Design and Evaluation of a Two-Tier Peer-to-Peer Traffic Information System

Shiao-Li Tsao and Chien-Ming Cheng, National Chiao Tung University

ABSTRACT

Decentralized traffic information systems realize real-time traffic information services without the need for a server infrastructure. However, existing systems rely on either the vehicular ad hoc network or application-layer peer-to-peer protocols over a broadband wireless network suffering from low lookup success rate, high lookup latency, and maintenance overhead of the P2P network. This article proposes a two-tier VANET/P2P architecture that exploits both VANET and P2P technology. In the low tier, vehicles form a VANET via intervehicle communication to exchange traffic information. On top of the VANET, a portion of the vehicles further establish a P2P overlay through a broadband wireless infrastructure to mitigate the disconnectivity problems of the VANET. Simulation results demonstrate that the two-tier architecture can significantly improve the lookup success rate compared to the single-tier VANET systems while reducing lookup latency and maintenance overhead compared to the single-tier P2P systems.

INTRODUCTION

Intelligent transportation systems (ITSs) have attracted considerable interest in recent years. A real-time traffic information service is one of the most promising ITS applications. Conventional approaches suggest a traffic management center to collect road condition data from roadside traffic sensors, allowing drivers to determine current traffic conditions. Unfortunately, the installation and maintenance of a central server and roadside equipment may be prohibitively expensive. With the aid of Global Positioning System (GPS) and wireless technology, vehicles on roads can act as sensors and exchange information about the traffic conditions they experience through wireless communications. Such a decentralized approach can be quickly deployed and offers a low-cost traffic information service without the need for a server infrastructure.

In early decentralized systems, vehicles utilize intervehicle communication (IVC) [1] to disseminate and query traffic information in a hop-by-hop manner. However, the IVC network may become disconnected under low vehicle densities. To overcome this problem, vehicles may form an application-layer peer-to-peer (P2P) network and share their traffic information with each other through the broadband wireless infrastructure such as third generation (3G) or WiMAX. However, the communication delay in the infrastructure network could be on the order of hundreds of milliseconds, and it may introduce significant service latency when the traffic information lookup has to traverse several hops in a P2P overlay.

As vehicles are envisioned to carry multiple types of wireless interfaces, they can communicate with each other via not only short-range ad hoc communication such as IEEE 802.11p but also long-range infrastructure communication such as 3G or WiMAX [2]. This article proposes a two-tier vehicular ad hoc network (VANET)/P2P architecture that integrates an ad hoc network and an infrastructure-based P2P system to offer a decentralized traffic information service. In the proposed system, vehicles first exchange observed traffic information through IVC in the low-tier VANET. A portion of the vehicles having infrastructure connectivity are elected as superpeers. On top of the VANET, the superpeers further form a P2P overlay through the broadband wireless infrastructure. This high-tier P2P overlay can mitigate the disconnectivity problem of the VANET and improve the success rate of traffic information lookups.

In this article, we first classify decentralized traffic information systems into four architectural categories and present their designs, and propose the two-tier architecture. We then compare different architectures and evaluate their performance through simulation. Finally, we conclude this article.

DECENTRALIZED TRAFFIC INFORMATION SYSTEM

A number of decentralized traffic information systems have been proposed to reduce the maintenance costs of the centralized server approach. These systems have relied on traffic condition data collected and shared by vehicles themselves. A vehicle is assumed to be able to obtain its geographical position and moving speed via GPS or other means, having a digital map with road network information. Roads are divided into segments, and each segment is associated with a segment identifier (ID) and geographical position. The traffic conditions of each road segment

0163-6804/11/$25.00 © 2011 IEEE

In VANETs, vehicles communicate with each other through IVC, and periodically broadcast their current speeds and positions to neighboring vehicles. A part of the traffic information that a vehicle receives may also be propagated to its neighbors through broadcast messages.

are described in a traffic report that contains the road segment ID, traffic information, and a timestamp. Each vehicle generates its own traffic reports based on its observations and traffic messages obtained from other vehicles. The methods of deriving the statistical traffic information are beyond the scope of this article. Interested readers can refer to [3] for more information.

According to the use of wireless technologies and system designs, we categorize decentralized traffic information systems into four different architectures: single-tier VANET, single-tier P2P over VANET, single-tier infrastructure-based P2P, and two-tier VANET/P2P. This section presents the first three single-tier architectures, and the next section proposes the two-tier architecture.

SINGLE-TIER VANET

In VANETs, vehicles communicate with each other through IVC, and periodically broadcast their current speeds and positions to neighboring vehicles. A part of the traffic information a vehicle receives may also be propagated to its neighbors through broadcast messages. Based on the received messages, a vehicle can generate traffic reports. Figure 1a shows the single-tier VANET architecture.

A number of systems have been developed based on this architecture. In the Self-Organizing Traffic Information System (SOTIS) [4], vehicles continuously broadcast their driving status with parts of the information of other road segments that are heard from neighboring vehicles. Each vehicle gathers only traffic information of the local road segments (e.g., a radius of 50–100 km). StreetSmart focuses on discovering and disseminating congestion information [5]. Vehicles use data clustering algorithms to aggregate the collected data and exchange only the most significant information such as areas of unexpected speed. However, the traffic information may be outdated or incomplete, especially for road segments far away from the vehicle.

In VANETs, traffic information can be quickly disseminated among vehicles through IVC. However, the dissemination requires a sufficient number of vehicles in the network. When the vehicle density is insufficient, vehicles may not be able to form a fully connected VANET. In that case, traffic information cannot be distributed to all vehicles or successfully found. To improve the connectivity, additional roadside units connected via a backbone network could be used to exchange traffic information with vehicles via wireless communication [6]. However, the additional roadside units introduce extra installation and maintenance costs. Another issue for the single-tier VANET system is the broadcast storm problem in a high-vehicle-density environment if each node rebroadcasts every received message. A number of solutions have been presented to alleviate the problem [7]. For example, a vehicle rebroadcasts the query message only if it is closer to the location of the requested road segment than the previous node.

SINGLE-TIER P2P OVER VANET

The above architecture can be further extended to a P2P over VANET architecture. Vehicles form an application-layer P2P overlay network on top of the VANET. The P2P overlay can be unstructured such as Gnutella, or structured such as Chord [8]. The vehicles share their resources (i.e., traffic information) and retrieve resources from others through the P2P overlay. The application-layer P2P overlay communication relies on the routing protocol of the underlying VANET [9]. A vehicle should establish a routing path in the VANET first; then an application-layer message can be transmitted along the route to another vehicle.

The key difference between the P2P over VANET architecture and the previous architecture is the traffic information lookup. In the previous approach, a vehicle floods a query message to all neighboring vehicles within the IVC range. In this architecture, a vehicle explicitly forwards the query by exploiting the application-layer P2P lookup mechanism and the VANET routing. In an unstructured P2P overlay such as a Gnutella-based system, the lookup is based on time-to-live (TTL)-limited flooding in the overlay. If a vehicle does not have a report, it forwards the query to its Gnutella neighbors, not VANET neighbors, through the VANET routing paths. In a structured P2P overlay such as a Chord-based system, a vehicle examines its finger table to select the node whose identifier is closest to the key of the report. The vehicle directly forwards the query message to the node through the established VANET routing path. The lookup procedure continues until the query reaches the successor of the key. Moreover, because vehicles are usually moving, the participating vehicles and P2P overlay topology continuously change. The P2P overlays thus require performing periodic stabilization procedures. For example, in an unstructured P2P overlay such as Gnutella, vehicles must periodically send *PING* messages to their P2P neighbors. A *PONG* message is sent in reply if a P2P neighbor remains in the overlay. When a vehicle detects the departure of a neighbor, it randomly connects to another vehicle as its new P2P neighbor.

Recent studies of P2P file sharing systems in mobile and vehicular ad hoc networks have adopted the architecture. The P2P overlay enables users to locate the resources they need in such an environment. Although the architecture can also be applied to the traffic information system, maintaining the services is difficult due to dynamics of traffic information and high vehicular mobility. To improve performance of the application-layer P2P protocol, cross-layer approaches that extract useful information from the lower-layer protocol messages for supporting the construction and maintenance of the upper-layer P2P network were proposed [10].

The application-layer P2P overlay is utilized for vehicles to locate traffic information efficiently. Although the architecture may minimize redundant rebroadcasts of query messages, additional efforts are required for maintaining the P2P overlay. The transmission of lookup and maintenance messages through the P2P overlay requires the use of underlying VANET routing protocols and must introduce routing overhead in the bandwidth-limited VANET. Additionally, due to the P2P overlay being built on top of the VANET, the architecture also suffers from the same disconnectivity problem under low vehicle densities as the previous single-tier VANET system.

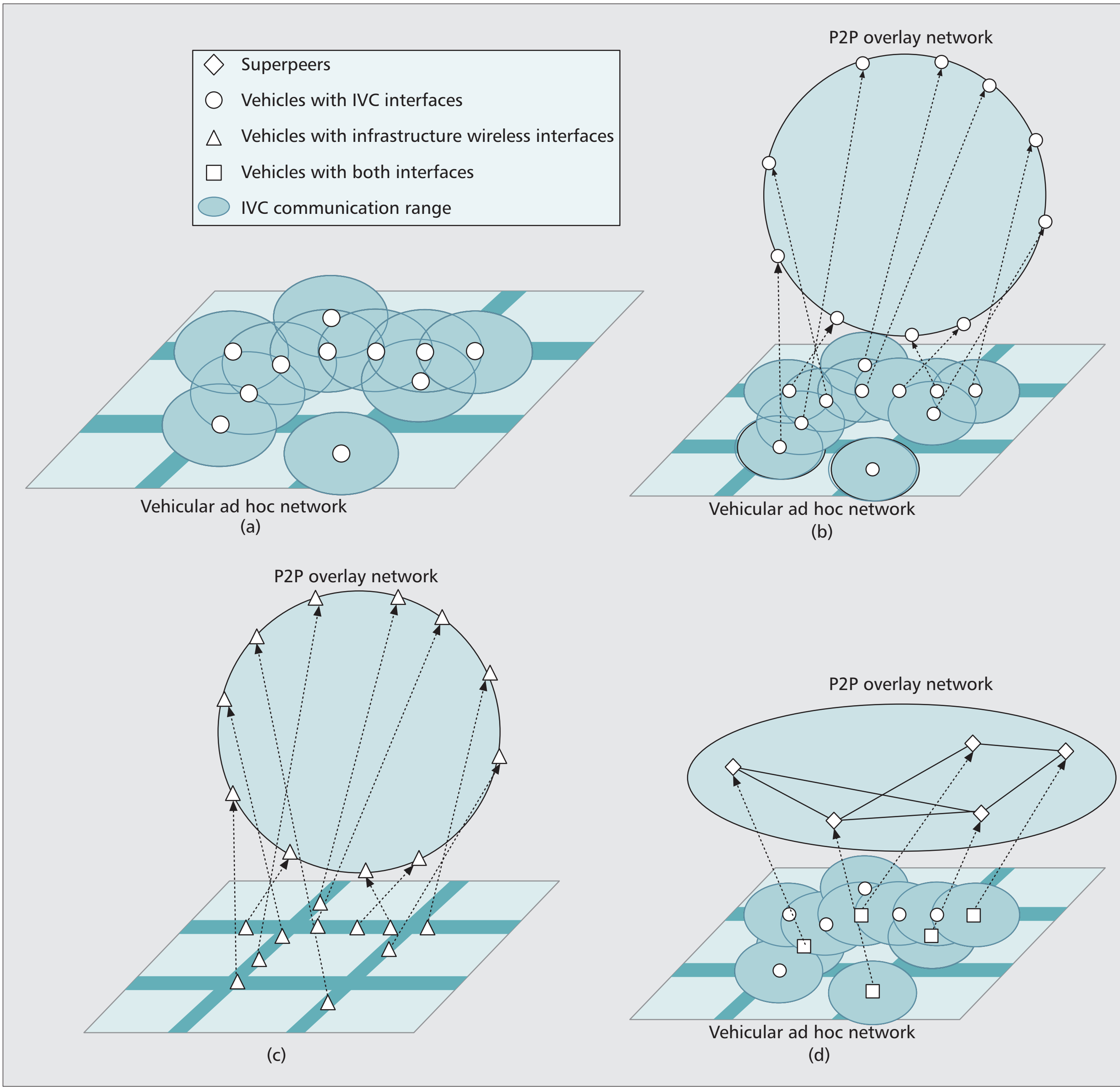

Figure 1. *Four architectural categories of decentralized traffic information systems.*

Single-Tier Infrastructure-Based P2P

Another single-tier architecture involves forming a P2P overlay through an infrastructure network. Vehicles are required to have a broadband wireless interface to access the infrastructure network. Vehicles communicate with each other through infrastructure communication instead of ad-hoc communication. The P2P overlay could be unstructured or structured. Figure 1c shows an example of the architecture based on a structured P2P [11]. In this system, vehicles form a structured P2P overlay and query traffic information through cellular communication, thereby avoiding the disconnectivity problem of VANETs. However, a previous study [12] indicated that structured P2P systems suffer from frequent node join/leave (i.e., churn), and they are less efficient than unstructured P2P systems in dynamic network environments such as mobile and vehicular networks. Although the approach utilizes an infrastructure communication system to avoid network disconnectivity, it does not utilize IVC, which is an efficient and low-latency solution for short-distance information exchanges. Therefore, this article proposes a two-tier traffic information system that combines a low-tier VANET and a high-tier P2P overlay.

A Two-Tier Traffic Information System

We propose a two-tier architecture for traffic information systems, shown in Fig. 1d. Vehicles are first organized into groups in VANETs. Sim-

The vehicles elected as superpeers utilize their infrastructure wireless interfaces to form a high-tier P2P overlay that could be unstructured or structured. The unstructured P2P approach that is resilient to overlay dynamics would be appropriate for the system.

ilar to the single-tier VANET architecture, traffic information is broadcasted and exchanged among vehicles through IVC. Some vehicles in the groups are selected to form a high-tier P2P overlay through infrastructure wireless communication. These vehicles are called superpeers and serve as a bridge between the high-tier and low-tier networks to handle message exchanges and lookups.

Superpeer Selection and Maintenance

Several distributed clustering algorithms, such as the Lowest-ID and Highest-Degree algorithms, have been proposed for mobile ad hoc networks (MANETs) and VANETs and can be applied to superpeer election in the proposed system. In these algorithms, nodes periodically broadcast information such as the node identifier or connectivity degree to neighboring nodes. After receiving the ID or connectivity information, a node can determine whether it is a clusterhead with the lowest ID or the highest connectivity in a cluster. In the proposed system, the clusterhead is called a superpeer, and other nodes in the cluster are called normal peers. The superpeers from different clusters further form a P2P overlay using infrastructure wireless communication. Note that the superpeers participate in both the VANET and P2P overlay, while normal peers only perform low-tier VANET operations. Due to high vehicular mobility, the topology of VANETs changes rapidly. Therefore, the superpeer election must be performed periodically to accommodate this dynamic topology. To reduce the overhead of information exchange in determining the superpeers, combining clustering messages with traffic information dissemination is preferable.

The proposed system uses the ID-based clustering algorithm because the algorithm is simple and could maintain stable clusters in VANETs. Each vehicle has a cluster ID that may differ from the ID used in a structured P2P overlay. The vehicle with the lowest ID in a cluster becomes the superpeer. However, the ID-based algorithm only forms single-hop clusters. To support multi-hop clusters, the proposed system combines Max-Min d-cluster formation [13] with the ID-based clustering selection. Therefore, vehicles can access any superpeers in d hops.

All normal peers rely on superpeers to access the high-tier P2P overlay; therefore, additional computation and communication costs are imposed on the superpeers. An issue of fairness arises as a vehicle serving as the superpeer all the time may be undesirable. To deal with this issue, one simple approach is to use a different cluster ID when a vehicle rejoins the system. For example, a vehicle can generate a different ID by hashing its original ID with a random number upon joining. The vehicle with the lowest ID will not be elected as the superpeer again because it may have a different ID. To achieve improved fairness, the ID generation can account for the time periods of being a superpeer. The longer the period, the higher the ID is generated next time. Moreover, an incentive mechanism can be incorporated into the traffic information sharing service so that users would be willing to take the role of superpeers.

High-Tier P2P Overlay Network

The vehicles elected as superpeers utilize their infrastructure wireless interfaces to form a high-tier P2P overlay that could be unstructured or structured. As mentioned above, the unstructured P2P approach that is resilient to overlay dynamics would be appropriate for the system.

In an unstructured P2P overlay such as a Gnutella-based system, because the geographical positions of road segments are well defined on a digital map and all vehicles are aware of their own locations, geographic routing (i.e., position-based routing) can be applied to the lookup mechanism. The geographic routing mechanism routes a query to the neighbors geographically close to the road segment in the query. This approach considerably reduces the number of lookup messages in the P2P overlay compared with the conventional flooding approach.

Traffic Information Lookup

Traffic information can be queried via IVC in the low-tier VANET. However, due to the limited connectivity of VANET, the lookup through IVC may be inefficient and prone to failure, especially when looking for traffic information on a distant geographical region. Therefore, the proposed system simultaneously performs the lookup in the VANET and P2P overlay. Normal peers broadcast query messages to superpeers via IVC. When a superpeer receives or originates a query, it sends the query to other vehicles in the P2P overlay via an infrastructure wireless interface. Depending on the adopted P2P approach, the P2P lookup could be flooding or structural. Upon receiving the query from other superpeers, a superpeer will reply if it has the requested traffic report. The superpeer that receives the replied report further broadcasts the report via IVC if a normal peer originates the query. Figure 2 provides an example of the proposed two-tier system based on a VANET and unstructured P2P overlay.

Comparisons and Issues

Table 1 summarizes the qualitative comparisons of the four architectures for realizing a decentralized traffic information system.

Connectivity of Network and Services

Vehicles participating in the single-tier systems are required to have either IVC interfaces for VANET and P2P over VANET systems, or broadband wireless network interfaces for infrastructure-based P2P systems. A vehicle cannot access the traffic information service if it does not support the required communication system. By contrast, the proposed two-tier system does not impose such a constraint on vehicles. A vehicle with only IVC capability performs the exchange and lookup of traffic information in the low-tier VANET as though it participates in VANET-based systems. Additionally, the vehicle can access the traffic information through superpeers and the high-tier P2P overlay. A vehicle with only infrastructure connectivity joins the P2P overlay where it can retrieve traffic information from other superpeers, which may connect to other vehicles using IVC. The proposed two-tier archi-

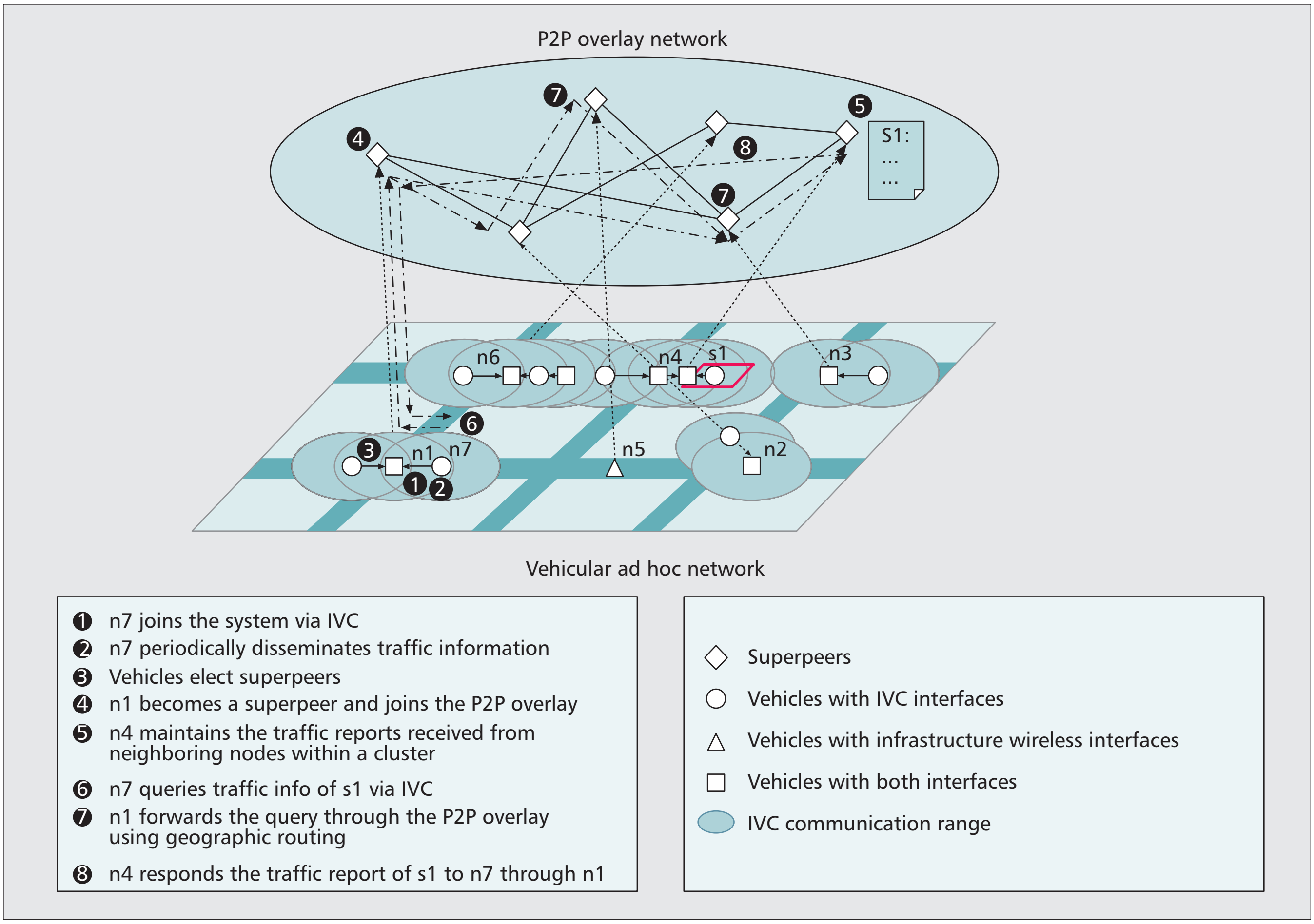

Figure 2. *An example of a two-tier traffic information system based on a VANET and unstructured P2P overlay.*

tecture is more flexible, so it can accommodate vehicles with different wireless technologies.

TRAFFIC INFORMATION DISSEMINATION

In both single-tier VANET-based and two-tier systems, vehicles periodically disseminate their observed traffic conditions via IVC. As a result, a vehicle can aggregate received traffic information to generate a traffic report, which is more accurate than that based on a single observation. Due to traffic information being disseminated and propagated in a single-hop or multihop broadcast fashion, a vehicle can have an overview of traffic conditions of an area, although the information may not be up to date. Due to the limited bandwidth of a VANET, the single-hop broadcast is preferred to avoid overhead of multi-hop broadcasts and broadcast storms.

By contrast, no such dissemination exists in the single-tier infrastructure-based P2P systems. Each vehicle knows only the traffic conditions of road segments it has visited and the traffic information of responsible road segments that the vehicle handles when using structured P2P approaches. A vehicle must perform a lookup to obtain the required traffic information.

TRAFFIC INFORMATION LOOKUP

In the single-tier VANET system, the lookup can achieve a low latency, for example, a few milliseconds, through direct communication between vehicles; but may fail due to network partitioning under low vehicle densities. As the density increases, an increase occurs not only in the connectivity, but also in communication interferences and collisions. Therefore, both the success rate and lookup latency increase when more vehicles participate in the system. An efficient lookup based on multi-hop communication remains a challenge for VANETs.

The single-tier P2P over VANET approach integrates the P2P lookup mechanism and VANET routing protocols to perform lookups in VANETs. With a P2P overlay built on top of the VANET, the approach inherits the network disconnectivity problem and bandwidth limitations of VANETs. Moreover, the application-layer P2P overlay relies on VANET routing to transmit lookup and maintenance messages over VANET. When the number of vehicles increases, routing, lookup, and maintenance messages are considerably increased in the VANET. This architecture suffers a scalability problem.

When an application-layer P2P overlay is built through an infrastructure network, the lookup performance depends mainly on the adopted P2P approach, regardless of the vehicle density. However, the infrastructure wireless communication has a higher transmission delay than IVC. Therefore, lookups in the single-tier infrastructure-based P2P systems achieve a high success rate but long latencies. In the proposed

Characteristics	System architecture			
	a. Single-tier VANET [4, 5]	b. Single-tier P2P over VANET [10]	c. Single-tier infra-structure-based P2P [11]	d. Two-tier VANET/P2P
Connectivity of network and services	Ad hoc vehicle-to-vehicle	Ad hoc vehicle-to-vehicle	Infrastructure	Either or both
Traffic information dissemination	Periodic broadcast via IVC	Periodic broadcast via IVC	None	Periodic broadcast via IVC
Traffic information lookup	Multihop broadcast in VANETs; lowest latency if success; success rate and latency increase with vehicle density	P2P lookup in VANET-based P2P overlay; performance worse than single-tier VANET	P2P lookup in infra-structure-based P2P overlay; high success rate and latency; performance depends on P2P approach	Multihop broadcast in VANETs with superpeer lookup in infrastructure-based P2P overlay; good balance between success rate and latency
P2P overlay construction	None	Overlay built on top of VANET	Overlay in infrastructure network	Superpeer-based overlay in infrastructure network
P2P system overhead	None	Overhead to maintain P2P overlay; VANET routing overhead for P2P related messages	Overhead to maintain P2P overlay	Superpeer selection; Less overhead to maintain superpeer-based P2P overlay

Table 1. *Comparison of architectures for decentralized traffic information systems.*

two-tier system, short-distance lookups can be performed quickly through the low-tier VANET, and the long-distance query can take advantage of the high-tier P2P overlay to mitigate the network disconnectivity problem. The radio resource of the wireless infrastructure is also limited; therefore, adaptive schemes that perform lookups between the two networks (according to road networks, vehicular mobility, and network conditions) to minimize the lookup overhead over the high-tier P2P overlay need to be further studied.

Peer-to-Peer Overlay Construction

Peer-to-peer traffic information systems differ from P2P file sharing systems in many aspects, including highly dynamic participants, high data update and query rates, and highly correlated data. These characteristics should be considered when designing P2P traffic information systems. In an unstructured P2P network such as a Gnutella-based system, the unstructured P2P overlay could accommodate the frequent changes of network topology. Vehicles collect traffic reports locally without publishing reports to other vehicles. In contrast, more efforts are needed in a structured P2P network, such as a Chord-based system, to maintain the overlay structure and publish reports to the responsible vehicles.

The traffic conditions along a route to the destination are usually queried simultaneously. By adopting the geographic routing scheme that forwards lookups through an unstructured P2P overlay, the lookup forwarding path approximately follows the route toward the destination. Therefore, fewer lookups are required to obtain the required traffic information. In contrast, an individual lookup must be performed for each road segment in the structured P2P system. Another structured P2P approach, Content Addressable Network (CAN) [8], uses a 2D coordinate space. The lookup routing path in the CAN space would come as close to the route in the road network as the geographic lookup routing in an unstructured P2P overlay. However, the CAN approach still requires considerable overlay maintenance overhead. The above characteristics cause the unstructured P2P approach to be more applicable than the structured approach for the decentralized traffic information systems.

The two-tier system organizes superpeers in a P2P overlay as a hierarchical structure. As a result, the overall maintenance and lookup overheads are reduced because they grow as a function of the number of participants. The hierarchical design improves the scalability and performance of the P2P systems. To reduce the load on superpeers and improve the performance of superpeer overlay, further improvements, such as a multilevel hierarchy and superpeer redundancy, are left for future work.

Performance Evaluation

We used the microscopic road traffic generator Simulation of Urban Mobility (SUMO) [14] to generate vehicular mobility traces that were then fed into the QualNet network simulator [15]. The road topology was a 5000 m × 5000 m grid road network, in which each road segment was 500 m with two lanes in each direction. The maximum vehicle speed was set to 13.9 m/s. The vehicle density varied from 1.8 to 10.9 vehicles/km. To maintain these densities, a new vehicle joined the network whenever an existing vehicle left. The vehicular network used IEEE

802.11a with lognormal shadowing, two-ray path loss, and Rayleigh fading. The radio range was 250 m. Each vehicle was equipped with both IVC and infrastructure wireless communication interfaces. We simulated each scenario for 200 s and 10 runs.

Gnutella and Chord were used as the representative unstructured and structured P2P approaches, respectively. In the Gnutella network, each node maintained 15 neighbors, and the geographic routing mechanism was applied to search traffic reports with a TTL of 7. The identifier space was set to 2^{15} in the Chord network. Both P2P networks performed stabilization every 10 s. The cluster size was set to one. The TTL value for searching in the VANET was infinite so that all connected vehicles in the VANET could receive the traffic reports and queries. These settings help us to understand the net improvement by introducing a P2P overlay.

In all scenarios, the P2P over VANET approach performs more poorly than the single-tier VANET approach with a success rate below 20 percent and lookup latency over 100 ms. Results of the P2P over VANET architecture are excluded from the comparisons in the figures below. Therefore, we consider five different design strategies among the other three architectures: the single-tier VANET approach (1T-VANET); the single-tier infrastructure-based P2P approach using Chord (1T-struct); the single-tier infrastructure-based P2P approach using Gnutella (1T-unstruct); the two-tier approach using Chord (2T-struct); and the two-tier approach using Gnutella (2T-unstruct).

Figure 3 shows the lookup success rate under different vehicle densities. This figure shows that the VANET system has the lowest lookup success rate, especially in low-density scenarios. This is because some lookups cannot reach the vehicles with the requested traffic reports in the disconnected VANET. This problem can be alleviated by increasing the density or introducing an infrastructure-based P2P overlay. Both single-tier structured and unstructured P2P approaches significantly improve the lookup success rate because vehicles can communicate with any other vehicles through infrastructure communication. For these approaches, incorrect neighbor or finger information on P2P nodes is mainly caused by churn, resulting in lookup failures. The unstructured P2P approach adapts to churn much more effectively than the structured P2P approach in a dynamic network, as the single-tier unstructured P2P system achieves nearly a 100 percent lookup success rate.

The two-tier structured P2P system outperforms the VANET system because it also conducts lookups over the P2P overlay and can mitigate the disconnectivity problem of the VANET. The two-tier structured P2P system has a success rate slightly lower than the single-tier system because the periodic superpeer selection may cause peer join/leave, and the structured P2P approach is vulnerable to churn. In contrast, the two-tier unstructured P2P system is resilient to churn and achieves nearly a 100 percent lookup success rate, further accelerating the lookup and reducing maintenance costs compared to a single-tier P2P system.

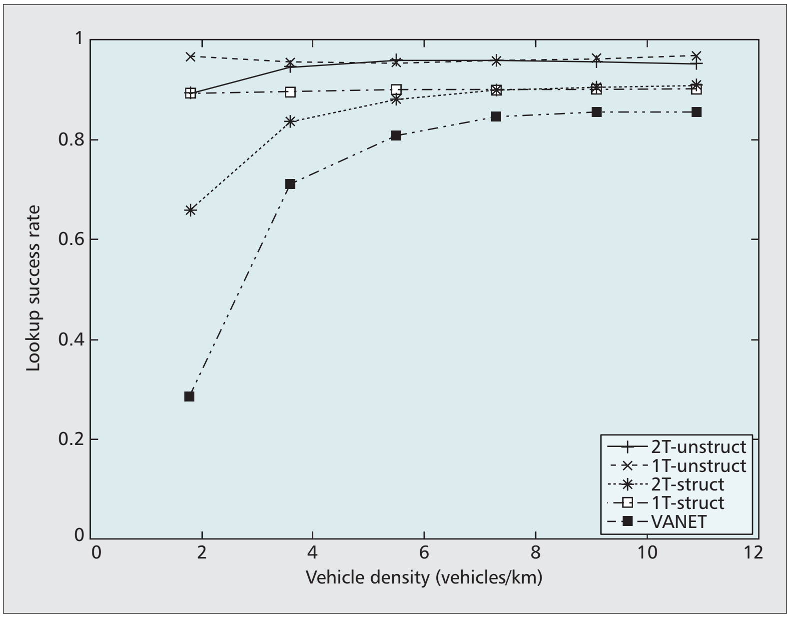

Figure 3. *Lookup success rate for different approaches.*

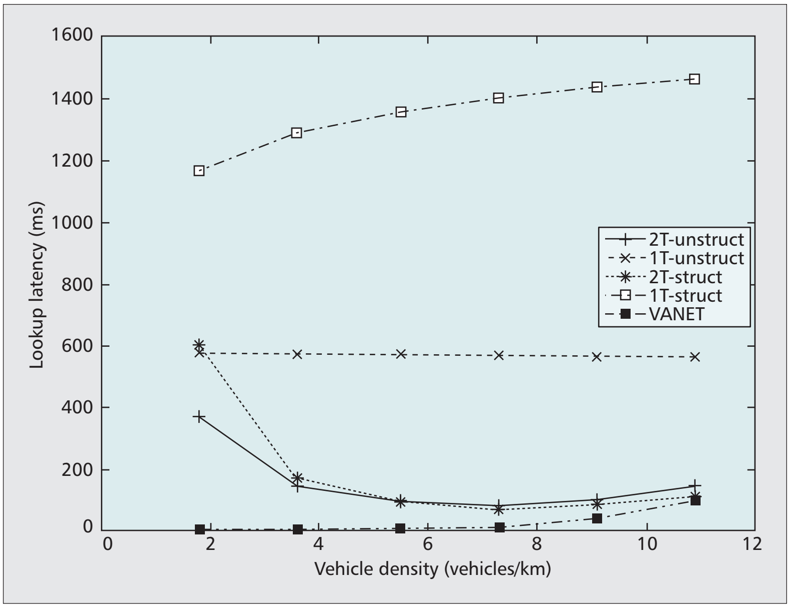

Figure 4. *Lookup latency for different approaches.*

Figure 4 shows the average latencies of successful lookups. The VANET system achieves the shortest lookup latencies because of low-latency IVC. The lookup latency and success rate both increase with the density because more vehicles are in a connected VANET, and a query must be propagated for more hops. The single-tier structured P2P system has the longest latency because the lookup hop count is proportional to the logarithm of the Chord network size. A successful lookup requires approximately six to eight hops as one-hop latency in infrastructure networks could be 200 ms long. Compared to the single-tier structured P2P system, the single-tier unstructured P2P

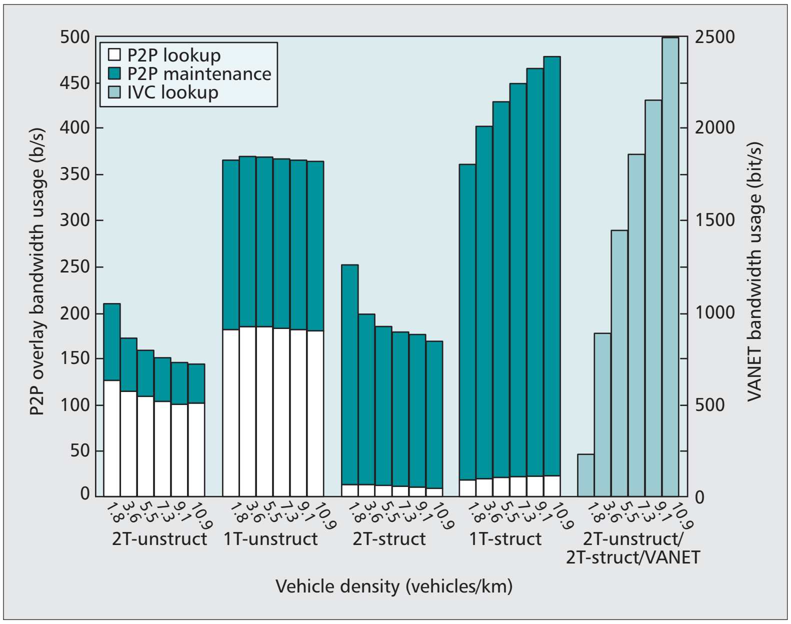

Figure 5. *Lookup and maintenance bandwidth usages for different approaches.*

system improves lookup latency by 50–60 percent, because the geographic lookup can reach every vehicle within three hops. By combining a VANET and infrastructure-based P2P overlay, lookups can be simultaneously distributed over the VANET and P2P overlay to improve the latency further. The two-tier systems outperform the single-tier P2P systems because low latencies can be achieved through lookups in VANETs. Moreover, the unstructured P2P approaches are more suitable for single-tier and two-tier traffic information systems because they achieve higher lookup success rates and introduce less lookup latencies than the structured P2P approaches.

Figure 5 shows the average bandwidth usage of VANET (that is, IVC) and P2P overlay (that is, infrastructure network) per vehicle. The right side of Figure 5 shows the bandwidth usage of IVC lookups. The bandwidth usage of VANET for single-tier VANET and two-tier VANET/P2P architectures significantly increases with the vehicle density. The single-tier P2P and two-tier systems occupy a certain infrastructure network bandwidth in performing the lookup and maintenance of the P2P overlay. The two-tier systems reduce bandwidth usage by 40-60 percent compared with the single-tier P2P systems because only some vehicles perform the P2P operations. Although the unstructured P2P approach requires more bandwidth for P2P lookups, it still outperforms the structured P2P approach because of less P2P maintenance overhead.

Conclusions

In this article, we investigate existing single-tier architectures and further propose a two-tier VANET/P2P system for providing decentralized traffic information services. We analyze design issues of different approaches and compare their performance through the SUMO traffic simulator and QualNet network simulator. Simulation results reveal that the two-tier architecture achieves much higher lookup success rates than VANET-based systems and outperforms single-tier infrastructure-based P2P systems in terms of success rate, latency, and maintenance cost. Open research issues for the new two-tier architecture such as adaptive lookup and routing in between VANET/P2P networks, superpeer selection and redundancy, and others are also identified in this article and should be further studied.

References

[1] M. L. Sichitiu and M. Kihl, "Inter-Vehicle Communication Systems: A Survey," *IEEE Commun. Surveys & Tutorials*, vol. 10, no. 2, 2008, pp. 88–105.
[2] P. Papadimitratos *et al.*, "Vehicular Communication Systems: Enabling Technologies, Applications, and Future Outlook on Intelligent Transportation," *IEEE Commun. Mag.*, Nov. 2009, pp. 84–95.
[3] P. Krishnamurthy, "Information Dissemination and Information Assurance in Vehicular Networks: A Survey," *Proc. iConference*, Feb. 2008.
[4] L. Wischhof, A. Ebner, and H. Rohling, "Information Dissemination in Self-Organizing Intervehicle Networks," *IEEE Trans. Intell. Transportation Sys.*, vol. 6, no. 1, Mar. 2005, pp. 90–101.
[5] S. Dornbush and A. Joshi, "StreetSmart Traffic: Discovering and Disseminating Automobile Congestion Using VANETs," *Proc. VTC '07-Spring*, Apr. 2007.
[6] C. Lochert *et al.*, "The Feasibility of Information Dissemination in Vehicular Ad Hoc Networks," *Proc. WONS*, Jan. 2007, pp. 92–99.
[7] B. Williams and T. Camp, "Comparison of Broadcasting Techniques for Mobile Ad Hoc Networks," *Proc. MobiHoc*, June 2002.
[8] E. K. Lua *et al.*, "A Survey and Comparison of Peer-to-Peer Overlay Network Schemes," *IEEE Commun. Surveys & Tutorials*, vol. 7, no. 2, 2005, pp. 72–93.
[9] F. Li and Y. Wang, "Routing in Vehicular Ad Hoc Networks: A Survey," *IEEE Vehic. Tech. Mag.*, vol. 2, no. 2, June 2007, pp. 12–22.
[10] C.-L. Liu, C.-Y. Wang, and H.-Y. Wei, "Cross-Layer Mobile Chord P2P Protocol Design for VANET," *Int'l. J. Ad Hoc and Ubiquitous Comp.*, 2009.
[11] J. Rybicki *et al.*, "Challenge: Peers on Wheels-A Road to New Traffic Information Systems," *Proc. ACM Mobicom*, 2007, pp. 215–21.
[12] Y. Chawathe *et al.*, "Making Gnutella-like P2P Systems Scalable," *Proc. ACM SIGCOMM*, Aug. 2003, pp. 407–18.
[13] A. D. Amis *et al.*, "Max-Min D-Cluster Formation in Wireless Ad Hoc Networks," *Proc. INFOCOM*, 2000, pp. 32–41.
[14] SUMO, http://sumo.sourceforge.net.
[15] QualNet, http://www.scalable-networks.com/products/qualnet.

Biographies

SHIAO-LI TSAO [M] (sltsao@cs.nctu.edu.tw) earned his Ph.D. degree in engineering science from National Cheng Kung University in 1999. His research interests include mobile communication and wireless networks, and embedded software and systems. From 1999 to 2003 he was with the Computers and Communications Research Laboratories of the Industrial Technology Research Institute as a researcher. He is currently an associate professor in the Department of Computer Science at National Chiao Tung University. He was a visiting professor at the University of Waterloo, Canada, in the summer of 2007, and ETH Zurich, Switzerland, in the summer of 2010. He has published more than 75 international journal and conference papers, and holds or has applied for 18 U.S. patents. He received the Young Engineer Award from the Chinese Institute of Electrical Engineering in 2007, the Outstanding Teaching Award of National Chiao Tung University, and the K. T. Li Outstanding Young Scholar Award from the ACM Taipei/Taiwan chapter in 2008.

CHIEN-MING CHENG (zjm@cs.nctu.edu.tw) is currently a Ph.D. candidate in the Department of Computer Science at National Chiao Tung University (NCTU), Taiwan. He received his B.S. degree from NCTU and his M.S. degree from National Tsing Hua University, Taiwan, both in computer science. His current research interests focus on mobile peer-to-peer protocols and services.