Optimal Vehicles and Coding Decision For Mobile Data Sharing in Vehicular Delay Tolerant Networks

Wenyu Ren, Yong Li, Depeng Jin, Li Su, Lieguang Zeng
Tsinghua National Laboratory for Information Science and Technology
Department of Electronic Engineering, Tsinghua University, Beijing 100084, China
Email: yong-li07@mail.tsinghua.edu.cn

***Abstract*—Vehicular Delay Tolerant Networks (VDTN) are used to distribute a large amount of mobile data by high-capacity device-to-device communication. Given a number of available vehicles in VDTN, the current vehicular data sharing models always utilize all of them to achieve the best effect, failing to balance the performance gained and cost of employing them. Taking the cost into account, we study the problem of the optimal number of vehicles to be deployed in the data sharing system, which considers using erasure codes to further increase the system efficiency if possible. By establishing the system goal which consists both the effectiveness and the cost of the vehicular network mathematically, we formulate the above problem as a utility function minimization problem. Finally, we solve the problem by theoretical derivation, and demonstrate the efficiency of the obtained solution through simulations using real vehicular traces of Beijing and Shanghai.**

I. INTRODUCTION

With the development of related technology and the progress of relevant researches, large scale vehicular networks are expected to be deployed and application based on them will emerge. Mobile data sharing is one of the most popular applications in the current cellular networks. With the already congested cellular networks, there is little chance that they have enough spectrum remained to provide for vehicular networks [1]. Moreover, the cost of building new infrastructure is beyond measure and violates the goal of vehicular networks. Therefore, vehicle-to-vehicle mobile data sharing without any infrastructure will probably be the competitive form of communication in vehicular networks. There is previous research concentrating on the benefits of distributed storage using erasure codes for peer-to-peer file sharing in vehicular networks [2]. However, as far as we known, there is no work taking the cost of deploying the vehicles into consideration, and existing solutions [2] put all the available vehicles in the network into use.

In this work, we take the cost into account and prove that it is not always true that the more the number of vehicles involved in the data sharing, the better the performance. We establish a mathematical method to decide the optimal number of vehicle to deploy in the network and whether to use erasure coding when storing the files.

II. SYSTEM OVERVIEW AND PROBLEM FORMULATION

In a vehicular mobile data sharing system, the service provider selects some vehicles willing to distribute data and store file on them. These vehicles are called helpers. These helpers then deliver the file to the subscribers, which are interested in the data, through vehicle-to-vehicle communication. We assume there are H helpers and N subscribers in the network. Each helper has a storage capacity of C MB for data sharing application, and there are total m different files of size M MB. Related to the subscribers, each of them subscribes s files. Note that it is required that $C \geq M$, so that each helper is able to store at least one file. To store all the m files in H helpers, we require $HC \geq mM$. Assume the number of potential helpers to the service provider is H_{max}. So the feasible region of H is $[mM/C, H_{max}]$,$(mM/C < H_{max})$.

There are two storage strategies available. One is use simple uncoded replication: each of the m files is stored in $\frac{mM}{HC}$ helpers. The other is using erasure coding. Each file is separated into k chunks from which n chunks of size M/k are generated. In our theoretical analysis, we use Maximum Distance Separable (MDS) erasure code [3]. We can use any k out of the n encoded chunks to reconstruct the original file.

During each communication contact, nodes can transmit the mobile data of d MB. We assume that the communication contact between vehicles obeys the Poisson process with contact rate λ. Poisson distributed contact rate has been validated to fit well to real vehicular traces and is widely used to model opportunistic vehicular systems [6]. The inter-meeting time between each pair of helper and subscriber should follow an exponential distribution with rate parameter λ. Let T represent the inter-meeting time of a selected subscriber with any of the H helpers. It is easy to demonstrate that T follows an exponential distribution with rate parameter $H\lambda$. So we have its expectation as $E(T) = \frac{1}{H\lambda}$. We use E to denote the number of encounters needed for each subscriber to reconstruct a desired file. As proved in [2], for uncoded replication, we have $E[E_{uc}] = \frac{Mm}{C} max(1, \frac{M}{d})$. The upper bound of expectation of E when erasure coding is used can be acquired as $E[E_{co}] \leq \frac{Mm}{C} max(1, \frac{C}{md})$.

Let D represent the time needed before each subscriber to reconstruct a file. Then we have

$$\begin{aligned} E[D_{uc}] &= E[E_{uc}T] = \frac{Mm}{HC\lambda} max(1, \frac{M}{d}), \\ E[D_{co}] &= E[E_{co}T] \leq \frac{Mm}{HC\lambda} max(1, \frac{C}{md}). \end{aligned} \tag{1}$$

The deployment of helpers will have some cost. It's reasonable to assume that this cost is linearly related to the number of helpers H. Thus we can denote the cost as $A_1H + A_2(A_1, A_2 > 0)$. For the uncoded replication, we can define a target function as $F_{uc}(H) = A_1H + A_2 + E[D_{uc}] = A_1H + A_3/H + A_2$, where $A_3 = \frac{Mm}{C\lambda} max(1, \frac{M}{d}) > 0$. For the coded scenario, from papers of digital fountain codes [4], we can denote the cost of coding as $A_4H + A_5(A_4, A_5 > 0)$. For a company, the parameter A_4 and A_5 can be decided according to the specific coding algorithm it uses. In this way, we can have another target function as $F_{co}(H) = A_1H + E[D_{co}] + A_4H + A_5$. As it is hard to get the analytic expression of $E[D_{co}]$, we use its upper bound in the function instead. So the function can be written as $F_{co}(H) = (A_1 + A_4)H + A_6/H + (A_2 + A_5)$, where $A_6 = \frac{Mm}{C\lambda} max(1, \frac{C}{md}) > 0$.

To get a combined function, we use a variable $code \in \{0, 1\}$ to represent the storage strategy. Let $code = 0$ stand for the uncoded replication and $code = 1$ stand for the erasure coding. Then we can write a combined target function as

$$F(H, code) = \begin{cases} A_1H + \frac{A_3}{H} + A_2, & \text{if } code = 0; \\ (A_1 + A_4)H + \frac{A_6}{H} + (A_2 + A_5), & \text{if } code = 1. \end{cases}$$

Thus, balancing the cost and effectiveness of the file sharing system in the vehicular network and finding the optimal solution of the number of helpers and storage strategy can be specified as the following optimization problem

$$\min F(H, code) \quad s.t. \; H \in \left[\frac{mM}{C}, H_{\max}\right] \text{and } code \in \{0, 1\}. \tag{2}$$

III. PROBLEM SOLVING

To solve the function minimization problem, we consider the uncoded and coded case respectively. In uncoded replication, we first discuss its minimization for $H \in (0, +\infty)$. By first and second derivative of the target function, it's easy to prove that $F_{uc}\left(\sqrt{A_3/A_1}\right)$ is the minimization for $H \in (0, +\infty)$. Then we define $H_{uc} = \arg\min F_{uc}(H)$ for $H \in [mM/C, H_{max}]$. We have

$$H_{uc} = \begin{cases} \sqrt{\frac{A_3}{A_1}}, \text{if } \sqrt{\frac{A_3}{A_1}} \in \left[\frac{Mm}{C}, H_{\max}\right]; \\ \frac{Mm}{C} \quad, \text{if } \sqrt{\frac{A_3}{A_1}} < \frac{Mm}{C}; \\ H_{\max}, \text{if } \sqrt{\frac{A_3}{A_1}} > H_{\max}. \end{cases}$$

In coded case, we define $H_{co} = \arg\arg\min F_{co}(H)$ for $H \in [mM/C, H_{max}]$. Similarly, we can get H_{co}.

Thus, the final solution can be represented as

$$(H, code)_{opt} = \begin{cases} (H_{uc}, 0)\,, \text{if } F_{uc}(H_{uc}) \le F_{co}(H_{co})\,; \\ (H_{co}, 1)\,, \text{if } F_{uc}(H_{uc}) > F_{co}(H_{co})\,. \end{cases}$$

To show the variation trend of the target function, we plot the uncoded and coded case with Matlab. The parameter settings are as follows: $A_1 = 20, A_2 = 2000, A_4 = 3, A_5 = 500, C = 1.5GB, m = 25, M = 100MB, d = 1MB$ and $\lambda = 1.31 \times 10^{-5} s^{-1}$ which is obtained from the Random Waypoint mobility model that $\lambda = 8wRv/(\pi L^2)$ by setting $w = 1.3683, L = 20000m, v = 15m/s$ and $R = 100m$. The target functions in uncoded and coded cases are shown in Fig 1. For both uncoded and coded cases, the value of target function first decrease with H increasing from a small value, then the function reaches its minimization and rise with the increasing H.

IV. TRAVE-DRIVEN SIMULATION

In this section, we use real trace-driven simulations to validate our solution. Our evaluation is based on two real traces of vehicles, Beijing trace and Shanghai trace [5]. For all the simulations, we randomly choose 50 subscribers and each subscriber randomly pick 100 out of 2500 files to subscribe. The bandwidth of the vehicle-to-vehicle communication is 100MBbps. Other parameter settings are as follows: $A_1 = 30, A_2 = 5000, A_4 = 5, A_5 = 1000, C = 100GB, m = 2500, M = 200MB$.

First, we define the full-recovery probability as the probability that a file can be fully recovered by a subscriber by a given time. We plot the full-recovery probability results in Fig 2. We can see that with the increase of H, the improvement in full-recovery probability is getting smaller. So the gain in effectiveness of the network for deploying extra helpers decreases as H increases.

Then we evaluate the target function based on the real traces. A_3 and A_6 are calculated from the simulation. The results are shown in Fig 3. From the results, we can observe that the value of target function is not monotone increasing with H. So it's not always optimal to deploy as many helpers as possible in the file sharing system. From our simulation results, we find we can cut the number of helpers at a cost of relatively small increase in average delay. We are able to reduce 40% of the helpers at a cost of 18.7% increase in delay in Shanghai case and 70% of helpers at a cost of 38.8% increase in delay in Beijing case.

REFERENCES

[1] Cisco visual networking index: Global mobile data traffic forecast update, 2009-2014, February 2010. http://www.cisco.com/en/US/solutions/ collateral/ns341/ns525/ns537/ns705/ns827/white paper c11-520862.html . .

[2] M. Sathiamoorthy, A. G. Dimakis, B. Krishnamachari, Fan Bai, "Distributed Storage Codes Reduce Latency in Vehicular Networks" in *Proc. of IEEE INFOCOM*, March 25-30, 2012, pp. 2646-2650.

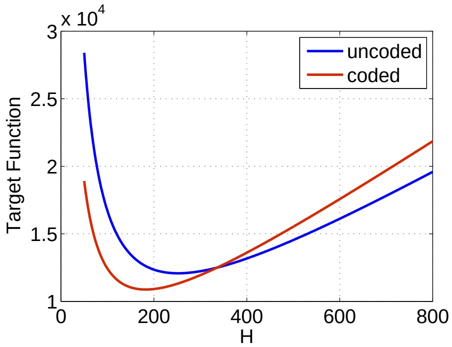
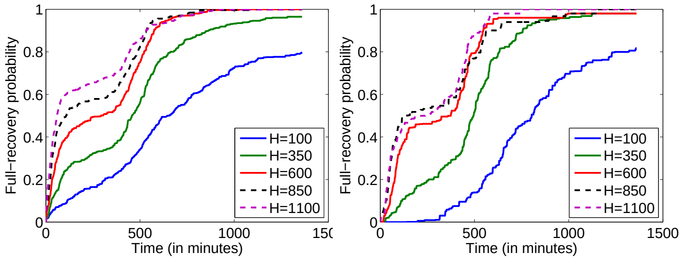
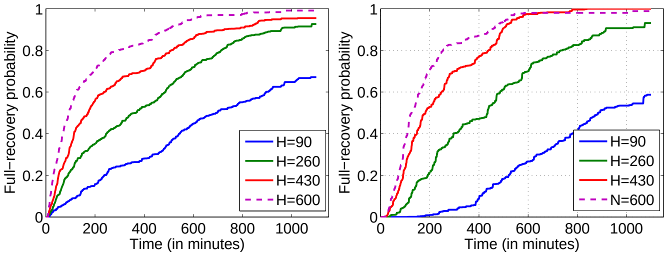


Fig. 1. A plot showing the value of target function in uncoded and coded cases with the changing of H.



(a) Beijing traces (uncoded) (b) Beijing traces (coded)



(c) Shanghai traces (uncoded) (d) Shanghai traces (coded)

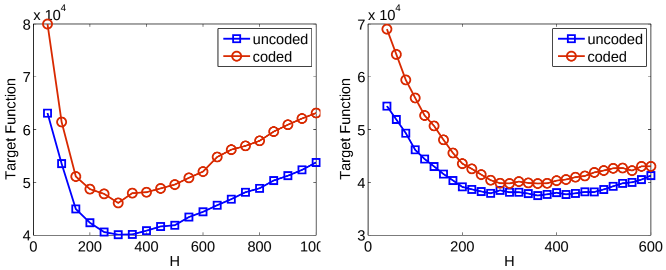
Fig. 2. Evaluating the full-recovery probability using Beijing and Shanghai traces.

[3] T. Richardson and R.Urbanke, Modern Coding Theory.Cambridge University Press, 2008.

[4] A. Shokrollahi (2006), "Raptor Codes", Journal of *IEEE Transactions on Information Theory*, 52 (6): 2551-2567.

[5] Y. Li, P. Hui, D. Jin, L. Su, and L. Zeng, "An Optimal Distributed-Malware Defense System for Mobile Networks with Heterogeneous-Devices," in *Proc. of IEEE SECON* (Salt Lake City, USA), June 18-21,2011, pp. 1-10.

[6] H. Zhu, L. Fu, G. Xue, Y. Zhu, M. Li, and L. Ni, "Recognizing exponential inter-contact time in VANETs," in *Proc. 29th IEEE INFOCOM* (San Diego, CA), March 14-19, 2010, pp. 1–5.



(a) Beijing traces (b) Shanghai traces

Fig. 3. Evaluating the target function using Beijing and Shanghai traces.