Consensus-based cooperative control approach applied to urban traffic network

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Outline

- Introduction
- Proposed solution in a simulated environment
- Modeling
- Consensus-based cooperative control
- Simulation (Open & closed loop)
- Results & conclusions

Introduction

- Current smart cities research aims to the integration of urban subsystems for the anticipation and control of daily situations and unexpected events in order to succeed under complex and potentially unstable conditions.
- Overall performance of the city is determined by the dynamic behavior of coupled physical subsystems which have different domains or timing aspects.
- One of the main challenges is the necessary cooperation among different entities such as vehicles or infrastructure systems and exploit the information available through networks of sensors deployed as infrastructures for smart cities.

Introduction

- The increasing number of sensors, actuators, communication systems and low cost computation already deployed in cities, enable new applications that can go beyond specific systems and cover different urban systems and scenarios.
- **In this work an algorithm for cooperative control of urban subsystems is applied in order to provide solutions for mobility related problems in cities.**

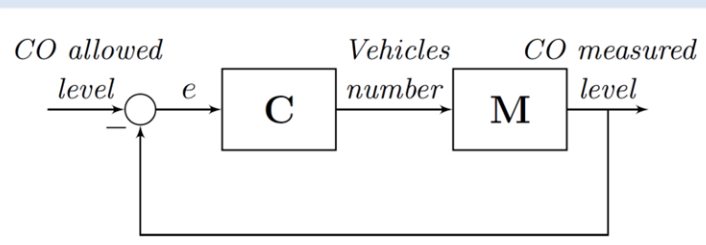
Proposed solution in a simulated environment

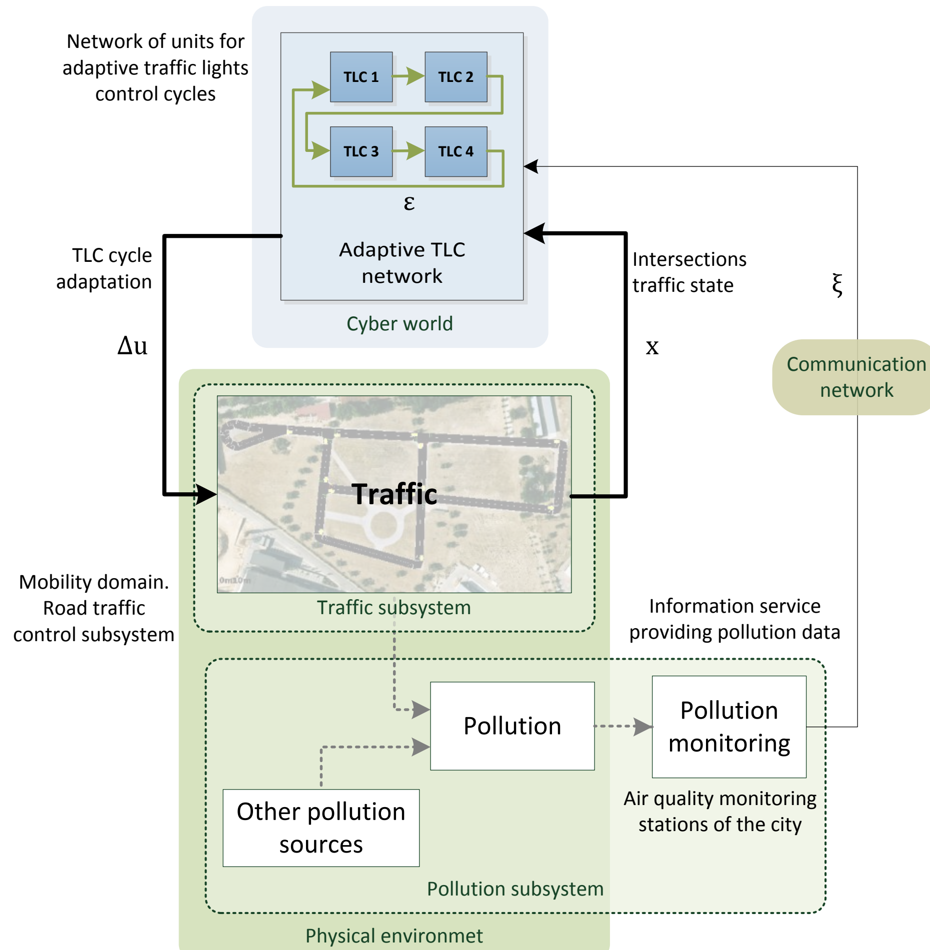
Goal:

- Improve performance of urban traffic networks, in specific regions of the city, based on air pollution information.

Scenario based on:

- Emission control scheme suggested by Andó et. al. [1]

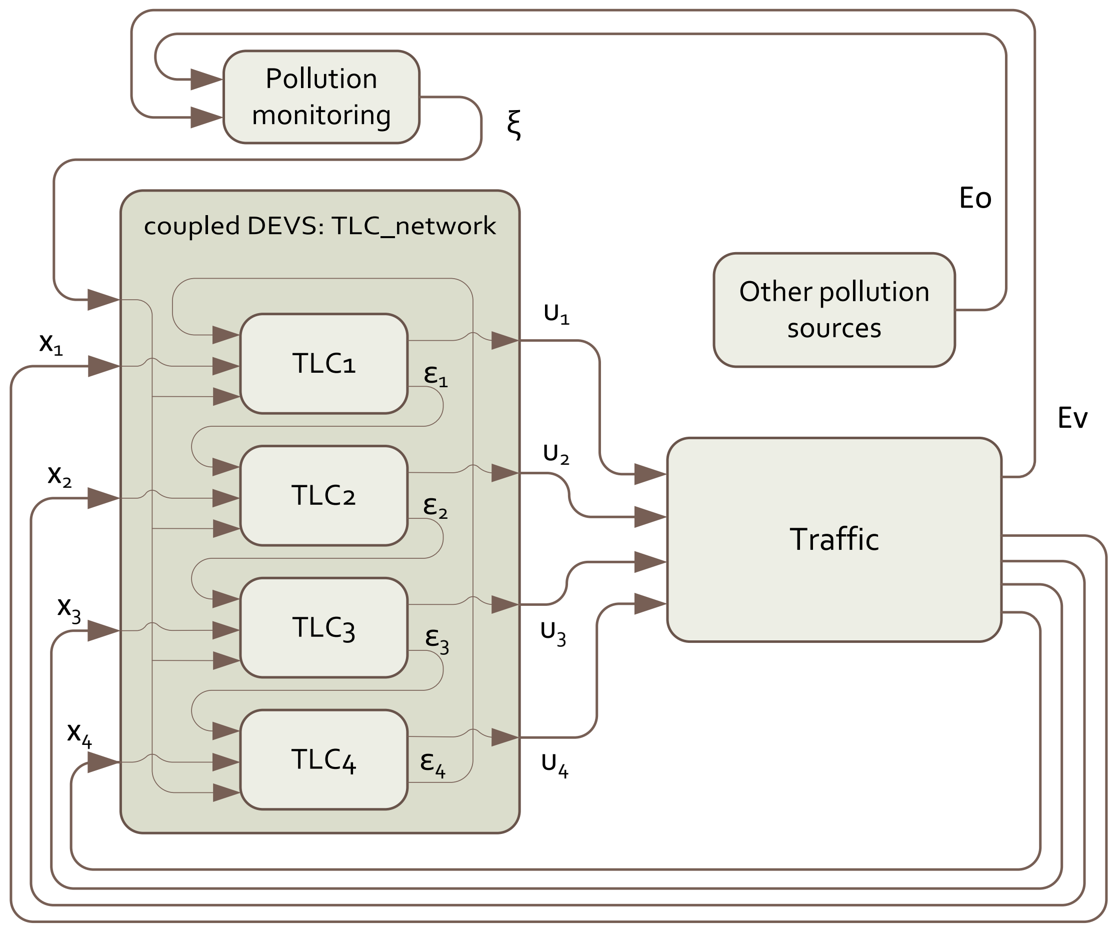




[1] B. Ando, S. Baglio, S. Graziani, E. Pecora, and N. Pitrone, "A predictive model for urban air pollution evaluation", in *Instrumentation and Measurement Technology Conference, 1997. IMTC/97. Proceedings. Sensing, Processing, Networking., IEEE*, 1997, pp. 1056-1059 vol.2..

Modeling: DEVS (Discrete Event Systems Specification)

- It enables specification of basic components and how they are connected together:
- atomic models, input ports, changing states, output ports, couplings.
- Atomic models:
  - Traffic-light control unit (TLC),
  - Pollution-monitoring system
  - Traffic system (i.e. road network, vehicles, traffic lights, etc.),
  - Other pollution sources
- Coupled models: TLC network



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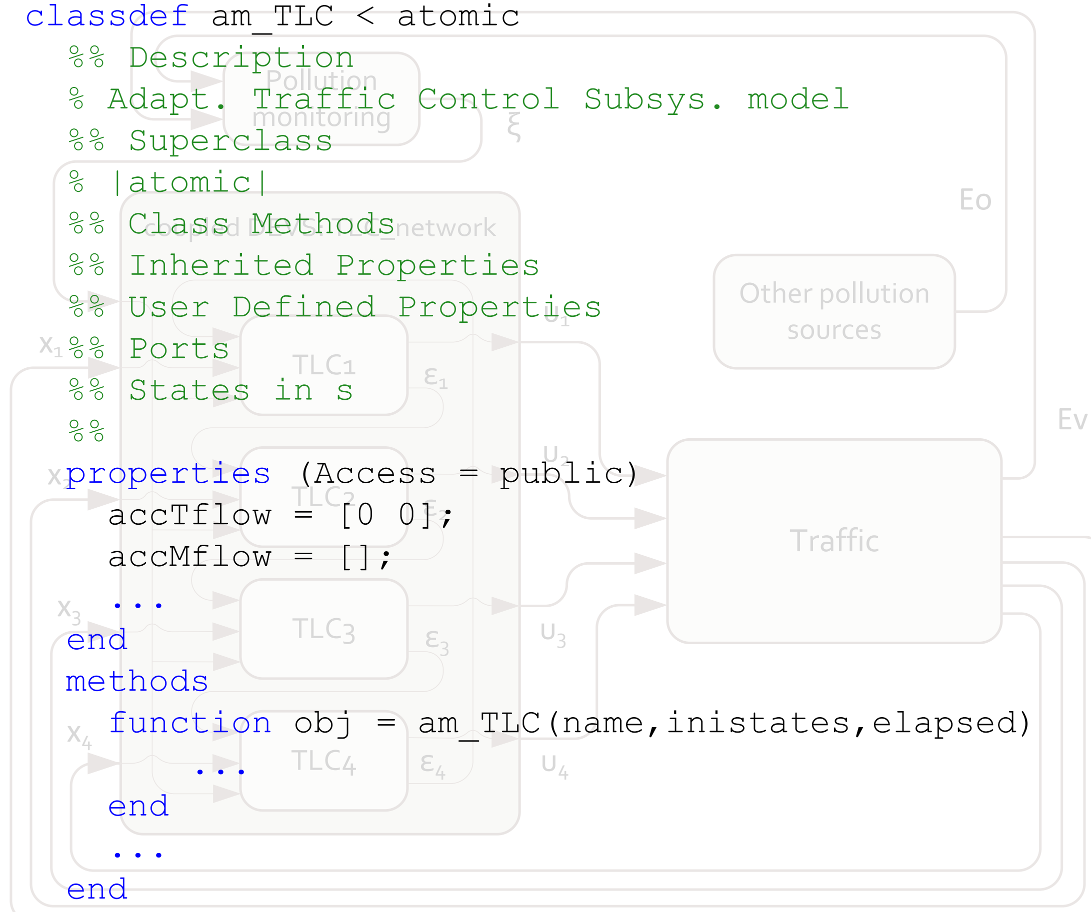



```
classdef am_TLC < atomic
  %% Description
  % Adapt. Traffic Control Subsys. model
  %% Superclass
  % |atomic|
  %% Class Methods
  %% Inherited Properties
  %% User Defined Properties
  %% Ports
  %% States in s
  %%
  properties (Access = public)
    accTflow = [0 0];
    accMflow = [];
    ...
  end
  methods
    function obj = am_TLC(name,inistates,elapsed)
      ...
    end
    ...
  end
end
```

Consensus-based decision-making

- Consensus: fundamental problem in the study of cooperative control for distributed multi-agent coordination.
- This approach deals with a set of systems each pursuing its own objectives as well as their common goals, employing communications between them.

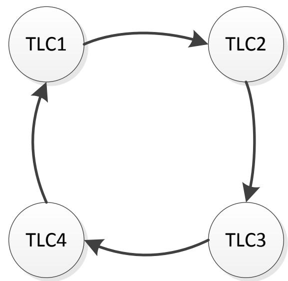
Why consensus?

- It's proposed in the literature as an SoS cooperative-control paradigm to extract greater benefits from the constituent systems of an SoS [2].
- Applications: cooperative control of vehicles, robots and rovers, wireless-sensor networks, traffic-optimization and control problems in urban environments

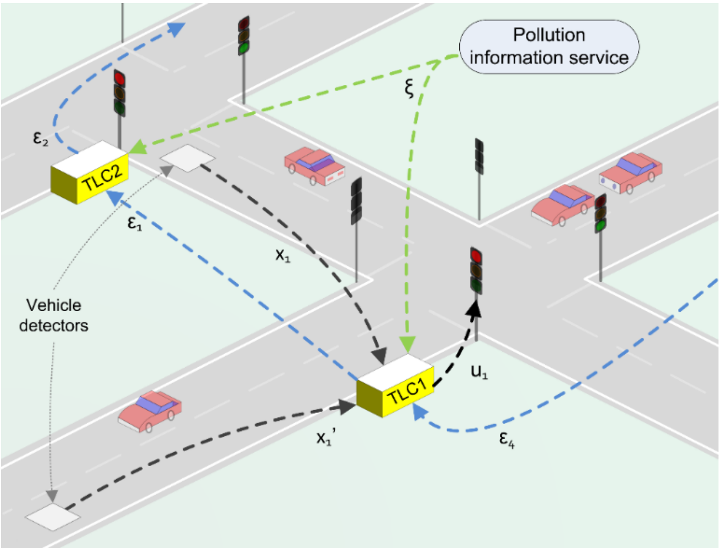
[2] T. Nanayakkara, F. Sahin, and M. Jamshidi, *Intelligent control systems with an introduction to system of systems engineering*: CRC Press, 2010.

Consensus-based cooperative control

1. Graph definition:



2. Representing system dynamics by a consensus state variable – estimation of pollutant concentration at each intersection



$$\varepsilon_i(k+1) = \varepsilon_i(k) + \alpha_i \xi(k-n) + \beta x_i(k-m) + \gamma \Delta u_i$$

Current value of consensus variable	Overall city pollution & intersection contribution factor	Measured total number of vehicles & relational factor to intersection emission	Control action in %: change of traffic light cycle & relational factor to local emissions

Consensus-based cooperative control

3. Consensus-based control law design

$$\Delta u_i(k) = -\frac{1}{\gamma}\left(\alpha_i \xi(k-n) + \beta x_i(k-m) + \lambda \sum_{j \in N_i} a_{ij}\left(\varepsilon_i - \varepsilon_j\right)\right)$$

- Feed-forward action related to local pollution data
- Feed-forward action related to local traffic data
- Consensus action based on consensus state of neighbors

Note: control action is restricted to a variation of ±50% over the initial value, to avoid large dissimilarities with pre-defined traffic-light cycle lengths.

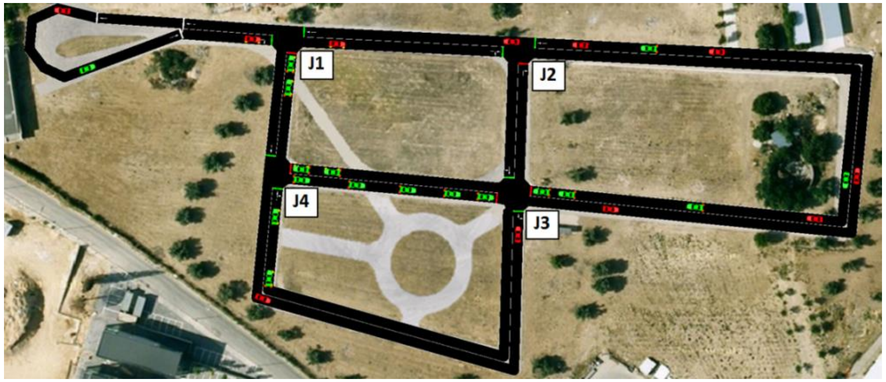
Open loop scenario simulation

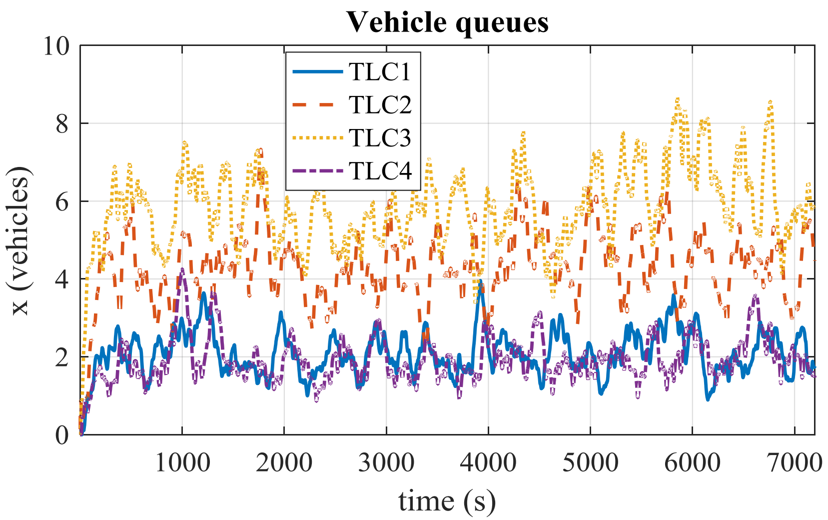
Based on an urban-like road network:

- 4 signalized traffic intersections & fixed traffic-light cycles
- Vehicles circulate following random routes.

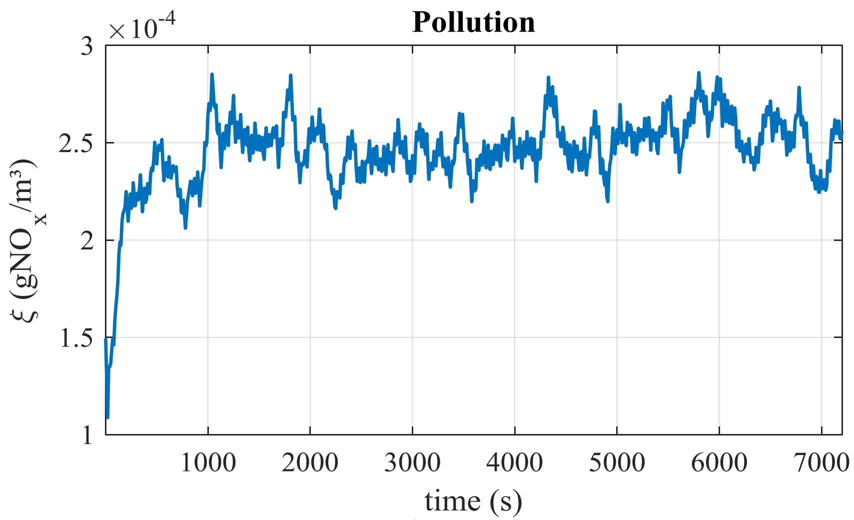
Tools:

- SUMO microscopic traffic simulator
- MatlabDEVS toolbox





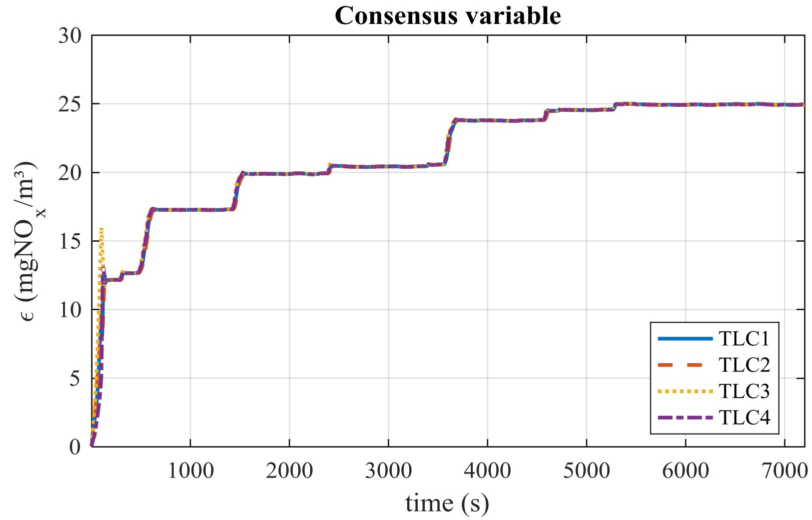
Traffic queues at intersections (AVG. vehicle queues for 20 secs at every approach)



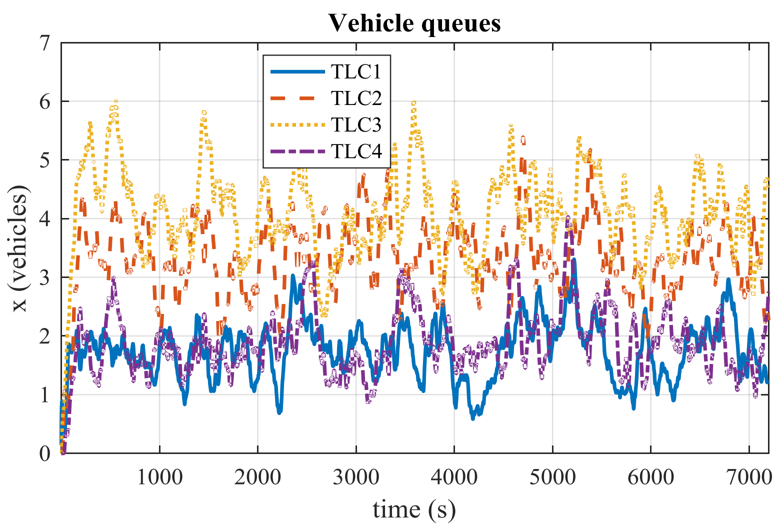
NO_x emissions (AVG. for 20 secs of the whole scenario)

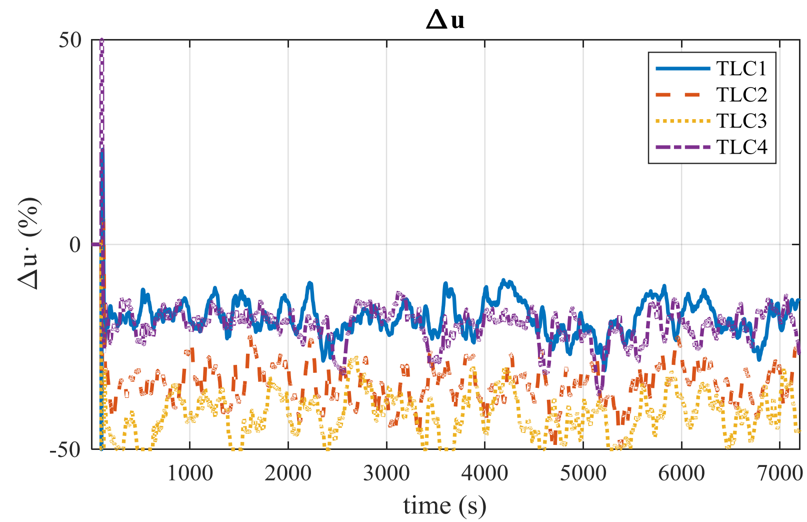
Closed loop scenario simulation

- Same scenario than open loop simulation
- Parameters of control system are specified in section 2.3 of the paper (pp. 4-5)



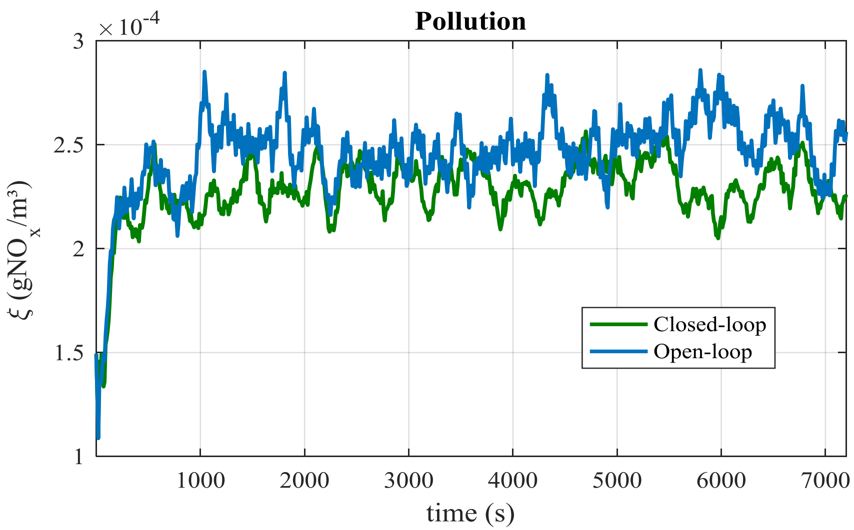
Vehicle queues at intersections (AVG. vehicle queues for 20 secs at every approach)





Simulation results

KPI (>100 scenario simulations)		Open-loop	Closed-loop	Differences relative to open-loop
Vehicle queues 1. $\frac{1}{t_f-t_s}\int_{t_s}^{t_f} \|x\|\, dt$	μ	13,4815	12,0382	**10,70** %
	max	15,0661	13,6345	9,50 %
Global pollution 2. $\frac{1}{t_f-t_s}\int_{t_s}^{t_f} \|\xi\|\, dt$	μ	$2,3879 \cdot 10^{-4}$	$2.3791 \cdot 10^{-4}$	0,37 %
	min	$2,2732 \cdot 10^{-4}$	$2,1910 \cdot 10^{-4}$	3,62 %



The effect of balancing consensus variables in every *TLC* produces a global reduction of vehicle queues

Conclusions

- Discrete event system specification (DEVS) modeling paradigm permitted operations with systems of a different nature and temporal behavior.
- Consensus-based control algorithms can be applied to the specific problems of traffic optimization.
- KPIs and simulations showed that the number of vehicles in queue decreased, while consensus state variable at each intersection tended towards a common value, demonstrating the validity of the proposed solution.

Thank you

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