A New High Throughput Internet Access Protocol for Vehicular Networks

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ABSTRACT

In this paper, we introduce a new cross-layer communication protocol for vehicular internet access along highways which is called the Controlled Vehicular Internet Access (CVIA) protocol. The objective of the new protocol is *to increase the end-to-end throughput while achieving fairness in bandwidth usage between road segments*. To achieve this goal, the CVIA protocol eliminates contention in relaying packets over long distances. CVIA creates single-hop vehicle clusters and mitigates the hidden node problem by dividing the road into segments and controlling the active time of each segment. Using an analytical throughput estimation model, the protocol parameters are fine-tuned to provide fairness among road segments. Simulation results confirm that the proposed CVIA protocol provides higher throughput and better fairness in multi-hop data delivery in vehicular networks when compared with purely IEEE 802.11 based protocols.

Categories and Subject Descriptors: C.2.1 [Network Architecture and Design]: Wireless communication; C.2.5 [Local and Wide-Area Networks]: Access schemes

General Terms: Design, Performance, Algorithms

Keywords: Wireless networks, multi-hop, internet, IEEE 802.11, IVC, vehicle, gateway, VANET

1. INTRODUCTION

As mobile wireless devices, such as PDAs, laptops, and mobile phones, become an essential part of our lives, "anytime, anywhere" connectivity becomes an increasingly important requirement for wireless systems. Since an average user spends hours in the traffic everyday, Internet access from vehicles is in great demand. The convergence of Internet and vehicular networks enables advanced applications such as web browsing, remote vehicle diagnostics, mobile office and real-time navigation information. End-to-end throughput is one of the key parameter for vehicular Internet access systems employing an infrastructure along the road. Although Dedicated Short Range Communication (DSRC) systems employ IEEE 802.11 protocol, multi-hopping using IEEE 802.11 protocol to access gateways outside the transmission range suffers from several problems leading to low end-to-end throughput and starvation of packets originating from the vehicles far away from the gateways.

The FleetNet project [1] investigates the integration of Internet and vehicular networks. This integration requires mobility support, efficient communication, discovery of services, and support of legacy applications. The proposed architecture contains stationary Internet gateways (IGW) along the road with two interfaces connecting the vehicular networks to the Internet.

In this paper, a new cross-layer protocol controlling both the medium access and packet forwarding for vehicular Internet access along highways is introduced. The objective of our new protocol is to *increase the end-to-end throughput while achieving fairness in bandwidth usage between vehicles.* To achieve this goal, the CVIA protocol eliminates contention in relaying packets over long distances. Our proposed protocol creates single-hop vehicle clusters, reducing the hidden node problem by dividing the road into segments and controlling the active time of each segment. Once vehicles send their packets using contention based methods in these single-hop clusters, the packets are relayed to their destinations without contention.

2. CONTROLLED VEHICULAR INTERNET ACCESS PROTOCOL (CVIA)

Internet access from vehicular networks is accomplished through fixed Internet gateways along the road. These gateways have two interfaces: A wireless interface for the vehicular network and another interface to connect to the Internet. Although the wireless interface of these gateways has a limited wireless coverage, their range can be increased with multi-hop communication. As a result, a gateway can communicate with a vehicle at a distance several times longer than its physical transmission range. The range of a gateway where it provides internet access service is called the *virtual transmission radius*. We assume that gateways send periodic service announcements to indicate the availability of the service in their physical transmission range. Vehicles are assumed to be equipped with GPS devices used for synchronization and obtaining vehicle positions. Vehicle positions

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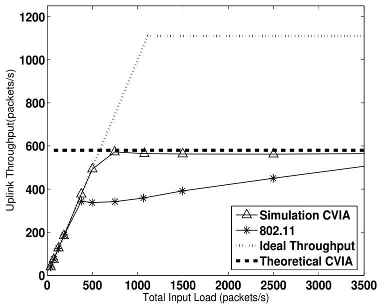

Figure 1: Uplink Throughput

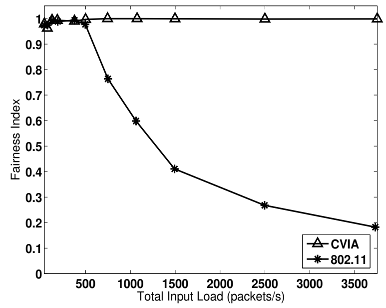

Figure 2: Fairness Index

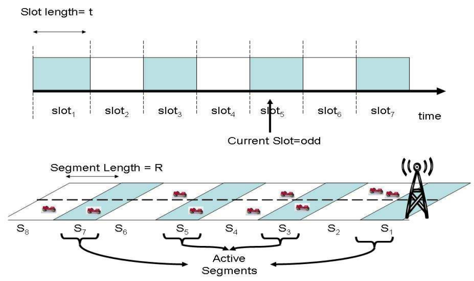

Figure 3: Slots and segments

obtained via GPS are exchanged among one-hop neighbors. When a vehicle enters the virtual transmission range of a gateway, it registers itself with the gateway.

2.1 Definitions

i. R: Physical transmission range.

ii. Segment i (S_i): Road is divided into segments of length R. The segment closest to the gateway is called S_1.

iv. Time Slot j (TS_j): Time is divided into slots whose duration is T_{slot}.

v. S_{i+}: S_{i+} is always the next segment in the direction of the packet dissemination.

vi. Active Segment: Segments where vehicle communication is allowed to occur are called active segments. S_i is active in TS_j if its segment number i and the current time slot number j are both even or both odd. When segment i (S_i) is active, its two neighbor segments become inactive. In the next time slot (TS_{j+1}), all segments change state where inactive segments become active and active segments become inactive. As shown in Figure 3, when the current time slot is T_5, the segments S_1, S_3, S_5, and S_7 become active.

vii. Temporary Router$_i^{out}$ (TR_i^{out}): In active segments, the packets are gathered in vehicles closest to the segment border in the direction of the packet dissemination. This vehicle where the packets to be relayed are collected is called $Temporary\ Router_i^{out}$.

viii. Temporary Router$_{i+}^{in}$ (TR_{i+}^{in}): At the end of an active time slot, TR_i^{out} moves the packets to the next segment (S_{i+}). In S_{i+}, the vehicle which receives all packets from S_i is called $Temporary\ Router_{i+}^{in}$.

ix. Packet Train In *Section 9.2.5.6 (RTS/CTS usage with fragmentation)* of the IEEE 802.11 standard [2], a method is introduced to send several packets with only one RTS/CTS handshake. We will refer to this transmission as *packet train*. In a packet train, after the first packet accesses the channel with RTS/CTS handshake, following DATA packets are sent without RTS/CTS handshake.

2.2 Packet Movement

In this section, the packet movement in the CVIA protocol is presented. (I) Let S_i be *inactive* in time slot j-1 (TS_{j-1}). This segment becomes active when a new slot (TS_j) starts. (II) In the active slot, the first state is the *vehicle position update state* where vehicles broadcast their current positions to their neighbors for $t_{max,update}$ amount of time. (III) In the next state before starting data transmission, *new temporary routers* are announced by TR_i^{in}. (IV) After the temporary router announcement, TR_i^{in} delivers the data train originating from other segments to TR_i^{out}. (V) The local packet gathering phase starts after the end of the packet train. However, if the train is long and $t_{max,delivery}$ amount of time is passed since the beginning of the active slot, packet train delivery stops and local gathering phase starts. (VI) When $t_{max,gather}$ amount of time passes since the beginning of the new slot, TR_i^{out} accesses the channel, creates a new packet train with equal number of packets from each segment and sends this train out of S_i to the TR_{i+}^{in}. To provide fairness, CVIA protocol attempts to control the contents of the packet trains going out of each segment and introduces *fairness among segments* by equating the number of packets from each segment in packet trains. To equate the number of packets from each segment, temporary routers utilize a fair queueing scheme while forming packet trains. This solution is scalable and stateless.

3. PERFORMANCE EVALUATION

To evaluate the performance of our CVIA protocol and the IEEE 802.11 protocol, simulations are performed with the following parameters: R= 350 m, *Data Rate*= 27 Mbps, *Payload*= 2312bytes, *Base Protocol*= 802.11a, *number of segments on each side of gateway*= 8, and *maximum number of packet retrials*= 10. For the fairness metric, we use the Jain's Fairness index defined as $FI = \frac{\left(\sum_{i=1}^{N} Thr_i\right)^2}{N\sum_{i=1}^{N} Thr_i^2}$, where Thr_i is the throughput of segment i. Note that FI=1 when segment throughputs are equal to each other.

As shown in Figure 1, the throughput curves of CVIA and IEEE 802.11 protocols follow the *ideal throughput* curve when the packet load is low. When the load is increased, the CVIA protocol reaches a saturation point. This saturation point is the channel usage capacity of the protocol and successfully estimated by the theoretical analysis. Although the throughput of IEEE 802.11 protocol keeps increasing, it suffers from a very serious problem: Increased load causes starvation for the outer segments. The effects of this phenomenon on fairness is depicted in Figure 2 where fairness index is very close to 1 for all loads in CVIA protocol, however fairness index of the IEEE 802.11 protocol drops drastically when the load is increased.

4. REFERENCES

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ANSI/IEEE Std.802.11, 1999. (a.k.a. ISO/IEC 8802-11:1999(E)).