Access Gateway Discovery and Selection in Hybrid Multihop Relay Vehicular Network

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Abstract—**Vehicular ad hoc network protocol with hybrid relay architecture is proposed for improving the success ratio. Access gateway estimation and a probability table based on the routing information are developed and applied in the backhaul-connected infrastructure network in order to estimate the access gateway region where the destination node locates and reduce the transmission flooding in wireless and wired network. The proposed Access Gateway Discovery mechanisms and Access Gateway Selection scheme have been shown effective by the significant improvement of success ratio in NS-2 simulation based on realistic vehicular mobility models.**

I. INTRODUCTION

Hybrid automotive networking architecture is a scheme combining the communication of roadside access gateways and vehicles. Integrating roadside access gateway communication and vehicular ad hoc relay communications, it is allowed to posses the advantage of both. (1) The highly developed wired network provides high speed transmission and strong connectivity (strong routing ability) and (2) The flexibility of ad hoc relaying communications enables the transmission to go beyond predetermined facilities. By integrating the infrastructure connectivity and ad hoc connectivity, the infrastructure-assisted vehicular ad hoc network has the following advantages:

- Opportunistic vehicle-to-vehicle communications
- Self-organizing vehicle-to-vehicle ad hoc relay
- Flexibility in roadside access point and on-board unit deployment
- Network-level diversity with both multihop relay and infrastructure-assisted transmission

In this paper, we will describe an automotive networking architecture that delivers messages through (1) peer-to-peer vehicular ad hoc relay, and (2) access gateway infrastructure. A mobility management mechanism that discovers and records the serving access gateway of vehicular nodes is described for message deliver in this infrastructure-assisted vehicular ad hoc network. The effectiveness of message delivery is evaluated with simulation on realistic vehicular mobility trace.

II. SYSTEM ARCHITECTURE

As shown in Figure 1, Access Gateways (AGs) are deployed to provide backhaul connectivity for Vehicular Nodes (VNs). VNs could transmit packets to AG or to other neighboring VNs. The closest AG of a VN is denoted as the Serving AG of this VN. Mobility Management Server maintains a Service AG Table that records the mapping between VNs and their Serving AGs. Automotive networking communications could be classified as V2I (Vehicle-to-Infrastructure), I2V (Infrastructure-to-Vehicle), and V2V (Vehicle-to-Vehicle) communications

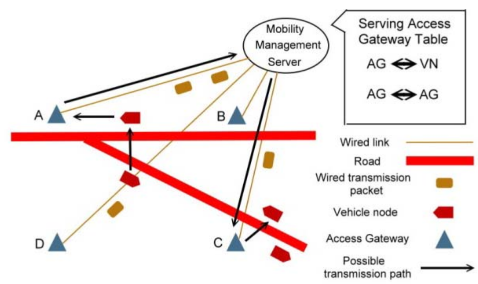

Figure 1: Hybrid Multihop Relay Vehicular Network

In V2I communications, the source VN seeks to transmit to a nearby AG. If there is an existing routing entry toward an AG, the VN sends packets to the AG through multihop relay. Otherwise, the VN will perform an AODV route discovery before transmitting packets to the AG.

In I2V communications, the source node is located in wired line network. The source node first connects to Mobility Management Server before actual data transmission. Based on the Service Access Gateway Table, the Mobility Management Server determines the serving AG and forwards packets to it. After receiving data packets, the Service AG will immediately forward packets to VN if a valid route entry exists. Otherwise, route discovery will be performed before sending packets to VN.

In V2V communications, the source VN might first seek multihop ad hoc relay route to the destination VN. If a valid route exists, the source VN will send packets toward the destination VN through the multihop relay route. If not, the packet transmission scheme is similar to the combination of V2I communications and I2V communications. The source VN will first transmit packets to its Serving AG. If a valid route to Serving AG exists, packets are sent to the Serving AG; otherwise, route discovery is initiated before packet transmission. Through Mobility Management Server, the Serving AG of the destination VN could be determined. Packets are forwarded to the Serving AG. Similarly, if a valid

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route to the destination AG exists, packets are sent to the destination; otherwise, route discovery is initiated before packet transmission.

A. Routing Protocol

Among various routing protocols for VANET, AODV (Ad-Hoc On-Demand Distance Vector Routing) [1] is one of the most effective routing protocols for vehicular multihop relay networks [2]. AODV is a reactive routing protocol. There is no routing overhead when there is no data packet to be sent. When a VN wants to send a packet, the route discovery process broadcasts a Route Request message to discover the destination node. Route Request messages are flooded up to a predetermined hop count, the maximum TTL value. If the destination receives Route Request, it replies with a Route Reply. The number of hops of the route discovery process is determined by the predetermined maximum TTL value. The tradeoff between the scope of route discovery and overhead of flooding routing messages is critical for the AODV performance. In this hybrid architecture, we apply the AODV with Internet Access for routing (AODV+) [3]. AODV+ protocol is modified to be used in hybrid wireless relay network where multihop ad hoc relay and wired backhaul connection coexist. However, in AODV+, the message through wired network can only be sent to a predetermined AGs. We create a Mobility Management Server that could handle the mobility of mobile nodes and facilitate the infrastructure-assisted routing between multiple AGs.

B. Mobility Management Aided Access Gateway Relay

In the proposed scheme, in terms of local ad hoc transmission, the operating of a VNs work just as the original AODV, a VN initiates route discovery when data packets arrive and there is no existing route to the destination. To reduce routing overhead, we would like to limit the amount of route discovery messages to be flooded. Thus the maximum request and reply hop counts is set to a smaller number than usual AODV operation. If the destination is found, the protocol operates just like the origin AODV. On the other hand, if the destination is not found as it might be out of reach, we will send packets directly to the nearest AG. We apply several mechanisms for the AG to find out which AG has the highest probability to find the destination. All AGs are connected to a backbone Mobility Management Server, which keeps a record of all the mobility information of VNs. At the Mobility Management Server, two kinds of information are recorded. One is the latest time that any VN has communicated with an AG. This is used by the Deterministic Serving AG Selection algorithm. The other is the probability of one AG that a VN will be found after it is discovered by another given AG. This is used by the Probabilistic Serving AG Selection algorithm.

C. Deterministic Serving Access Gateway Selection

Deterministic Serving Access Gateway Selection algorithm is based on the last visited AG of the destination VN to forward traffic. When an AG first receives a packet to relay, it sends a query message to the Mobility Management Server to retrieve the information which AG has most recently seen the packet's destination node. Then the AG directly sends the packet to this AG through the wired backbone network. When foreign AG receives the packet, it checks its AODV routing table. If the destination is known, the foreign AG relays the packet; otherwise, it sends a Route Request before relaying the data packet. In case no routes could be found after AODV route discovery, the AG again retrieves information from the Mobility Management Server**.** If the last reported AG is another AG instead, we know that the destination VN has moved away. Thus, we will forward the packet through the wired backbone to the new Serving AG of the destination VN.

D. Probabilistic Serving Access Gateway Selection

Probabilistic Serving Access Gateway Selection algorithm is based on not only the last visited AG of the destination VN, but also the historical mobility information to forward traffic. In fact, we integrate the Deterministic Serving AG Selection algorithm and the Probabilistic Serving AG Selection algorithm to achieve better system performance. We will only use a fresh entry, which is updated within the freshness time threshold t_{th} , in Deterministic Serving AG. If a valid table entry exists in Deterministic Serving AG Table, we will look it up and apply the AG selection. If not, we will look up in the Probabilistic Serving AG Table.

If the latest visiting record of the destination node is reported by the AG itself, we know that no other AG has recently communicated with the destination node. Under this situation we have no accurate information of the destination node, thus we apply the heuristic that there is a tendency of VNs traveling under similar paths from AGs to AGs, as vehicles usually move along a limited number of roads. We try to estimate the probability of VNs moving from one AG to another AG. Probabilistic Serving AG Selection is the method that uses this probabilistic information. For example, if the AG at this point is AG *A*, than it connects to the Mobility Management Server and checks for all $\mathrm{P(A, i)} > p_{th}, i \in all\ AGs$. *P*(*A*, *i*) is the probability that a VN travels from AG *A* to AG *i*. The probability threshold of finding a candidate AG is denoted as p_{th}.These AGs are the most likely AGs we may find the destination node, thus we replicate the packet and send it to these AGs. To avoid unnecessary route discovery flooding, if a valid route to the destination node, the packets are dropped immediately at these AGs.

E. Updating Serving Access Gateway Table

1) Deterministic Serving Access Gateway Table Update

The Deterministic Serving Access Gateway Table is used to record the last time we find the node, since it may be the most likely place to find the VN. There are two cases to update the table.

- **Direct Neighbor Discovery**: Whenever an AG discovers that a VN is its one-hop neighbor, it updates the table entry.
- **AODV Route Discovery**: Whenever an AG discovers an AODV route to a VN, it updates the table entry.

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2) *Probabilistic Serving Access Gateway Table Update*

The Probabilistic Serving Access Gateway Table is designed as a self-learning mechanism, that is, we do not have to set the table manually. At the beginning, the Probabilistic Serving Access Gateway Table initiates its value using the geographical location of AGs; the moving probability from AG *i* to AG *j* is inversely proportion to the distance between AGs.

$$\text{PTable[i][j]} = \frac{\text{distance}^{-1}(\text{i, j})}{\sum_{k=1}^{n} distance^{-1}(i,k)}$$

During the protocol operation, the system begins to learn, we record the time values when one AG discovers the VN and then another AG discovers it afterwards. We can update the probability from these statistics.

$$\text{Probability[i][j]} = \frac{\text{F(i, j)}}{\sum_{k=1}^{n} F(i,k)}$$

$$\text{F(i, j)} = \text{Number of times found from } \text{AG}_\text{i} \text{ to } \text{AG}_\text{j}$$

Since we want the table to be gradually adapts to vehicular mobility, we use an exponential moving average-based learning model to update the PTable. The system parameter α indicates the learning rate of the table. The new PTable is updated with

$$\text{PTable[i][j]} = \alpha \cdot \text{PTable[i][j]} + (1-\alpha) \cdot \text{Probability[i][j]}$$

In the example shown in Figure 1, initially PTable[A][D] is larger than PTable[A][B] and PTable[A][C] because of their distance in the given topology. As the time passes, the value of PTable[A][B] and PTable[A][C] will excess PTable[A][D] as the process learns to fit to the network condition better.

F. Access Gateway Discovery

In addition, VNs have to know which AG is nearest to it. Several methods to discover the Serving AG are described below.

- **Access Gateway Advertising**: The most efficient way is through the AG advertisement. When a VN receives the Gateway advertisement message, the VN sets the AG to be the default route, which will be used when no AODV route toward a destination exists.
- **Route Request**: When a AG receives an AODV Route Request, even if it does not know the exact route to the destination, it assumes that the source would want to know if there is a AG. Thus, it sends an AODV Route Reply with a flag telling that this is a reply from an AG.
- **Forwarding Route Reply**: Similarly, when intermediate nodes relay AODV Route Reply messages from an Access Gateway, they automatically learn that the route toward an Access Gateway through the reverse path.

There are two modes of Access Gateway Discovery: Proactive and Reactive. In Reactive Access Gateway Discovery mode, the AGs do nothing else rather than sending Route Reply messages when receiving Route Request messages. In Proactive Access Gateway Discovery mode, the AGs periodically send Gateway advertisement messages to nearby VNs. The hop count of the Gateway advertisement messages can be optimized based on deployment scenarios. When the VNs receive a Gateway advertisement, they know that there is an Access Gateway on the reverse path. The VNs send a reply telling the Serving Access Gateway to update the Deterministic Serving Access Gateway Table. After a route to a Serving Access Gateway is discovered, the route to an Access Gateway is stored as a route to destination "DEFAULT" in VNs. We only record the multihop relay route to the closest Serving AG.

III. PERFORMANCE EVALUATION SETTING

We evaluate the infrastructure-assisted VANET by running simulations in ns-2 (Network Simulator 2). IEEE 802.11 based MAC and AODV+ [4] routing protocol is used. Short messaging traffic is used in our simulation. The inter-arrival time between short messages is exponentially distributed. Short messages are delivered with UDP protocol. By setting the expected value of inter-arrival time, various traffic load conditions could be simulated. In V2V communications, the source and destination node pairs are randomly selected among VNs. In I2V communications, the source is a given infrastructure node while destination nodes are randomly selected from VNs. In V2I communications, the destination is a given infrastructure node while source nodes are randomly selected from VNs.

The simulation topology is 2400 meter by 2400 meter. The number of AGs is 4, 9, 16, and 25 in respective simulation scenarios. Each AG is linked to a backbone Mobility Management Server. They also connect to each other by wired backbone network.

We use the mobility model "Restricted Random waypoint on a City Section" based on realistic vehicular mobility model [5], it is a mobility model for cars traveling randomly along streets of cities. The city road sample is downloaded from U.S. Census Bureau's TIGER database [6]. The mean speed on each road in the map and the limit speed are determined by the real world information. Since the generated model is based on the real vehicular mobility, the simulations results give realistic evaluation of the proposed vehicular network scheme. The PAUSE time parameter indicates the mobility of VNs. For smaller PAUSE time value the mobility of VNs is greater. The basic PAUSE time is set to 10s, and 2s in our simulation. By using this vehicular mobility generator, we generate simulation scenarios of 50, 100, 150, 200 VNs.

IV. PERFORMANCE EVALUATION

A. Success ratio and Gateway Discovery

In Figure.2, we observe that for the two Methods of AG discovery, there are some fundamental differences between them. The idle time in the figure represents the expected inter-arrival time between short message traffic. As the transmitted packet rate decreases, the success ratio of Reactive Gateway Discovery decreases. On the contrary, for Proactive Gateway Discovery, the traffic load does not significantly affect the successful delivery ratio. The critical issue for successful

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packets transmission is that the Deterministic Serving Access Table to obtain accurate information. When the traffic load is heavy, Reactive Gateway Discovery can obtain information from the transmitted packets, while Proactive Gateway Discovery obtains little benefit. However, when the load of this network is light, the Reactive Gateway Discovery loses the opportunity to obtain information; thus, the success ratio drops dramatically. Meanwhile, Proactive Gateway Discovery has the similar performance.

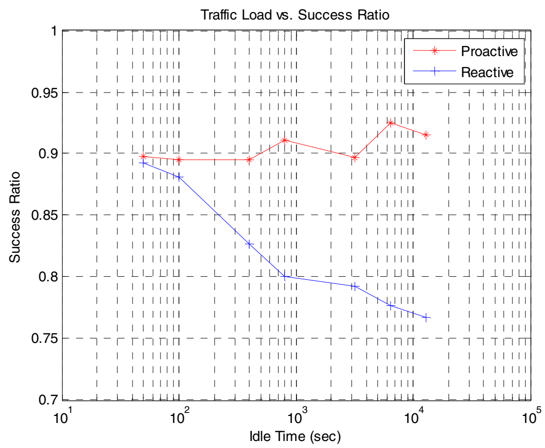


Figure 2: Success ratio in Proactive/Reactive Gateway Discover

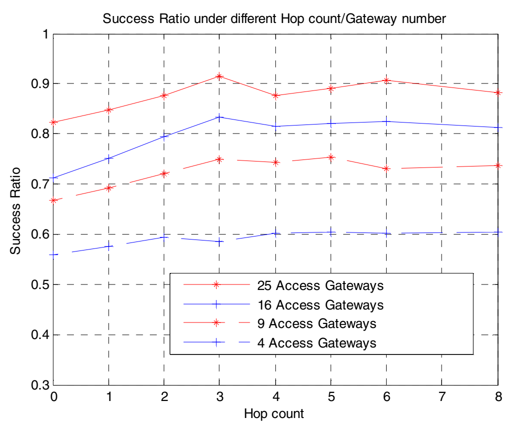


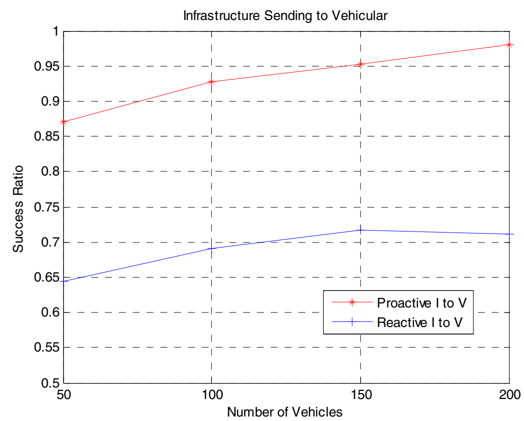
Figure 3: Success ratio V.S. Hops of Gateway advertisement

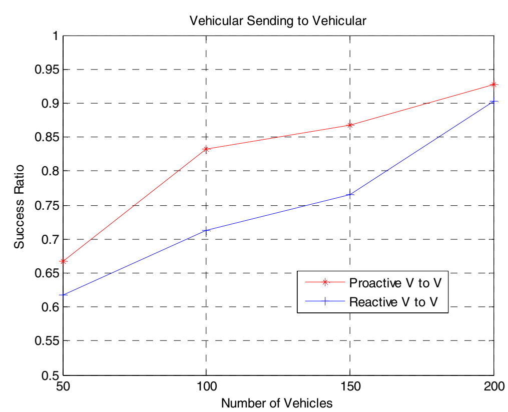
B. Scope of Proactive Gateway Advertisement

In the previous subsection, we can notice that for higher performance of this mechanism, we should apply AGs to use Proactive Gateway Discovery modes. The maximum number of hop count allowed for Gateway advertisement broadcasting defines the scope of Gateway advertisement, and thus the effectiveness and the overhead of Proactive AG Discovery. As shown in Figure.3, we find that as the number hop counts grow increase, the successful delivery ratio poses similar trend regardless of the number of AGs. As the number of hop count grows larger than 3, there is no significant improvement in the performance. On the other hand, the system performance is significantly affected by the density of AGs. The higher the density of AGs, the easier a VN could find a route toward backbone connection or toward another VN through infrastructure-assisted transmission.

C. Comparison Of V2V/V2I/I2V Communications

We simulate these three types of traffic models (V2I, V2V, and I2V) with the same amount of traffic load. As shown in Figure 4, the Proactive AG Discovery mode always performs better than Reactive AG Discovery mode. In addition, the successful delivery ratio increases as the number of VNs increase. When there is enough VNs to maintain network connectivity and valid route entries, the scheme performs well. As the number of VNs increases, a VN has greater chance to maintain a valid route toward another destination VN through ad hoc relay or a valid route toward an AG. It is more challenging to transmit from vehicular to vehicular since it involves more vehicular multihop relay and more transmission from and to AGs.





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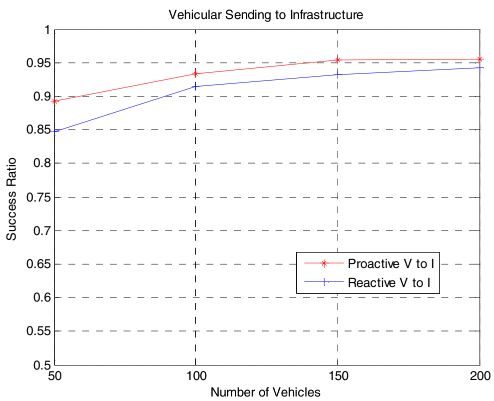

Figure 4: Successful delivery ratio in V2I, V2V, and I2V

However, in pure I2V scenario with Reactive Gateway Discovery, VNs do nothing when they have no data packets to transmit. As a result, the AGs obtain very few information in Reactive Mode, thus, the successful delivery ratio of reactive infrastructure to vehicular message is relatively low.

In V2I communications, as long as there is network connectivity between the VN and any AG, the protocol can guarantee the successful transmission. In this case, the successful ratio performance is not affected by whether it applies Proactive or Reactive AG Discovery mode, since the data packets are sent by VNs. The different between the proactive and reactive schemes are the time need for route discovery. In proactive scheme, VNs usually have valid routes toward AGs. On the contrary, in reactive scheme, VNs might need to initiate AODV route discovery process and results in higher delay, although the successful ratio might be similar.

D. *Message Delivery Delay Time*

Figure 5 shows the distribution of the message delivery delay time in both Proactive and Reactive AG Discovery. The simulation setup is similar to the setting in Section 4.3 and the number of AGs is 16 and the inter-arrival time values of exponential short message traffic are 50 and 100 seconds for heavy and light traffic scenario respectively.

All curves show the similar trend in the distribution of delay time. At least 70 percents of success transmissions lay in the first section which the delay time is below 0.1 seconds. The infrastructure assisted VANET architecture is suitable in deliver delay-bounded short messages, which will be used to deliver road traffic information or transportation alert. The transmission whose delay time is below 3 seconds is 89.12% percents at least. The simulation results show that with aid of the wired-link network and Mobility Management Server, the transmissions conducted by MMS-assisted transmission keep low delay time and increase the success ratio. With Proactive AG Discovery, the message delay time could be effectively reduced with up-to-date routing information. The low hop count of advertisement message also limits the signaling overheads. In addition, frequent short message transmission also increase the hit rate of multihop relay routing cache; thus, the route discovery time and data message delivery time is reduced.

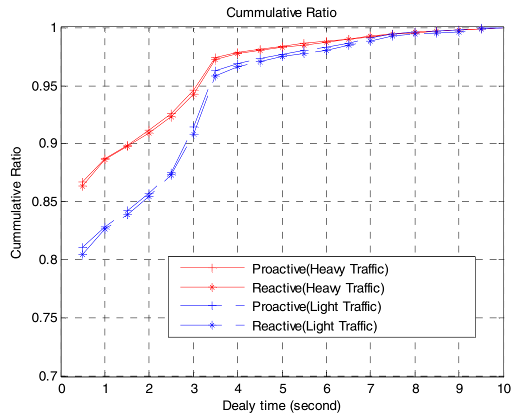

Figure 5: Cummulative distribution of delivery delay

V. Conclusion

We proposed a hybrid multihop relay vehicular network architecture. VNs transmit data packets through multihop VANET relay or through the AG infrastructure. The mobility management server maintains the service AG information to assist data delivery through wired line backbone and AGs. Proactive AG Discovery scheme effectively improve vehicular communications through AGs. The delay of data message delivery is low and the routing overhead is limited as the gateway advertisement is limited. The proposed automotive architecture is useful in supporting telematics applications based on delay-sensitive messaging.

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