can be achieved by intentionally caching cellular data at a small set of users, then the data item is disseminated to other requesters upon opportunistic contacts.

A critical concern of this offloading paradigm is that the data is not guaranteed to reach the requester before a given deadline, due to the intermittent transmission path and the high dynamics of mobility trace. If the delay period ends, the remaining part of data yet has to be obtained via cellular network. Therefore, the key challenge is to leverage the trade-off between the traffic being offloaded and the users' delay requirement. Meanwhile, some research in Ref. [5] reveal a fact that the same data is often delivered repeatedly to individual requesters, which exacerbates the traffic load imposed on cellular network. To address these challenges mentioned above, we must answer the following questions: which users should be

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selected as caching nodes and how many copies of the content should be injected to the mobile users.

In this paper, we first quantitatively interpret the offloading revenues on the cellular operator side associated with the scale of caching users. To maximize offloading revenues, we propose a viable method by minimizing the number of caching locations which cover all the requesters and provide reliable data accessibility. Second, we define the α-path-set and β-neighbor-set to measure the probabilistic relationship between a node-pair. Third, based on β-neighbor-set, we formulate the problem of finding the optimal caching users as a set-cover problem, based on α-path-set, we schedule the dissemination process from the caching users to the requesters by exploiting multi-path routing with controllable data copies. Finally, a cache replacement policy is designed based on both the requesting frequency and expiration time. To summarize, the key contributions are three-fold:

1) To the best of our knowledge, this is the first attempt to formulate the cache optimization problem as a classical set-cover problem, which can be solved as an integer linear programming (ILP) and achieves the maximum offloading revenues.

2) We develop a centralized caching protocol which contains the following parts:

a) The selective algorithm of caching location based on set-cover.

b) The cached-data dissemination strategy based on multi-path routing.

c) The cache replacement policy based on data popularity.

3) We conduct our extensive simulations on real-world mobility traces. The simulation results show that our proposed caching protocol is more efficient and appropriate than the previous caching schemes in offloading scenario.

The rest of the paper is organized as follows. Sect. 2 reviews the related work. Sect. 3 highlights our motivation of caching in offloading scenario and provides the network model. Sect. 4 describes the details of the set-cover based caching scheme. Sect. 5 evaluates the performance of our proposed scheme by trace-driven simulations. Sect. 6 concludes the paper.

2 Related work

There is a rich series of studies on cellular network offloading and delay tolerant networks (DTNs) that draw some inspiration to our design.

Mobile data offloading has become an indispensable measurement to reduce the traffic burden on cellular network. A latest survey [6] of offloading techniques classifies existing strategies into two categories according to various requirements: AP and terminal-to-terminal based. In the former case, Hoteit et al. [7] evaluate the capacity and energy saving gain by passpoint-hotspot offloading under different placement and AP-selection schemes. In Ref. [8], a deployment algorithm based on the density of user request frequency is proposed, which nearly achieves the optimal offloading ratio. In the latter case, the offloading process can be realized by exploiting terminal-to-terminal connections, which employs a delay-tolerant approach. Most studies in Refs. [2,5,9] mainly focus on pre-determining a set of users as offloading assistants between cellular networks and users. Moreover, a reverse auction-based incentive framework is designed in Ref. [4] to trade-off between the offloaded traffic and users' satisfaction.

An MSN is a specific type of DTN, which lacks stable and persistent end-to-end routing paths, due to unpredictable node mobility. Meanwhile cooperative caching for DTNs has been extensively studied in recent years. In Ref. [10], a cooperative cache-based content delivery framework is established based on the maximization of overall subscription served probability. Gao et al. [11] propose to actively cache data at some network central locations in response for data accessibility. Except for caching at users, Ying et al. [12] investigate where to deploy throwboxes in large-scale DTNs. Some research [13–15] also design caching schemes by exploiting social attributes such as degree centrality, betweenness, etc. Moreover, Zhuo et al. [15] propose a social-based caching framework under the impact of contact duration.

Comparatively, in this paper, we first interpret the offloading revenue on the cellular side, which is determined by the number of caching users. Second, we first formulate the caching framework as an ILP by connecting it with the classical set-cover problem. Third, the caching protocols applied for DTN are processed in distributed manner, while in offloading scenario, the optimal caching performance can be achieved with aid of cellular centralized control.