Computer Communications 000 (2016) 1–14

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Information-centric cost-efficient optimization for multimedia content delivery in mobile vehicular networks

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ARTICLE INFO

Article history:
Available online xxx

Keywords:
Cost-efficient
Multimedia content delivery
Vehicular networks
Information-centric networking
Mixed integer programming

ABSTRACT

Providing high-quality multimedia services is a challenging and high-cost task in mobile vehicular networks due to intermittent connectivity, highly dynamic capacity, mostly associated to heterogeneous hosts distribution and their high mobility. Information-centric networking (ICN), which adopts novel content-based dissemination instead of the traditional host-based one, has great potential to accomplish cost-efficient quality-oriented multimedia delivery. This paper proposes a novel cost-Efficient Multimedia content Delivery approach (EcoMD) in vehicular networks leveraging the ICN features. In EcoMD, two essential factors are first analyzed and modeled: content mobility and supply-demand balance, and then, a mixed integer programming (MIP) optimization is formulated to minimize the economic cost associated to guaranteed the quality level of multimedia services. To resolve this NP-hard problem, heuristic mechanisms are proposed covering three aspects: priority-based path selection, least-required source maintaining and on-demand caching enhancement. By comparison with existing state-of-the-art solutions, simulation results demonstrate how EcoMD provides an improved performance in terms of start-up delay, jitter, playback continuity, and Quality of Experience (QoE) while particularly reduces the economic cost.

1. Introduction

According to the Cisco statistics, video in various forms will account for 80–90% of the global consumer traffic by 2017 [1]. Multimedia applications will become extremely popular in future. With the wide spread adoption of diverse mobile devices and wireless network technologies, it is both an opportunity and a challenge to deliver multimedia services (i.e. classic or 3D video, online gaming, street viewing, etc.) in mobile wireless network environments [2–4].

Lately, a variety of emerging wireless technologies such as WAVE/IEEE 802.11p, LTE, LTE-A, *etc.* have been developed to support multimedia delivery in vehicular networking via vehicle-to-infrastructure (V2I), vehicle-to-roadside unit (V2R) and vehicle-to-vehicle (V2V) communications [5–7]. Providing high-quality multimedia streaming services over Vehicular Ad-hoc Networks (VANET) has become a hot research topic [8]. However, most of the current research efforts did not consider the economic aspects when pursuing high quality multimedia delivery. For example, assuming that a WiFi access can support a low resolution video chat, it would involve higher costs if the same service is offered over a 4G/LTE channel. As video streaming is the largest contributor to the network traffic, it is of great interest to focus on cost-efficient high quality multimedia delivery [9,10].

The current network design puts the high quality multimedia delivery in difficulty when attempting to offer user services in high mobile networks [11]. The main problems and challenges include: (i) resources are usually associated with host locations which leads to poor support for high mobility users; (ii) connection-oriented sessions come with great control overhead due to the frequent changes of topology; (iii) different address spaces are adopted in heterogeneous networks which aggravates the management issues related to maintaining the address consistency. At the root of these problems is that the traditional host-to-host data exchange is not well suited to the frequently-moving video transfers in dynamic VANETs [12]. In this context, novel network architectures are considered to address these challenges [13].

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http://dx.doi.org/10.1016/j.comcom.2016.07.014
0140-3664/

Information-Centric Networking (ICN) [14] has gained momentum as a candidate architecture for the future Internet. ICN focuses on "*what*" content users want to access instead of "*where*" the content resides, and tries to build novel *content-based* communication models, replacing traditional *host-based* ones [15]. This peculiarity allows the requester to retrieve content from the nearest providers, and avoids long routes to certain host addresses. Besides, the in-network caching performed at every ICN-based node has the potential to cope with the problem of intermittent connectivity [16,17].

By leveraging these features, ICN opens up many beneficial avenues for efficient multimedia delivery in highly dynamic VANETs. In our recent works, content delivery in ICN has been studied from diverse perspectives [18–20]. To the best of our knowledge, there are no specific works on cost-efficient approaches for multimedia delivery in VANETs. In this context, this paper proposes a novel approach for cost-Efficient Multimedia content Delivery (EcoMD) in vehicular networks by making use of information-centric data management means. The main novel contributions of EcoMD can be summarized as follows:

- EcoMD makes use of inherent multi-path, multi-source and multi-caching features in vehicular network environments.
- EcoMD is based on modeling the multimedia delivery process, considering two essential factors: content mobility and provider supply-demand balance. A mixed integer programming (MIP) optimization is formulated to minimize the economic cost associated to guaranteed quality levels for the multimedia services. The proposed MIP optimal problem is proven as NP-hard.
- EcoMD includes three newly designed heuristic solutions for the NP-hard problem focusing on finding sub-optimal solutions by considering (i) priority-based path selection, (ii) maintaining the least number of sources and (iii) on-demand in-path caching enhancement, respectively.
- EcoMD evaluation is based on extensive comparative simulation-based testing. The results demonstrate the efficiency of the proposed heuristic solutions and show how the proposed method outperforms other state-of-the-art solutions in terms of both quality-related and cost-efficiency-related metrics.

2. Related works

Several scientific contributions related to efficient multimedia delivery have been made recently [21–23]. Some of this research has addressed multimedia delivery over VANETs or emerging ICN. This section briefly discusses the most significant related works in the context of the research described in this paper.

Utilizing Peer-to-Peer (P2P) networks as platform for media streaming dissemination over VANETs is an attractive research topic. Naeimipoor et al. [24] proposed a hybrid video dissemination protocol that deploys a receiver-based relay node selection technique. Asefi et al. [25] proposed an adaptive medium access control retransmission scheme for video streaming over VANETs, which significantly reduced playback freezes while introducing a small increase in start-up delay. Rezende et al. [26] proposed a receiver-based solution, called REDEC, to conduct video transmission without the selection of relay nodes. Another protocol, VIRTUS [27], is proposed for video streaming over VANETs made use of the reactive aspects of receiver-based solutions to achieve performance improvements. Zhou et al. [28] developed a joint media service dissemination and cache update scheme in distributed manner for P2P-based vehicular networks. Our previous work [8] has also proposed an adaptive Quality of Experience (QoE)-driven user-centric Video on Demand scheme in urban multi-homed P2P-based vehicular networks. Despite all the solutions proposed, due to both unreliability and limited bandwidth in VANETs, providing high quality media streaming in VANETs remains a big challenge.

Table 1
Comparison of existing works.

	Multimedia	ICN	VANET	Economy
Multimedia in VANETs [22]-[28]	Yes	**Little**	Yes	**Little**
ICN for multimedia [29]-[37]	Yes	Yes	**Little**	**Little**
ICN for VANETs [38]-[39]	**Little**	Yes	Yes	**Little**
EcoMD proposed in this paper	Yes	Yes	Yes	Yes

The emergence of ICN has opened up a novel avenue to address quality-oriented video sharing issues and been proved to be a highly promising method. Detti et al. [29] introduced a P2P solution for live streaming of video content over the ICN, which increased the quality of video playback for small sets of neighboring devices. Lederer et al. [30] investigated the implementation of multimedia streaming within the ICN environment and integrated DASH and ICN. Piro et al. [31] undertook a thorough survey of the ICN-based multimedia systems and available tools, whereas Zhu et al. [32] proposed an audio conference tool for Named Data Networking (NDN). Han et al. [33] presented an adaptive retransmission scheme to overcome video packet losses in content-centric wireless networks. Liu et al. [34] performed an implementation of dynamic adaptive video streaming using a content centric networking approach. Additionally, Li et al. [35] proposed NF-DASH, an application-layer combined DASH and ICN solution for video traffic engineering. Detti et al. [36] presented a cooperative video streaming application running on top of ICN, whereas Li et al. [37] introduced a cooperative caching strategy for the treatment of large video streams with on-demand access. Although many researches contribute to the multimedia over ICN, most of them focus on video streaming over static network and do not consider the complexity of mobility scenarios such as those experienced in VANETs.

ICN-based communications over VANETs have also been researched [38–42]. Amadeo et al. [38] confirmed ICN's potential as a very promising networking solution for future VANETs, whereas Arnould et al. [40] proposed a new network architecture targeting hybrid VANETs based on an ICN architecture. TalebiFard et al. [41] adopted a selective random network coding approach and proposed a content-centric solution for information dissemination in vehicular network environments. Additionally, Wang et al. [39] applied the NDN concept in V2V communications, and proposed a data name design to develop a simple traffic information dissemination application. However, these proposals focus on general information dissemination, and do not consider the specifics of multimedia streaming applications, although these are highly important to be considered, as they are characteristics which significantly affect multimedia service quality.

Table 1 summarizes our related work investigation, and contrasts the proposed EcoMD with existing research in the areas of multimedia delivery in VANETs, ICN for multimedia and ICN communications in VANETs. It can be noted how very little research work focuses on the cost-efficiency in ICN-based multimedia delivery in VANET scenarios. Therefore, this paper fills this gap in the literature and introduces EcoMD, as a cost-efficient solution for information-centric multimedia streaming over VANETs.

3. EcoMD overview

EcoMD targets a realistic urban vehicular environment, in which vehicles are driven along the roads and inter-communicate, as illustrated in Fig. 1(a). Each vehicle accessing VoD services can obtain the desired video content from one of the following potential

Please cite this article as: C. Xu et al., Information-centric cost-efficient optimization for multimedia content delivery in mobile vehicular networks, Computer Communications (2016), http://dx.doi.org/10.1016/j.comcom.2016.07.014