A two-level urban traffic control for autonomous vehicles to improve network-wide performance

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Motivation:
- Manual versus autonomous vehicles
- Also on traffic network level
Autonomous vehicles at junctions → autonomous intersection without physical traffic lights
Junction traffic model

\[ \hat{S}(k+1) = \hat{S}(k) + \hat{d}(\hat{S}(k)) \cdot v(k) \cdot T \]

To avoid collision, condition \(|d_A - d_B| > d_{\text{min}}\) must be valid at all times.

This constraint is considered later in the control design.
Emission model was also considered in the control design

• Traffic emission mainly consists of $CO$, $NO_x$, $HC$, and $CO_2$.

• For microscopic (vehicle based) emission the COPERT IV model was adopted:

$$ef(v) = \alpha_2^p v^2 + \alpha_1^p v + \alpha_0^p,$$

where $\alpha_i^p$ denotes the emission parameters for pollutant $p$. 
Network traffic model

\[ n_z(k + 1) = n_z(k) + T \sum_{w,z} \alpha_{w,z}q_{w,z}(k) - q_z(k) \]

Macroscopic Fundamental Diagram (MFD)
Two level optimization using SUMO traffic simulator and MATLAB

Microscopic level optimization

Macroscopic level optimization

- Simulation conditions
  - valid
  - invalid
  - Terminiation
- traci.simulationStep
- update system status
- update traffic profile
- update junction status
- call junction optimizer
- apply optimized speeds
- call macroscopic optimizer
- mod(step,20) = 0
- step = step + 1
- true
- false
Low level control in order to avoid collision

\[ J(k), \quad u(k + l - 1) \in \mathbb{U}, \]
\[ x(k + l) \in X, \]
\[ l = 1, 2, ..., K \]

\[ J(k) = \sum_{l=1}^{K} \sum_{i=1}^{N_{\text{vehicles}}} \left[ \alpha [1 + p_i] v_i^2 (k + l) + \beta [v_i(k + l) - v_i(k + l + 1)]^2 + \gamma f_i^2 (v_i(k + l)) \right], \]

\[ D = [d_{il}]_{N_{\text{vehicles}} \times K}, \]
\[ \min(D) > d_{\text{min}} \]

→ Nonlinear Model Predictive Control (MPC)

Highest mobility
Lowest emission
Priority parameter
Avoid collision
Acceptable distance

Constrained optimization
Macroscopic level control

Priority parameter is calculated based on the MFD model:

\[ p_z = \begin{cases} 0, & n_z \leq n_z^* \\ \frac{n_z - n_z^*}{n_z^*}, & n_z > n_z^* \end{cases} \]
Simulations

MATLAB+SUMO (TraCI)  http://www.dlr.de/
Test network with 4 intersections
Prediction and control horizons = 20 seconds
MPC optimizer: nonlinear (fmincon)
Visual results

Actuated
(time gap based actuated control)

Autonomous intersection control
The comparison of network mobility between the traditional and proposed methods.
Results

The comparison of CO$_2$ emission (based on HBEFA v3.1 data) between the traditional and proposed methods.
Conclusion and future work

• The performance of proposed control was justified:
  • High performance
  • Higher mobility
  • Lower emission

• Problems to overcome within the control design:
  • Disturbance can be present in the system, e.g. pedestrian crossing
  • Solution for the transition period (when traditional and autonomous cars are running together)
Thank you for your attention!!

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