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

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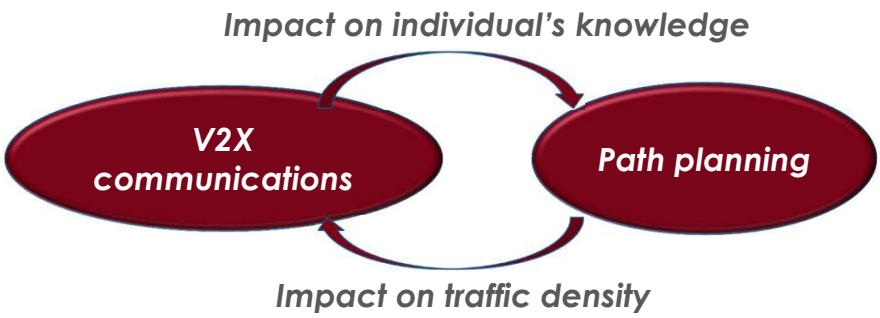
Research motivation

--- 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



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

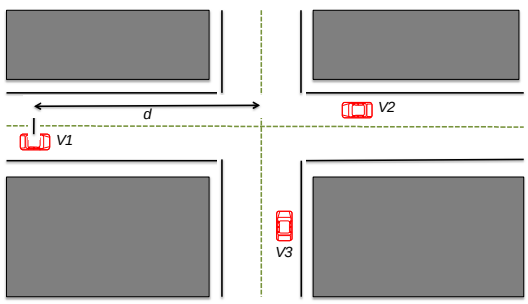
  - **MAC behavior** for CAMs transmissions: defines the performance of message delivery over the wireless channel shared by multiple users

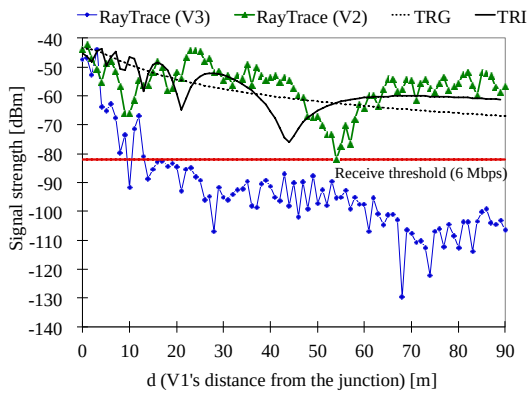
V2V Communications -- Channel model--

- Two-ray ground ground reflection model (TRG)

$$Ltrg[dB] = \begin{cases} Lfs = 20\log_{10}\left(4\pi\frac{d}{\lambda}\right), d \le d \\ Lfs = 20\log_{10}\left(4\pi\frac{d^2}{h_t h_r}\right), otherwise \end{cases}$$

- Two-ray interference model (TRI) $L_{tri}[dB] = 20\log_{10}\left(4\pi\frac{d}{\lambda}\left|1+\Gamma_{\perp}e^{j\varphi}\right|\right)$



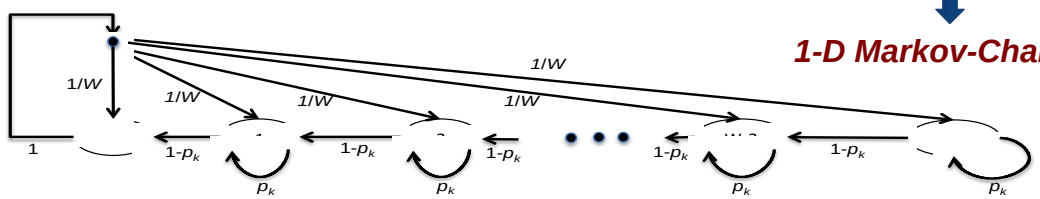


- Both TRI or TRG (simpler) can be used for signal estimation for vehicles on the same road
- It is difficult to expect communications between vehicles on crossing roads

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

1-D Markov-Chain



Channel access probability (saturated channel)

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

Channel access probability

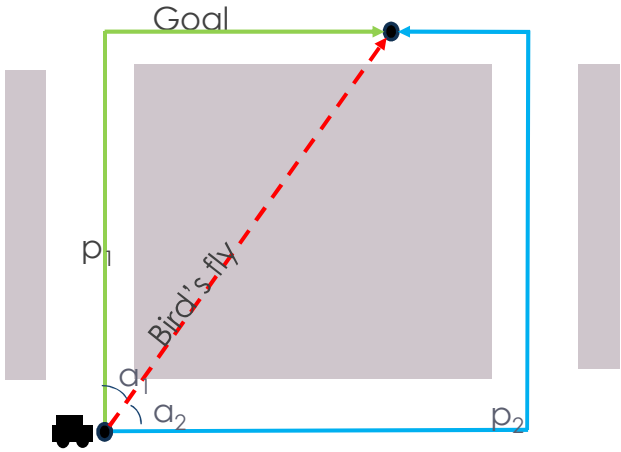
$$\tau = \left(1 - \exp\left(-\lambda Y_s\right)\right) \times \tau_s$$

Comm. success probability

$$P_s = \left(1-\tau\right)^{N-1}$$

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.



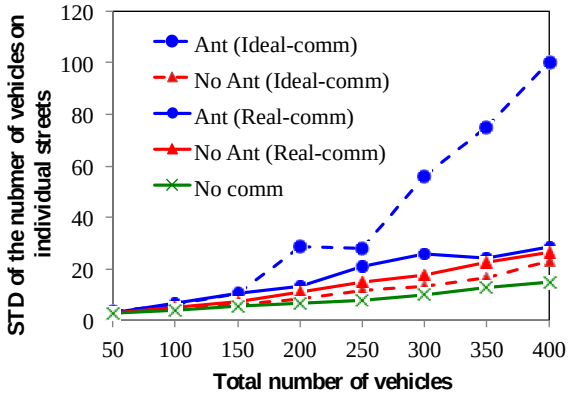
$$a_1 < a_2 \quad \begin{cases} \text{Compass} : a_1 & (p_1 \textit{ is always chosen}) \\ \text{Ant} : \max(\#\text{Cars}(a_1), \#\text{Cars}(a_2)) & (p_1 \textit{ or } p_2) \\ \text{No-Ant} : \min(\#\text{Cars}(a_1), \#\text{Cars}(a_2)) & (p_1 \textit{ or } p_2) \end{cases}$$

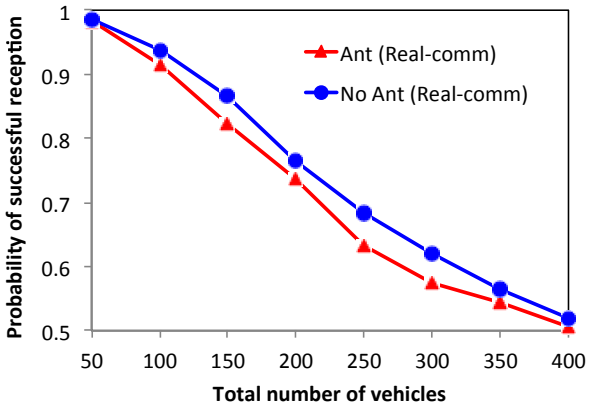
Experiments: NetLogo multi-agent simulator

- 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

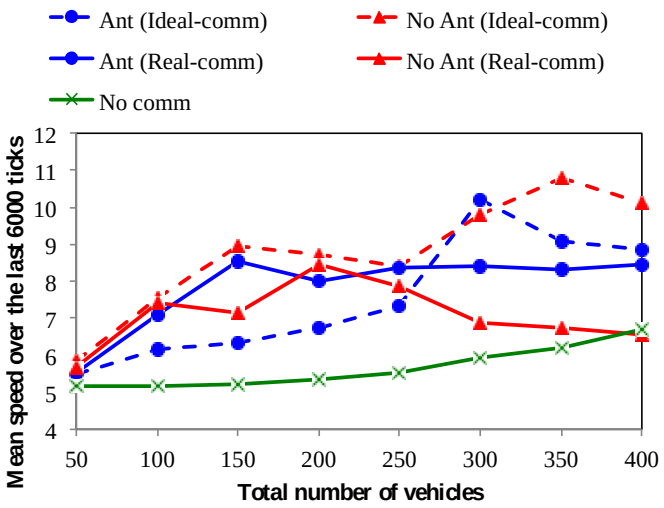
Communications impact





- 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 $X^- \subset C_{free} \subset X^+$
- Sampling algorithms : sample N configurations and retain those in C_{free}. If there is a path between 2 samples, retain it ; otherwise, re-sample.
  - Works well for high dimensional problems.