Emergent Behaviors and Traffic Density among Heuristically-Driven Intelligent Vehicles using V2V Communications

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Research motivation
--- Path planning of Intelligent vehicles in urban roads ---

- **V2X communication**
  - Research on the domain of wireless communications
  - Limited study about the impact of communication on the traffic behavior

- **Path planning**
  - Research in the domains of AI and Robotics
  - Assumption of perfect communication

*Impact on individual’s knowledge*

*V2X communications*  
*Path planning*

*Impact on traffic density*
Research overview

• Objective
  • Study of collective behavior of vehicles, which individually plan their path based on information exchange.

• Modeling
  • Vehicles’ mobility: accelerate, decelerate or stop?
  • Finite state automaton
  • V2V communication: who can communicate with whom?
  • Signal propagation and MAC model
  • Path planning: which path to take?
  • Compass/Ant/No-ant heuristics

• Simulation-based experiments
Intelligent vehicle: Finite state automaton

1. Initial state:
   Randomly assigned position and goal (destination)

2. If the vehicle is on a straight road accelerate *(speed limit)* or decelerate *(collision avoidance, or red traffic light)*.

3. If the vehicle reaches an intersection choose the exit (N/E/S/W) of the intersection based on information obtained from the *V2V communication* and the path-planning heuristics.

4. If the vehicle reaches its goal location, randomly assign a new goal.
V2V communications

• Vehicles periodically broadcast **Cooperative Awareness Messages (CAM)** over the IEEE 802.11p technology

• Key factors that define communications performance
  • V2V signal propagation characteristics of the 802.11p in urban scenarios: defines communications range between vehicles
  
  • **MAC behavior** for CAMs transmissions: defines the performance of message delivery over the wireless channel shared by multiple users
V2V Communications -- Channel model--

- Two-ray ground ground reflection model (TRG)
  \[ L_{\text{TRG}} = 20 \log_{10} \left( \frac{4 \pi d^2}{\lambda} \right) \text{ when } d \leq d_s \]

- Two-ray interference model (TRI)
  \[ L_{\text{TRI}} = 20 \log_{10} \left( \frac{4 \pi d^2}{n \lambda} \right) \text{ otherwise} \]

- Both TRI or TRG (simpler) can be used for signal estimation for vehicles on the same road
- It is difficult to expect communications between vehicles on crossing roads
V2V Communications – MAC Model --

- IEEE 802.11p MAC: same as IEEE 802.11e
  - Prioritized channel access for different access categories
- Transmission of CAMs
  - A single AC
  - Broadcast: no retransmission

\[
\tau_s = b(0) = \left[ 1 + \frac{W - 1}{2(1 - p_k)} \right]^{-1}
\]

\[
\tau = (1 - \exp(-\lambda Y_s)) \times \tau_s
\]

\[
P_s = (1 - \tau)^{N-1}
\]
Path-planning heuristics

- **Compass**: Take the **shortest path** to the goal without considering vehicle density.

- **Ant**: Take the **most popular road**, which leads to the goal.

- **No-ant**: Take the **least congested road**, which leads to the goal.

\[
\begin{align*}
  a_1 &< a_2 \\
  \text{Compass} & : a_1 \quad (p_1 \text{ is always chosen}) \\
  \text{Ant} & : \max(\#\text{Cars}(a_1), \#\text{Cars}(a_2)) \quad (p_1 \text{ or } p_2) \\
  \text{No-Ant} & : \min(\#\text{Cars}(a_1), \#\text{Cars}(a_2)) \quad (p_1 \text{ or } p_2)
\end{align*}
\]
Experiments: NetLogo multi-agent simulator

- Scenario: Manhattan streets, traffic lights, traffic regulations, up to 400 vehicles

- Communications:
  - No communication.
  - Ideal communication: no communications error
  - Realistic communication: message delivery probability for a given transmitted CAM is calculated based on propagation/MAC models

- Path planning
  - Compass: No communication
  - Ant: with/without communication
  - No-Ant: with/without communication
Communications impact

- Ant/No-ant strategies show their expected behavior when comm. is ideal.
- And/no-ant strategies fail to show their expected behavior when comm. is realistic.
- Communications failure → Strategy failure
Emergent behaviors

- Communications has a positive impact on the collective behavior.
- Ideal communications: No-ant behavior outperforms ant-behavior.
- Realistic communications: the difference between ant and no-ant behaviors is small.
Conclusion

• Study on emergent traffic behavior of several hundreds vehicles as a function of V2V communication and path planning heuristics

• Vehicle mobility: finite state model
• V2V communications: channel and MAC models
• Path planning heuristics: compass/ant/no-ant

• Achieved insights
  • Communications impact is positive for the emergent vehicles’ behavior
  • Path planning strategies may not obtain their expected behavior due to the communications errors in realistic road environment
Thank you!

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Path-planning for Intelligent Vehicles

- Grid-based with a search algorithm (e.g., A*).
  - The finer the grid, the longer the search.
- Potential fields: attracted to goal, repulsed from obstacles.
  - Might be trapped in local minima.
- Paving-based search. Generate 2 sub-pavings such that $X^- \subset C_{\text{free}} \subset X^+$
- Sampling algorithms: sample N configurations and retain those in $C_{\text{free}}$. If there is a path between 2 samples, retain it; otherwise, re-sample.
  - Works well for high dimensional problems.