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Performance and Stability Comparison of Vehicular Congestion Control Algorithms

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Vehicular Networking

- The Key goal of VANET is safety applications
  - i.e. Cooperative Adaptive Cruise Control (CACC)

  - It is important to have the most recent information of other vehicles → time matters!

Congestion Control

- A naïve approach is to periodically (generate and) transmit information messages
  - It might not work when it's needed!

- There are multiple existing congestion control protocols that are trying to reduce the channel congestion
- They are not being compared in the same environment

Contribution

- We picked two of these existing congestion control protocols
  - Decentralized Congestion Control (DCC)
    - Developed by ETSI to be used across Europe
  - LInear MEssage Rate Integrated Control (LIMERIC)
    - Developed by Toyota InfoTechnology Center
- We will compare these two congestion control protocols under similar condition in the same scenario

Decentralized Congestion Control (DCC)

- General Idea:
  - Measure the Channel Busy Percentage (CBP)
  - Find the Message Rate match from the look-up table
  - Generate and send out Basic Safety Messages with that rate

The percentage of the time that channel has been busy over a period

The frequency of message transmission

Messages that are containing vehicle's information such as speed, location, etc.

State	Channel load	Message rate
RELAXED	< 30%	10 Hz
ACTIVE1	30-39%	5 Hz
ACTIVE2	40-49%	3.33 Hz
ACTIVE3	50-59%	2.5 Hz
RESTRICTIVE	> 60%	2 Hz

Cooperative Awareness Message (CAM) Generation Rules

- If interval constraint satisfies, then: (to make sure no more messages will be generated than DCC can send out)
  - Check for dynamic condition: (If vehicle needs to update its status)
    - (i) heading changed > 4° , or
    - (ii) position changed > 4 meters, or
    - (iii) magnitude of speed changed > 0.5 m/sec
  - If one of (i), (ii), or (iii) met, then generate a new CAM

- If Vehicle didn't send a CAM in last second
  - After 1 second from last CAM generating time, a new CAM must be generated anyway

LIMERIC: Adaptive Approach Toward Channel Load

- General Idea:
  - Keep the channel load at near-optimum level, independent from vehicle density

$\beta > 0$

linear gain adaptive parameter, Impacts stability, convergence speed

$$r_j(t) = (1 - \alpha) r_j(t-1) + \beta(CBR_g - CBR(t-1))$$

$0 < \alpha < 1$

contraction parameter, Impacts fairness, convergence speed

Target CBR

Current CBR

Simulation Settings

Length of the highway = 4 Km

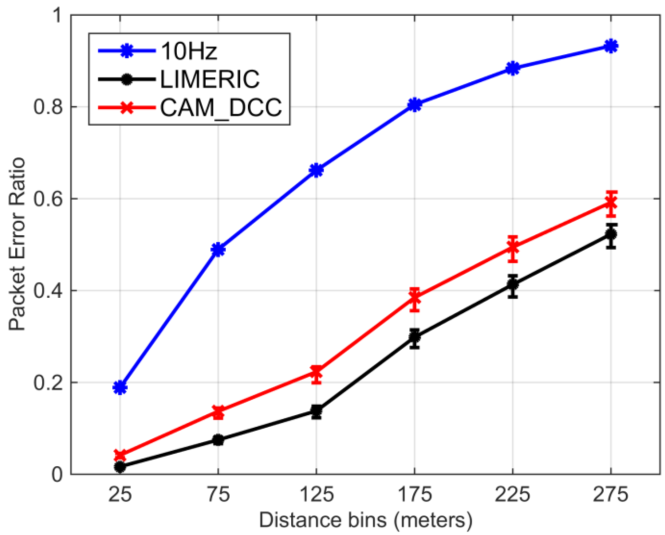
- 1000 nodes with uniformly distributed starting positions on the road
- Vehicle speeds up to 20 m/s
- Nakagami propagation model (~500 m transmission range)
- Channel load measured every 100ms over all nodes
- Time of first transmission for each node uniform randomly chosen in interval [0 0.5]sec after simulation start
- Simulation time = 200sec
- LIMERIC target = 79

Performance Metrics

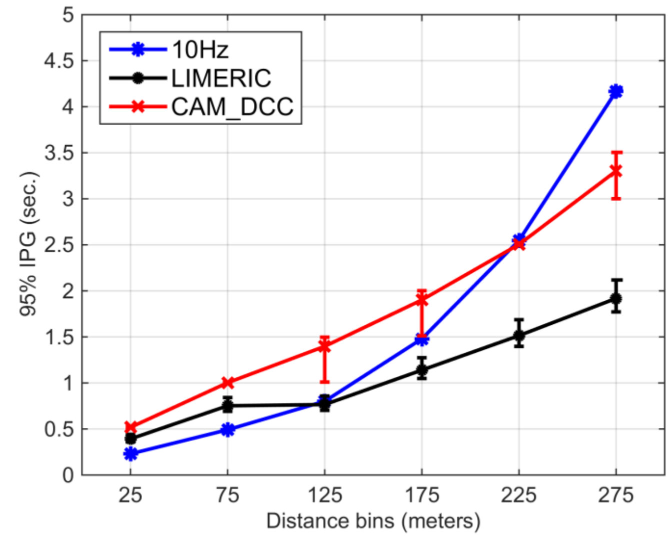
- Packet Error Ratio (PER)
  - the ratio of the number of missed packets at a receiver from a particular transmitter to number of packets sent by that transmitter
- 95^{th} Percentile Inter-Packet Gap (95% IPG)
  - Near worst-case elapsed time between successive successful packet receptions from a particular transmitter
- Channel Busy Percentage (CBP)
  - the percentage of the time during which the wireless channel is busy over the period of time during which CBP is being measured

All Metrics Comparison for 1000 nodes density

PER



95th% IPG

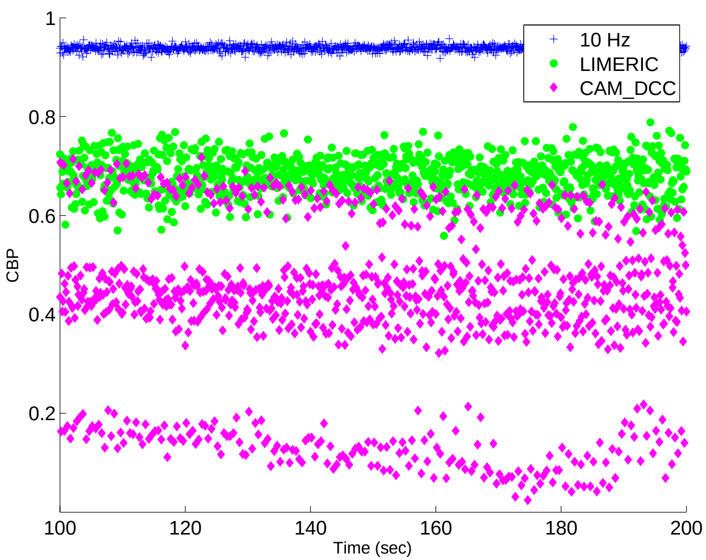


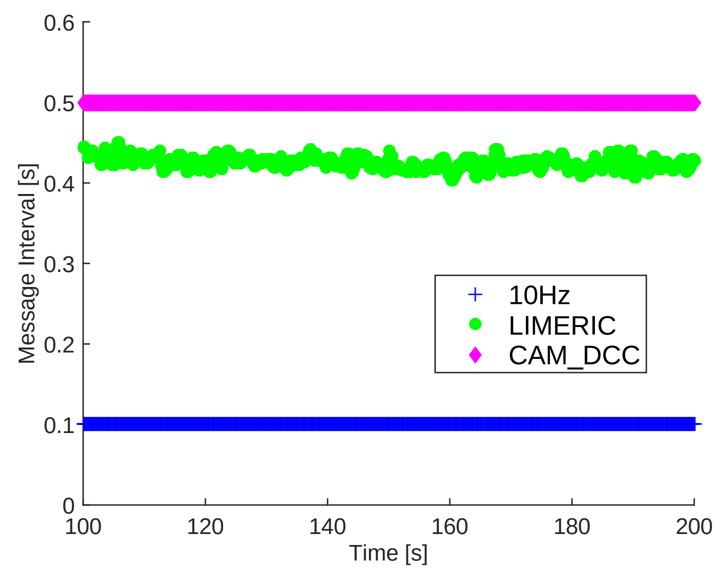
- Calculation is done for all the message transmissions where the transmitter located on the winding part of the road
- These metrics are averaged for these transmissions grouped in distance bins [50 m] between each pair of transmitter and receiver

Higher 95^{th}% IPG, while the PER is also higher → more packet collisions

Channel Load Analysis

- In the left plot, each colored dot represents a CBP value sampled every 100 msec, and the right plot is the corresponding message interval choices.
- The simulation has run for 100 seconds and 100 sec onward (transients from the initialization phase are removed)
- The number of vehicles in these simulations is 1000



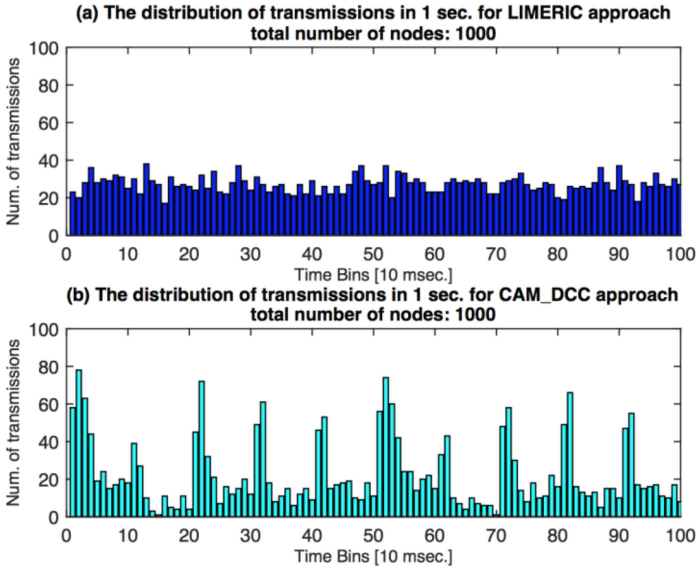


Observation: Unstable Channel Load for CAM-DCC

DCC Instability Causes

- What about the number of transmissions in a short time bin?

1. Synch CBP measurements with deterministic scheduling of transmissions
   - Even if vehicles don't measure the CBP at the same time, the DCC behavior is deterministic.



2. Limited choices for message rate
   - Nearby vehicles measure similar CBP and are therefore likely to choose exactly the same rate

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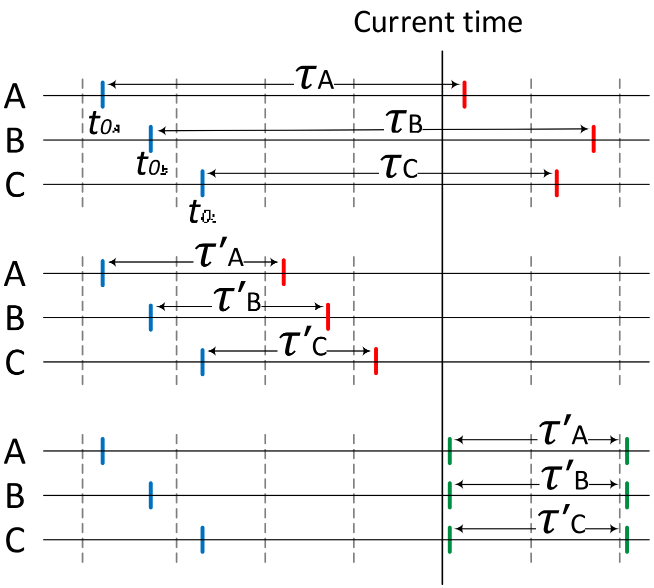
Clustered CAM Transmission Example

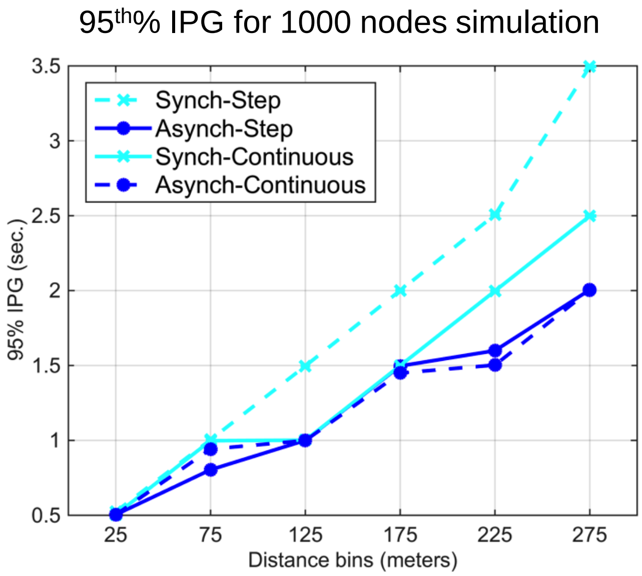
- The first planned transmissions are spread out in time as expected.
- A new CBP measurement becomes available before the planned CAM transmissions
- At this time (labeled as Current time) all three vehicles reevaluate their message rate.
- If the CBP measurement is low, they will choose shorter message, which changes the planned time for the next CAM generation.

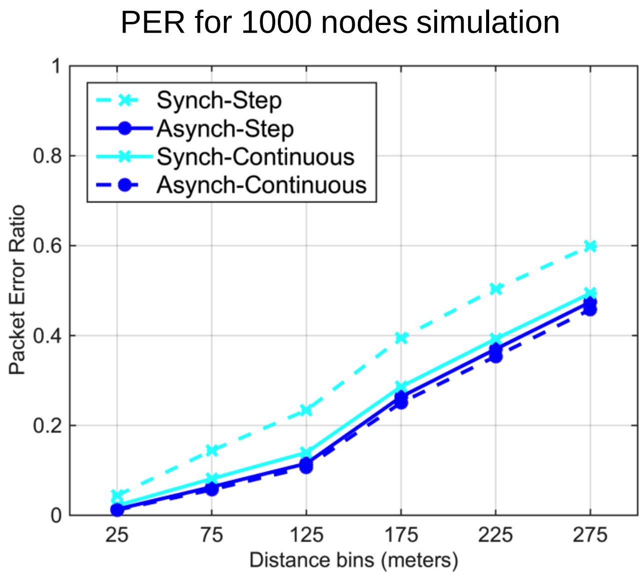


- This is an example of deterministic scheduling, which leads to a simultaneous message transmission.

Alternative Designs

- Based On the observations, the source of this clustered CAM transmission is the same time point to make the message rate decision, and limited choices of message rates.
- We designed three alternatives to remove one of these causes at each(Asynch-Step and Synch-Continuous), and for the last one, removed both causes (Asynch-Continuous)





Summary

- We compared two Vehicular networking channel congestion control protocols
  - LIMERIC shows lower Packet Error Rate. It also can deliver safety messages more frequently
- While LIMERIC effectively spread transmissions over time, DCC shows a deterministic behavior for choosing its transmission intervals
- Two Causes for DCC's unstable channel
  - Deterministic nature of choosing transmission intervals
    - Could be relaxed by Asynchronous CBP measurements across all vehicles
  - Limited number of message rate choices in look-up table
    - Using more table entries

Thank You

Questions?