A Two-Tier VANET/P2P System for Information Retrieval in Vehicular Environments

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***Abstract*—With advances in information and communication technologies, vehicles on roads can cooperatively share and retrieve information in a distributed manner to support Intelligent Transportation Systems (ITS) services such as traffic management and infotainment services. A system is needed to retrieve information and data from moving vehicles and roadside facilities in an efficient manner. However, existing distributed vehicular systems rely on either vehicular ad hoc networks (VANETs) or application-layer peer-to-peer (P2P) protocols over an infrastructure-based wireless network suffering from low success rate or long latency in information retrieval. In this work, we propose a two-tier VANET/P2P system that integrates low-tier VANETs and a high-tier infrastructure-based P2P overlay. The proposed two-tier system aims to achieve high success rate, reduce latency, and minimize overhead for information retrieval in vehicular environments.**

Keywords-information retrieval; peer-to-peer computing; two-tier VANET/P2P system; vehicular network

I. INTRODUCTION

Advances in information and communication technologies enable vehicles on roads to cooperatively share information and data to support intelligent transportation systems (ITS) services, such as vehicle safety, traffic management, and infotainment services, without requiring a server infrastructure. For example, current traffic conditions in a specific road segment can be obtained by sending queries to the vehicles either driving on the road segment or near the area. The growing necessity for sharing and retrieving required information among vehicles has motivated the creation of an information retrieval system in vehicular environments.

Information sharing and retrieval require the support of wireless communication to transmit and receive data to and from moving vehicles. Inter-vehicle communication (IVC) based on short-range communication technologies such as IEEE 802.11p provides direct and low-latency communication between vehicles without requiring an infrastructure support. Vehicles communicate with each other in a hop-by-hop manner to establish vehicular ad hoc networks (VANETs). A service architecture over VANETs was proposed in [1] to provide users with time-sensitive information regarding traffic conditions and roadside services. In [2], vehicles construct an application-layer peer-to-peer (P2P) overlay network on top of VANETs to support content delivery in vehicular networks. However, these VANET-based systems require a sufficient number of vehicles participating in VANETs. VANETs may become disconnected, and thus, information and data may not be delivered to vehicles where low vehicle densities occur.

On the other hand, long-range infrastructure-based wireless communication such as UMTS and LTE can offer a wide range of communication to vehicles without suffering from a network disconnectivity problem. Recent research [3] has utilized infrastructure-based cellular communication and P2P networking technology to implement a cooperative traffic information system among vehicles. However, significant service delays may be introduced in this type of system because of limited network bandwidths and high communication latencies through base stations and mobile communication core networks.

Vehicles have been envisioned to support multiple wireless access technologies. To take advantage of direct inter-vehicle and infrastructure-based communications, we propose a two-tier VANET/P2P system that integrates low-tier VANETs and a high-tier infrastructure-based P2P overlay for information retrieval in vehicular environments [4]. In low-tier VANETs, vehicles can directly exchange and collect information using IVC efficiently. In addition, certain vehicles are selected to establish a P2P sharing overlay through infrastructure-based communication to alleviate the disconnectivity problem in VANETs. In the proposed system, information can be retrieved through lookups performed in the low-tier VANETs and high-tier P2P overlay with high success rate, low latency, and low overhead.

II. TWO-TIER VANET/P2P INFORMATION RETRIEVAL SYSTEM

In the two-tier information retrieval system, vehicles are assumed to be equipped with two wireless communication interfaces: one for direct ad hoc communication and the other for infrastructure-based communication. Vehicles are first organized into groups in VANETs. Some vehicles in the groups are selected to form a high-tier P2P overlay through infrastructure-based communication. The information is shared among vehicles moving on roads, and may be requested by other vehicles. The required information can be retrieved through lookups performed in the low-tier and

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high-tier networks. Fig. 1 shows an example of the proposed two-tier VANET/P2P system.

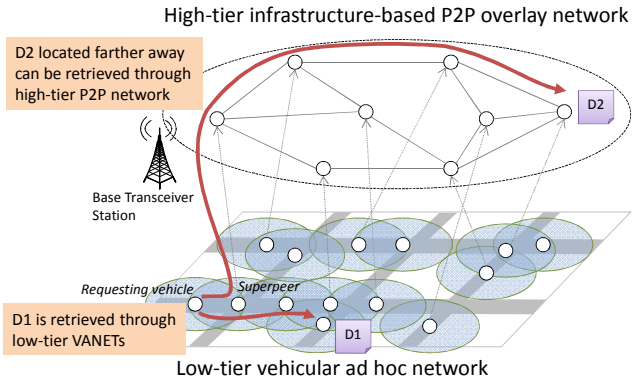

Figure 1. Example of a two-tier VANET/P2P information retrieval system.

A. *Superpeer Selection in Low-Tier VANETs*

All vehicles participant in low-tier VANETs and communicate with each other through IVC. Only a portion of vehicles are selected to form a high-tier P2P overlay. These vehicles, called superpeers, serve as a bridge between the low-tier and high-tier networks. The superpeers also handle message exchanges and lookups in the high-tier P2P overlay.

Several distributed clustering mechanisms, such as lowest-identifier (ID) algorithm, used to form group structures in mobile and vehicular ad hoc networks can also be applied to the superpeer selection in the two-tier system. The current system simply adopts an ID-based mechanism. Each vehicle is assigned with a unique node ID. Vehicles periodically broadcast messages through IVC to exchange their information (e.g., node ID and current location) with neighboring vehicles. After these exchanges, the vehicle with the lowest ID is elected as a superpeer in a cluster.

B. *High-Tier P2P Overlay Organization*

The vehicles elected as superpeers utilize their infrastructure-based communication interfaces to form high-tier P2P overlay where the superpeers cooperatively provide information retrieval services to other vehicles. Due to high vehicle mobility, the superpeers and P2P overlay topology continuously change in such highly dynamic environments. Therefore, an unstructured P2P networking model which has been shown to be more resilient to overlay dynamics would be appropriate for the two-tier system. We apply Gnutella, a widely used unstructured P2P networking model, to the high-tier P2P overlay in the two-tier VANET/P2P system.

C. *Information Sharing and Retrieval*

In VANETs, vehicles cooperatively share their data with nearby vehicles and collect information available in their areas. A user in a vehicle may send an inquiry for information, such as traffic conditions and available services for a specific location. A retrieval of information from the two-tier VANET/P2P system requires performing lookup queries in both the low-tier VANETs and high-tier P2P overlay. In VANETs, an information lookup is performed among vehicles in a hop-by-hop manner until a vehicle storing the requested information is located. To alleviate the broadcast storm problem, a time-to-live (TTL) mechanism and geographic forwarding scheme are used to forward the lookup geographically closer to the destination at each hop.

By contrast, only superpeers are responsible for performing lookups in the high-tier P2P overlay. A superpeer may originate a lookup request for information itself or receive a request originated by other vehicles within the same cluster. In a Gnutella-based P2P overlay, TTL-limited flooding is typically used. If the requested information is not stored locally on a node that receives the lookup, the node forwards the lookup to its P2P neighbors until a node storing the requested information is located or the TTL value of the lookup becomes zero. To improve lookup performance, the P2P system also applies a geographic routing mechanism to the lookups in the Gnutella-based P2P overlay.

A performance evaluation of the two-tier VANET/P2P system and other single-tier systems through the SUMO traffic simulator and QualNet network simulator has been presented in [4]. Results show that the proposed two-tier system achieves a higher lookup success rate than single-tier VANET-based systems and outperforms single-tier infrastructure-based P2P systems in terms of lookup latency and overhead.

III. Conclusion and Future Work

This paper presents a two-tier VANET/P2P system to support information retrieval for vehicular environments in an effective and efficient manner. The proposed system has been shown to improve the performance of information retrieval in terms of success rate, latency, and overhead compared to existing solutions. Our ongoing work is to develop an adaptive lookup protocol to route lookup requests between the low-tier and high-tier networks according to vehicle mobility and network conditions. Other improvements such as network-aware superpeer selection and dynamic multi-tier hierarchy are parts of our future work.

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