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ECDS: Efficient collaborative downloading scheme for popular content distribution in urban vehicular networks

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ABSTRACT

The recent development of the Vehicular Ad-hoc Networks (VANETs) has motivated an increasing interest in in-vehicle consumption, and hence, the Popular Content Distribution (PCD) has become a heated issue. Compared with PCD solutions based on the widely-used cellular networks and Dedicated Short Range Communications (DSRC), solutions based on Collaborative Downloading (CD) are more economical and efficient. Due to the limited bandwidth, the On-Board Units (OBUs) passing through a Road Side Unit (RSU) can only download a portion of the popular content. To get over that drawback and to effect a collaborative downloading, a P2P network should be constructed among the OBUs which fall out of the RSUs coverage. In this paper, we address the efficient collaborative downloading scheme (ECDS) for PCD in urban traffic scenarios. To adapt to the rapid-changing characteristics of the VANET topology, a new cell-based clustering scheme is proposed, which greatly simplifies the modeling. Besides a strategy of inter-cluster Relay Selection is proposed to construct a pear-to-pear (P2P) network of scale-free property, which will help enhancing the information spread. Furthermore, another inter-cluster strategy of generation selection is to be collaborated to accelerate the dissemination process in the P2P network. The comparison experiments to two up-to-date collaborative PCD protocols demonstrate the high performance of the proposed scheme, i.e. ECDS.

1. Introduction

Vehicular Adhoc NETworks (VANETs), which provide high-rate data communication between the *On-Board Units* (OBUs) and *Road Side Units* (RSUs), are among the most successful industrial applications of the *Internet of Things* (IoT) [1]. RSUs are deployed along the roads so that OBUs may request any internet-based service (e.g. multimedia, TV shows, games, real-time traffic concerns, etc.). Recent development and standardization in VANETs have aroused commercial interest in in-vehicle consumptions, e.g. entertainment-on-the-wheel [2]. The service-oriented vehicular networks have attracted a great deal of investment in both the development of in-vehicle devices and large-scale deployment of wireless infrastructures [3,4].

Today, wireless entertainment devices, e.g. mobile TVs, intelligence terminals, etc., are commonly equipped by vehicles. Service providers can publish popular multimedia contents through the RSUs to the OBUs in the *Area of Interest* (AoI), a process which is known as *popular content distribution* (PCD) [5,6]. The “popular contents” range from newly released movies, popular music, infotainments to

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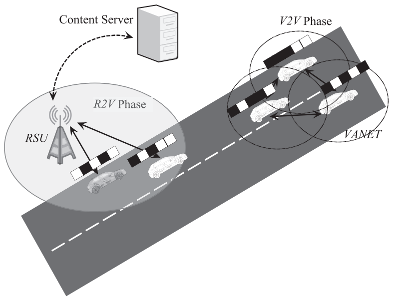

Fig. 1. Two phases of collaborative downloading.

local digital maps, and real-time traffic information, which are usually large files [7]. In the usual content downloading service, different OBUs download different files. However, in PCD, most of the OBUs in the AoI request the same content. Efficient downloading of popular content to drivers and passengers will be a critical marketing strategy for information service providers [8].

Existing solutions for PCD can be classified into two types: solutions based on cellular networks (GPRS, 3 G, 4 G, etc.) , and those based on DSRC [9,10]. The cellular network-based solutions have drawbacks in the high communication cost. Moreover, when the number of OBUs is large, the bandwidth is still limited. The DSRC based solutions suffer from the high cost of deploying a large number of hotspots at roadsides, providing the ubiquitous coverage envisaged with DSRC. In addition, communications between the vehicles and the hotspots may be frequently interrupted due to the high speed of the vehicles.

Collaborative downloading is a data dissemination method which allows the distribution of information among cooperative vehicles, and many researches [5–7,11,12] have indicated that collaborative PCD schemes can achieve lower downloading delay. In collaborative PCD, the content is divided into several generations (blocks) with equal size. As shown in Fig. 1, when the OBUs are within the coverage of the RSUs, they receive different generations, and this phase is known as the *R2V phase*; when the OBUs are out of the coverage of the RSUs, they form the VANET and exchange the generations, the phase known as the *V2V phase*. Those two phases alternate to complete the PCD.

Collaborative downloading on the Internet has been extensively studied, and several protocols (e.g. BitTorrent [13], eDonkey2000 [14], etc.) have been widely used and achieved strong performance. Due to the high speed of vehicles and the difficulty of predicting the vehicles' trajectories in urban scenarios, the direct application of the CD protocols of the application layer for the Internet to vehicular networks performs much worse. For example, for only 20 OBUs, the *SPAWN* protocol [15], a protocol similar to BitTorrent, takes almost 3 min to download a file only 1.6MB in size.

Rapid change and unpredictable topology are among the main characteristics of the VANETs, and this creates challenges for modeling urban vehicular networks [16]. Indeed, if treating the OBUs as nodes, the positions of the nodes are changing. Referring the idea of cellular division from the Cell Transmission Model (CTM) [17] and position-based routing strategies [18–20], each lane can be divided into successive homogeneous cells with the same size, and the OBUs in the same cell form a cluster. Therefore, the OBUs' movement on the road can be transformed to the action of leaving the old cell and joining the new cell. By treating the cells as nodes, the positions of the nodes remain unchanged, which greatly simplifies the modeling of the VANETs. IEEE 802.11p supports up to six service channels. Due to the recent researches and standardization (e.g. IEEE 1609.4) regarding dual ratio multichannel operation [21], intra-cluster generation dis-semination and inter-cluster generation exchange can be performed simultaneously, by using different ratios.

The relay selection and generation selection are two core issues that should be considered in a collaborative PCD scheme. Due to the limited number of channels, only a small number of the transmissions between the OBUs can be carried out simultaneously, otherwise severe packet collisions may be caused. Relay selection is the strategy to determine the priority of nodes, as only the nodes of high priority can access the channels and broadcast their generations. Due to the limited bandwidth, each node can only broadcast a small number of generations at each time step when accessing the channels. Generation selection is the strategy used to determine which generations one node should broadcast.

For the relay selection, the basic idea in our scheme ECDS is to make the high density and high downloading rate cells be of high probability to obtain the missing generations. As a result, the generations may be accumulated to some of the high density cells quickly, then be distributed by these cells to the surrounding cells. The basic idea under our scheme is not derived from experience alone, and the transmission process analysis from the complex network theory provides the theoretical support. The “high density first” principle ensures that the high density cells are of high degree, and the “high downloading rate first” principle ensures that the cells prefer to choose the cells of high degree as relays, thus leading to the *Matthew Effect* [22]. With these two principles, there are only a small number of cells of high degree, which we refer to as core cells. The majority of cells of low degree can connect to the core cells within a few hops, and this topology structure is similar to the *BA scale-free network* [23]. Pastor-Satorras and Vespignani [24] researched the epidemic spread process in different topologies, and discovered that the virus spread most quickly in scale-free networks. Recent researches [36,37] theoretically confirms their finding. PCD in VANETs is similar to the virus spread, and this is the chief reason ECDS is effective.

For the generation selection, the node accessing the channel first broadcasts the generation which the neighboring cells of the highest density and at high downloading rate require for, breaking the tie by broadcasting the generation which the most neighboring nodes require for.

Our contribution: In this paper, we address the V2V phase of collaborative PCD, and propose the ECDF, an efficient collaborate downloading scheme for popular content distribution in urban vehicular networks.

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