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Internet Access Protocol Providing QoS in Vehicular Networks with Infrastructure Support

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Abstract— **Controlled vehicular Internet access protocol with QoS (CVIA-QoS) is a cross-layer solution for vehicular multihop networks spanning MAC and routing functions with infrastructure support. CVIA-QoS employs fixed gateways along the road which perform periodic admission control and scheduling decisions for the packet traffic in their service area. The CVIA-QoS protocol is based on CVIA protocol that was designed only for the best-effort traffic. The most important contribution of the CVIA-QoS protocol is providing delay bounded throughput guarantees for soft real-time traffic which is an important challenge especially for a mobile multihop network. After the demands of the soft real-time traffic is met, CVIA-QoS supports the best-effort traffic by allocating the remaining bandwidth.**

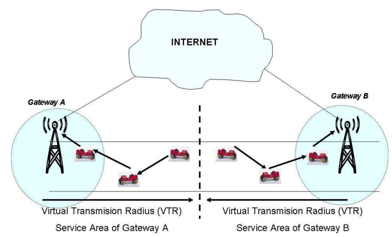

Fig. 1. Communication Model

I. Introduction

Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication systems have the potential for enabling new safety applications and extending existing ones to vehicles and their passengers. Although most of the research in DSRC targets only safety applications, the convergence of Internet and vehicular networks enables important applications such as web browsing, voice and video streaming, remote vehicle diagnostics, mobile office, gaming, and real-time navigation information. These applications can attract great demand and have important impact on the market penetration rate of V2V and V2I systems. The market penetration rate of the wireless equipment is a critical parameter for the success of the V2V systems. The simulation results of [1] show that information relayed via equipped vehicles can be transmitted at the level of the practical use when the penetration rate is over 20%. On the other hand, a lot of V2I applications can still work even if only one vehicle with the wireless equipment is in the market. Because of the market penetration rate obstacle, deployment time of the V2I systems is expected to be earlier than V2V systems [2]. Once the the number of wireless equipment using V2I is above a threshold, V2V applications can be enabled.

In recent years, several research efforts target V2V and V2I systems. Among these, the FleetNet project [3] investigates the integration of the 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 vehicular networks to the Internet [4]. Vehicles communicate with distant IGWs via multi-hopping. This architecture is useful not only to connect vehicles to other networks but also to connect isolated vehicle groups to each other [5]. FleetNet uses an IPv6 based addressing solution to address the vehicles. However, in these proposals, there are no specific solutions describing how to solve the data movement problem over multiple hops. In [6], we introduced a fair and high-throughput internet access protocol, CVIA, for multihop vehicular networks. Although the CVIA protocol provides fairness and high throughput for vehicular Internet access, it is not suitable for applications like video and voice streaming which require throughput and delay guarantees.

In this paper, a new controlled vehicular Internet access protocol with QoS support (CVIA-QoS) is proposed. The CVIA-QoS protocol is a cross-layer solution for vehicular multihop networks spanning MAC and routing functions. CVIA-QoS protocol uses admission control for soft-real time traffic to provide delay bounded throughput guarantees. To achieve this goal, fast and slow packet propagation methods are defined for real-time and best effort traffic, respectively. The real-time sessions send registration requests to the gateways that do scheduling and admission control decisions periodically. After the demands of the soft real-time traffic is met, the remaining bandwidth is allocated to the best effort traffic. CVIA-QoS protocol provides much lower and bounded delay to soft-real time traffic when compared with original CVIA protocol. Furthermore, once admitted by the gateway, the throughput level of the real-time sessions is not affected by the increase in the best effort traffic.

II. Assumptions and Internet Access Model

We consider a vehicular network which accesses the Internet through fixed Internet gateways along the road. These gateways have two interfaces: A wireless interface for the vehicular network and another interface connected to the

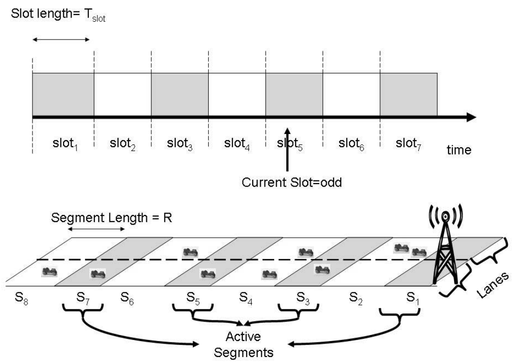

Fig. 2. Slots and Segments

Internet. Although the wireless interface of these gateways has a limited wireless coverage, their range can be increased with multi-hop communication as shown in Figure 1. 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 service area. We also assume that the uplink and the downlink packets are transmitted over two frequency separated channels.

Vehicles are assumed to be equipped with GPS devices used for time synchronization and obtaining vehicle positions. Vehicle positions obtained via GPS are exchanged among one-hop neighbors. When a vehicle enters the virtual transmission radius of a gateway, it registers itself with the gateway. In this work, each vehicle is assumed to have one access point to the wireless medium. All devices inside the vehicle (e.g., laptops, PDAs, vehicle's onboard computer, sensors, etc.) use this interface to communicate with the outside world, creating an aggregated traffic going in and out of the vehicle. The devices inside the vehicle establish a mobile network. We assume that mobility management is handled by the proposed network mobility solutions in the literature [7].

III. Controlled Internet Access Protocol [6]

In this section, we present the CVIA protocol on which our proposed CVIA-QoS protocol is based. CVIA is a cross-layer communication protocol for vehicular internet access along highways. The protocol functions span MAC and network layers. The objective of the protocol is *to increase the end-to-end throughput while achieving fairness in bandwidth usage between road segments* for the best effort traffic. The CVIA protocol aims to solve two main problems of IEEE 802.11 protocol in multi-hopping along a highway: Low throughput and starvation of packets originating from vehicles far away from gateways.

The CVIA protocol forms temporary single hop clusters to mitigate the hidden node problem as it is unlikely for a vehicle to be *a hidden node* for a transmission between two vehicles in a single hop vehicle cluster. To form these clusters, the time is divided into slots and the service areas of the gateways are divided into segments as shown in Figure 2. In each time slot, the CVIA protocol allows transmissions only in the segments which are far away from each other, i.e., the transmission in one segment does not interfere with the transmissions in the other active segments. To let the transmission occur in all segments, the active segments are switched periodically and a new set of segments becomes active in each time slot.

The packet traffic is controlled by designated vehicles in segments called the temporary routers (TR) as shown in Figure 3. In each time slot, temporary router which is responsible for the outbound traffic receives packets originating from other segments and local packets from its own segment. At the end of the time slot, all packets are moved out to the next segment together without contention.

A. Definitions

i. Communication Range R: The physical transmission range of the vehicles as well as the gateway.

ii. Virtual Transmission Radius (VTR): The radius of the service area of the gateway where it provides Internet access service.

iii. Segment i (S_i): Fixed section of VTR of length R. The segment closest to the gateway is denoted by S_1.

iv. VTR length N: The number of segments in VTR of a gateway.

v. Time Slot j (TS_j): Time duration of length T_{slot}.

vi. Neighboring Segment S_{i+}: The neighboring segment in the direction of packet dissemination. S_{i+} is the neighboring segment of S_i closer to the gateway in the uplink channel and the neighboring segment of S_i farther away from the gateway in the downlink channel.

vii. Neighboring Segment S_{i-}: The neighboring segment in the opposite direction of the packet dissemination.

viii. Interference Parameter (r): $r = \lceil \frac{\text{interference range}}{R} \rceil + 1$.

ix. Active Segment: Segments where vehicle communication is allowed to occur in a time slot. S_i is active in TS_j if $(i \ mod \ r)$ equals to $(j \ mod \ r)$. Note that there are $r-1$ inactive segments between two active segments according to the active segment definition.

In Figure 2, when the current time slot is T_5 and $r = 2$, segments S_1, S_3, S_5, and S_7 become active. In this example, when segment i (S_i) is active, its two neighboring segments (S_{i-},S_{i+}) become inactive. In the next time slot (TS_{j+1}), all segments change states where inactive segments become active and active segments become inactive.

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

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

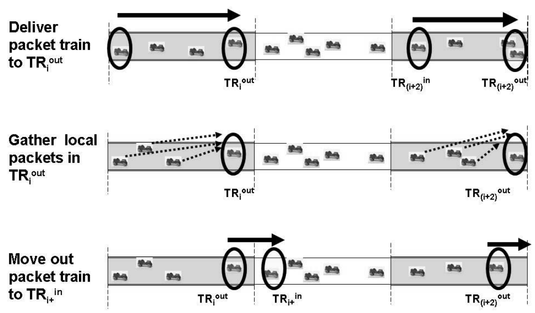

Fig. 3. Packet Movement Types

xii. Packet Train: It is a method where several packets are sent with only one RTS/CTS handshake among the same source and destination pair.

B. Packet Movement Types:

CVIA employs two vehicles as temporary routers in each active segment i: TR_i^{out} and TR_i^{in}. All packets entering a segment go through TR_i^{in} and all packets leaving the segment go through TR_i^{out}. We choose TR_i^{in} as the closest vehicle to S_{i-} and TR_i^{out} as the closest vehicle to S_{i+}. The CVIA protocol uses three types of packet movements as shown in Figure 3:

1) TR_i^{in} delivers the packet train originating from other segments to TR_i^{out},
2) Local packets of the segment is gathered by TR_i^{out},
3) TR_i^{out} creates a new train using packets received in (1) and (2), and sends it to TR_{i+}^{in} in S_{i+}.

C. Protocol Phases

I. Inactive Phase: Vehicles in inactive segments do not access the channel. Inactive and active segments are determined using the slot number i and segment number j, i.e. S_i is active when $(i\ mod\ r)$=$(j\ mod\ r)$. Vehicles compute i and j as follows: $i = \left\lfloor \frac{\Delta d}{R} \right\rfloor$, and $j = \left\lfloor \frac{\Delta t}{T_{slot}} \right\rfloor$, where Δd is the distance of the vehicle to the gateway and Δt is the time passed since an absolute reference point, e.g., 12:00 pm. Note that vehicles obtain their positions and synchronize their clocks using GPS. The vehicles learn the positions of gateways from a digital road map database or the service announcement packets broadcast periodically by gateways.

II. Temporary Router Selection Phase: At the beginning of each time slot, next temporary routers are selected by TR^{in}s. Since the topology of the vehicular network changes fast, new temporary routers must be selected periodically. The selected routers are called $TR_{i,next}^{out}$ and $TR_{i,next}^{in}$ until they become active. $TR_{i,next}^{out}$ and $TR_{i,next}^{in}$ must stay inside the segment for an amount of time called the *router lifetime*; therefore, they should be away from the segment borders by a certain distance. The details of the Temporary Router Selection Phase is presented in [6].

III. Intra-segment Packet Train Movement Phase: TR_i^{in} starts delivering the packet train received from S_{i-} in the previous slots to TR_i^{out}. To avoid contention, TR_i^{in} has the highest access priority and waits only SIFS duration before accessing the channel.

VI. Local Packet Gathering Phase: After the intra-segment packet train movement ends, the channel becomes idle for DIFS duration and vehicles access the channel using a contention based channel access scheme. In this local packet gathering phase, vehicles employ the DCF method of the IEEE 802.11 standard. Each node has the same priority and they directly send their packets to TR_i^{out}. To decrease the number of collisions, each vehicle starts this packet gathering phase with a random backoff counter.

VII. Inter-segment Packet Train Movement Phase: TR_i^{out} has the highest channel access priority among the vehicles in the LPG phase. When time left in the active slot is just enough to move out packets in the queues, TR_i^{out} accesses the channel and ends the LPG phase. The new packet train is moved to TR_{i+}^{in} before the end of TS_j. Note that all the packets pass through S_1. Therefore, each TR_i^{out} can send out at most $(C/N) \cdot\ (N-i+1)$ packets where C is the capacity of the protocol. These packets are buffered in TR_{i+}^{in} until S_{i+} becomes active.

D. Performance of the CVIA protocol

In [6], it is shown through simulations that CVIA has up to 80% higher end-to-end throughput capacity when compared with the IEEE 802.11 protocol . In addition, the CVIA protocol distributes the throughput fairly among segments while the vehicles far away from the gateway suffer from starvation under the IEEE 802.11 protocol.

Although CVIA is a successful communication protocol for the best-effort traffic, it is not suitable for real-time applications. In CVIA, the packets experience high delays that is directly proportional to the number of segments in the virtual transmission range as packets move only one segment in each time slot. In addition, due to lack of an admission control mechanism, the protocol cannot provide guaranteed throughput to real-time sessions.

IV. CVIA-QoS

CVIA-QoS protocol is designed to provide throughput guarantees and fixed delay bound to soft real-time applications like voice and video streaming in linear vehicular networks. The best effort traffic is handled with the remaining bandwidth after allocating resources for real-time traffic. In CVIA-QoS, one time slot is divided into two periods, namely high priority period (HPP) and low priority period (LPP). Unlike the CVIA protocol, packets admitted to HPP is delivered to the gateway in *one time slot*. Furthermore, an admission control mechanism is introduced where admission decisions are made by the gateways and executed by the temporary routers.

At the beginning of the HPP, sessions that request service in HPP send registration packets to outbound temporary routers. Once these requests are collected in all segments,

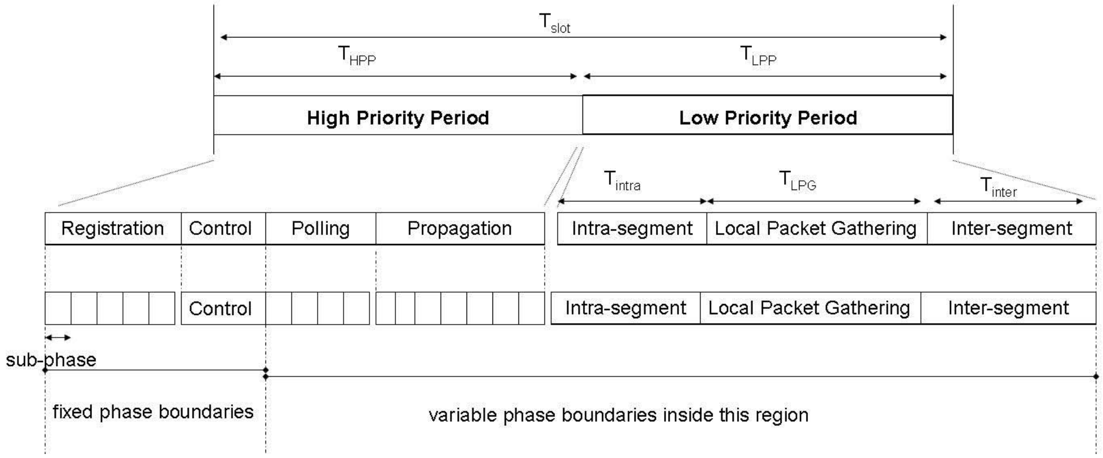

Fig. 4. Phases in the CVIA-QoS protocol

they are delivered to the gateway. To grant end-to-end throughput guarantees to sessions, the gateway uses the information about the new session requests, buffer status of the temporary routers and the information about already active sessions. The session admission decisions and time allocations for different phases in the time slot are sent to temporary routers. Temporary routers poll the vehicles that are granted access. After the polling phase, the collected packets from all segments are propagated to the gateway in packet trains in one time slot. Since the maximum length of LPP is T_{slot}, the network delay of the packets admitted to HPP are bounded by T_{slot}. In the remaining time, the original CVIA protocol is used to serve the best effort traffic in LPP.

A. Phases in the CVIA-QoS Protocol

In CVIA-QoS, time is divided into slots of T_{slot}. Each time slot is composed of High Priority and Low Priority periods as shown in Figure 4.

High Priority Period:

1) Registration Phase: Vehicles with new real-time sessions and vehicles with active sessions that enter a new segment send short registration packets to TR^{out}s using IEEE 802.11 protocol without RTS/CTS handshakes. Vehicles start this phase with preset random backoff counters to decrease the probability of packet collisions at the beginning. If a registration packet is received successfully by TR^{out}, an ACK packet is sent to the vehicle. To mitigate the hidden node problem, fixed length subphases are defined in the registration phase. In each subphase, a new set of segments become active to send registration packets. Segment i becomes active in sub-phase k if $i \ mod \ r = k \ mod \ r$, i.e., There are $r-1 = \lceil \frac{\text{interference range}}{R} \rceil$ inactive segments between two active segments. As a result, after r sub-phases, all segments will have become active once. If 5 ms time is allocated for the registration phase in a 100 ms time slot, 80 new session initiations in a second can be received on the average from each segment.

2) Control Phase: After the Registration Phase, a control packet train is initiated by the furthest TR^{out}. Control trains are forwarded by only TR^{out}s and TR^{in}s during their propagation. Each TR^{out} includes the new high priority session requests and each TR^{in} includes the number of low priority packets in its buffer. Based on this new information and the information about the existing active sessions, the gateway makes scheduling and admission control decisions as described in Section IV-B. In the second control train, the schedules are sent from the gateway to all TRs. In this control train originating from the gateway, the lengths of all phases and sub-phases until the end of the current time slot are announced. The fixed length and variable length phases are shown in Figure 4. For N=8, 2 ms is sufficient for the control phase to deliver all the information to the gateway.

3) Polling Phase: Based on the schedule received from the gateway, TR^{out}s poll the vehicles with active sessions. In response to polling, vehicles send their data packets. Acknowledgments to data packets are piggy-backed in the polling packets by TR^{out}s. Similar to the Registration Phase, r polling sub-phases are employed to mitigate the hidden node problem in the polling phase. The length of the polling phase depends admitted real-time packets, the number of segments in the virtual transmission range, and r.

4) Propagation Phase: In the propagation phase, high priority packets collected by TR^{out}s are moved towards the gateway in fast packet trains. The packet trains are initiated in parallel by segments $\{S_N, S_{N-r}, S_{N-2r}, ..., S_r\}$. This phase is also composed of several sub-phases. Segment i becomes active in sub-phase m if $i \ mod \ r = m \ mod \ r$.

When S_i becomes active, the fast train originating from S_{i-} is moved to TR_i^{out}. Then, all local packets collected in the segment are attached to the packet train. At the end of each sub-phase, TR_i^{out} sends the packet train to TR_{i+}^{out} in the next segment. With this approach, all polled packets are delivered to the gateway in one time slot. As a result, network delay experienced by real-time packets admitted to HPP is bounded by T_{slot}. As in polling phase, the length of the propagation phase depends on admitted real-time traffic, the number of segments in the virtual transmission range and r. The total length of the polling and propagation phases can cover all the remaining portion of the time slot.

Low Priority Period:
The phases in this period are identical to the packet movement phases of the original CVIA protocol presented in Section III-C, namely Intra-segment Packet Train Movement Phase, Local Packet Gathering Phase, Inter-segment Packet Train Movement Phase. Note that the packet train utilizing the low priority time period is referred to *Slow Packet Train* since the packets can propagate one segment in each time slot (T_{slot}) and the packets are buffered in TR^{in}s.

B. Scheduling and Admission Control

The gateways are responsible for accepting session initiation requests and determining the lengths of the phases and sub-phases in a time slot. They schedule first the best-effort packets buffered in the network, then packets of the existing active real-time sessions, followed by packets of new sessions, and finally new packets of the best-effort traffic.

The CVIA protocol introduces a bound on the maximum length of LPP. The maximum ratio of the LPP to slot time is called $Ratio_{max}$. This bound also implies a bound on the minimum length of HPP. Increasing the length of the LPP increases the number of new low priority packets accepted to the network. These packets are buffered in TR^{in}s; therefore, the longer the length of LPP, the higher the number of packets buffered in the network. In the CVIA-QoS, packets buffered in the network are scheduled before accepting new real-time session requests. Hence, the buffered packets in the network decrease the response time of the protocol when a bursty real-time demand is encountered. The algorithm scheduling algorithm has four main steps:

1) ***Schedule low priority packets in the buffers of*** TR^{in}***s:*** Packets cannot be buffered in temporary routers longer than the routers' lifetime beyond which they may leave its segment. Since the CVIA-QoS protocol does not drop any packet once admitted to the network, the gateways first allocate time for the buffered best-effort packets.
   a) Although the buffered packets are best effort packets, they can be scheduled to HPP or LPP depending on the real-time load. If there is remaining time in minimum HPP length after real-time load is scheduled, this capacity is filled with buffered best effort packets. First the gateway computes the length of HPP for the case when all real-time packets are scheduled. If $T_{HPP}/T_{slot} < 1 - Ratiomax$ then the buffered best effort packets are scheduled to HPP until $T_{HPP}/T_{slot} = 1 - Ratio_{max}$.
   b) All buffered packets not scheduled to HPP is scheduled to LPP. To achieve this schedule, a minimum time interval is allocated for Intra-segment (T_{intra}) and inter-segment (T_{inter}) packet movement phases.
2) ***Schedule already accepted high priority traffic:*** The packets of the already accepted sessions are scheduled to HPP. With scheduling already accepted traffic before accepting new requests, CVIA-QoS protocol satisfies the minimum throughput guarantees given to real-time sessions in the previous slots.
3) ***Schedule packets from new sessions:*** After scheduling the packets of the existing sessions, the gateway attempts to schedule new sessions as long as the sum of the length of HPP and the time allocated to buffered best-effort packets does not exceed T_{slot}, i.e.,
$$T_{HPP} + T_{intra} + T_{inter} < T_{slot} \quad (1)$$
4) ***Schedule new best-effort packets :*** If there is still some remaining time in the current time slot, it is dedicated to new best effort packets. To gather these new packets, T_{LPG} amount of time is allocated to Local Packet Gathering Phase in LPP. In addition, enough time to move those packets to the next segment is added to T_{inter}. Note that if the real-time traffic is very high, no new best-effort packet is admitted to the network by setting $T_{LPG} = 0$ if the real-time demand exceeds the capacity of the time slot.

V. PERFORMANCE EVALUATION

The performance of CVIA-QoS is assessed through simulations. In the simulation scenarios, simulated vehicles move on a linear highway segment with 2 lanes, one for each direction of traffic flow. The vehicles randomly enter the service area with exponentially distributed inter-arrival times. On the average, there are 34 vehicles/km per lane. Each vehicle is assigned a speed from a Gaussian distribution with a mean of 90 km/h and standard deviation 5 km/h at the beginning of the simulation. The assigned speeds do not change during simulation. The common parameters of the simulations are: Transmission Range=350 m, Data Rate=27 Mbps, Payload=2000 or 500 bytes, Base Protocol=802.11a (DSRC), Maximum Number of Packet Retrials=10, interference range to transmission range ratio=1. The protocol parameters are: T_{slot}=100 ms, N=4 or 8, and r=2. Other parameters of the MAC layer and the physical layer are taken from the ASTM E2213-02 standard document [8].

A. Results

1) Length of HPP: Figure 5 shows the length of the high priority period when the real-time packet demand is increased in the system. When real-time demand is high, the length of the HPP can grow until it reaches $T_{slot} = 0.1s$. The speed of this response depends on the maximum allowable number of packets in the TR buffers and the number of segments (N) in the virtual transmission radius of the gateway. As a result, for a given real-time load, HPP reaches its final length after a transient period. Figure 5 shows the length of HPP at steady state. For high N, the length of the HPP phase is longer because it takes longer to deliver packets originating from the furthest segment. It can be deduced that increasing the service area of the gateway increases the overhead of CVIA-QoS.

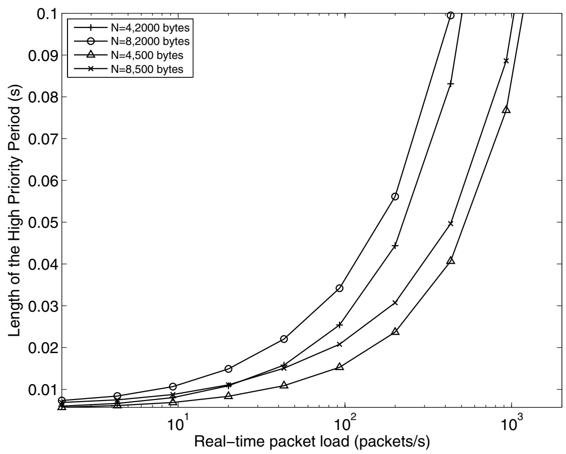

Fig. 5. Length of HPP

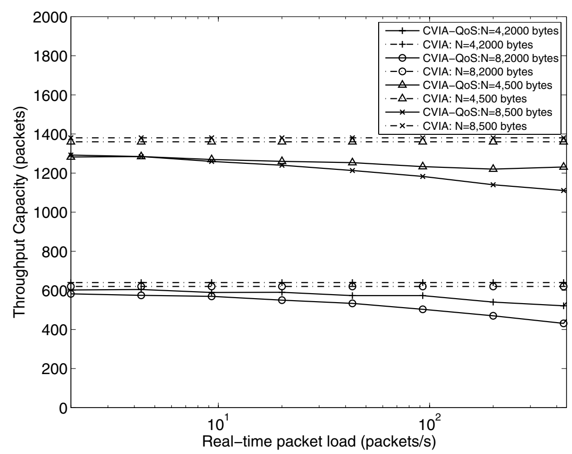

Fig. 6. Throughput Capacity

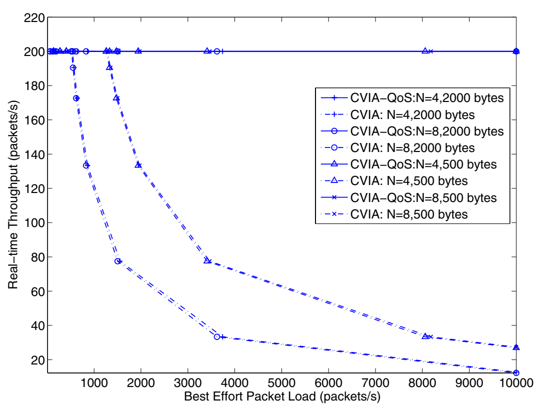

Fig. 7. Real-time throughput in CVIA and CVIA-QoS protocols (real-time demand is 200 packets/s)

2) Throughput Capacity: In this scenario, we consider a system at saturation where all vehicles have always new packets to send. Figure 6 shows the throughput capacity of CVIA-QoS and CVIA when the real-time load is increased in the system for different N and payload values. Throughput capacity of CVIA-QoS is always smaller than CVIA since CVIA-QoS protocol allocates some portion of its throughput to provide delay bounded throughput guarantees to real-time traffic. Any real-time packet admitted to the system reserves bandwidth in segments on its path within the same time slot. As a result, when the N is high, the capacity of the system decreases for both payloads as shown in Figure 6.

3) Effect of Best-Effort Load on Real-time Throughput: Figure 7 shows the effect of the increase in the best-effort load on the real-time throughput. In all scenarios, real-time demand is 200 packets/s and it remains constant. In CVIA, real-time and best effort packets contend for the same channel. Therefore, when best effort load increases, the share of real-time packets in the total-end to-end throughput decreases. On the other hand, since the CVIA-QoS protocol employs admission control and polls the real-time packets without any contention, the throughput of the real-time traffic is not affected by the background best-effort load in the channel.

VI. Conclusions and Future Work

In this paper, a new channel access and routing strategy for vehicular Internet access along highways with QoS support is introduced. The CVIA-QoS protocol use periodic admission control and scheduling for soft real-time traffic to provide delay bounded throughput guarantees. After the demands of the soft real-time traffic is met, CVIA-QoS supports the best-effort traffic by allocating the remaining bandwidth. In our future work, the CVIA-QoS protocol will be improved by allowing coordination of multiple gateways and multi-segment reservation strategies.

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