Performance Evaluation of a Mixed Vehicular Network with CAM-DCC and LIMERIC Vehicles

Bin Cheng*
Joint work with
Ali Rostami*, Marco Gruteser*
*WINLAB, Rutgers University, USA

Gaurav Bansal†, John B. Kenney†
†Toyota InfoTechnology Center, USA

Katrin Sjobergć
ćVolvo Group Trucks Technology,
Introduction

• V2V communication has the potential of significantly improve the traffic efficiency and driving safety
  – Collision avoidance
  – Road hazard awareness
  – Route guidance

• Safety application requirements
  – Transmit safety messages several times per second
  – Channel load increases as the vehicle density increases

• IEEE 802.11p standard---Specifies MAC and PHY protocols for V2V
  – Cannot efficiently mitigate the congestion when the vehicle density is very high
  – Congestion control algorithm is necessary
    • LIMERIC --- A linear adaptive algorithm proposed by Toyota ITC
    • DCC --- A control framework proposed by ETSI
Introduction

- Mixed network
  - An algorithm has been deployed
    1. *Do the DCC vehicles experience performance changes after LIMERIC vehicles are introduced?*

2. *If a performance difference does exist, how can it be reduced?*

- DCC is assumed to be deployed for day one application, DCC vehicles are gradually replaced by LIMERIC vehicles
LIMERIC

- Adapt the transmission rate in a way such that channel load is driven towards a target

\[ r_j(t) = (1 - \alpha)r_j + \beta(CBP_g - CBP(t - 1)) \]

\[ 0 < \alpha < 1 : \text{contraction parameter, impacts fairness, convergence speed} \]

\[ \beta > 0 : \text{linear gain adaptive parameter, impacts stability, convergence speed} \]
Decentralized Congestion Control (DCC)

- DCC regulates safety message generation and transmission by a state machine
  - Mapping channel load to a state
  - RELAXED, ACTIVE, RESTRICTIVE
  - Each state defines a set of parameters for controlling the transmission behaviors, e.g. *transmission rate*, transmission power, data rate etc.

**Two Algorithms both use channel load as input**

*The way they use it is different*
Simulation Setup

- Set-up a road topology in SUMO, 4000 m highway with 375 winding section in the middle region, 3 lanes in each direction
- Simulations in ns-2.34
  - Transmission range = 500 m
  - Number of vehicles = 1000
  - CBP measurement period = 100 ms; All vehicles measure CBP at the same time
  - Speed: 19 m/s (inside lane), 18 m/s (middle lane), 17 m/s (outside lane)
  - Simulation time = 200 s
Simulation Setup

- **LIMERIC**
  - Algorithm parameters: target CBP = 79%, $\alpha = 0.1$, $\beta = 0.033$

- **CAM-DCC:**

<table>
<thead>
<tr>
<th>Channel load</th>
<th>State</th>
<th>Packet Tx interval</th>
<th>Packet rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 30 %</td>
<td>RELAXED</td>
<td>100 ms</td>
<td>10 Hz</td>
</tr>
<tr>
<td>30-39%</td>
<td>ACTIVE 1</td>
<td>200 ms</td>
<td>5 Hz</td>
</tr>
<tr>
<td>40-49%</td>
<td>ACTIVE 2</td>
<td>300 ms</td>
<td>3.33 Hz</td>
</tr>
<tr>
<td>50-59%</td>
<td>ACTIVE 3</td>
<td>400 ms</td>
<td>2.5 Hz</td>
</tr>
<tr>
<td>&gt;60%</td>
<td>RESTRICTIVE</td>
<td>500 ms</td>
<td>2 Hz</td>
</tr>
</tbody>
</table>
Simulation Results

• Performance evaluations in mixed networks
  – Performance change
  – Performance difference

• Metrics
  – Packet Error Rate (PER)
  – Inter-Packet Gap (IPG) --- main metrics

• Metrics calculation
  – Based on transmissions carried out on the winding section
  – Organized into distance bins (bin size = 50 m)
  – Calculation breaks down to LIMERIC transmitters and CAM-DCC transmitters
PER

No major performance changes

Alleviate synchronized transmissions
No major performance changes after introducing LIMERIC nodes
Performance difference between LIMERIC and DCC

A mixed network with percentage 50%-50%
Reduce Performance Difference

- Target CBP of LIMERIC 79% -> 68%
- Shifted-up CAM-DCC look-up table

<table>
<thead>
<tr>
<th>Channel load (default)</th>
<th>Channel load (shifted-up)</th>
<th>State</th>
<th>Packet Tx interval</th>
<th>Packet rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 30%</td>
<td>&lt; 40%</td>
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<td>ACTIVE 2</td>
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</tr>
<tr>
<td>50-59%</td>
<td>60-69%</td>
<td>ACTIVE 3</td>
<td>400 ms</td>
<td>2.5 Hz</td>
</tr>
<tr>
<td>&gt;60%</td>
<td>&gt;70%</td>
<td>RESTRICTIVE</td>
<td>500 ms</td>
<td>2 Hz</td>
</tr>
</tbody>
</table>
## Reduce Performance Difference

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alternative 1</strong></td>
<td>LIMERIC target CBP = 79%, CAM-DCC look-up table = <strong>shifted-up</strong></td>
</tr>
<tr>
<td><strong>Alternative 2</strong></td>
<td>LIMERIC target CBP = 68%, CAM-DCC look-up table = <strong>default</strong></td>
</tr>
<tr>
<td><strong>Alternative 3</strong></td>
<td>LIMERIC target CBP = 68%, CAM-DCC look-up table = <strong>shifted-up</strong></td>
</tr>
</tbody>
</table>
Alternative 1 --- 79%, shifted-up table

Performance gap maintains
Alternative 2 --- 68%, default table

Performance gap is closing
Alternative 3 --- 68%, shifted-up table

Performance difference diminishes
Conclusion and Future Work

- This first study of mixed network operation did not reveal any major performance change.
- It shows promise for co-existence of vehicular congestion control algorithms.
- The performance difference between the two algorithms can be controlled through careful adjustments in algorithm parameters.
- The conclusions of this work should be confirmed through simulations with a broader set of scenarios.
Thank You
Reference

PER of pure CAM-DCC network is higher due to synchronized transmissions.
95th Percentile IPG

**LIMERIC**

IPGs are increasing

**CAM-DCC**

DCC operates in RESTRICTIVE state
Alternative 1 --- 79%, shifted-up table

Performance difference maintains
Alternative 2 --- 68%, default table

Performance gap is closing
Alternative 3 --- 68%, shifted-up table

Difference is almost diminished
Introduction

• Several congestion control algorithms are under investigation
  – LIMERIC: a linear adaptive algorithm proposed by Toyota ITC
  – DCC: a control frame work proposed by ETSI
  – Take channel load (i.e. CBP) as input and regular the transmission behaviors
Background---Safety Messages

- Basic Safety Message (BSM) in US, Cooperative Awareness Message (CAM) in Europe
  - position information, time stamp, heading, speed, driving direction, path history, vehicle type
- BSM generation
  - have not specified
  - 10 BSM/second rate in most tests and trials
- CAM generation
  - time condition: message interval, provided by DCC, expires
  - dynamic condition:
    - (i) heading changed > 4°
    - (ii) position changed > 4 meters
    - (iii) magnitude of speed changed > 0.5 m/sec
  - after 1 second even above two conditions are not met
Message Rate Control

Each vehicle computes its message rate $r_i(t)$ adaptively based on channel load (Channel Busy Ratio).

**Goals:** controlled load, convergence, fairness