CARS: Context Aware Rate Selection for Vehicular Networks

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Vehicular networks today

- Ubiquity of WiFi
  - Cheaper, higher peak throughput compared to cellular
- New applications
  - Traffic Management
  - Urban Sensing (eg. Cartel)
  - In-car Entertainment
  - Social Networking (eg. RoadSpeak, MicroBlog)

**Requirement**: High throughput
What is rate selection?

- **802.11 PHY: multiple transmission rates**
  - 8 bitrates in 802.11a/g (6 – 54 Mbps)
  - 8 bitrates in 802.11p (3 – 27 Mbps)
- **Different modulation and coding schemes**

<table>
<thead>
<tr>
<th>Link Quality</th>
<th>Bitrate</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>Underutilization</td>
<td>✓</td>
</tr>
</tbody>
</table>
Rate selection problem in vehicular networks

Rate Selection: Select the best transmission rate based on link quality in real-time to obtain maximum throughput
Outline

- Introduction
- **Existing solutions**
- CARS: Context Aware Rate Selection
- Evaluation
- Conclusion
Existing rate selection algorithms

- Basic scheme in all existing algorithms
  - **Estimation**: Use physical layer or link layer metrics to estimate the link quality
  - **(Re)Action**: Switch to lower/higher rate

**Question**: How well do these algorithms work in vehicular environments?
Existing schemes + vehicular networks: Experiment

- Outdoor experiments comparing
  - SampleRate [2005]
  - AMRR [2004]
  - ONOE [2005]
- 5 runs per rate algorithm
- 5 runs per fixed rate
- Slow Mobility: 25 mph
- Metrics
  - Average goodput
  - Supremum goodput (maximum among all runs for all rates)
Existing schemes + vehicular networks: Results

Underutilization of link capacity
Existing schemes + vehicular networks: Analysis

- Rapid change in link quality due to distance, speed, density of cars
- Problems:
  1. Estimation delay
  2. Sampling requirement
  3. Collisions vs. channel errors
Problem 1: Estimation delay

Link conditions change faster than the estimation window - the rate adaptation *lags* behind
Problem 2: Sampling Requirement

- When an idle client starts transmitting, there are no recent samples in the estimation window.
- Packet scheduling causes bursty traffic.
- Results in anomalous behavior.
Problem 3: Collisions vs. errors

- Hidden-station induced losses should not trigger rate adaptation [CARA06, RRAA06]
- Lower rate prolongs packet transmission time, aggravating channel collisions
- Use of RTS/CTS causes additional overhead
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CARS at a glance

- Rapid change in link quality due to distance, speed (context)
- Vehicular nodes already have this context information
- Use this cross-layer information at the link layer to estimate link quality and perform proactive rate selection
CARS: reactive + proactive

Link Quality: Error Function

\[ E_C = f(distance, speed, bitrate, len) \]

- Proactive
- Predicted error as a function of context information

\[ E_H = f(bitrate, len) \]

- Reactive
- Short-term loss statistics from estimation window
Proactive rate selection using $E_c$

$$E_c = f(distance, speed, bitrate, len)$$

- **Model** link error rate as a function of context information and transmission rate
  - Empirically derived using data from outdoor experiments
- Simple model is sufficient because of discrete rates in 802.11
- Context recalculation frequency = 100 ms
CARS Algorithm

Function \texttt{CARS\_GetRate}

\textbf{Input:} $\text{ctx, } \alpha, \text{len}$

\textbf{Output:} $\text{rate}$

1: \textbf{for all } $\text{rate}_i$ \textbf{do}

2: \hspace{1em} $\text{PER}_i = \alpha \cdot E_C(\text{ctx, rate}_i, \text{len}) + (1 - \alpha) \cdot E_H(\text{rate, len})$

3: \hspace{1em} $\text{Thr}_i = f(\text{rate}_i, \text{PER}_i, \text{num\_retr})$

4: \textbf{end for}

5: \text{Return } \text{rate}_i \text{ with maximum } \text{Thr}_i
CARS Implementation

- The CARS algorithm was implemented on the open-source MadWifi wireless driver
  - ~ 520 lines of C code
- Context information obtained from TrafficView [2004]
  - Generic /proc interface:
    - Any other app can be extended to provide a similar interface
- Extensively tested by means of vehicular field trials and simulations
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CARS Evaluation

- **Effect of Mobility:** How does CARS adapt to fast changing link conditions? (Field trial)
- **Effect of Collisions:** How robust is CARS to packet losses due to collisions? (Field trial)
- **Effect of Density of Vehicles:** How does the throughput improvement scale over large number of vehicles? (Simulation study)
Effect of mobility: Setup

Scenarios

- **Stationary**: Base case
  - Cars are stationary next to each other.
- **SlowMoving**: A simple moving scenario
  - Cars are driving around the Rutgers campus: ~25mph speeds
- **FastMoving**: A more stressful moving scenario
  - Cars are driving on New Jersey Turnpike: ~70mph speeds in high car/truck traffic conditions
- **Intermittent**: A scenario with intermittent connectivity
  - Cars move in and out of each other's range periodically - Hot-spot scenario

Workload:

- UDP traffic from TX to RX using iperf
- Duration of experiment - 5 minutes
Effect of mobility: Results

![Graph showing the effect of mobility on goodput with different scenarios: Stationary, SlowMoving, FastMoving, and Intermittent. The x-axis represents the scenario types, and the y-axis represents goodput in Mbps. The graph displays two sets of data: SampleRate and CARS.]
Effect of mobility: Analysis

Scenario: Intermittent

Reactive vs. Proactive
Effect of vehicle density - Setup

- **Hotspot scenario:**
  - Road of length 5000 m with multiple lanes
  - Base station in the middle of the road

- **Workload:**
  - Video stream: 1500 packets of size 1000 bytes each
  - UDP: transmission rate 100 packets per second
  - RTS/CTS disabled
  - Max_retransmits: 4

- **ns-2 with microscopic traffic generator**
  - Compared CARS with AARF and SampleRate
Effect of vehicle density - Results

![Graph showing goodput (Mbps) against number of vehicles for different scenarios: CARS, Sample, AARF. The graph indicates the impact of vehicle density on goodput.](image)
Effect of vehicle density - Analysis
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Conclusion

- Existing rate adaptation algorithms under-utilize vehicular network capacity
- CARS: uses context information to perform fast rate selection
- Significant goodput improvement over existing algorithms