User-Satisfaction-Based Media Services over Vehicular Networks

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***Abstract*— A challenging problem of providing media services over vehicular networks is how to optimize the media content dissemination and vehicle cache update by intelligently considering opportunistic vehicle meet and different service requirements. In this work, we study this problem in the context of P2P-based vehicular networks, and develop fully dynamic service schemes with the goals of maximizing the total user-satisfaction and achieving certain fairness. We first construct a general user-satisfaction model according to the network's transmission mechanism, as well as different media's delay-satisfaction characteristics. Then, we formulate the media service as an optimization problem, and propose a joint content dissemination and cache update scheme. We also provide the exact steps to achieve the optimal solution at equilibrium given the user-satisfaction function. It is worth noting that the proposed scheme is designed in a distributed manner which is amenable to online implementation for vehicle networks. In addition, we provide extensive simulation results which demonstrate the effectiveness of our proposed schemes.**

***Index Terms*— vehicular networks; media service; user-satisfaction; optimization**

I. Introduction

With the proliferation of the distributed peer-to-peer (P2P) cooperative transmission technologies, P2P-based vehicular networks have recently received a substantial amount of interests [1], [2]. Actually, supporting media services over vehicular networks is a very interesting problem and can greatly benefit our daily life [2], [3]. For example, highway hazards and traffic jams messages can be used to improve traffic safety and efficiency, and entertainment services such as MP3 music, videos news can also be provided to the users in the moving vehicles.

Generally speaking, the problem of heterogeneous media services over P2P-based vehicular networks is, compared to traditional content delivery or data dissemination, further complicated by the heterogeneity in both the network environments and the application contents, including i) **content dissemination**: how to distribute the different media contents to adapt dynamic vehicular networks and achieve optimal user-satisfaction? ii) **cache update**: how to update each vehicle's cache in the context of mobile opportunistic meet environment? The above two problems interact with each other, and thus form a challenging user-centric media-aware network service problem across the heterogeneous services, dynamic network and multiple vehicles.

In this work, our objective is to propose a distributed heterogeneous media service scheme for P2P-based vehicular networks so as to maximize the total user-satisfaction. We first identify an objective function that incorporates the media characteristics and user-satisfaction, and then explore how to construct a stable, distributed, dynamic and fair system that optimizes for this objective. Although some data dissemination protocols can be obtained via extending current algorithms in [4], [5] that are known to achieve the maximum system capacity or throughput for P2P networks. However, these works completely ignore the media content or mobile opportunistic environment. Consequently, these solutions may not be optimal for vehicular networks. It is important to emphasize that compared with general data dissemination, media services in vehicular networks are characterized by **media content** and **service time**. Specifically, it is necessary to design different service fashions according the characteristics of different media contents. In addition, the service time, which is defined as the elapsed time between the service demand and its fulfillment, can not be neglected in vehicular networks.

The rest of the paper is organized as follows. Section II describes the heterogeneous media service model for vehicular networks. In Section III, we propose a distributed heterogeneous media service scheme to maximize the total user-satisfaction by jointly considering content dissemination and cache update. Then, extensive simulation results and comparisons are provided in Section IV. Section V concludes the paper.

II. System Model and Description

A. Vehicle Meet

Consider a vehicular network of $\mathcal{V} = \{1, 2, ..., i, ...\}$ vehicles (users) and $\mathcal{M} = \{1, 2, ..., m, ...\}$ media services. $|\mathcal{V}|$ and $|\mathcal{M}|$ represent the number of vehicles and media services, respectively. For a media service m and vehicle i, we define $X_{m,i} = 1$ if vehicle i is in possession of service m, and $X_{m,i} = 0$ otherwise. The matrix $\mathcal{X} = (X_{m,i})_{m\in\mathcal{M}, i\in\mathcal{V}}$ represents the states of the distributed cache of the whole system.

We denote the total number of service m in the system by $X_m = \sum_{i\in\mathcal{V}} X_{m,i}$. In addition, we assume that all vehicles have the same cache size of c. It should be noted that this is not a critical assumption and most of the following results can be trivially extended to different cache sizes. Hence, media content allocation $\mathcal{X}$ should satisfy the constraint of the cache

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size

$$\sum_{m\in\mathcal{M}} X_{m,i} \le c,\ \forall i \in \mathcal{V}. \tag{1}$$

Vehicles may meet with each other in an opportunistic way, and this provides the opportunity for media services. We suppose that meets between every two vehicles follow independent and memoryless processes. This helps us to find the optimal scheme before evaluating them using real traces for this complex system. We assume that vehicle i meets vehicle j according to a Poisson process with rate $\mu_{i,j}$. Specifically, if each vehicle meets with others with the same probability, namely $\mu_{i,j} = \mu$ for all vehicles, we call this as a *homogeneous meet*. If the meet probability of each vehicle is independent from each other, this is a *heterogeneous meet*.

B. Media Service

Each media content stored at vehicle i ($i \in \mathcal{V}$) has a time-stamp, indicating when it is originally downloaded. $T_{m,i}(t)$ is the time-stamp of user i's media content m ($m \in \mathcal{M}$) at time t. Vehicle i will copy vehicle j's media content m if they satisfy the V2V communication and the content stored at j is newer than that of i, *i.e.*, $T_{m,i} < T_{m,j}$. Then, both of their time-stamps become $\max\{T_{m,i}, T_{m,j}\}$ after their communication.

In addition to the media service content, we are also interested in the age $A_{m,i}$ of the media m stored in each vehicle i's cache, and it can be defined as

$$A_{m,i}(t) = T - T_{m,i}(t),\ m \in \mathcal{M},\ i \in \mathcal{V}, \tag{2}$$

where T is the current time. In particular, $A_m = \sum_i A_{m,i}$ denotes the average age of m in the vehicular networks.

Vehicles demand for media services in the form of requests. The process of demand for different services has different rates, reflecting heterogeneous media contents. We denote R_m the total rate of demand for media service m and $\rho_{m,i}$ for the probability of demand at vehicle i. Hence, vehicle i makes a new request for service m with rate $R_m\rho_{m,i}$. The probability $\rho_{m,i}$ can capture different popularity profiles in different vehicle populations. Without loss of generality, media services can be arrayed according to demand in a decreasing order (*i.e.*, $R_m \ge R_n$ for $m \le n$). To depict the real vehicular networks environment, we assume that the distribution of the vehicle demand follows the *Pareto* model $R_m \propto m^{-\omega}$ ($\omega > 0$) for all $m \in \mathcal{M}$.

C. User-Satisfaction Function

Since vehicles may demand heterogeneous media services, we need a flexible model to account for their satisfaction. Let $h_m(t)$ be the satisfaction function for media service m, which represents the degree of satisfaction for the consuming time t between the service request and fulfillment. Since users always prefer to fulfill the service demand as soon as possible, $h_m(t)$ should be a non-increasing function of time t. The satisfaction function depends on various factors, including the user behavior as well as the media service. In the following, we present several typical satisfaction functions:

- **Threshold function**: $h_m(t) = \mathbf{1}_{t\le\tau}$. This function corresponds to delay-sensitive media service such as live video. If the service time t beyond a given tolerate threshold τ, the user will give up this service request.
- **Try-Best function**: $h_m(t) = \exp(-\tau t)$. In this case, media service can be fulfilled at any time, though, the sooner the better (*e.g.*, music entertainment).
- **Reward function**: $h_m(t) = \frac{t^{1-\tau}}{\tau-1}$, $1 < \tau \le 2$. This satisfaction function corresponds to critical emergency media service, *e.g.*, road hazards message, high-way information, which varies very quickly. In this case, a large reward is provided for a prompt demand fulfillment.

III. Distributed Media-Service Scheme

We define $G_{m,i}(\mathcal{X})$ to be the expected gain generated by a request for service m from vehicle i. The *total user-satisfaction* in terms of all the vehicles is given by

$$G(\mathcal{X}) = \sum_{m\in\mathcal{M}}\sum_{i\in\mathcal{V}} R_m\rho_{m,i}G_{m,i}(\mathcal{X}). \tag{3}$$

Therefore, we have the optimization problem

$$\begin{aligned} \max \quad & G(\mathcal{X}) \\ s.t. \quad & \textstyle\sum_{m\in\mathcal{M}} X_{m,i} \le c \\ & X_{m,i} \in \{0,1\}, \forall i \in \mathcal{V}, \forall m \in \mathcal{M}. \end{aligned} \tag{4}$$

A. Content Dissemination and Cache Update

We denote function $h'_m(t)$ as the first-order differential satisfaction function h_m under continuous time meet model,

$$h'_m(t) = \frac{dh_m(t)}{dt}. \tag{5}$$

The value of $h'_m(t)$ is always positive as $h_m(t)$ is a non-increasing function. $h'_m(t)$ can be interpreted as "gain sensitivity" over service time (*i.e.*, amount of decrease in gain is incurred per unit increase in service time). Note that when $h_m(t)$ is not derivable (*e.g.*, the threshold function), $h'_m(t)$ is not defined as a function but as the distribution. The second row of Table I shows the expression of $h'_m(t)$ for all the introduced satisfaction functions.

Lemma 1: For the given Poisson vehicle meet model, $G_{m,i}(\mathcal{X})$ can be expressed as

$$h_m(0^+) - (1 - X_{m,j}) \int_0^\infty \exp\left(-t\sum_{i\in\mathcal{V}} X_{m,i}\mu_{i,j}\right) h'_m(t)dt, \tag{6}$$

where $j \in \mathcal{V}$, and $j \ne i$.

Proof: The proof progress is similar to *Lemma 1* of [6], so it is omitted here. ■

In the case of homogeneous vehicle meet model, the general expression (6) can lead to a closed form. Specifically, the expression only depends on $(X_{m,i})_{m\in\mathcal{M},i\in\mathcal{V}}$ and the number of services $(X_m)_{m\in\mathcal{M}}$. Similarly, if all $|\mathcal{V}|$ vehicles follow the same number of media services (*i.e.*, $\rho_{m,i} = 1/|\mathcal{V}|$), the total user-satisfaction is given by

$$G(\mathcal{X}) = \sum_{m\in\mathcal{M}} R_m\left(h_m(0^+) - (1 - \frac{X_m}{|\mathcal{V}|}) \int_0^\infty e^{-t\mu X_m} h'_m(t)dt\right). \tag{7}$$

TABLE I

DIFFERENT FUNCTION EXPRESSIONS UNDER DIFFERENT USER-SATISFACTION FUNCTIONS

Model	Threshold function	Try-Best function	Reward Function
Satisfaction func. $h_m(t)$	$\mathbf{1}_{t\leq\tau}$	$\exp(-\tau t)$	$\frac{t^{1-\tau}}{\tau-1}$ $(1<\tau\leq 2)$
Diff. satis. func. $h'_m(t)$	Dirac. at $t=\tau$	density $t\mapsto -\tau\exp(-\tau t)$	density $t\mapsto -t^{-\tau}$
Total user-satis. func. $G(\mathcal{X})$	$\sum_m R_m(1-e^{-\mu\tau X_m})$	$\sum_m R_m\big(1-\frac{\tau}{\tau+\mu X_m}\big)$	$\sum_m R_m X_m^{\tau-1}\frac{\mu^{\tau-1}\Gamma(2-\tau)}{\tau-1}$
Priority func. φ	$R_m\|\mathcal{M}\|\mu\tau e^{-\mu\tau X_m}/\|\mathcal{V}\|$	$R_m\frac{\mu}{\tau}\big(\|\mathcal{M}\|+\|\mathcal{V}\|\frac{\mu}{\tau}X_m\big)^{-2}$	$R_m(\mu\|\mathcal{M}\|)^{\tau-1}(X_m\|\mathcal{V}\|)^{2-\tau}\Gamma(2-\tau)$
Popularity func. ϕ	$\frac{\mu\tau\|\mathcal{V}\|}{y\|\mathcal{M}\|}\exp\{-\frac{\mu\tau\|\mathcal{V}\|}{y\|\mathcal{M}\|}\}$	$\left(1+\frac{\tau y\|\mathcal{M}\|}{\mu\|\mathcal{V}\|}+\frac{\mu\|\mathcal{M}\|}{y\|\mathcal{V}\|\tau}\right)^{-1}$	$(y\|\mathcal{M}\|)^{1-\tau}(\mu\|\mathcal{V}\|)^{\tau-1}\Gamma(2-\tau)$

In the case of homogeneous meet, $G(\mathcal{X})$ is a concave function of X_m ($m\in\mathcal{M}$). According to [7, *Theorems 3.4-3.7*], the relaxed total user-satisfaction can be found by using a gradient decent algorithm. Here the term "relaxed" means that X_m is allowed to take real value in the optimization operation. It should be noted that (7) can also be extended to a heterogeneous meet model, and corresponding characteristics remain the same [7, *Theorems 4.2-4.3*].

TABLE II

CDCU SCHEME

```
Input:
Initial MSC value of media service m in vehicle i is MSC_{m,i} = 0;
Popularity function φ and priority function ϕ;
Output:
Optimal Joint Content Dissemination and Cache Update Scheme;
Procedure CDCU
if (vehicle i begins requesting media service m)
    if (vehicle i meets vehicle j)
        if (vehicle j can not provide service m)
        MSC_{m,i} = MSC_{m,i} + 1;
        else
        Vehicle i copy media content m for vehicle j;
        The popularity function of m is set φ(MSC_{m,i}) ≥ 1;
        The priority of m in vehicle i's cache is set ϕ(MSC_{m,i});
        m replaces the minimum priority media in i;
            if (φ(MSC_{m,i}) ≥ 0)
            i transmits forwardly m to j' it meets from then on;
            m replaces the minimum priority media in j';
            φ(MSC_{m,i}) = φ(MSC_{m,i}) − 1;
            if (j' has the media m)
            m will be reserved in both vehicles;
            MSC_{m,i} = MSC_{m,i} − 1;
            endif
        endif
    endif
endif
```

In order to get the optimal total user-satisfaction, we propose the joint *content dissemination and cache update* (CDCU). CDCU implicitly adapts to current dissemination, cache update and collection of requests without the explicit estimators or feedbacks of the popularity of media services or current cache allocation, which is very important for the dynamic vehicular networks. Specifically, each vehicle keeps a *Media Service Counter* (MSC) for each new request instead of estimating popularity of each service as [2]. Whenever a request is fulfilled for a particular service, the final value of the corresponding counter is proportional to the service popularity, which is used to calculate the number of new disseminations of that service. Since each vehicle's cache is limited, new media content inject must take place other media contents, we also use MSC and "freshness" to set the priority for each media content. The exact implementation steps of CDCU are presented in Table II. Since popularity and priority functions are very important, we describe in Section III-B precisely how to set them given the knowledge of user-satisfaction.

B. Popularity and Priority Functions

According to the boundary and rounding effects [7], it is difficult to derive a closed form expression for maximizing the total user-satisfaction if X_m ($m\in\mathcal{M}$) only takes integer values. However, when the number of media services $|\mathcal{M}|$ becomes very large, X_m may take larger value (this is particularly true for popular media services). In this case, the difference between the optimal solution and the relaxed optimization (where X_m may take real values) is proportional to $1/|\mathcal{M}|$ [7]. As the number of media services becomes large, their differences tend to become small. In this section, we use this rule to find a simple equilibrium condition for the given relaxed optimization problem.

Since the objective function (4) is a classic multi-variant optimization problem, it is difficult to take the derivative of $G(\mathcal{X})$ with respect to $\mathcal{X}$ directly. To get around the difficulty, motivated by [8], we take logarithm operator on $G(\mathcal{X})$ to get $G(\widetilde{\mathcal{X}})$. Since the variant relativity can be reduced by this logarithm operator, we can decompose $G(\widetilde{\mathcal{X}})$ using sub-function summation method [8]. For any $\widetilde{\mathcal{X}}=\lg\mathcal{X}=\lg(X_m)_{m\in\mathcal{M}}$, we denote by $\frac{\triangle G}{\triangle\widetilde{X}_m}(\widetilde{\mathcal{X}})$ the *unit increment* obtained when a media service m is provided. It can be defined as

$$\frac{\triangle G}{\triangle\widetilde{X}_m}(\widetilde{\mathcal{X}})=G\big(\lg(X_1,...,X_{m-1},X_{m+1},...,X_{|\mathcal{M}|})\big)-G(\lg\mathcal{X}). \tag{8}$$

It is observed that, for a given m, the unit increment $\frac{\triangle G}{\triangle\widetilde{X}_m}(\widetilde{\mathcal{X}})$ is independent from $\widetilde{X}_n$ for $n\neq m$. Note that this is intuitive, as for a fixed number of service times of a given media, the service time of this media service is independent from other services. In other words, we may get $\frac{\triangle G}{\triangle\widetilde{X}_m}(\widetilde{\mathcal{X}})=G'_m(\widetilde{X}_m)$, where

$$G'_m(\widetilde{x})=R_m(1-\frac{\widetilde{x}}{|\mathcal{V}|})\int_0^\infty(1-e^{-\mu t\widetilde{x}})h'_m(t)dt. \tag{9}$$

Therefore, the value of total user-satisfaction can be decomposed for each media service m,

$$G(\widetilde{\mathcal{X}})=\sum_{m\in\mathcal{M}}G'_m(\widetilde{X}_m). \tag{10}$$

Since the concavity of the function $G(\widetilde{\mathcal{X}})$, the functions G'_m ($m \in \mathcal{M}$) in (10) are all non-increasing. As to our CDCU scheme, G'_m can be viewed as the integration of popularity function ϕ and priority function φ. According to the G'_m characteristics described above, we can get the following theorems on ϕ and φ.

Theorem 1: (*Expression of the priority function*) Let X be the solution of relaxed total user-satisfaction maximization and $\widetilde{X} = \lg X$, we have

$$\frac{R_m}{A_m}\varphi(\widetilde{X}_m) = \frac{R_n}{A_n}\varphi(\widetilde{X}_n),\ \forall m, n \in \mathcal{M}, \tag{11}$$

where we define φ as:

$$\widetilde{X} \mapsto \int_0^\infty \frac{\sum_m h'_m(t)}{|\mathcal{M}|}\frac{\sum_m A_m(t)}{|\mathcal{M}|}\mu t e^{-\mu t\widetilde{X}}dt. \tag{12}$$

We now describe the relationship between the priority function and popularity function. We first observe that the expected value of MSC for service m is proportional to $1/X_m$, since whenever a vehicle meets with others, there is roughly a probability $X_m/|\mathcal{V}|$ of media service m can be provided. Hence, we can set the priority function $\phi(|\mathcal{V}|/X_m)$ as a first order of X_m. In addition, for each vehicle cache, new media content replace m with probability $X_m/c|\mathcal{V}|$. Moreover, the media service ability is inverse-proportional to the number of the media service $|\mathcal{M}|$ for all the system services. Therefore, the service number of each media m follows the set of differential equations:

$$\frac{dX_m}{dt} = \frac{R_m}{|\mathcal{M}|}\phi(\frac{|\mathcal{V}|}{X_m}) - \frac{X_m|\mathcal{M}|}{c|\mathcal{V}|}\sum_{n\in\mathcal{M}}\frac{R_n}{|\mathcal{M}|}\phi(\frac{|\mathcal{V}|}{X_n}). \tag{13}$$

In a stable steady state, the creation of new services is equal to the deleted or replaced services. Hence we have

$$R_m \cdot \frac{c|\mathcal{V}|}{X_m|\mathcal{M}|}\phi(\frac{|\mathcal{V}|}{X_m}) = \sum_{n\in\mathcal{M}}\frac{R_n|\mathcal{V}|}{X_n}\phi(\frac{|\mathcal{V}|}{X_n}). \tag{14}$$

The right hand side (RHS) of (14) is a constant which is independent of m, so

$$\frac{R_m}{X_m}\phi(\frac{|\mathcal{V}|}{X_m}) = \frac{R_n}{X_n}\phi(\frac{|\mathcal{V}|}{X_n}),\ \forall m, n \in \mathcal{M}. \tag{15}$$

Alternatively, the steady state of this scheme satisfies the equilibrium condition of *Theorem 1* if and only if we have:

$$\varphi(x) = \frac{|\mathcal{M}|}{cx}\phi(\frac{|\mathcal{V}|}{x}), \forall x > 0, \tag{16}$$

where ϕ is defined in *Theorem 1*. Therefore, it is easy to get the following lemma.

Lemma 2: (*Relationship between the priority function and popularity function*) Given the media service counter y, the system achieves the maximum total user-satisfaction when the popularity function $\phi(y)$ and priority function $\varphi(y)$ satisfies:

$$\phi(y) = \frac{c|\mathcal{V}|}{y|\mathcal{M}|}\varphi(\frac{|\mathcal{V}|}{y}),\ \forall y > 0. \tag{17}$$

Therefore, we can derive the following theorem.

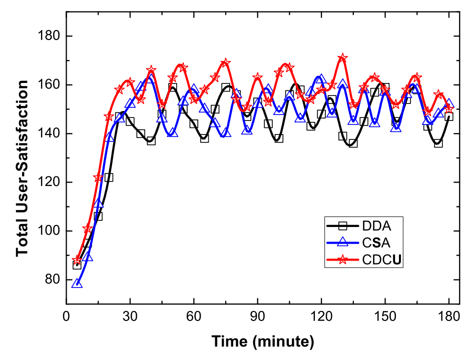

Fig. 1. Performance comparison when $\omega = 1$, $\mu = 0.03$, Threshold:Try-Best:Reward=1:1:1.

Theorem 2: (*Expression of the popularity function*) The steady state of CDCU satisfies the equilibrium condition if and only if

$$\phi(y) \propto \frac{c|\mathcal{V}|}{y|\mathcal{M}|}\int_0^\infty \mu t e^{-\mu t\frac{c|\mathcal{V}|}{y|\mathcal{M}|}}h'_m(t)dt. \tag{18}$$

Outline of the Proof: The basic idea to proof the steady state is to decouple the coupled ϕ (coupled over $|\mathcal{M}|$ and $|\mathcal{V}|$) by introducing an auxiliary variable and an additional constraint, and then use Lagrange dual decomposition to decouple the constraints. The core proof procedure is similar to the proof in [9, *Theorem 3*]. ■

IV. Numerical Results

In this section, we evaluate the performance of the CDCU and MASF schemes using extensive simulation based on real traces. To reveal performance improvements, we compare them with two alternative algorithms: 1) Direct Dissemination Algorithm (DDA) [1]; 2) Content Sharing Algorithm (CSA) [2]. To make the comparisons fair, we apply the user-satisfaction functions proposed in this paper to DDA and CSA, and employ our cache update method for DDA and content dissemination strategy for CSA.

In our simulation setup, 150 vehicles with 50 media services move within a fixed region of $5km \times 5km$. Each vehicle has 5 media services and can initiate requests for its interested media services. When vehicles enter into the RSU coverage, RSU will broadcast 5 media services chosen randomly from the available 50 media servers, and the broadcast contents update every 10 minutes. Once the vehicles go out the coverage, they begin to demand the services they desire. If can not be served locally, these service demands will be sent to other encountered vehicles. Specifically, we tune the priority function φ and popularity function ϕ according to Table I which has been derived from the different satisfaction functions.

We first evaluate the performance of the CDCU scheme. Fig. 1 shows the total user-satisfaction along time. In this example, $\omega = 1$, $\mu = 0.03$, and the three kinds of user-satisfaction ratio are $1 : 1 : 1$. The proposed CDCU scheme can be seen to achieve a higher performance than the other two

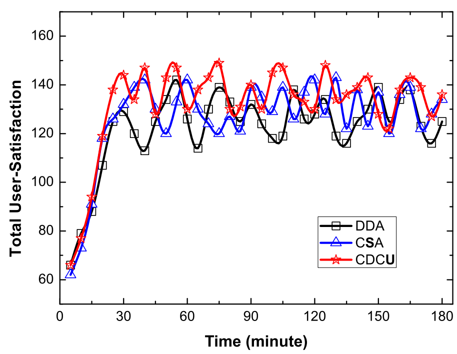

Fig. 2. Performance comparison when $\omega = 2$, $\mu = 0.05$, Threshold:Try-Best:Reward=1:2:1.

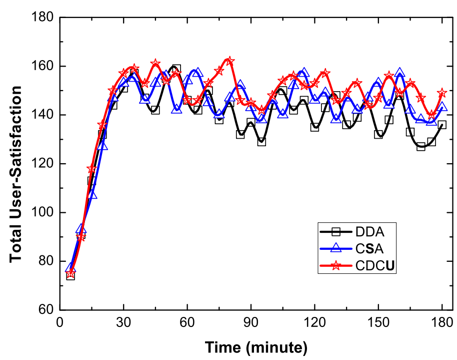

Fig. 3. Performance comparison under heterogeneous meet environment, $\mu \in [0.01, 0.1]$.

schemes. In particular, the average total user-satisfaction using the proposed CDCU is 152.7 while it is 142.8 using DDA and 145.9 for the case of CSA. Thus, the proposed CDCU can achieve almost 9.9 and 6.8 performance gains comparing to the DDA and CSA scheme, respectively. Fig. 1 also shows that the performance achieved by the CDCU is sometimes closed to or worse than the performance of the alternative algorithms. That is because the CDCU does not provide the service as soon as the demand is required, while it records the waiting time to fulfill the content dissemination. In Fig. 2, we repeat the results for different ω, μ values, and user-satisfaction ratios, and similar observations can be held.

In order to evaluate CDCU in more practical vehicular networks, we relax the homogeneous meeting assumption. In particular, each meet $\mu_{i,j}$ is a random variable which follows the Poisson distribution in $[0.01, 0.1]$. Fig. 3 presents the performance comparison of the previous three methods. It is observed that our proposal also has advantage over the competing algorithms. In addition, we test the proposed CDCU scheme in a dynamic environment where vehicles can join or leave the given network randomly, and the other settings are identical to those of Fig. 3. To avoid the case of unsatisfactory service due to the short stay in the vehicular networks, the vehicles join or leave the networks every 30 minutes. We

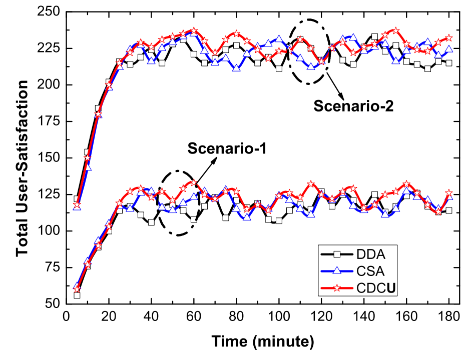

Fig. 4. Dynamic environment test (Scenario-1: $|\mathcal{V}| = 100$, $|\mathcal{M}| = 30$, $c = 3$; Scenario-2: $|\mathcal{V}| = 200$, $|\mathcal{M}| = 80$, $c = 10$).

employ two scenarios: Scenario-1 denotes $|\mathcal{V}| = 100$, $|\mathcal{M}| = 30$, $c = 3$, and Scenario-2 represents $|\mathcal{V}| = 200$, $|\mathcal{M}| = 80$, $c = 10$. Fig. 4 presents the performance results under different scenarios, which again demonstrate the efficiency of the proposed CDCU scheme.

V. Conclusions

In this paper, we develop a distributed heterogeneous media service scheme that jointly solves the service fashion, content dissemination, cache update and fairness problems for P2P-based vehicular networks. Importantly, unlike conventional media service schemes focus on optimal QoS or system throughput, our work aims at achieving maximal user-satisfaction and certain fairness by jointly considering media-aware distribution and opportunistic transmission. Extensive simulation results are provided which demonstrate the effectiveness of our proposed schemes.

References

[1] J. Zhao and G. Cao, "VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks," *IEEE Transactions on Vehicular Technology*, vol. 57, no. 3, pp. 1910-1922, May 2008.

[2] Y. Zhang, J. Zhao, G. Cao, "Roadcast: A Popularity Aware Content Sharing Scheme in VANETs," *Proc. of IEEE ICDCS 2009*.

[3] M. Dikaiakos, A. Florides, T. Nadeem, L. Iftode, "Location-Aware Services over Vehicular Ad-Hoc Networks using Car-to-Car Communication," *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 8, pp. 1590-1602, Aug. 2007.

[4] S. Ioannidis, A. Chaintreau, L. Massoulie, "Optimal and Scalable Distribution of Content Updates over a Mobile Social Network," *Proc. of IEEE INFOCOM 2009*.

[5] M. Musolesi and C. Mascolo, "Designing Mobility Models Based on Social Network Theory," *SIGMOBILE Mobile Computing and Communications Review*, vol. 11, no. 3, pp. 59-70, July 2007.

[6] J. Reich and A. Chaintreau, "The Age of Impatience: Optimal Replication Schemes for Opportunistic Networks," *Proc. of ACM CoNEXT 2009*.

[7] S. Boyd and L. Vandenberghe, "Convex Optimization," *Cambridge University Press*, United Kindom, 2004.

[8] L. Kleinrock, "Queuing Systems, Volume II: Computer Applications," *Wiley Interscience*, New York, USA, 1976.

[9] L. Zhou, X. Wang, W. Tu, G. Mutean, and B. Geller, "Distributed Scheduling Scheme for Video Streaming over Multi-Channel Multi-Radio Multi-Hop Wireless Networks," *IEEE Journal on Selected Areas in Communications*, vol. 28, no. 3, pp. 409-419, Apr. 2010.