Social Cooperation for Information-Centric Multimedia Streaming in Highway VANETs

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Abstract**—**High-quality multimedia streaming services in Vehicular Ad-hoc Networks (VANETs) are severely hindered by intermittent host connectivity issues. The Information Centric Networking (ICN) paradigm could help solving this issue thanks to its new networking primitives driven by content names rather than host addresses. This unique feature, in fact, enables native support to mobility, in-network caching, nomadic networking, multicast, and efficient content dissemination. In this paper, we focus on exploring the potential *social cooperation* among vehicles in highways. An ICN-based COoperative Caching solution, namely ICoC, is proposed to improve the quality of experience (QoE) of multimedia streaming services. In particular, ICoC leverages two novel social cooperation schemes, namely *partner-assisted* and *courier-assisted*, to enhance information-centric caching. To validate its effectiveness, extensive ns-3 simulations have been executed, showing that ICoC achieves a considerable improvement in terms of start-up delay and playback freezing with respect to a state-of-the-art solution based on probabilistic caching.

Keywords—Social Cooperation; Caching; ICN; Multimedia Streaming; Highway VANETs

I. INTRODUCTION

As people tend to spend more and more time in vehicles, there is a strong demand to provide drivers and passengers with multimedia infotainment services. More importantly, many safety-related applications become powerful if relying on multimedia technologies. For example, videos clips of an accident situation or emergency scenario ahead can provide more precise and rich information for drivers to make timely decisions. Therefore, efficient multimedia streaming in Vehicular Ad hoc Networks (VANETs) becomes desired for the future Intelligent Transportation System (ITS) [1].

Nowadays, several wireless technologies can be used to set up a vehicular network, such as IEEE 802.11p, DSRC/WAVE, enabling vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-Roadside Unit (V2R) and vehicle-to-universe (V2U) (including satellite, GPS, pedestrian, public safety and so on) communications (as shown in Fig. 1). Besides, Peer-to-Peer (P2P) systems have been thoroughly investigated in the last decade as a possible solution for multimedia streaming services in VANETs [2][3]. Nevertheless, high quality multimedia streaming still faces great challenges for practical applications in highway. This is mainly ascribed to several inherent challenging obstacles: dynamic topologies due to high-mobility, intermittent connectivity in sparse network infrastructures as well as frequent handover in harsh propagation environments. The effects of these obstacles are amplified for multimedia services because the host-to-host IP connectivity: (i) provides limited support to mobility; (ii) does not fit the requirements of emerging applications, which target content sharing and dissemination rather than host-to-host data sessions [4][5][6]. Hence, a novel networking paradigm is needed to overcome the current challenges of multimedia delivery in highly mobile and dynamic environments.

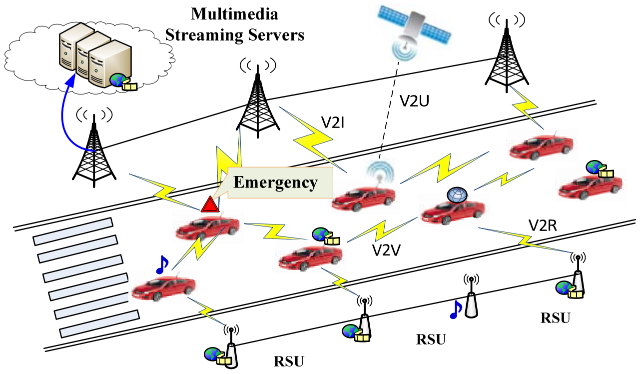

Fig. 1 Multimedia streaming in highway VANETs

Recently, Information Centric Networking (ICN) paradigm has been proposed and gained significant popularity in the research community [7][8][9]. ICN focuses on content retrieval by replacing *host-based addressing* with *content-based addressing*, which cares of "*what*" contents a user wants to access instead of "*where*" the contents are located. In other words, the content requester can obtain the content and need not to maintain the consistent connection with a certain host. Also, the in-networking caching coupled with name-based networking primitives have all the potential to counteract the negative effects of intermittent connectivity because they enable native support to mobility, nomadic communications, multicast, and multi-path routing. For these reasons, Information-Centric Multimedia Streaming (ICMS) is expected to provide remarkable benefits for VANETs.

A highway VANET is featured by linear traffic, sparse infrastructure constructions, large spacing between vehicles, and potential overtaking. Some technologies, such as Data muling [10], have been exploited in order to broaden the set of nodes that can be reached by a given vehicle. However, the definition of an effective cooperation strategy, able to optimize

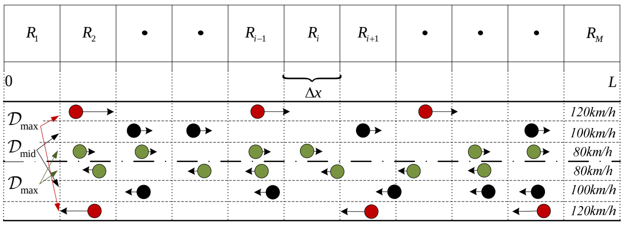

Fig. 2 Highway scenarios

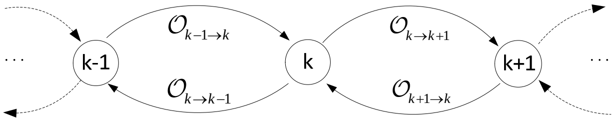

Fig. 3 Transition between adjacent lanes

the quality of experience (QoE) of streaming services in challenging highway scenarios, is still an unsolved issue.

We believe that the ICMS will further amplify its power in highway VANETs by leveraging cooperative caching among vehicles. This paper focuses on exploring the potential social cooperation among neighbor vehicles in highway to improve the utilization of caching resources. In particular, we propose a highway-customized ICN-based cooperative caching mechanism, namely ICoC, aimed at maximizing video playback quality without excessive startup delay and minimizing the playback freezing ratio. To demonstrate its effectiveness, extensive simulations have been executed, showing that ICoC achieves a considerable improvement in terms of start-up delay and playback freezing with respect to the probabilistic caching adopted in [11], where no cooperative caching is performed.

This paper is organized as follows. Section II introduces an overview of related work. Section III presents the system models used. Section IV details the proposed ICoC mechanism. Section V evaluates the performance through extensive simulations. Finally, section VI concludes this paper.

II. RELATED WORK

ICN-based data dissemination over VANETs is gaining momentum in the research community. Amadeo *et al.* [12] designed a content-centric vehicular networking (CCVN) architecture by leveraging the ICN paradigm, where CCVN protocol runs on top of IEEE 802.11p as a replacement of TCP/IP. Later, TalebiFard *et al.* [13] also assumed a content-centric paradigm for information dissemination in VANETs and enhanced its performance by adopting a selective randomized network coding. Besides, Wang *et al.* [14] applied the Named Data Networking (NDN) concept to V2V communications, and proposed a smart randomized scheduling based on the geo-location information and a proactively push data mechanism to speed up the data propagation. However, all these proposals focus on the data dissemination mechanisms without explicitly addressing the subtle interactions between caching and QoE in multimedia streaming services.

Caching mechanisms are also researched in ICN at a broader extent. Psaras *et al.* [11] proposed probabilistic in-network caching aiming to reduce caching redundancy and make more efficient utilization of available cache resources. Vasilakos *et al.* [15] presented a selective neighbor caching approach for enhancing seamless mobility in ICN architectures. Saha *et al.* [16] proposed a novel solution to overcome the problem of uncooperative caches in ICN. Ming *et al.* [17] propose an age-based cooperative cache scheme aiming at reducing network delay and publisher load. Nevertheless, a specific caching mechanism should depend on its application scenario greatly. All above contributions do not consider and explore the characteristics of harsh highway VANETs.

To bridge the gap, this contribution leverages the precious lessons gained from the past and explores social cooperation mechanisms to optimize the QoE of multimedia streaming services special in highway VANETs.

III. SYSTEM MODELS

A. Highway Traffic Model

On the highway, vehicles are with high speeds but relative linear motion along the lanes. We consider that each highway has bidirectional vehicle traffic, and each direction owns multiple lanes. In order to simplify the model, the same traffic model is used in the two directions and we discuss the situation in one direction only. We assume that the vehicles arrive in the desired region following a Poisson process with a vehicle arrival rate $\lambda > 0$ (number of vehicles per second). Let $X(t)$ denote the number of vehicles arriving in targeted area $\mathcal{R}$ of a certain lane during an period of time $(0,t)$. The probability mass function of $X(t)$ can be expressed as follows:

$$\Pr\left(X(t)=k\right)=\frac{(\lambda t)^k e^{-\lambda t}}{k!}, k\in\{0,1,2,\cdots\} \tag{1}$$

Based on this, the inter-arrival time of vehicles τ follows an exponential distribution. The average inter-arrival time $\bar{\tau}$ is:

$$\bar{\tau}=\frac{1}{\lambda} \tag{2}$$

Let v denote the speed in each lane. The average distance between vehicles in each lane can be expressed as follows:

$$\bar{\mathcal{D}}=v\cdot\bar{\tau}=\frac{v}{\lambda} \tag{3}$$

It is a fact that each lane in the highway has set a separate speed limitation and the speed of vehicles varies in different lanes (as shown in Fig. 2). Once a vehicle enters the highway, it should be regulated by speed limitations of lanes. Thus, the fastest lane (with the highest vehicle speed) has the largest inter-vehicle space. On the contrary, the slowest lane has the smallest inter-vehicle space. To be more realistic, we further consider the overtaking cases in highway by using a transition probability. Fig. 3 shows the transition process between adjacent lanes. The vehicles in the k-th lane may change to the adjacent lane with the probability of $\mathcal{O}_{k\to k-1}$ and $\mathcal{O}_{k\to k+1}$, respectively.

B. Hybrid Multimedia Naming Design

In classic NDN, each *Interest* or *Data* packet carries the name of the content. Thus, naming scheme plays a critical role in the process of identifying, discovering and retrieving content.

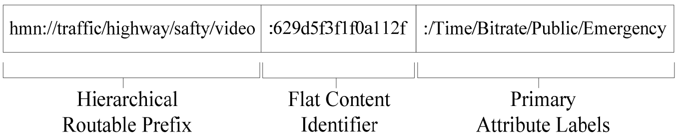

Fig. 4 Hybrid media naming design

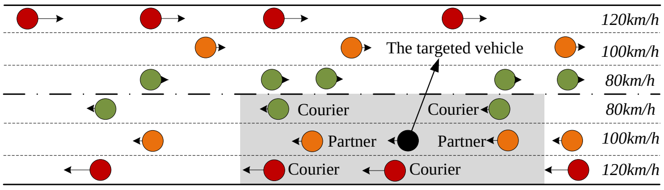

Fig. 5 Potential social cooperation among vehicles

A unique name serves many fundamental functions: (1) identifies a mutable or immutable content or information object; (2) is used to look up and access data in network cache; and (3) is used for routing and forwarding. However, a good data naming design must allow data publishers to describe precisely their catalogues, and data consumers to express their queries [19]. More importantly, it must support efficient lookup and high scalability [20]. Specially for multimedia streaming in vehicular networks, we consider that some important attributes should be carried in the names, such as the streaming bitrate, required time, public or not, emergency level as so on. These attributes help to find the desired video content precisely with high QoE levels.

Based on this, the format should be optimally designed. Currently, there are mainly two formats for the naming in ICN. DONA [7] introduces the flat names, where CCN [8] adopts the hierarchical names. However, flat names are difficult to aggregate, which bring a poor scalability for large-scale objects. Hierarchical names have good aggregation to improve scalability, but bring a low lookup efficiency especially for long names.

We considered a novel improved name format, which capitalizes the strengths of hierarchical and flat names, also carries the primary attribute labels (as shown in Fig. 4). In detail, this naming format includes three parts: Hierarchical Routable Prefix (HRP), Flat Content Identifier (FCI), and Primary Attribute Labels (PALs). Each part adopts its own structure, which benefits for its special function.

HRP is used to route and forward the content efficiently thanks to its high aggregation and hierarchical components. FCI can be a digest of the whole content or a digest of suffixes which is used to identify the content chunk and accelerate the content and caching discovery. The digest can be produced with coding methods, such as hash functions. PALs include a sequence of additional important attribute information for the content, such as timeliness, caching strategy, playback bitrate requirement, and priority level, which are very useful for advanced QoE optimization strategies. Besides, PALs can be used to indicate the potential following data and aggregate multiple requests for several segments, which will provide great benefits for the prefetching of video.

In the following sections, we will propose the ICN-based cooperative caching based on all above models and considerations.

Algorithm 1: Partner-assisted cooperation

```
$\Phi_i$ : the partners of $i$ based on a hello packet detection;
if vehicle $i$ requests video segment $k \in \mathcal{M}$ then
    if the playback buffer is not filled then
        calculate available space in playback buffer: $\Omega_i$ ;
        predict the following requests: $\{k \oplus 1, \cdots, k \oplus N\}$ ;
        send out the Interest $\mathcal{I}_k$ for segment $k$ carrying PALs including : PO, $\{k \oplus 1, \cdots, k \oplus N\}$ ;
    end if
endif
if a partner $p$ in $\Phi_i$ receives $\mathcal{I}_k$ then
    $p$ obtains the information of PALs carried;
    if $p$ is willing to undertake this task then
        $p$ assists to download segments $\{k, \cdots, k \oplus N\}$ ;
    elseif
        $p$ discards $\mathcal{I}_k$ and does nothing else;
    end if
endif
```

IV. ICN-BASED COOPERATIVE CACHING

We consider a general scenario that a vehicular user wants to retrieve a video, which includes a sequence of multimedia segments. According to [18], a given vehicle sends out an *Interest* packet containing the formatted content name when it starts an information-centric delivery. We focus two kinds of potential social relations among vehicles, namely *partners* and *couriers*, jointly based on the location and lane information, which are illustrated in Fig. 5. With reference to a given vehicle *i*, we define as *partner* nodes, the set of vehicles in the same lane of *i* and within its one hop communication range. Due to the tiny relative speed, the partners can maintain relative reliable communication links. On the contrary, the vehicles in adjacent lanes within the communication range of *i* are called *couriers*. Since a *courier* has a different speed with respect to *i*, it can be used to relay *Interest* and *Data* to remote vehicles. Each vehicle can know their *partners* and *couriers* thanks to ad hoc hello packets exchanged among vehicles. In the following, we propose two cooperation mechanisms leveraging the functions of partners and couriers.

A. *Partner-assisted cooperation*

Due to the high-mobility of vehicles, the download process from RSUs will be interrupted frequently, which brings an unstable downlink bandwidth. Besides, there is a high probability that neighbor vehicles will not carry segments of the desired video if no interaction among neighbors is performed. All these motivate us to develop efficient cooperative caching in ICN to improve the utilization of steady V2V links by promoting neighbor caching.

To guarantee smooth playback of videos, we focus on how make use of these partners and propose a highway-costumed partner-assisted cooperation caching mechanism, which is detailed in Algorithm 1. This mechanism is triggered when the playback buffer of the requester is not filled, which means there is still space to store the following video segments. If a given vehicle recurs to the cooperation from its partners, it

Algorithm 2: Courier-assisted cooperation

```
$\Gamma_i$ : the couriers of $i$ based on a hello packet detection;
$\theta$ : the category of couriers;
if vehicle $i$ requests video segment $k \in \mathcal{M}$ then
  send out the Interest $\mathcal{I}_k$ for segment $k$;
  if no response for $\mathcal{I}_k$ is received within the timeout then
    predict the following requests: $\{k \oplus 1, \cdots, k \oplus N\}$;
    resend out the Interest $\mathcal{I}_k^{'}$ for segment $k$ with PALs
    including : CO, $\theta$, $\{k \oplus 1, \cdots, k \oplus N\}$;
  endif
endif
if a courier $c$ in $\Gamma_i$ receives this Interest then
  if $c$ is willing to undertake this task then
    $c$ assists to distribute the Interest along the road;
  endif
endif
if a node $n$ matches the Interest then
  $n$ obtains the $\theta$ from the Interest' PALs;
  $n$ deliver the Data with PALs including: CO, $\overline{\theta}$;
endif
```

first sends out *Interest* packets with PALs including: the label of *Partner-assisted On (PO)* and potential following requests. The potential following requests can be predicted by means of the prefetching mechanism [21]. We let " $\oplus$ " denote a predicting operator, for example $k \oplus i$ denote the i -th request after the request of segment k. Once one of its partners receives this *Interest* packet, it would obtain these PALs and determine whether it undertakes this cooperation task depending on its willing or its current status. If it accepts this task, it will assist to download/cache contents from RSU and its neighbor vehicles. Since the *partners* of one given vehicle will provide a relative high and steady upload bandwidth, this partner-assisted cooperation enables to provide great benefits for shortening the startup delay as well as improving the available download bandwidth.

B. Courier-assisted cooperation

In highway, sparse vehicles may lead to a not connected topology. This situation will affect the discovery of potential data providers in ICMS. Since vehicles in different lanes have also different speeds, *couriers* can be used as "interest mules" and "data mules" to promote the multimedia delivery among disconnected network islands. In practical, a pair of couriers in two directions may be used separately during the ICN-based delivery. If the courier has a higher speed than the tagged vehicle, it is called the *front-courier*, which can post the data to vehicles onwards. Vice versa, it is a *back-courier*, in case of vehicle with a smaller speed.

To alleviate the provider discovery problem in sparse highway, we explore the features of couriers and propose the courier-assisted cooperation mechanism, which is shown in Algorithm 2. Different from the partner-assisted cooperation, courier-assisted cooperation aims to enlarge the searching range of each Interest. When the *partners* of a vehicle cannot provide enough copies of asked contents, the assistance of *couriers* come into play. This situation can be detected by a time-out expiration of an *Interest* request. In this case, the *Interest* is retransmitted by setting in the PALs: the label of *Courier-assisted On (CO),* category of couriers (front, back or both) and potential following requests. Once one of its couriers receives this kind of packets and checks the PALs, it may carry and distribute the *Interest* packets along the road which assists to promote the content discovery. When any vehicle or RSU matches this *Interest*, it will send out the desired data also with PALs: the label of *CO* and category of couriers. Note that the category of couriers in *Data* is dependent on the one in corresponding *Interest* packet. If one courier receives this *Data* and satisfies the requirements of PALs, it will cache and assist to deliver the *Data* back to the requesting node.

The courier-assisted cooperation caching enables to promote the content discovery, especially in a sparse situation. Frankly, this cooperation is probabilistic and may result in a long delay. However, it can alleviate the influence for playback smoothness by means of precisely predicting the following desired segments, and prefetching them in advance.

V. SIMULATION EVALUATION

To build our simulation platform, we adopt the network simulator NS-3 [22]. Based on this, the ndnSim [23] module of ns-3 was customized and extended in order to embrace ICoC functionalities. In our experiments, a straight highway scenario with three lanes is considered. To be realistic, the speed in three lanes is set as 80km/h, 100km/h and 120km/h respectively, and the width of each lane is set as 3.75m [24]. 100 vehicles move in highway lanes with a length of 5km and 5 RSUs are located along the highway uniformly by an equal spacing distance of 1km. All RSUs are connected to a multimedia server with 10 Mbps bandwidth. Since the speed determines the density of vehicles in each lane, we initially distribute all vehicles in three lanes by ratio of 40%, 33% and 27% (from the low lane to the fast lane). According to [25], we consider three discrete data rates at the MAC layer: 2Mbps if the transmission distance d is less than 50 meters, 1Mbps if $50 \le d < 150$ meters, and 500kbps if $150 \le d < 300$ meters (the one-hop transmission distance); each vehicle may change to its adjacent lane with a probability of 5%. As in [3], we consider a 5400s-long video divided in 180 segments, each of which is about 0.47 MByte in size. The buffer size is essential for the smoothness of the playing, while its configuration is dependent on the selected player. We consider the buffer in each node contains 5 video segments at most.

As 802.11p is not available in ns-3 currently, we adopt the 802.11a to emulate of 802.11p. We believe that this choice does not affect the nature of the problem to be evaluated. The ad hoc wifi is adopted in the mac layer. NDN stack is installed in each vehicle and RSU. We compare the performance of ICoC with respect to a probabilistic caching (PC) algorithm that caches with probability of $p = 0.3 \sim 0.7$ [11]. The simulation conducts one vehicle requests a continuous sequence of multimedia segments in order. Based on the sequence number of segments, we predict the following

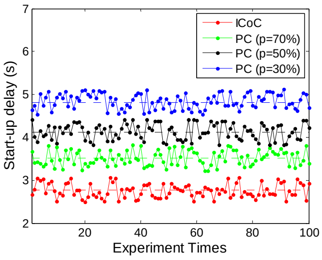

Fig. 6 Start-up delay

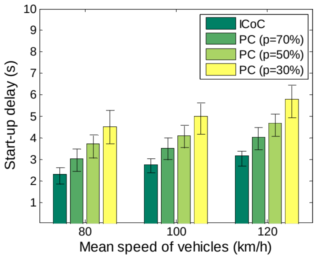

Fig. 7 Start-up delay vs. Speed (95% CI)

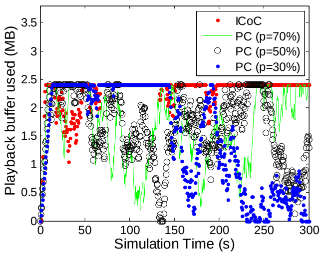

Fig. 8 Playback buffer used

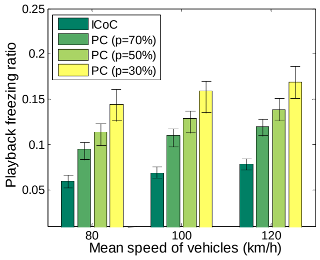

Fig. 9 Playback freezing ratio (95% CI)

segments which will be requested. Two main QoE metrics are observed including the startup delay and the playback freezing ratio. We execute this experiment 100 times and report average values and 95% confidence intervals (CI).

(1) Start-up delay: Start-up delay is defined as the time between sending the *Interest* packets and starting to play the video. A smaller start-up delay means a better QoE. Similar with [26], we assume one video starts playing when the buffer is filled with 5-second long media data. The requesting vehicle locates in the middle lane fixed with a speed of 100 km/h.

Fig. 6 clearly shows the start-up delay variation in different experiment rounds. We observe that ICoC is able to lower the startup delay with respect to the probabilistic caching whatever the considered caching ratio. That is because the partner-assisted cooperative caching adopted enables the steady neighbor peers to assist the content delivery and makes full use of the reliable transmission links. Besides, the courier-assisted cooperation mechanism enables to assist to discover the potential video providers. We further compare the start-up delay in different lanes of the highway, which is mainly effected by the mobility speed of vehicles. Fig. 7 shows the average start-up delay and the deviation at different speeds. As the speed of vehicles increases, vehicles become sparser according to the highway traffic model (in section III). Hence, it affects the transmission quality among vehicles and RSUs, and thus worsens the start-up delay. Moreover, it is noted that there is a small deviation in ICoC, which indicates ICoC enables to utilize relative steady delivery links thanks to the partner- and courier-assisted cooperation schemes.

(2) Playback freezing: We evaluate the playback freezing through computing the utilization of playback buffer and the probability of playback buffer being empty during the playback process.

The Fig. 8 shows the condition of occupied playback buffer in a simulation round. We observe ICoC keeps a high occupied playback buffer. Although there is an obvious decreasing during 30-40s, it can recover quickly to stop from emptying the playback buffer. On the opposite, the playback buffer remains often empty when probabilistic caching is used. To further assess the average playback freezes in different lanes, we compute the probability of playback freezing during the video retrieval process. Fig. 9 presents the results in different lanes. In this figure, ICoC has the least probability of playback freezing among four solutions. That is because the cooperative caching can promote the provider's discovery and improve the utilization of playback buffer, and reduce the probability of emptying the buffer. In addition, the probability of playback freezing increases with the speed of vehicles. The reason is that in fast lane there are fewer partners to be used due to the bigger space interval. Besides, the high speed shortens the communication time with a certain RSU, which reduces the efficiency of caching contents from RSUs.

VI. CONCLUSIONS

This paper first characterized the highway traffic and information-centric delivery, and designed a hybrid multimedia naming to enable advanced QoE optimization. Based on this, we explored the potential social cooperation among vehicles in highway and proposed an innovative highway-customized ICN-based COoperative Caching solution, namely ICoC, to improve the QoE of multimedia delivery. Specifically, the partner-assisted cooperation and courier-assisted cooperation are developed to enhance the caching efficiency for ICMS in highway VANETs. Simulation results show that ICoC achieves an improved QoE with respect to the probabilistic caching in terms of start-up delay and playback freezing. In the future, we will explore cooperation based on highway infrastructures such as toll station assisted and more social cooperation to promote the multimedia streaming in ITS.

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