Poster: Roadside Unit Caching Mechanism for Multi-Service Providers

Zhiwen Hu, Zijie Zheng, Tao Wang, and Lingyang Song
School of Electronics Engineering and Computer Science
Peking University, Haidian District, Beijing, China
{zhiwen.hu, zijie.zheng, wangtao, lingyang.song}@pku.edu.cn

ABSTRACT

Roadside units (RSUs) with caching abilities are becoming an important part for the future transportation system, enabling both Internet accesses and local caching services for vehicular users. In this paper, we address the caching problem which involves the coexistence of multiple service providers who intend to cache their own contents into the RSUs by competitions to improve the data disseminations. And we propose a mechanism based on multi-object auctions, which can achieve a sub-optimal outcome. Simulation results also show the effectiveness of our solution.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*wireless communication*

Keywords

Vehicular network, road-side caching, multi-object auction

1. INTRODUCTION

With the application of the high-end facilities on vehicles and the deployment of roadside units (RSUs), vehicular users can resort to resource-intensive online services, which may drain the limited wireless resources due to large amount of data requests. One way to relief the burden of the system is to equip the RSUs with caching abilities. Therefore popular contents of service providers (SPs) that requested by vehicular users can be obtained without the crowded backhaul links from RSUs to the Internet [1].

However, the diversity of the vehicular traffic and the overlapping of adjacent RSUs make it quite complicated to optimize the caching scheme. Moreover, the competitions caused by the coexistence of multiple service providers are challenging the feasibility of applying caching schemes in practical scenes. In this paper, we propose a novel mechanism based on multi-object auctions to solve the problem with the consideration of both difficulties above. Simulation results have testified the effectiveness of our solution, where the average download percentage of vehicular users has elevated remarkably with the proposed auction mechanism.

MobiHoc'15, June 22–25, 2015, Hangzhou, China.
ACM 978-1-4503-3489-1/15/06.
http://dx.doi.org/10.1145/2746285.2764867.

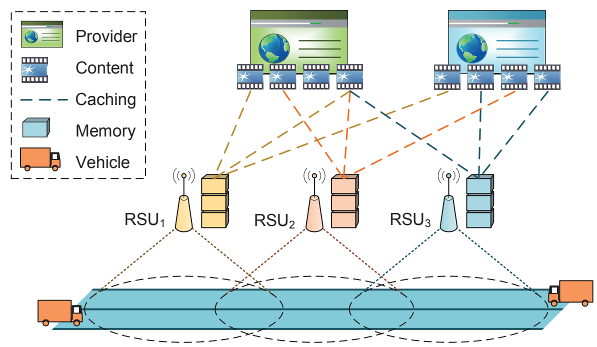

Figure 1: System model for vehicular caching among multiple content providers.

2. SYSTEM MODEL

We consider a two-way street where RSUs with caching abilities are equidistantly distributed. Vehicular users that move in both directions can get accesses to nearby RSUs and therefore download contents from the Internet. We assume that each vehicular user starts to download one of the contents once he drives into the street. During the whole journey, users can always continue downloading if there are RSUs nearby, but experience higher download speed if the desired contents are cached in nearby RSUs. The downloading process may not complete by the end of the street, so we aim to maximize the average download percentage for vehicular users. Our model is demonstrated in Fig. 1.

Contents: We denote the content providers by $\mathcal{P} = \{P_l | 1 \leq l \leq L\}$ and all of their contents by $\mathcal{C} = \{C_n | 1 \leq n \leq N\}$. These contents are assumed to have the same size S, and only differ in their popularity. The popularity of C_n is denoted by ϕ_n, representing the probability of C_n being requested by each vehicular user. And to normalize the probability, we also have $\sum_{n=1}^{N} \phi_n = 1$.

RSUs: We denote RSUs by $\{RSU_m\}$, where $1 \leq m \leq M$. The caching ability of each RSU is U, representing that each RSU can cache no more than U contents at the same time. The coverage length of a RSU in the street is denoted by l, and the total length of the street is L_s.

Vehicular traffic: We suppose that the traffic condition on each side of the road is uniform in a period of time, and the vehicular speed v and the vehicular density d can also be predicted. The traffic flow $f = v \cdot d$ represents the average number of vehicles that travel through the street per second from a given direction. On one side of the street, we denote these three parameters by v_1, d_1 and f_1 respectively, while on the other side of the street, by v_2, d_2 and f_2 respectively.

Wireless traffic: We assume that the backhaul-link between any RSU to the Internet has a constant transmission rate r_{back} for each user, while the down-link between an RSU and one of its nearby vehicles has a variant transmission rate r_{down} which depends on the vehicular density. We suppose that $r_{down} = \min\left\{\frac{r_{max}}{l(d_1+d_2)}, r_{max}\right\}$, where r_{max} is the maximum download rate and $l(d_1+d_2)$ is the number of vehicles that are under the RSU's cover. The final transmission rate to vehicular users is (1) r_{down} for cached contents and (2) $\min\left\{r_{down}, r_{back}\right\}$ for uncached contents, and we denote them by r_c and r_u respectively for simplicity.

Effective coverage length: We first use the boolean matrix Λ to represent the caching scheme, whose element $\lambda_{m,n} = 1$ if RSU_m caches C_n, and $\lambda_{m,n} = 0$ if not. Based on this, we use $L(\Lambda, n)$ to denote the length of the street which is under the cover of RSUs that cache C_n, where $L(\Lambda, n)$ shows the effective coverage length of C_n.

Download percentage: Once the vehicular user determines to download C_n when entering the street, the final download percentage for him is given by

$$\begin{cases} D_{1,n} = min\{1, \left[r_c \frac{L(\Lambda,n)}{v_1} + r_u \frac{L_s - L(\Lambda,n)}{v_1}\right]/S\}, \\ D_{2,n} = min\{1, \left[r_c \frac{L(\Lambda,n)}{v_2} + r_u \frac{L_s - L(\Lambda,n)}{v_2}\right]/S\}, \end{cases} \quad (1)$$

where $D_{1,n}$ is for the users who request C_n from the left entrance, and $D_{2,n}$ is for the right. To take into account the popularity of different contents, we can calculate the average download percentage from both entrances given by

$$\begin{cases} D_1 = \sum_{n=1}^{N} \phi_n D_{1,n}, \\ D_2 = \sum_{n=1}^{N} \phi_n D_{2,n}. \end{cases} \quad (2)$$

Objective function and constraint: We aim to maximize the average download percentage on both sides of the street. The weight of each side depends on f_1 and f_2, so we give the final objective function and its constraint as

$$\begin{cases} \arg\max\left\{D_1 \cdot \eta_1 + D_2 \cdot \eta_2\right\}, \\ s.t. \ \sum_{n=1}^{N} \gamma_{m,n} \le U, \quad \forall m, \end{cases} \quad (3)$$

where $\eta_1 = f_1/(f_1+f_2)$, $\eta_2 = f_2/(f_1+f_2)$, and the constraint shows the limited storages of RSUs.

3. AUCTION BASED SOLUTION

3.1 The proposed mechanism

In our system, $U \cdot M$ memory blocks of RSUs are used to cache contents. The complexity brought by overlapping among RSUs makes the optimization problem intractable. So we propose a multi-step multi-object auction mechanism to give a sub-optimal solution. Our proposal is to auction for U times, in which way the u^{th} memory blocks of all the M RSUs are auctioned off in the u^{th} auction.

In the u^{th} auction, there are N contents playing the role of bidders and M memory blocks from different RSUs playing the role of objects, which can be denoted as $\{B_n\}$ and $\{O_m\}$ respectively. The valuation that B_n estimates O_m is denoted by $v_{n,m}$, which can be calculated as:

$$v_{n,m} = \phi_n\left[(D_{1,n}^{t\prime} - D_{1,n}^{t})\eta_1 + (D_{2,n}^{t\prime} - D_{2,n}^{t})\eta_2\right], \quad (4)$$

where $D_{1,n}^{t}$ and $D_{2,n}^{t}$ are based on the current allocation, while $D_{1,n}^{t\prime}$ and $D_{2,n}^{t\prime}$ are based on the hypothesis that content C_n is allocated to RSU_m.

3.2 The core algorithm

Our algorithm of multi-object auction is originated from [2], which uses bipartite graph to get a perfect matching among bidders and objects. This algorithm guarantees the maximum social welfare, and is proved to satisfy the VCG principle, where bidders' best strategy is to bid truthfully.

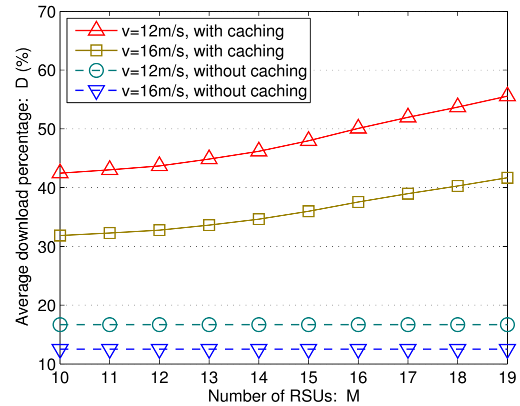

Figure 2: Average download percentage with different vehicular speed v and numbers of RSUs M.

The first step is to add $N - M$ virtual objects with zero valuations therefore the numbers of bidders and objects are equal, and also, the initial prices of objects are all set as zero. Given the valuation matrix and the prices of objects, a preferred-object graph can be established, which is essentially a bipartite graph where each bidder node is only connected to the object nodes which bring most profit. By continually applying breadth-first-search (BFS) in this graph, the matching is enlarged until no more augmenting path exists. If we get a perfect matching, then the auction is completed, otherwise a set of constricted object nodes can be found during BFS. We raise the price of this set of objects until at least one of the bidders changes his most preferred objects, leading to a new structure of the preferred-object graph. And we repeat these steps until the graph contains a perfect matching which represents the auction result.

4. SIMULATION RESULTS

Without the loss of generality, we only simulate one situation where $v_1 = v_2 = v$ and $d_1 = d_2 = d$. We set $N = 100$, $U = 15$, $d = 0.1m^{-1}$, $r_{back} = 1Mbps$, $r_{max} = 100Mbps$, $S = 500Mbits$, and we let ϕ_n obey Zipf-like distribution. The simulation result is shown in Fig. 2, where the impact of vehicular speed v and numbers of RSUs M is illustrated.

By comparing the differences between the strategies that with and without caching, we can see the effectiveness of our algorithm in elevating average download percentage. With a fixed number of RSUs, a lower vehicular speed results in a higher download percentage due to the longer download time. And with a fixed vehicular speed, more RSUs being deployed can also benefit the outcome of our solution.

5. ACKNOWLEDGEMENTS

This work was supported by the National 973 Project under Grant 2013CB336700, by the National Natural Science Foundation of China under Grants 61222104 and U1301255, and 61428101.

6. REFERENCES

[1] R. Ding, T. Wang, L. Song, Z. Han, and J. Wu. Roadside-Unit Caching in Vehicular Ad Hoc Networks for Efficient Popular Content Delivery. In *proc. IEEE Wireless Comunication and Networking Conference (WCNC)*, New Oleans, US, April 2015.

[2] G. Demange, D. Gale, and M. Sotomayor. Multi-item auctions. *Journal of Political Economy*, 94(4):863–872, August 1986.