SYSTEM-OF-SYSTEMS THAT ACT LOCALLY FOR OPTIMIZING GLOBALLY

EU FP7 - SMALL/MEDIUM-SCALE FOCUSED RESEARCH PROJECT (STREP)
FP7-ICT-2013.3.4: ADVANCED COMPUTING, EMBEDDED AND CONTROL SYSTEMS
D) FROM ANALYZING TO CONTROLLING BEHAVIOUR OF SYSTEM OF SYSTEMS (SOS)

5th Consortium Meeting

Simulation study of the adaptive decentralized approach for the signal control of urban traffic networks developed within Local4Global

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Local4Global
Contact Information

For information regarding this Project: Check the Project Web-Site: http://local4global-fp7.eu

	Participants
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2	ETHZ – Eidgenössische Technische Hochschule Zürich
3	RWTH – RWTH Aachen University
4	IK4 – IK4 TEKNIKER
5	TUC – Technical University of Crete
6	TRV – TRANSVER GmbH
7	TUM – Technische Universtität Muenchen

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EU FP7 - SMALL/MEDIUM-SCALE FOCUSED RESEARCH PROJECT (STREP)
FP7-ICT-2013.3.4: ADVANCED COMPUTING, EMBEDDED AND CONTROL SYSTEMS
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Discussion items

- Purpose of study
- The investigated control scheme
- Small-scale study
- Large-scale study
- Next steps

<u>Main study contributors</u>

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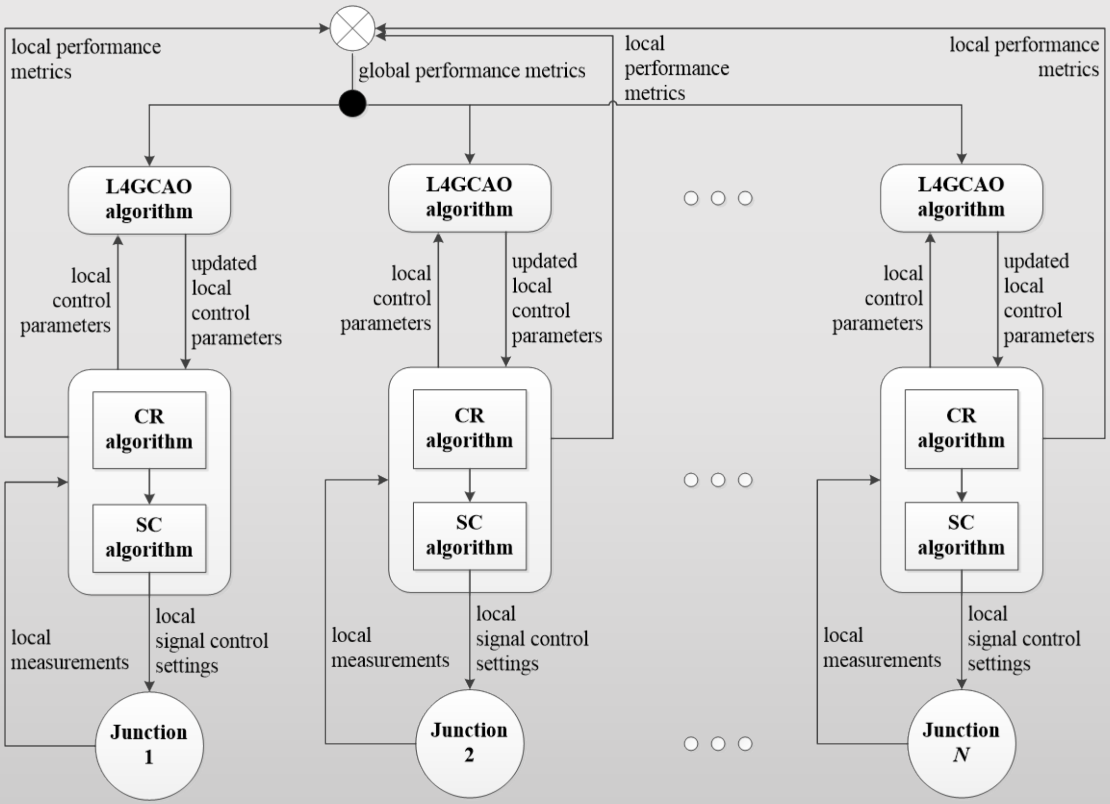
- I. Michailidis, E. Kosmatopoulos (CERTH)

Purpose of study

- Small-scale study:
  - Verify software performance of the tools developed within Local4Global for the traffic control case
  - Observe and verify the resulting control behaviour
- Large-scale study:
  - Investigate under realistic traffic conditions the performance and efficiency of the L4GCAO (Local for Global Cognitive Adaptive Optimization) algorithm
  - Compare the performance of the decentralised control approach of L4GCAO against the performance of CAO, its centralised counterpart
- Main goals:
  - Suggest any necessary modifications/improvements in all aspects (theoretical / software)
  - Produce project dissemination material (journal publications / conference presentations)

The investigated control scheme
Overview



- Cycle time update via a cycle regulation (CR) algorithm that constitutes a variant of the feedback-based control law of TUC (Traffic-responsive Urban Control) strategy (Diakaki et al., 2003); CR runs once per cycle time
- Green splits update via a split control (SC) algorithm that adopts a variant of the max pressure (MP) algorithm proposed by Kouvelas et al. (2014); SC runs once per cycle time
- Tuning of control parameters of CR/SC algorithms via the L4GCAO algorithm (Kosmatopoulos et al., 2015); L4GCAO runs at large time intervals (e.g. once per day)

The investigated control scheme
The cycle regulation (CR) algorithm

$$C(k) = \begin{cases} C_{\min} + K_1(\sigma(k) - \sigma_0), & \sigma(k) \le \sigma_{cr} \\ C_{\min} + K_1(\sigma_{cr} - \sigma_0) - K_2(\sigma(k) - \sigma_{cr}), & \sigma(k) > \sigma_{cr} \end{cases}$$

$$C \in [C_{\min}, C_{\max}]$$

- k: current control period
- $C_{\min}$: minimum permissible cycle time (s)
- $\sigma(k)$: average maximum load (veh) of a pre-specified number of links
- σ_0, σ_{cr}, K_1, K_2: control parameters tunable via L4GCAO

The investigated control scheme

The split control (SC) algorithm (1)

$$p_z(k) = \frac{x_z(k)}{x_{z,\max}} \cdot S_z$$

$$P_i(k) = \max\left\{0, \sum_{z \in v_i} p_z(k)\right\}$$

$$G_i(k) = \frac{P_i(k)}{\sum_{i \in F} P_i(k)} \left(C(k) - L\right)$$

- k: current control period
- p_z, P_i: link and stage pressures, respectively
- S_z: link saturation flows (veh/h)
- v_i: set of links receiving right of way during stage i
- F: set of signal control stages
- G_i: green time of stage i (s)
- L: lost times (s)
- x_z, $x_{z,\max}$: link load and capacity, respectively (veh)

The investigated control scheme
The split control (SC) algorithm (2)

- Application of control constraints via solution of problem A
- Enhancement of the importance of specific stages via setting resulting g_i equal to $b_i g_i$, with b_i corresponding importance factors tunable via L4GCAO
- Re-solution of problem A setting $G_i = b_i g_i$
- In problem A, $g_{i,\min}$ is the minimum permissible green time of stage i (s)

$$
pr.\mathbf{A} = \begin{cases} \text{Given } G_i(k) \ \forall i \in F : \\ \text{Find } g_i(k) \text{ for which} \\ \phi = \dfrac{1}{2} \sum_{i \in F} \dfrac{\left(g_i(k) - G_i(k)\right)^2}{G_i(k)} \rightarrow \min\limits_i \\ \text{s.t.} \\ \sum_{i \in F} g_i(k) + L = C(k) \\ g_i(k) \geq \mathrm{g}_{i,\min} \quad \forall i \in F \end{cases}
$$

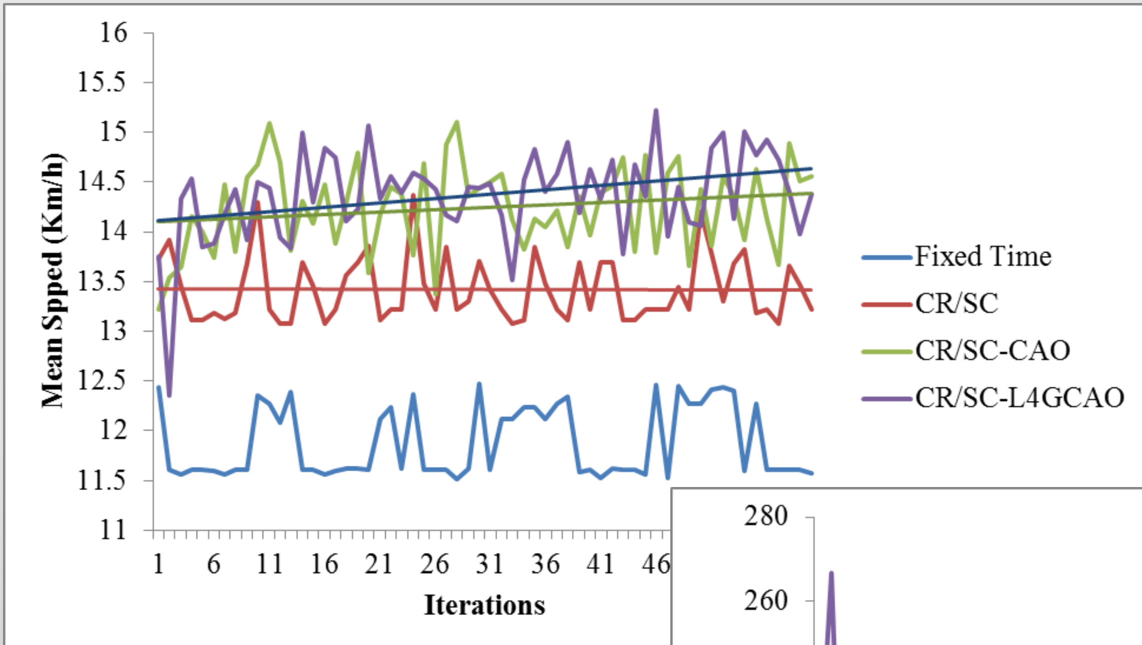
Small-scale study
Overview

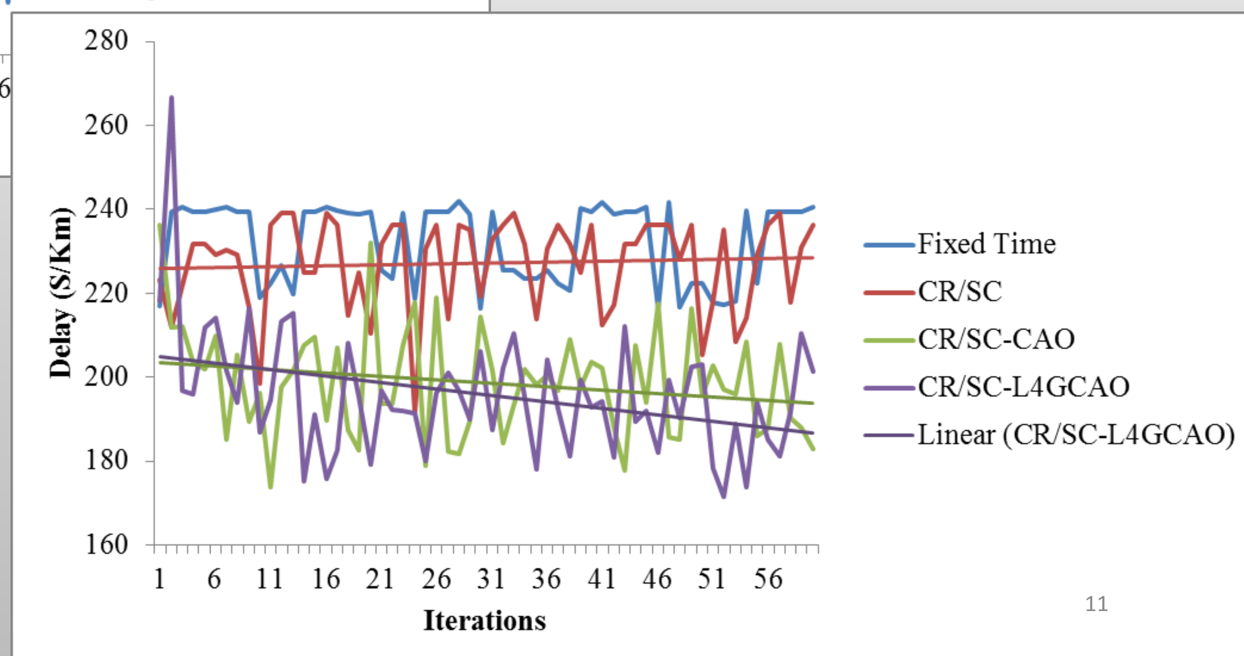
- Purpose:
  - Software verification
  - Control behaviour observation
  - Preliminary performance evaluation
- Tools: Use of an AIMSUN microscopic traffic simulation model of a 2 closely located junctions
- Demand scenario: Involves congested traffic conditions due to high demands during a 20 min peak period within a total 1-h simulation horizon
- Compared control cases:
  - *Reference control case*: Fixed 90 s cycle time plans with a time delay among the start of the cycle times of the two junctions in order to create a green wave
  - *Control case 1*: Application of CR/SC algorithms with centralised tuning of control parameters via CAO
  - *Control case 2*: Application of CR/SC algorithms with decentralised tuning of control parameters via L4GCAO

Small-scale study
Results

- Software verification:
  - Some problems and errors in the employed software tools were identified and corrected
  - Several performance criteria for the fine tuning of the control parameters were examined (sum of local mean speeds, network speeds, sum of local productivities, and network productivity); the sum of local productivities was selected
- Control behaviour, efficiency and performance:
  - CR/SC improve traffic conditions compared to reference control case without any tuning effort; mean speed increases by 13.24% on average over 60 iterations
  - Parameter tuning improves CR/SC performance; compared to reference case, mean speed increases by 19.91% and 21% on average, with CAO and L4GCAO, respectively
  - Overall performance presents an improvement trend with both CAO and L4GCAO
  - L4GCAO achieves a slightly better performance than CAO; this conclusion cannot be generalised

Small-scale study
Network performance trends



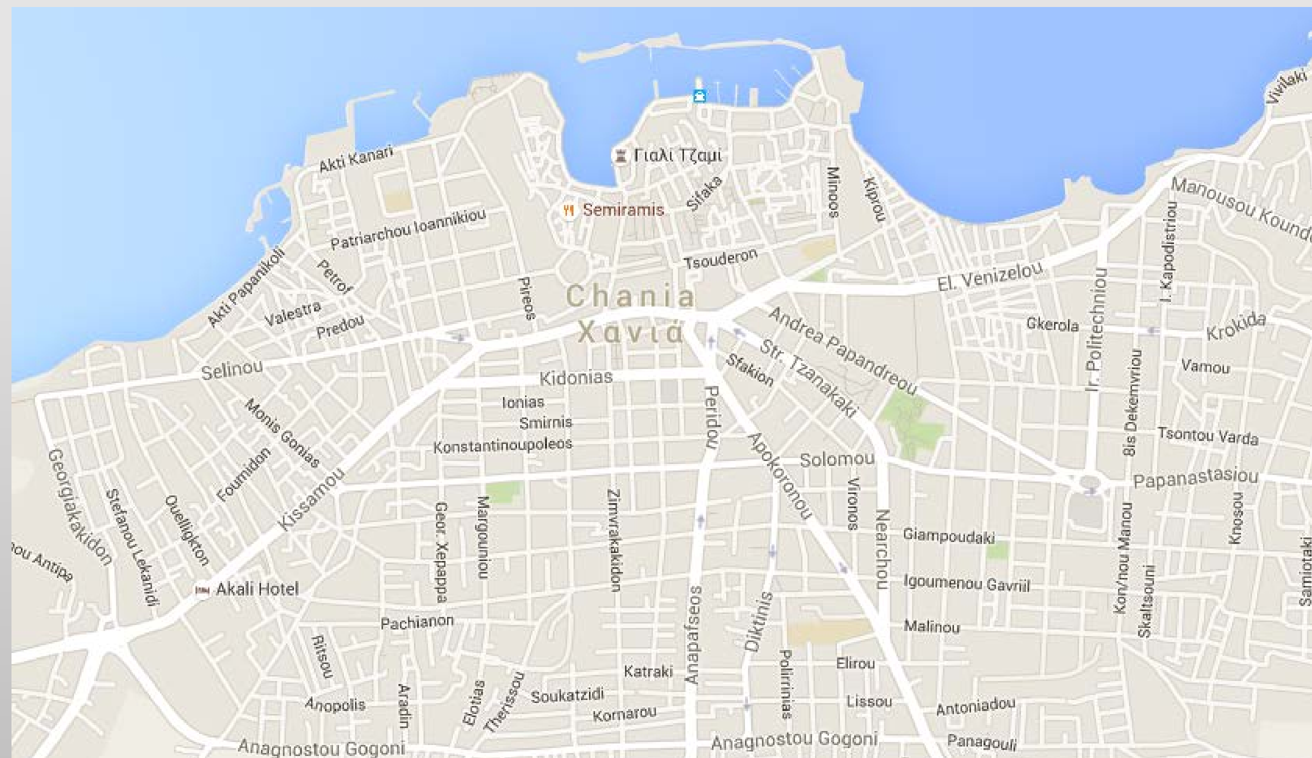


Large-scale study
Overview

- Purpose: Evaluation of developed control concepts under realistic traffic conditions in large-scale networks
- Tools: Use of an AIMSUN microscopic traffic simulation model of the city centre of Chania, Greece
- Control cases:
  - *Reference control case*: Fixed 90 s cycle time plans; they correspond to one of the fixed predefined network-wide signal plans used by the existing traffic control system
  - *Control case 1*: Application of CR/SC algorithms with centralised tuning of control parameters via CAO
  - *Control case 2*: Application of CR/SC algorithms with decentralised tuning of control parameters via L4GCAO
- Performance criteria:
  - Mean speed at the network (km/h)
  - Average delay time per vehicle (s/km)

Large-scale study
The network under study

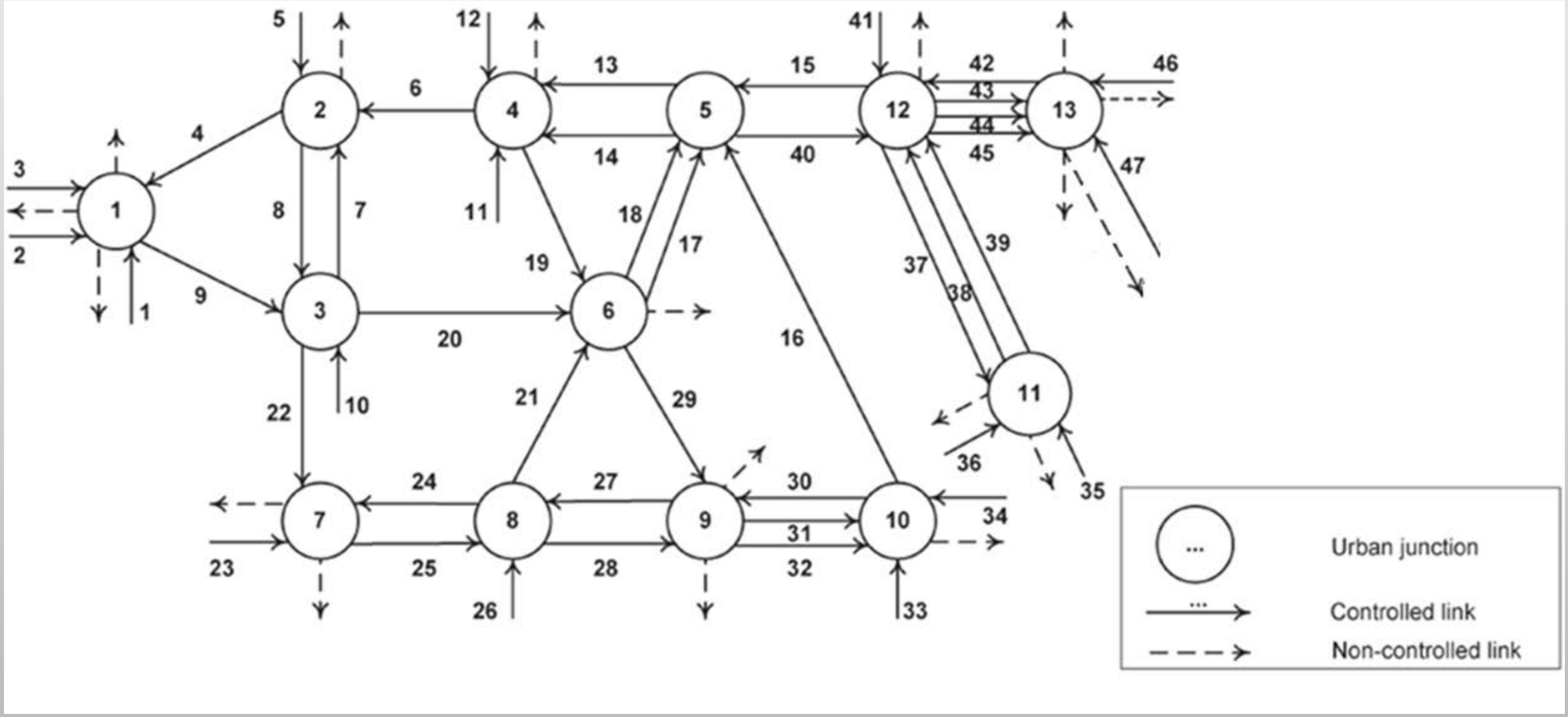
- City centre of Chania, Greece
- 13 junctions with 3-5 links entering links each
- Detector loops typically located either around the middle of the corresponding links or some 40 m upstream the stopline



- Traffic network characteristics and control constraints suggested by the system operators during a past study (Kouvelas et al, 2011)

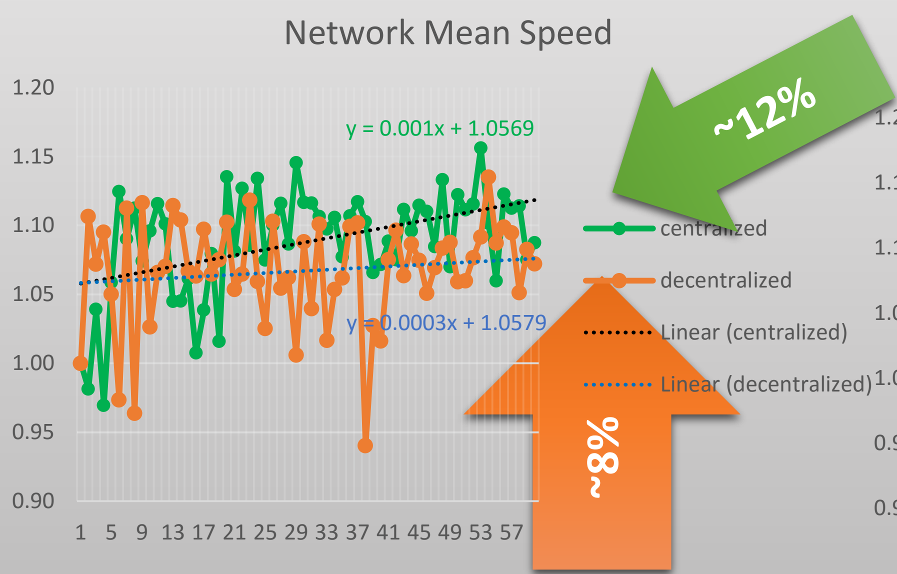
Large-scale study
Simulation characteristics

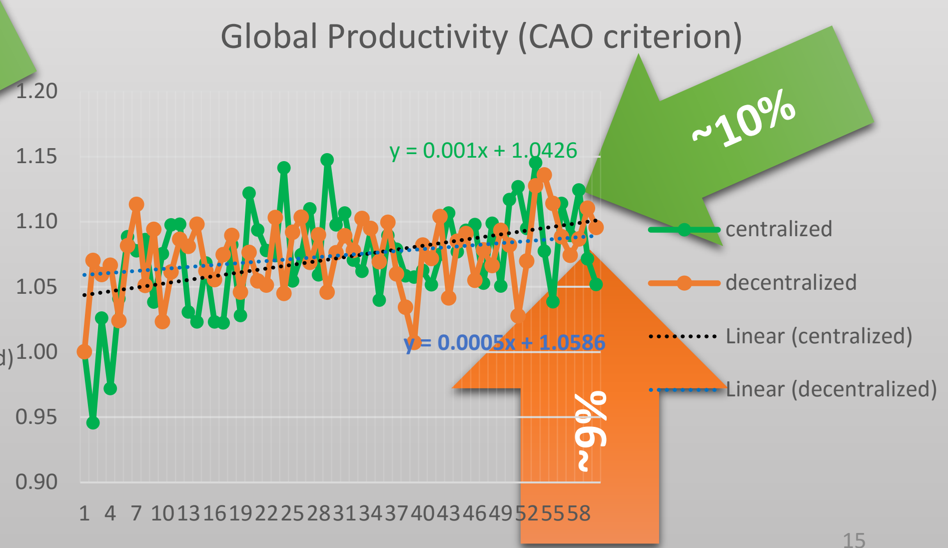
- Simulation step: 0.5 s
- Simulation horizon: 1 h
- Demand scenario: involves congested traffic conditions due to high demands during a 20 min peak period



Large-scale study
Results: Network performance

- 60 iterations with the same network feed
- Network performance: Productivity = NetworkMeanSpeed*NetworkDemand
- Decentralised and Centralised architectures were tested (maximum improvements 14.7% and 13.6% with respect to CAO criterion)
- Centralised trend (y=ax+b; a=0,001)
- Decentralised trend (y=ax+b; a=0,0005)





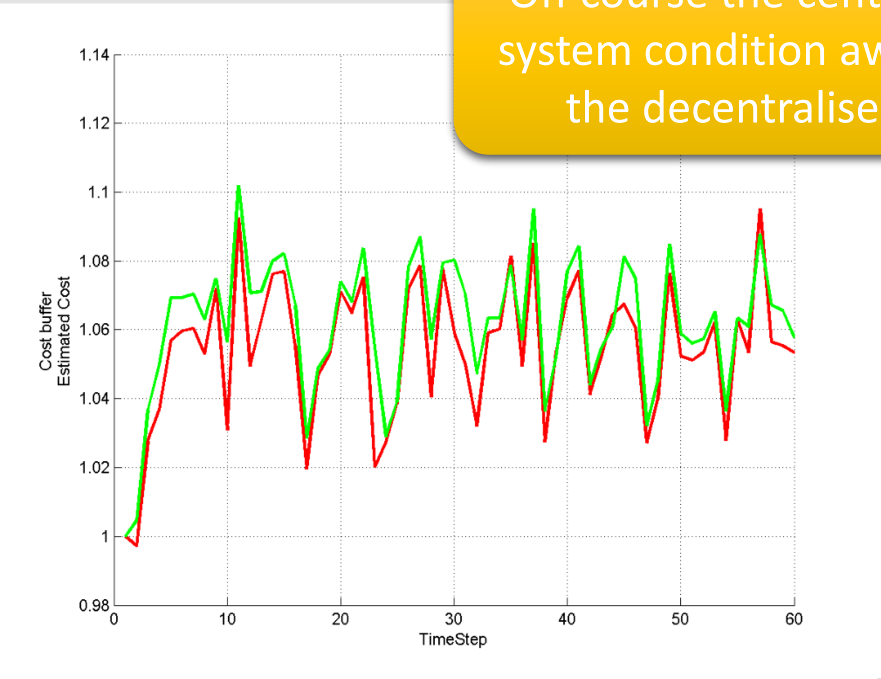
Large-scale study
Results: L4GCAO performance estimator

Very good approximation of the performance function (criterion)

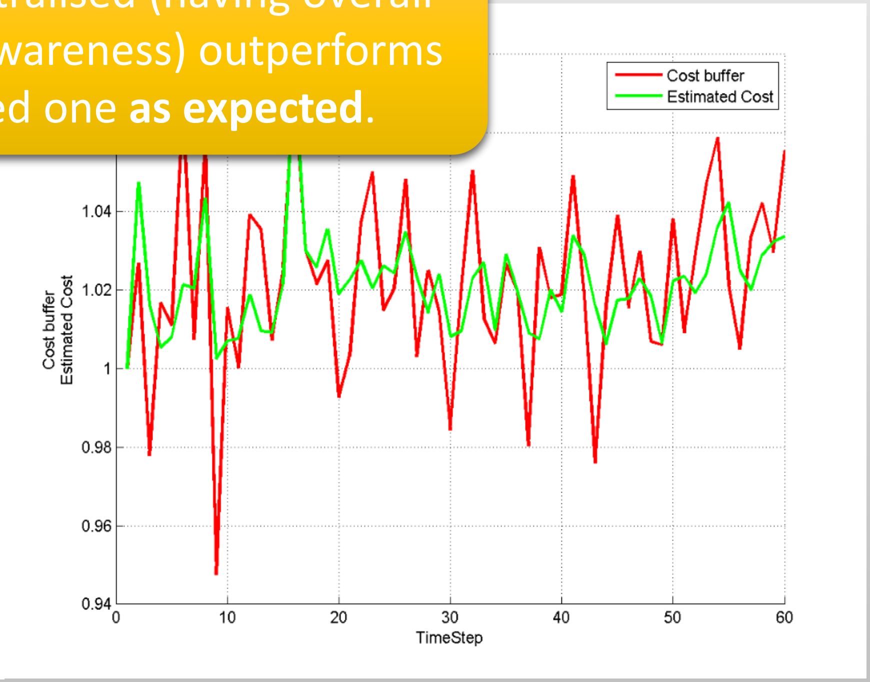
$J_{est} = F(theta_i)$

in both centralised and decentralised cases

Off course the centralised (having overall system condition awareness) outperforms the decentralised one **as expected**.



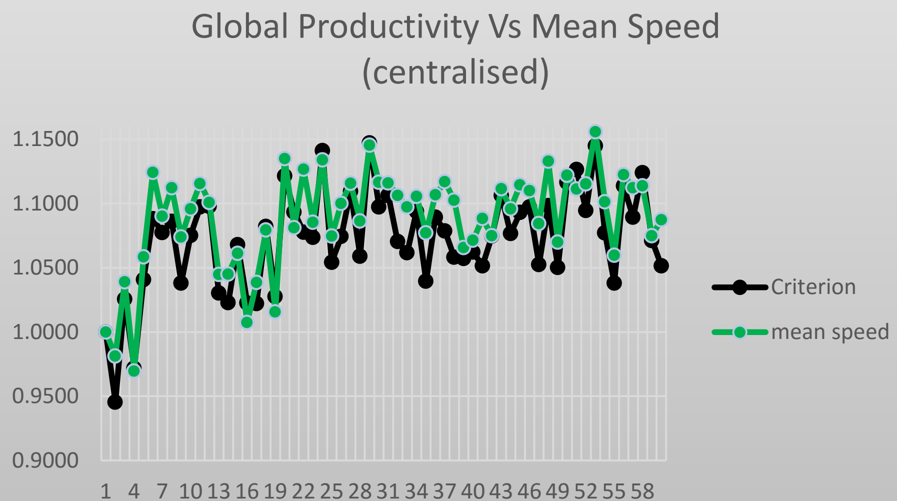
Centralised Simulation

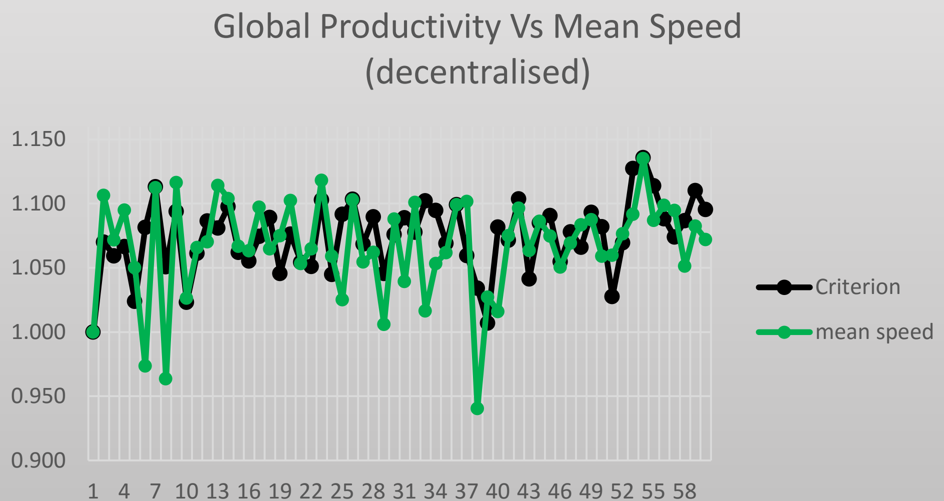


Decentralised Simulation (Region1)

Large-scale study
Results: Actual vs Estimated performance

- Decentralised best iteration using:
  - criterion = 54 (13,6%)
  - mean speed = 54 (13,5%)
- Centralised best iteration using:
  - criterion = 29 (14,7%) → mean speed (14,54%) the second best
  - mean speed = 53 (15,6%) → criterion (14,5%) the second best
- There is a possibility of misfit between actual & estimated performance in larger improvement areas, which may cause poorer performance within the optimisation scheme (i.e. measurements fail)





Large-scale study
Conclusions

- Estimated performance criterion might mislead L4GCAO tool especially in higher improvement areas
- Decentralised convergence performance is slightly poorer than the centralised; as expected
- In all cases positive convergence trend was observed
- Even from the early stages of the optimisation process, substantial performance improvements are observed
- Investigations so far do not involve noise; this is the next investigation step

Next steps

- Present AIMSUN-based investigation results in 9th Triennial Symposium on Transportation Analysis (TRISTAN IX)
- Prepare papers for conferences such as:
  - 24th Mediterranean Conference on Control and Automation (MED)
  - 5th Symposium arranged by European Association for Research in Transportation (hEART)
  - 5th International Conference on Transportation and Traffic Engineering (ICTTE)
- Prepare corresponding journal publication(s) (under consideration)
- Application and evaluation of the improved software concepts/tools to the Local4Global traffic case study in cooperation with the respective partners; in both simulated and real traffic conditions

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TUC / DSSL

Leader of WP2, Task 2.1 and D2.1

- The Technical University of Crete (TUC) was founded in 1977 in Chania, Crete, Greece, with the mission to develop modern engineering specialties, place emphasis on research in fields of advanced technology, and establish close cooperation with the industry and other production organizations in Greece (www.tuc.gr)
- The Dynamic Systems and Simulation Laboratory (DSSL) is the particular TUC's unit involved in Local4Global project. DSSL (www.dssl.tuc.gr):
  - Belongs to the section of Decision Systems of the School of Production Engineering and Management, was founded in 1988, and has been headed since 1994 by Prof Markos Papageorgiou
  - Has profound knowledge and broad experience in the theories of modelling, simulation, statistics, optimisation, automatic control, and their practical application to traffic and transportation systems, water networks, production systems, and further areas
  - Has been involved in numerous research and demonstration projects at a national, European and international level, gaining a remarkable experience through the implementation, testing, and evaluation of its several techniques and tools in real conditions
  - Will bring all the knowledge and experience in Local4Global and will gain by extending its perspectives in several respects

TUC – Key people involved

- Prof. Markos Papageorgiou

  - Person in charge of scientific and technical/technological aspects
  - WP2 Leader
  - Member of the Steering Committee

- Prof. Ioannis Papamichail

  - Contact person for administrative, financial and legal matters
  - RTD

- Dr. Christina Diakaki

  - Contact person for scientific and technical/technological aspects
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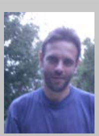
  - RTD

- Dr. Diamantis Manolis



  - RTD

Questions?

Thank you!