PROJECT FINAL REPORT

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1. Final publishable summary report

The developed Local4Global (L4G) system is a new generic and fully-functional system for controlling Technical Systems of Systems (TSoS) - also referred as Systems-of-CyberPhysical Systems. With L4G, the constituent systems (subsystems) of the TSoS are reacting and interacting depending only on their local environment towards optimizing the emerging TSoS performance at the global level. In other words, *Local4Global enables the constituent systems to operate and act, locally, in a distributed fashion without sacrificing, however, global performance*. This is made possible by equipping the TSoS constituent systems' control mechanisms with powerful-yet-computationally efficient learning, evolution and self-organizing characteristics capable of leading to (near-)optimal global TSoS performance. The development of L4G was based on methodologies (ingredients) developed, tested and evaluated - either in real-life or by means of simulations - in a variety of large-scale TSoS applications including Building Energy Management TSoS, Cooperative Traffic TSoS, Smart Grid/Micro Grid TSoS and Robotic Swarms. In all of these applications, the Local4Global system exhibited its *capability to provide substantial improvements in terms of global performance and KPIs while requiring minimum installation and operational costs both as far as it concerns the infrastructure required and the person effort for programming and tuning the TSoS operations.* The two main L4G Use Cases, correspond to a cooperative traffic control (Munich, Germany) Use Case and energy management (E.ON ERC building, RWTH Aachen University) Use Case. The demonstrations of L4G in these 2 Use Cases exhibited that it is a " fully-functional", "ready-to-use " system (L4G final product) - delivered in the form of an embedded, web-based, "plug-and-play" software system for generic TSoS. Most importantly, they exhibited the substantial cost savings and improvements in activities of everyday life. From the demonstration tests it could be observed that the Local4Global system is capable of delivering an average improvement of 22% in the Traffic network performance as well as an improvement of 27.5% in terms of Building Energy Efficiency, respectively. These improvements were made possible at minimum installation and operational costs as there was no need for a cumbersome programming, calibration or any other activity involving tedious human intervention and effort or the need for the deployment of an expensive infrastructure. It must be also emphasized that the L4G Building Energy Efficiency system was among the 4 winners of the international innovation contest Intelligent Energy Management Challenge organized by the Swedish Energy Agency and Swedish Incubators & Science Park, leading to an agreement for the potential implementation of L4G to many different buildings and districts in Sweden.

To this end, detailed exploitation and business plans regarding the L4G potential products were made. Among these potential products, the two most promising ones, the Local4Global ADAPTEENG-CLIMA (for building energy efficient control) and the Local4Global Mobility Tool (for Speed Navigation of vehicles) were further analysed and more thorough exploitation and business plans were made.

1.1. The Challenge

Despite the many impressive examples of human inventiveness, our technological advances for management and control of **Technological System-of-Systems (TSoS)** are still pale in comparison with the elegance, effectiveness and supreme functionality found in **Natural System-of-Systems (NSoS)** such as e.g., biological systems, the human brain, animal herds (swarms), teams of interacting/cooperating humans and ecological systems. The human developments, systems and methodologies for controlling the behaviour of TSoS, such as, e.g., transport and energy/water systems, emergency crisis management systems and complex industrial production systems, are by no means comparable to the "wisdom and effectiveness" of NSoS. In NSoS, a large number of constituent systems - operating, interacting, adapting, evolving and self-organizing in a fully-autonomous and local manner - achieves a highly efficient, self-adjusting, self-organizing and dependable performance of the overall NSoS. Even in cases where the NSoS constituent systems possess a highly heterogeneous nature and are mutually interacting and communicating through a very complicated and constantly changing topology, environment and hierarchy, the emerging NSoS is enabled to very effectively profit from each constituent system's "speciality" and comparative advantages towards successfully and rapidly meeting the overall NSoS goals and objectives.

What mostly characterizes NSoS is that local behaviour and interaction of the constituent systems leads to satisfaction of the NSoS goals at the global level without the need for a supervisor that gives direct orders and tells each constituent system what to do. In fact, each constituent system is "an autonomous unit that reacts depending only on its local environment" and its own capabilities. In cases where there is a supervisor or leader in the NSoS, it provides only with high-level goals for the overall NSoS, rather than specific commands to the constituent systems. Moreover, as the constituent systems operate in a local and autonomous fashion, the overall NSoS achieves to operate without the need for an "expensive and complete infrastructure", i.e.,

without the need to provide to each and every constituent system with complete information stemming from all over the NSoS. Most importantly, there is no need for tedious re-design and re-configuration operations whenever one or more constituent systems are to enter or leave the NSoS or when some of the constituent systems are malfunctioning (e.g., diseased cells or organs in a biological NSoS): the learning, evolution and self-organizing attributes of the NSoS make sure that constituent systems enter or leave the NSoS "smoothly" and, moreover, that the "healthy" constituent systems' actions can compensate for any malfunctioning of some of the NSoS constituent systems.
Apparently, if the above powerful attributes of NSoS were possible to be transferred and embedded into TSoS, this would lead not only to more effective and efficient TSoS operations but, most importantly, it would lead to TSoS that are significantly easier, safer and more reliable and economical to design, deploy, operate, monitor and re-configure.

1.2. Addressing the challenge: the project's proposition

The Local4Global (L4G) project is an attempt to address such an ambitious goal: to develop a new, generic and fully-functional methodology/system for controlling TSoS which optimizes the TSoS performance at the global level without the need of deployment and operation of an expensive sensor and communication infrastructure and, most importantly, without the need for the use of elaborate and time/effort consuming modelling, analysis, programming and control design tools.
With the tools offered by the L4G project, the TSoS constituent systems are operating as fully autonomous units that react and interact depending only on their local environment in order to optimize the TSoS emerging performance at the global level. There is no need for an elaborate and tedious effort to deploy the L4G system or to re-design/re-configure it in cases of changes in the topology, environment or hierarchy of the TSoS. In essence, the L4G methodology provides a "plug-and-play control mechanism" for the constituent systems with the ability to fully exploit each constituent system's abilities by embedding within it learning, evolving and self-organizing capabilities. Moreover, there is no need for an elaborate, "expensive" infrastructure that provides each and every constituent system with information coming from all over the TSoS. The L4G methodology/system is applicable to generic TSoS that comprise highly heterogeneous TSoS. Moreover, it is, by its very nature, totally scalable and computationally efficient.
The key idea of L4G is the following:

- Each of the constituent systems (subsystems) of the TSoS operates locally: a decision-making (control) mechanism uses local measurements to obtain the local actions (control signals) in each of the constituent systems. No communication or coordination between the different constituent systems is required. The decision making mechanisms depend on a set of control (tunable) parameters: different choices for these control parameters lead to different control actions.
- Periodically (e.g., once every hour or on a daily basis), the constituent systems send their performance (constituent system performance) to a control centre (one number per constituent system is sent to the centre). The control centre aggregates this information in order to obtain the global TSoS performance.
- The global TSoS performance is sent to each of the constituent systems (one number is sent to each constituent system). Using this single number information, the constituent systems *fully autonomously tune (update)* the control parameters of their own decision making mechanisms.

As it was demonstrated, both by means of theoretical analysis and simulation or real-life experiments, the above logic can optimize globally the overall TSoS performance, provided the constituent systems' decision making mechanisms are embedded with suitable learning, evolution and self-organizing mechanisms (which are described in more detail in section 1.6).

1.3. Who can benefit from Local4Global[2]

To better understand "who can benefit from Local4Global", let us first see why and when L4G solutions perform better than other solutions: the existing solutions for deploying TSoS control and optimization typically require (a) a sensor/actuator infrastructure that involves "dense" communication between the different sensor/actuator elements and, most importantly, (b) a tedious human-based involvement in modelling, analysis, programming, verification and calibration of the TSoS control mechanisms. Contrary to these solutions, L4G does not require either (a) or (b): the way of achieving to optimize TSoS performance without requiring (a) or (b) is by employing self-learning and self-adjusting: using their embedded self-learning and self-adjusting mechanisms, the TSoS control mechanisms automatically update (tune) their

[2] *For a more use-case-specific analysis on identified and expected beneficiaries from Local4Global's advances the reader is referred to subsection 1.8 below.*

control parameters towards optimizing the TSoS performance. Apparently, the price paid when L4G is applied is that a transient period is present, during which the L4G learning mechanisms learn the optimal policy.
It must be emphasized that the L4G performance during the transient period is safe - as exhibited both by the theoretical analysis and the simulation experiments performed in the L4G project, (see Figure 1 for indicative figures from simulative cases considered within the evaluation process of the project) - with no risk of poor or unsafe behaviour during this period. Nevertheless, the presence of such a transient period when L4G is applied is inevitable.

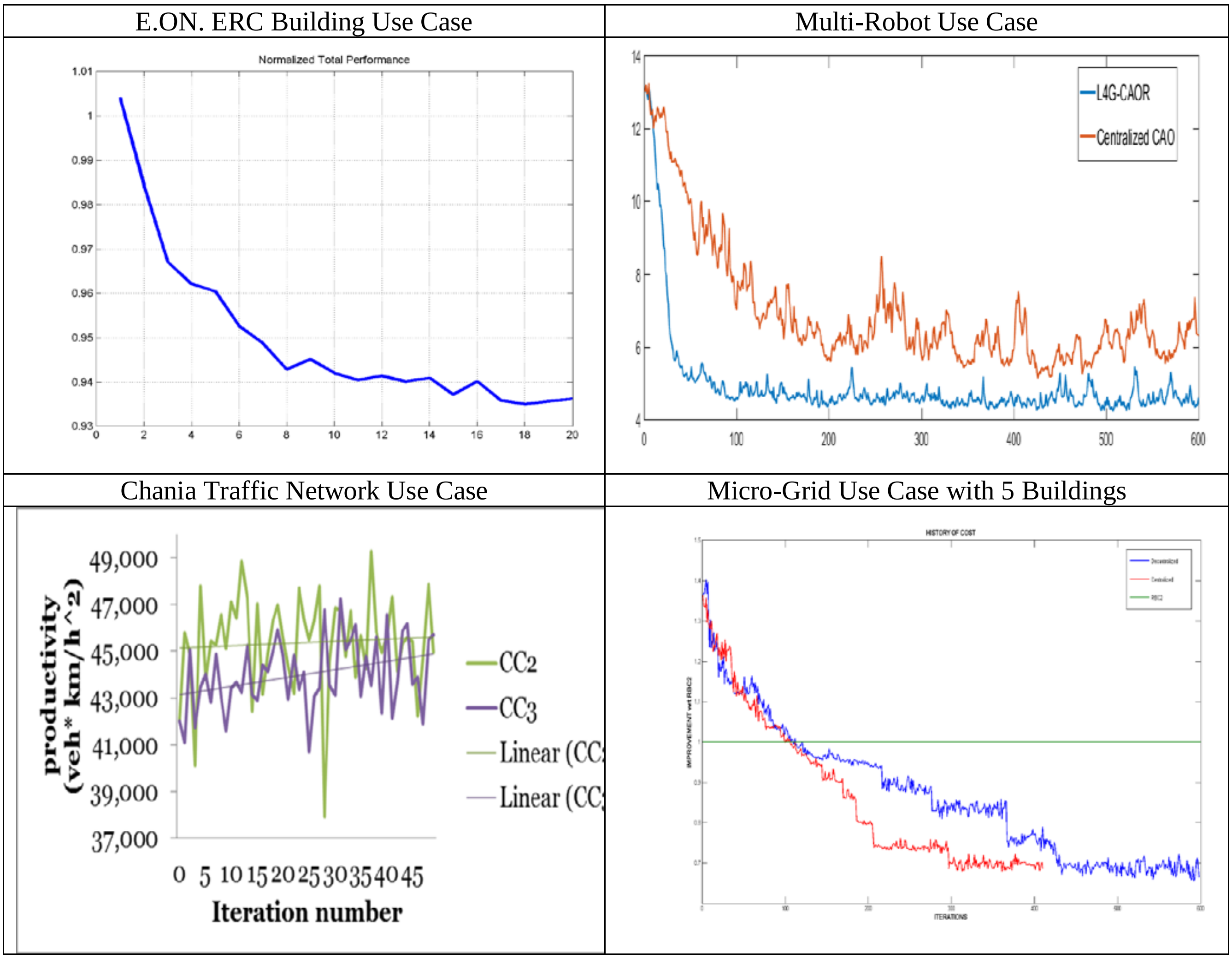


Figure 1. Performance Criterion Evolution during different L4G simulative applications.

Having the above in mind, in cases where

- it is affordable and cost-effective to deploy a "dense" infrastructure and to employ personnel for modelling, analysis, programming, verification and calibration, it may be preferable not to adopt L4G in order to avoid the presence of the transient period. Such cases correspond usually to small-scale TSoS such as e.g., automated vehicles where safety is the top priority and it is preferable to invest on a "dense" infrastructure and a very elaborate design of the decision making mechanisms rather than allowing phenomena such as transient periods which may put safety on risk.
- the "dense" infrastructure is already there and big investments have been already made for modelling, analysis, programming, verification and calibration. An example of such TSoS is the case of existing urban traffic control systems being operational for many years. In these systems, a centralized communication sensor/actuator infrastructure is available and, moreover, large investments have been made for programming, verifying and tuning the control logic over the years of system operation. As a result, even if L4G has the potential to significantly improve the performance of the system, the inevitable

presence of the transient period along with the unforeseen risks of deploying a new system, discourage the authorities from adopting L4G.

On the other hand, the L4G system can be of significant value to TSoS applications in cases where the presence of the "transient period" is either inevitable no matter what solution is employed or in cases where the costs for deploying the infrastructure and/or employing the personnel for programming, verifying and tuning the control logic render the deployment of existing solutions extremely expensive:

- The cases of affordable-to-the-"everyday"-home-owner, "plug-n-play", building energy efficient systems, the case of speed navigation apps for cooperative vehicles and the case of robotic swarms deployed over unknown environments (for e.g. performing search and rescue or inspection missions) are typical examples of TSoS where the presence of a transient period is inevitable no matter what solution is employed. As it is practically impossible to program, verify and tune a control and optimization strategy for each single building, each single vehicle and its driver and each different type of robotic swarm mission, the control strategy embedded within such TSoS examples must possess some type of learning attributes so as to learn the individual TSoS characteristics. This, in turn, implies that a transient period is inevitable in all of these examples.
- The cases of building energy efficient systems for large-scale buildings or the case of newly installed urban traffic control systems are examples of TSoS where implementing one of the existing solutions is highly expensive as it requires not only an elaborate infrastructure but, most importantly, a highly expensive manual-based programming, verifying and tuning procedure.

Local4Global can be highly beneficial not only to the areas of the above mentioned cases (*Building Energy Efficient Control, Intelligent Traffic Systems and Robotics*). The generality of the L4G tools together with the fact that L4G is of plug-n-play nature, guarantee the direct transferability of the Local4Global system to many other TSoS, where the presence of the "transient period" is either inevitable no matter what solution is employed or in cases where the costs for deploying the infrastructure and/or employing the personnel for programming, verifying and tuning the control logic render the deployment of existing solutions extremely expensive:

- *large-scale manufacturing and production plants, airport and seaport terminal control operations*
- *control of internet services, computer and communication networks,*
- *control of large-scale MEMS, smart materials, etc.,*
- *control of large-scale water distribution or sewer networks, multi-reservoir or irrigation systems,*
- *Smart Grid.*

In many of these TSoS, several different designs for the deployment of elaborate control systems have been proposed but there are very few full-scale implementations of such systems in practice. This is largely due to the hesitation of the system operators to deploy an expensive infrastructure or to adopt complex control systems, whose performance may heavily depend on many control parameters (which are difficult to understand and thus to calibrate). The self-learning and self-adjusting attributes of Local4Global together with its minimum infrastructure requirements and the fact that Local4Global can provide information at the global (macro) level can tremendously help in increasing operator's confidence and willingness to adopt Local4Global.

The enhancement of existing as well as future TSoS designs/applications with efficiency, robustness, safety and adaptability through the use of Local4Global system in conjunction with the great savings resulting from its application is expected to boost a new market. This market includes not only TSoS areas where control implementations are in a premature stage or do not exist at all, but also market sectors where the high cost of maintenance of the control and management system has so far hindered the deployment of control/management systems. Such market sectors include control systems in third-world or developing country economies; the deployment and operation of such systems in these countries is not affordable, not only due to the high maintenance and operational costs (which can be significantly reduced by the use of Local4Global), but also due to the lack of highly-educated, experienced personnel, capable of taking over the manual fine-tuning process.

The successful application of the Local4Global system in the Building Efficient Energy Management (BEEM) Use Case implies that Local4Global is capable of providing a very inexpensive system (service) for producing great energy savings in, e.g., an apartment building or of a building neighbourhood. All the residents of the apartment building/building neighbourhood have to do is to install and configure a smartphone-like application in a similar way they install and configure any other device at their home. In other words,

Local4Global opened the way towards the development of "plug-and-play" control systems, similarly to the way plug-and-play systems for communication and the internet operate: no need for an expensive infrastructure and, moreover, no need for a - or a team of - engineer(s) responsible for modelling, preparing, calibrating and tuning the system.
The impact and consequences of the availability of such a system can be significant and not only limited to areas and systems where no sophisticated control is currently employed (due to the requirement for an elaborate infrastructure). It can also be of great significance to areas and systems where, despite that the infrastructure is there, current control and management systems "cannot do the job". The most prominent example is traffic and transport systems: the infrastructure is there (most of the traffic networks are equipped with all necessary sensor/actuator/communication infrastructure), but the control and management systems cannot cope efficiently with congestion, unless a very time-consuming calibration procedure is involved. The typical situation is that such a calibration procedure lasts from few weeks to several months without the guarantee that it will be always successful (there are several reported examples where such a calibration procedure has failed to produce any improvements).
Moreover, the Intelligent Transportation Systems (ITS) industry is a market area that substantially accelerated within the last two decades and has a worldwide turnover that amounts to dozens of billions of euros (note that the cost of road traffic congestion in Europe alone exceeds € 120,000,000,000 per year). The general ITS market includes a variety of products, some of which are deemed “traditional”, others being relatively recent and yet others being labelled as ‘emerging’. A common characteristic of most related applications is the system complexity that stems from a number of factors including geographical extent, the involvement of humans (e.g., drivers), the notoriously increasing demand for traffic and the interaction of various traditional and emerging technologies (wireless communications, satellite technologies, location technologies, etc.). This high level of complexity is a significant burden for the broad deployment of existing products or the introduction of new and emerging products. In this context, the need for appropriate adaptive optimisation of interacting distributed systems (constituent systems) is one of the challenges that may decelerate the related market expansion. The generic, easily applicable and automated self-tuning enabled by the Local4Global approach is expected to accelerate the corresponding marketing and deployment developments for both available and emerging products in this branch of industry.

1.4. Highlights of achievements

The development of L4G was based on methodologies (ingredients) developed, tested and evaluated - either in real-life or by means of simulations - in a variety of large-scale TSoS applications including Building Energy Management TSoS, Cooperative Traffic TSoS, Smart Grid/Micro Grid TSoS and Robotic Swarms. In all of these applications, the Local4Global system exhibited its capability to provide substantial improvements in terms of global performance and KPIs while requiring minimum installation and operational costs both as far as it concerns the infrastructure required and the person effort for programming and tuning the TSoS operations. The two main L4G Use Cases, represent a cooperative traffic control (Munich, Germany) Use Case and energy management (E.ON ERC building, RWTH Aachen University) Use Case. The demonstrations of L4G in these 2 Use Cases exhibited that it is a " fully-functional", "ready-to-use " system (L4G final product) - delivered in the form of an embedded, web-based, "plug-and-play" software system for generic TSoS. Most importantly, they exhibited the substantial cost savings and improvements in activities of everyday life. From the demonstration tests it could be observed that the Local4Global system is capable of delivering an average improvement of 22% in the Traffic network performance as well as an improvement of 27.5% in terms of Building Energy Efficiency, respectively. These improvements were made possible at minimum installation and operational costs as there was no need for a cumbersome programming, calibration or any other activity involving tedious human intervention and effort or the need for the deployment of an expensive infrastructure. It must be also emphasized that the L4G Building Energy Efficiency system was among the 4 winners of the international innovation contest Intelligent Energy Management Challenge organized by the Swedish Energy Agency and Swedish Incubators & Science Park, leading to an agreement for the implementation of the system to many different buildings and districts in Sweden.
To this end, detailed exploitation and business plans regarding the L4G potential products were made possible based on tangible economic projections of Local4Global’s advantages as derived by the evaluation analysis. Among these potential products, the two most promising ones, the L4G ADAPTEENG-CLIMA (for building energy efficient control) and the Local4Global Mobility Tool (for Speed Navigation of vehicles) were further analysed and more thorough exploitation and business plans were made so as to take full advantages of the very nice attributes of these products, especially the following ones:

ADAPTEENG-CLIMA	L4G Mobility Tool
The main economic benefit from the *L4G ADAPTEENG-CLIMA* product for the building owners/users are the significant savings in energy bills, which are equivalent to ***average annual energy savings of 309.4-771.4€/year for an average household***, resulting in **a payback period of 3 to 6 months (if BA system is available) or 6 to 12 months (if not).**	The main economic benefit from the *L4G Mobility Tool* for the average European driver are the savings in ***vehicle's fuel consumption at an average of more than 400€/year savings*** with the purchase of a low-cost application (***operation cost less than 10€/month or 25% surcharge on savings***) and without any additional hardware (except a conventional GNSS-based navigator or a smartphone).

1.5. The Pilots

Within Local4Global two use case sites were considered, for real-life implementation, tests and evaluation of the ICT tools developed according to the description of work, as listed and described below:

- Cooperative Traffic TSoS Use Case: B13 Road Munich, Germany
- Efficient Building TSoS Use Case: E.ON ERC, Aachen, Germany

1.5.1. Cooperative Traffic TSoS Use Case: B13 Road Munich, Germany

The Bavarian Road Administration defined a test site to test and evaluate the outcomes of Local4Global, namely the Federal Road B13 in the north of Munich (Germany). This road section with a length of more than 7 km allowed for the test of new technologies in a rural environment with comparably long distances between intersections and high-speed sections (see Figure 2). The Bavarian Road Administration identified this road, because of the high traffic loads and good potential for improvement. The road stretch is equipped with traffic signal components by Siemens. Traffic light configuration and harmonization of signalling times was achieved in cooperation with the local road authorities. Moreover, control of cooperative vehicles was also integrated within the overall scheme by setting up a bidirectional communication between vehicles and a control centre (server) at IK4's premises: smartphones were used to deliver the route and speed recommendations as calculated by the Local4Global system to the drivers. On the other hand, information from the vehicles was used within the control centre in order to optimize traffic signal control considering the prevailing traffic conditions.

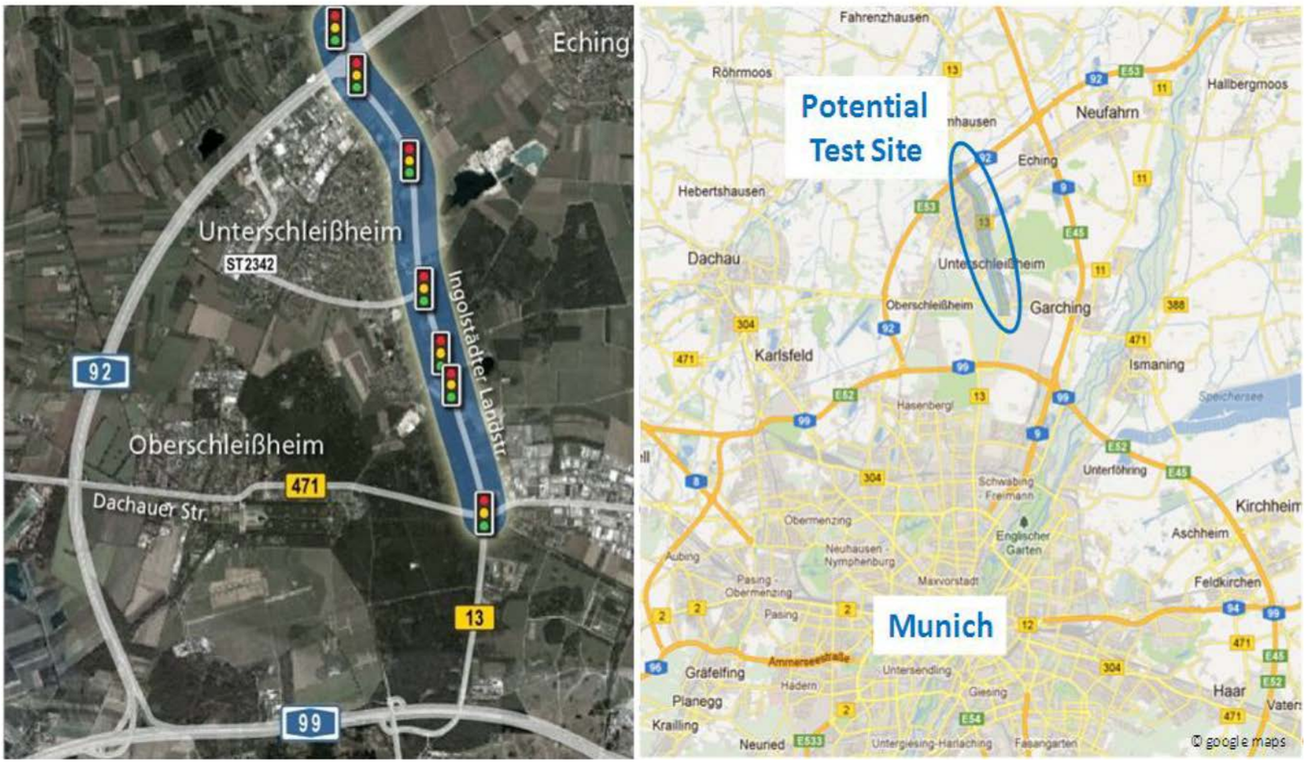


Figure 2. B13 Federal Road, Munich Suburban Region, Germany

Constituent Systems (see Figure 3):

- **Junction controllers** that control the green times of the stages at a second-by-second basis. The sensor information they receive is: (a) the flow (veh/h) and occupancy (%) at the links (road segments) approaching or leaving the junction; and (b) the location and speed of cooperative vehicles that are in the vicinity of the junction. In addition, each junction controller receives appropriate information from all adjacent controllers so as to coordinate the decentralised actions and enable efficient operation at the network level.
- **Cooperative vehicles** that decide their routes and speed so as to optimize their travel time. The sensor information they receive is (a) their location and speed and (b) the flow and occupancy of link (road segment) they are currently present.

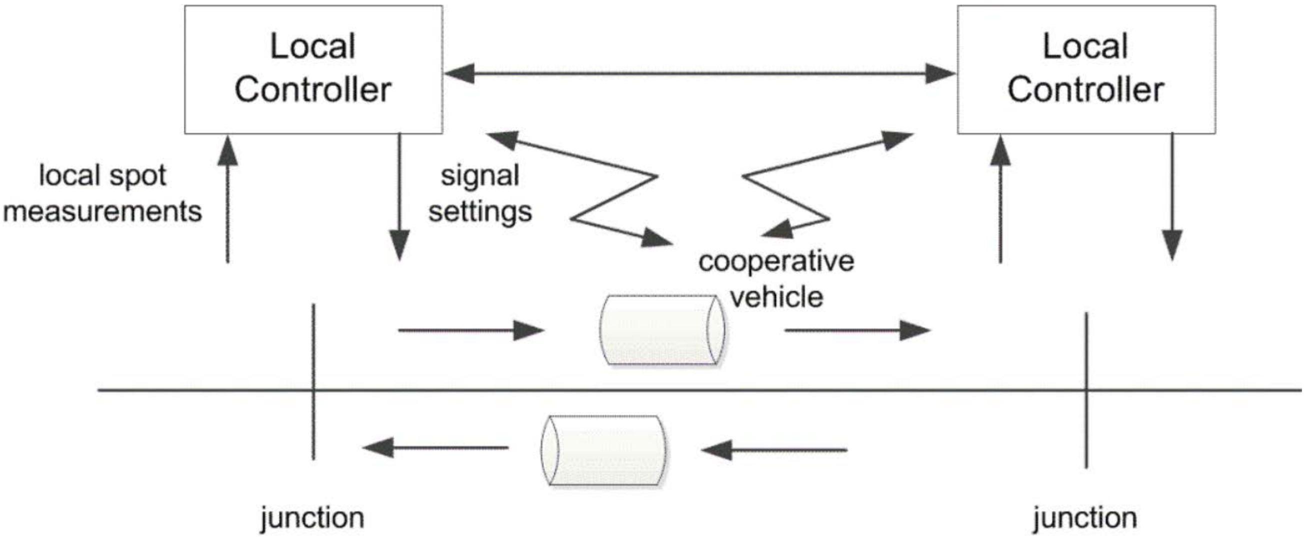


Figure 3. Overall traffic SoS: interacting local controllers and cooperative vehicles

1.5.2. Efficient Building TSoS Use Case: E.ON ERC, Aachen, Germany

The E.ON ERC Main Building, located in Aachen Germany, served as the 2nd Local4Global Building Use Case. The main reason for choosing this building to serve as the Local4Global Building Use Case is the fact that the building is equipped literally with all possible renewable energy generation elements and energy/thermal influencing elements that can be found in real-life buildings. Moreover, the overall building control infrastructure comprises a quite complex hierarchical system with different control elements affecting the building thermal and energy consuming performance at different levels and in a quite complex manner. Furthermore, it has to be emphasized the fact that the building contains a large number of rooms and offices with totally different characteristics and purposes (laboratories, office rooms, conference spaces, data centre rooms, etc.). Finally, it has to be emphasized the fact that the building is subject to severe and abrupt weather as well as occupant behaviour changes.

The building site is situated in Aachen, which is a city in the west of North Rhine-Westphalia, Germany. Figure 4 provides an impression of the building’s façade and floor plans. The façade is designed in a grey-black metallic coating with a unitized curtain walling. The all over appearance is simple and quite artless but representative and presentable.

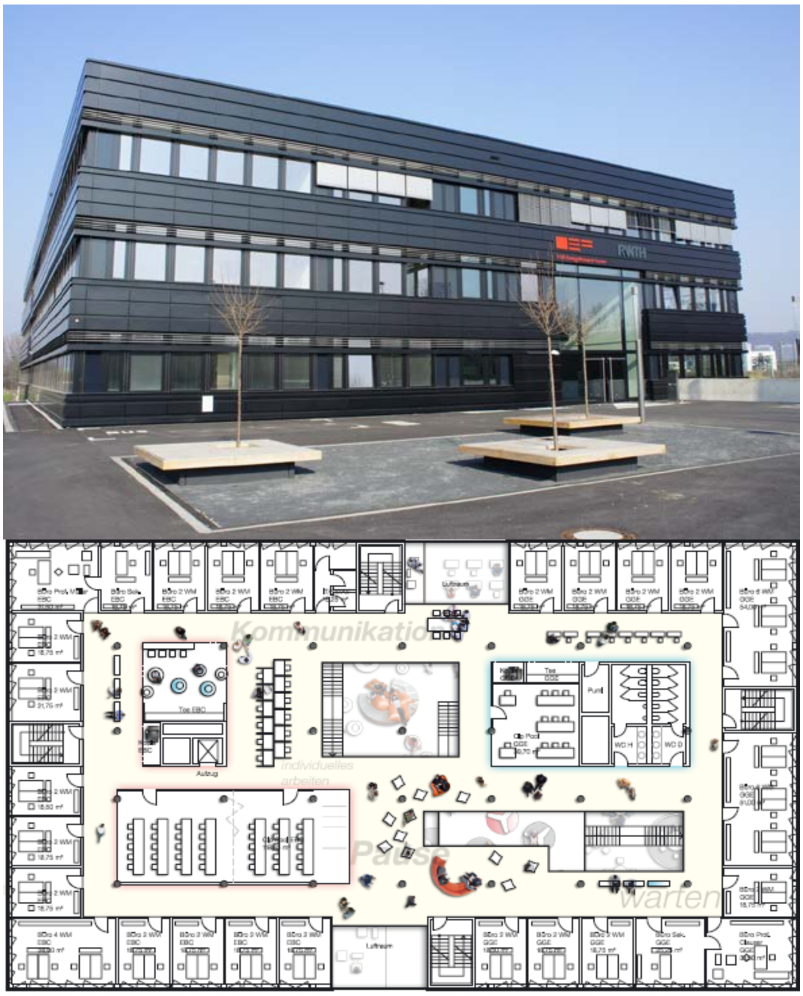


Figure 4. E.ON. ERC Office Building Overview (top) and Floor-plan (bottom).

The building is the new headquarter of the E.ON Energy Research Center at the RWTH Aachen University. The building particularly integrates the following usable areas: office rooms and staff facilities (e.g. computer rooms, in the following called CIP-Pools), seminar and conference rooms, laboratories, common areas as well as areas for LAN- and server equipment. Offices, conference rooms, common areas and CIP-Pools have demand for cooling, heating and ventilation dependent on the outside weather conditions. LAN- and server-equipment has permanent cooling demand. Laboratories have volatile and unpredictable demand for process heating and process cooling. Heating loads occur mainly during winter - load transitions - and summer - cooling loads. The design constraints for the energy concept are kept with thermal comfort following EN 13779, indoor air quality 2 (IDA 2), with a temperature spread between 20 and 26 °C, which must not be exceeded for more than 50 hours per year.

Constituent Systems:

The building control automation system is distributed to **different types of controlled constituent systems**:

- Two **sorption supported AC units** that humidify, dry, cool and heat fresh air in order to satisfy the time-depending demand. They are shifting heat to cold via an open sorption process and use an adaptive heat recuperation. Currently, a sophisticated rule-based control strategy is implemented in order to decide which operation mode appropriate, that uses twelve adjustable set points per unit.
- A total of four separate **concrete core activation** zones that serves as a base load cooling and heating system in office rooms with a very high inertia. The control strategy of the CCA can be freely adjusted. At the moment a heating curve is implemented. Four each zone, 11 control parameters can be set.
- A total of 86 **facade ventilation units** (one per small office, two per large office). Their purpose is to maintain a certain room temperature, that can be adjusted by the user or automatically controlled and to not exceed a certain threshold of VOC (volatile organic compounds) and of CO_2. They are able to cool, heat and ventilate. Further the ventilation units are equipped with waste heat recuperation with adjustment possibility of the recuperation ratio. The sensor information they receive is room temperature, user

presence, user room temperature feedback, CO2 and VOC ratios, humidity and outdoor temperature to mention the most important out of 40 control parameters.

1.6. The Results

The optimization and control of the operations in TSoS has recently attracted the interest of many researchers. The vast majority of the existing approaches assume perfect or sufficient knowledge of the dynamics of the overall TSoS, i.e., the dynamics of each and every constituent system along with their interactions with the other constituent systems and the external environment. However, the requirement for perfect or sufficient knowledge of the TSoS dynamics renders the overall TSoS control design practically infeasible in many TSoS applications, as they typically involve a large number of constituent systems with highly complex and uncertain dynamics. Moreover, even if the dynamics of the overall TSoS were known, the current state-of-the-art in control systems is not able to provide computationally efficient, practically implementable solutions to problems of the scale, complexity, heterogeneity and constantly changing structure/topology/hierarchy of TSoS. To circumvent this problem, localized and oversimplified controllers can be employed which, however, put optimality or even efficiency at stake. There are two main attributes within the L4G approach:

- The first is that it does not require a model of the TSoS dynamics but rather, by employing self-adaptive mechanisms, it is capable of achieving to learn an efficient control strategy for the TSoS.
- The second attribute is its L4G nature: each of the controllers of the constituent systems operates using only local information plus information about the time-history of the global performance index the TSoS is attempting to optimize.

In such a way, the computational and communication requirements of the control strategy are the minimum ones. The development of L4G control algorithm is based on methodologies (ingredients) recently developed, tested and evaluated in a variety of real-life large-scale applications by the L4G partners (the so-called Parametrized Cognitive Adaptive Optimization – PCAO). It is emphasized that PCAO, which is applicable for the solution of dynamic optimization problems (or, equivalently, to optimal control problems for nonlinear systems), uses as one of its basic ingredients the Cognitive Adaptive Optimization – CAO algorithm which is applicable for the solution of static adaptive optimization problems. Same as in the PCAO case, the TSoS-related algorithm L4G-PCAO uses as its basic ingredient the algorithm L4GCAO which is the TSoS-related version of the algorithm CAO. In real-life TSoS paradigms, the L4G-PCAO control approach considers a separation/distinction of the global level optimization problem into constituent sub systems level, forming up the global TSoS. The main idea of the whole approach is to solve several optimization problems in parallel, by utilizing local information, so as to achieve and improve global system control performance. Theoretical investigations and analysis, regarding the L4G system, as well as the consisting modules, were performed so as to establish a concrete algorithmic basis that guarantees:

- a fully scalable and computationally efficient implementation
- to efficiently perform locally and without the assumption of perfect and complete knowledge about the overall TSoS state and dynamics.
- identifying and predicting the emerging and evolutionary characteristics at the macro-level and of controlling the overall TSoS dynamics in such a way that its emergent and evolutionary behaviour is moving in the "right direction".
- controlling the emergent and evolutionary behaviour of TSoS by adaptively assigning different objectives and tasks to different TSoS subsystems.

In the following, the main S&T results/foregrounds of the project are briefly described according to the following subsections:

- the main results of the L4G control system (Subsections 1.6.1 & 1.6.2);
- the main S&T results/foregrounds for Cooperative Traffic TSoS (Subsection 1.6.3);
- the main S&T results/foregrounds for Building TSoS (Subsection 1.6.4); and
- the main S&T results/foregrounds for the simulative complementary test cases considered for more thorough evaluation analysis of Local4Global tools (Subsection 1.6.5).

1.6.1. Local 4 Global methodology: main results

L4G aims at developing, testing and evaluating a new ground breaking, generic and fully-functional methodology/system for controlling TSoS where autonomous constituent systems reacting and interacting depending only on their local environment, optimise the emerging TSoS performance at the global level. To enable such control approach, the following questions had to be answered at first: (1) What are the requirements for modelling and analysing the properties of generic TSoS? (2) What are the software requirements for implementing the pursued L4G control approach to generic TSoS? (3) What are the requirements from the practical point of view of real-world TSoS cases? The answer to the first question defines the control theoretical framework for the development of the L4G control approach, the answer to the second question defines the framework for the software implementation of the L4G control approach, and the answer to the third question refines the framework of both the control theoretical development and the software implementation of the L4G control approach in view of requirements posed by real-world applications.

Based on the aforementioned identified requirements the main methodological/algorithmic "ingredients" - that were integrated towards the development of the final L4G System - were also developed. There are basically three different ingredients that have been developed that serve the basic modules of the integrated L4G system (see Figure 5). The first of these ingredients is the **learning mechanism** of L4G which renders it able to "just-enough-learn-and-control" the TSoS dynamics. The second is the **situation awareness mechanism** which uses local measurements in order to re-construct the part of the global information needed in order to calculate - locally - the optimal actions. The third ingredient has to do with cooperatively optimizing the performance of the different constituent systems **(distributed optimizer).** It has to be emphasized that in all three different ingredients, special attention has been given so as to minimize the computational as well as the communication requirements. A final module (**Control for Learning and Learning to Control - C4L/L2C**) is responsible for integrating the three aforementioned mechanisms (learning mechanism, situation awareness mechanism and the distributed optimizer) towards implementing the control actions and the automated tuning mechanisms of each constituent system.

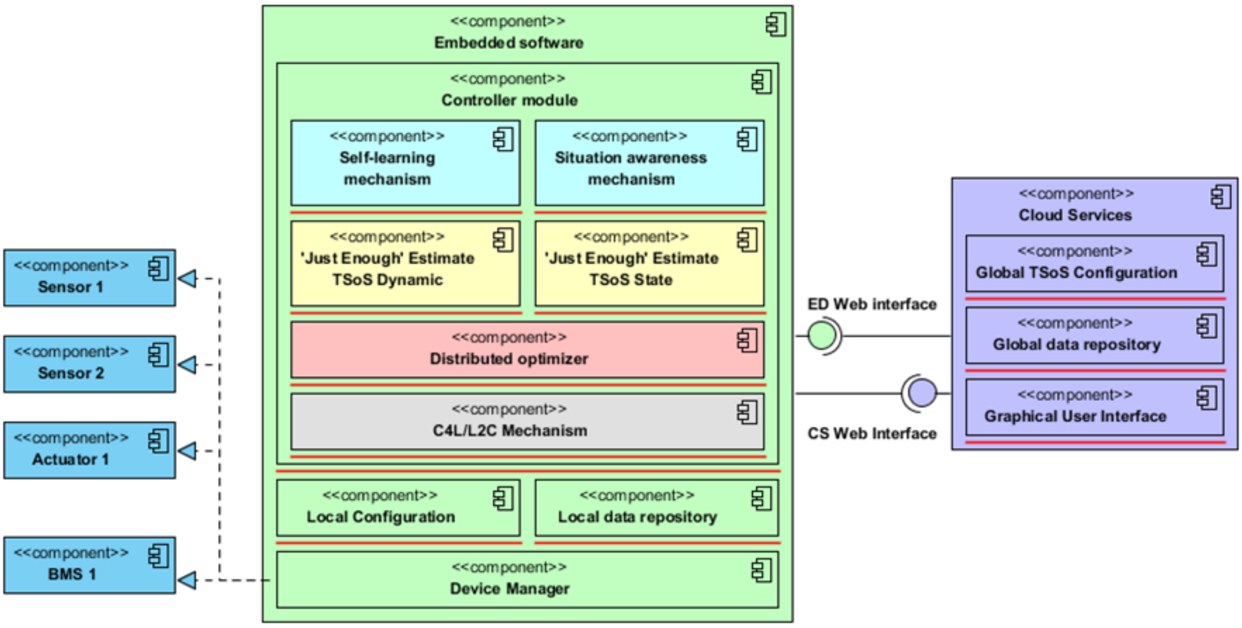


Figure 5. The L4G System and its implementation

Verification tests through extensive simulations were conducted in order to ensure all valuable features of the final implemented L4G Methodology/System. More precisely, the:

- Development of a distributed optimization module to accompany and cooperate with the Self-Learning and Situation Awareness Mechanisms;
- Development of the components and the overall L4G system (methodology);
- Integration of all different L4G components and mechanisms and delivery of the final ready-to-be-deployed product,

were considered. Consequently, the following have been accomplished: (a) the methodological and algorithmic finalization of the integrated L4G system, (b) the implementation of the methodological/algorithmic concepts of the integrated L4G system into a fully-functional software applicable to generic TSoS (c) the interfacing of this software with the simulation models of the two Local4Gloval use cases and the verification (proper functioning and debugging) of the software for these two use cases and (d) preliminary simulation experiments using simplified models of the use cases so as to check the efficiency of the integrated L4G system.

Based on the presented theoretical S&T results/foregrounds accomplished, the consortium members identified three core exploitable products, two of them closely related to and derived from the foreseen project's use cases activities, as follows:

- L4G Generic TSoS optimization tool
- L4G Mobility tool - Cooperative Traffic TSoS use case
- AdaptEEng clima - Building TSoS use case.

1.6.2. Local 4 Global Generic TSoS optimization tool: main results

L4G (Generic) Tool is an embedded, web based plug & play fully functional software system for generic TSoS mountable locally to each constituent system. L4G system can be embedded in generic Cyber Physical Systems and Systems-of-Systems producing substantial performance and Quality-of-Service improvements with the requirement of using the minimum possible infrastructure and minimum installation/operation effort. It is not limited to areas and systems where no sophisticated control is currently employed (due to the requirement for an elaborate infrastructure). It is also be of great significance to areas and systems where, despite that the infrastructure is there, current control and management systems "cannot do the job" such as large scale transportation, traffic and energy systems.

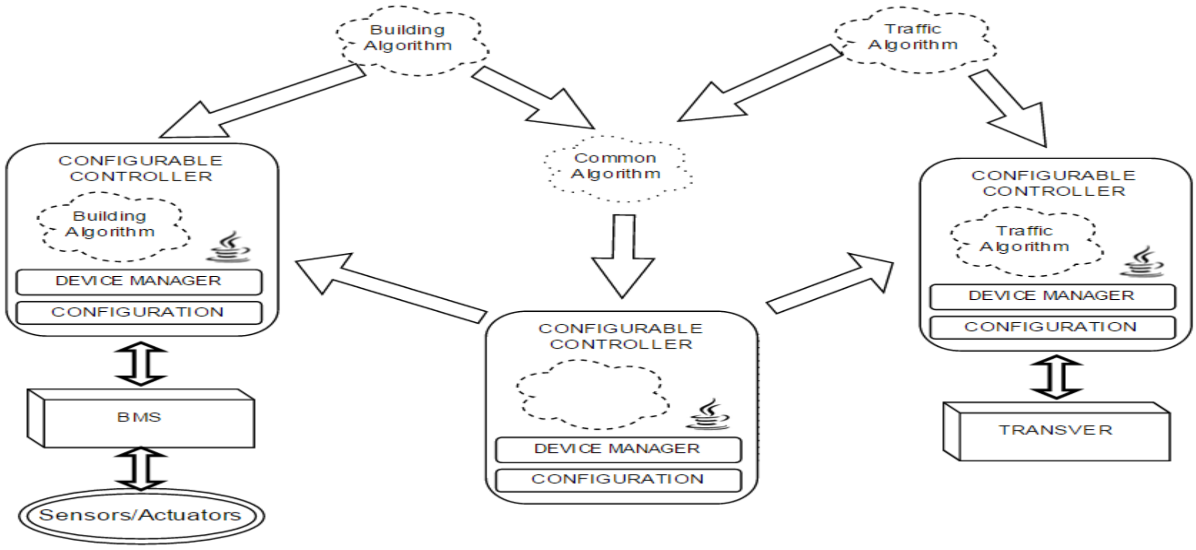


Figure 6. Configurable generic platforms

In order to design a generic configurable system, both use case requirements were studied and their common similarities were extracted (see Figure 6). These similarities would be used to define the interfaces, a collection of the common functionalities the system and their components would offer.

The L4G system provides these functionalities:

- Asset monitoring and control mechanisms: The system is able to access different assets of the system, being able to obtain information and applying control actions.
- Real-time configurable control logic: The system has a control logic based on different configurable parameters, which is able to be modified on real-time.
- Global situation awareness and optimization: The system is able to be aware of consequent systems and is able to 'tune' its behaviour in order to achieve a better performance at higher TSoS level.
- Extensive and adaptable components: The system is able to adapt to different implementations and deployments, modifying components and adding new ones as needed.
- Multi-protocol support: The system is able to connect to different data sources and assets, implementing different communication protocols.

L4G (Generic) Tool is able to perform efficiently without any tedious pre-application investigations due to its adaptive capabilities, based only on locally available measured data, which allow a periodic control law recalibration and adaptation on-the-fly.

1.6.3. Cooperative Traffic TSoS use case: main results

Today vehicle's fuel consumption is a major issue for drivers everywhere in the world since road transport accounts for about 345 billion litres of oil-based annual fuel consumption in EU-27, according to published statistics. Recent analysis[3] of driving data for nearly half a million vehicles in the EU concludes that there is an increasing discrepancy between laboratory and on-road fuel consumption. While in 2001 the offset was below 10%, by 2011 it had increased to around 25% (official values: 5.4lt/100km or 1200€/year; on-road values: 6.7lt/100km or 1500€/year) and by 2013 to 30% (official values: 5.1lt/100km or 1130€/year; on-road values: 6.6lt/100km or 1480€/year) both for gasoline and diesel cars.

This growing gap between official and on-road values means that today's vehicles on average consume at least 30% more fuel than suggested by the manufacturers' sales brochures which is equivalent to 350€/year more, while the target for 2020 is 3.8lt/100km or 850€/year. With petrol cost an average of 1.17€/lt in Europe[4], vehicle owners spend almost as much on petrol as on the vehicle itself. A typical European driver covering 19200 km/year will spend more than 17700€ on petrol over the lifetime[5] (or more than 1480€/year) of a vehicle purchased in 2013 with average fuel efficiency (6.6lt/100km), while for professionals transport costs are even higher.

According to statistics, nearly all European drivers are at least somewhat concerned about fuel economy. The results indicate that 25% would be willing to pay at least 270€ for a 5% improvement in fuel economy, 900€ for a 10% improvement and 2300€ for a 25% improvement. General message from recent research findings is that most improvement can be made by reducing the number of acceleration events i.e. reducing vehicle stop event as it is the most important type of acceleration event.

Based on this analysis the L4G consortium worked towards developing a commercial version exploiting the ***L4G Mobility tool.***

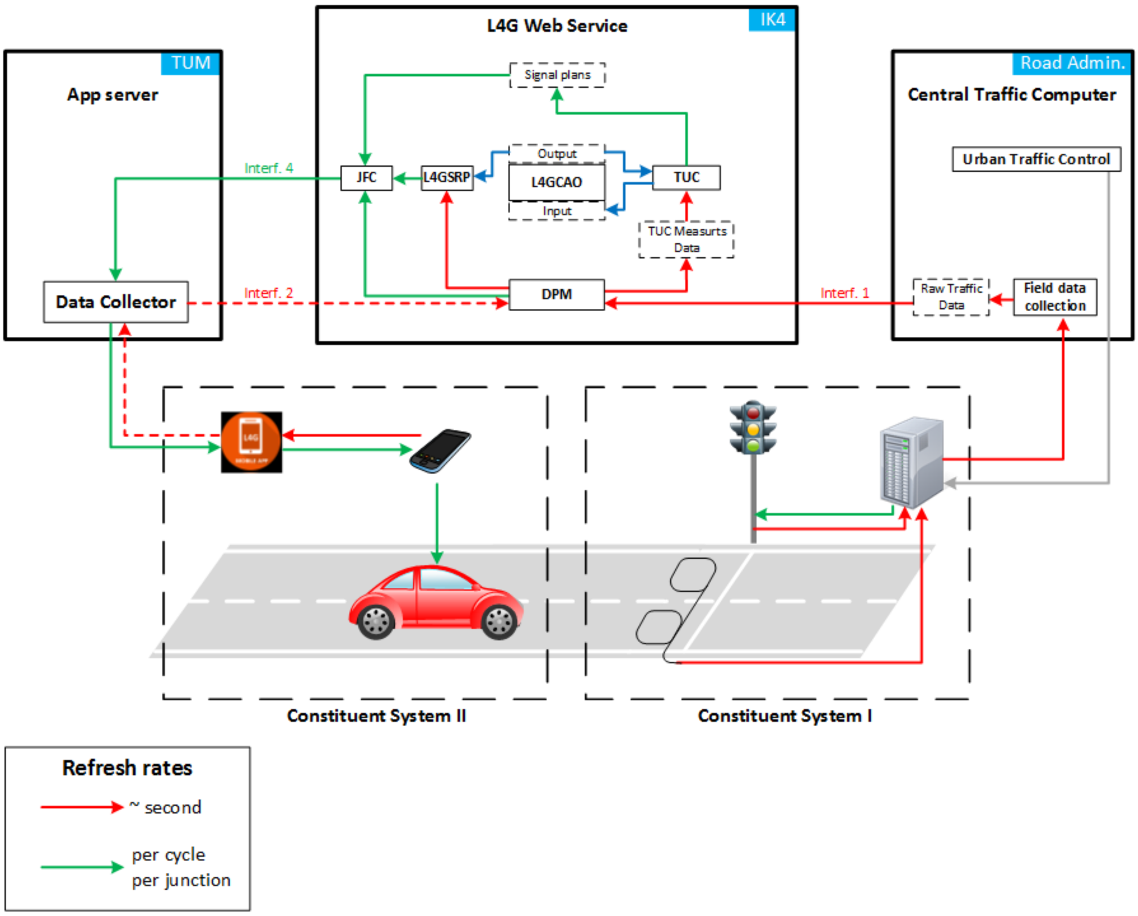


Figure 7. L4G Mobility tool: functional view

Figure 7 illustrates the components of the L4G traffic use case test bed architecture that were implemented for evaluation. ***Constituent System I*** represents the ***L4G traffic detection and signal control system***, while ***Constituent System II*** represents the ***L4G driver speed recommendation service***.

[3] http://www.theicct.org/sites/default/files/publications/EU_vehiclemarket_pocketbook_2013_Web.pdf, ICCT, 2013a
http://www.theicct.org/sites/default/files/publications/EU_pocketbook_2014.pdf, ICCT, 2014
[4] http://autotraveler.ru/en/spravka/fuel-price-in-europe.html
[5] 12 years on average

Traffic data was collected from the field and used to generate demand for the simulation. This data was prepared through a data processing module and then sent to the controller (labelled TUC for Traffic-responsive Urban Control) to give input to the L4GCAO. The L4GCAO, using this data, optimized a signal control method, which was sent back to the controller to be applied as signal plans. The simulated traffic response resulting from the applied signal plans was then collected by the controller to generate subsequent signal plans in a cyclic process.
In fact, there was ***no need for installing within the vehicles extra equipment and - most importantly - the drivers aren't required to get involved into extra activities other than their usual are***. Using the GIS/GNSS information provided within the GNSS-navigator as well as additional GIS information, weather conditions (available either through the internet or stored offline) , traffic lights information and/or traffic conditions (from a traffic management centre), the *L4G Mobility tool* provides to the driver speed profiling commands which assist to significantly reduce fuel consumption. ***These speed profiling commands are provided to the driver in an extremely safe, non-distractive, easy-to-follow manner and are tailored to his/her particular driving style, as originally designed in KOLIBRI solution*** (a project where two of L4G partners, TUM and TRV, participated)**.** Last, but not least, the *L4G Mobility tool* addresses the needs of all different types of vehicles' drivers, professionals or not, everywhere in the world who cover several kilometres daily in either suburban or urban areas and use either a smartphone or a GNSS-based navigator.
Evaluation Results
The test bed for the L4G Mobility tool, is a road stretch with seven signalized intersections in the north of Munich, Germany.
The two types of constituent systems are:

- Signalized intersections, which regulate the traffic lights in the network;
- Co-operative vehicles, which are vehicles capable to receive speed recommendations through mobile devices (C2X).

The respective local controllers are the traffic light controller (cabinet) and the mobile app hosted on the drivers' smartphones.
For practical and legal conditions, the control logic for the first type of constituent systems is not hosted directly in the controller, rather at the central level in the same location of the optimizer (L4GCAO) but deals separately with each constituent system of type I, for which he keeps record separately of inputs and outputs: as if the control logic is locally hosted.
To establish the closed loop control system, the signalling system technical operator (Siemens, a private third party service provider to the road authority) was also required to cooperate in establishing the different gateways and connections, as well as supplying the predefined libraries of signalling programs to the intersection-level signal controllers. Correspondence between the parties implementing the control system and the providers of the controllers indicated compliance to move forward with the implementation. The tempo at which the multi-partied process evolved appeared to be lower than what would allow all the planned steps to be achieved in time. Notwithstanding, Siemens, had always displayed their compliance as the controller operators to cooperate in the installation of the control hardware required to implement the L4G system, as documented in the different email exchanges and the provided services that were either offered or effectively delivered to the project representatives throughout the implementation process.
Simulation-based Evaluation
Since the real-world traffic behaviour under the L4G control system could not be investigated, simulations became the primary method of evaluation. Data could be collected from the detectors in the road, and was used as demand information to run the simulations, so that the simulations would be based on the real demand. The resulting traffic behaviour, however, was analysed with data generated by the simulations.
The signal control system within the VISSIM model communicates and exchanges data with the L4G Optimization System via a Microsoft Excel macro file (the simulation engine), while the co-operative vehicles are simulated through a Python application. The application reads the position and speed of the C2X vehicles, and the speed recommendations and signal plan information from the L4G Optimization system.
Simulations were performed for three scenarios following two demand patterns, as shown in Table 1: Simulation Scenarios and Demands, with the demands categorized by off-peak and peak hours. The study period consists of the weekdays from June 6 to July 1 of 2016. Test trips were also taken in the field on the 16^{th} of June to evaluate the baseline condition.

Table 1: Simulation Scenarios and Demands

Scenarios	Off-peak hours 9:30 – 14:30	Peak hours 15:00 – 20:00
Baseline (Existing scenario)	Baseline 1	Baseline 2
L4G (Using the L4G system for traffic signal control)	L4G 1	L4G 2
L4G-C2X (Using the L4G system for traffic signal control with 10% of vehicles having C2X co-operation)	L4G-C2X 1	L4G-C2X 2

The simulation results show a better network servicing capability. The system throughput, measured as the number of vehicles that have left the network during the simulation run, is shown in Table 2. These values indicate that the traffic network under L4G signal controls is capable of servicing more vehicles than under baseline signal controls, especially during peak hours.

Table 2: System Throughput (served vehicles leaving the Network)

Scenario	Off-Peak Hours	% Increase	Peak Hours	% Increase
Baseline	22733	--	25677	--
L4G	23035	1%	28071	9%
L4G-C2X	23682	4%	28036	9%

Less latent demand is produced in the L4G scenarios due to increased servicing capabilities, as shown in Table 3. Latent demand constitutes of vehicles, which at the end of the simulation still wait to enter the network; they are not thus included in the active vehicles. The decreased latent demands support the increased throughput in demonstrating a higher capacity for the L4G scenarios to accommodate more vehicles. Again, the advantage of the L4G system is more evident during the peak hours.

Table 3: Latent Demand

Scenario	Off-Peak Hours	% Increase	Peak Hours	% Increase
Baseline	2246	--	5472	--
L4G	1855	-17%	3419	-38%
L4G-C2X	1904	-15%	3483	-36%

Moreover fuel consumption and gas emissions results show an improvement during peak hours as shown in the table below.

Table 4: Fuel consumption and gas emissions results

Difference compared to baseline (negative is improvement)	**L4G**		**L4G-C2X**	
	Off-Peak	**Peak hours**	Off-Peak	Peak hours
Fuel Consumption per Vehicle (L/veh)	0,160	-0,529	0,153	-0,480
CO2 emissions (kg/veh)	0,391713	-1,296088	0,3739752	-1,1757729
HC emissions (kg/veh)	0,001266	-0,004189	0,0012086	-0,0037998
NOx emissions (kg/veh)	0,001103	-0,003650	0,0010531	-0,0033108
CO emissions (kg/veh)	0,010850	-0,035899	0,0103584	-0,0325667

The GKPI 1 for the traffic use case, is the average network mean speed (ANMS). For off-peak hours, although the L4G system accommodates an increased throughput, the average network speed is not significantly different. For peak hours, the L4G scenarios even perform consistently better over all the simulated days.

Table 5: ANMS results (GKPI1)

	Peak hours				Off-Peak hours		
	ANMS [Km/h] Baseline	ANMS [Km/h] L4G	ANMS [Km/h] L4G-C2X		ANMS [Km/h] Baseline	ANMS [Km/h] L4G	ANMS [Km/h] L4G-C2X
Average over the 4 weeks simulation	16,18	22,96	23,13		21,52	21,66	21,93
Improvement to the baseline		42%	43%			1%	2%

The Traffic Use Case GKPI when calculated as a time-weighted average (over both peak and off-peak hours) shows an improvement of 22% compared to the baseline.

It should be noted at this point that the 2 examined demand scenarios (off-peak and peak) correspond to significantly different prevailing traffic conditions along the arterial not only with respect to the different levels of traffic demands and loads along the arterial and secondary streets but most importantly with respect to their direction of movement. The off-peak scenario covers a part of the morning peak hours, which carry heavy traffic loads from the North to the South direction of the arterial, while the peak scenario covers the afternoon and evening peak hours, which carry heavy traffic loads in the opposite direction (i.e. from South to North). At the same time, the traffic-responsive decisions of the applied L4G control approach are not directly implemented but used to select one among 45 pre-specified and authorized signal plans, available within a library prepared specifically for the Munich test-bed due to application specific constraints set by the corresponding road authorities. These library plans include interphase periods much higher than the necessary for reasons of safety and movement of the other junction users (e.g. the pedestrians), which include also constant and occasionally high green times for specific traffic streams that should be respected at all times. As a consequence, the green time available for reallocation according to the real needs of vehicular traffic is limited, and along with the limited number of available library plans decrease significantly the ability of the implemented control approach to respond as efficiently as actually could to the real needs of the vehicular traffic at all times and all prevailing traffic patterns and conditions. The library plans clearly favor the traffic streams serving the direction from South to North, thus the improvements achieved while applying the L4G control approach during the peak demand scenario are more significant not only when compared to the corresponding baseline scenario, but also when compared to the application of the L4G control approach during the off-peak demand scenario.

$GKPI_{TrUC}$ = 22 %
as a time-weighted average of both peak and off-peak hours results

Real-life-based Technical Evaluation

TUM implemented together with IK4 the connection between the TUM application server and the L4G web service (IK4). The TUM application server provided data to the smartphone app. So, the following shortly summarizes key points (technical evaluation) of this implementation; the real life experience with fixed signal data has been recorded in a short video clip.

Figure 8: About 1km before the traffic light

Figure 9: At the traffic light

The TUM application server polled the IK4 server every 15 seconds for new data, for every junction and prepared the data for the smartphone clients to save bandwidth. Data to the smartphone was only transmitted, if the server had new data (MD5 hashes). The smartphone also polled with 15s. The connections were configured with proper timeouts. Connection problems and timeouts were logged. If the connection (poll) fails for some sequential trials or the last information (successful poll) is too old (time limit). The app shows an error screen (fail safe).For the planned field tests, the application gathered the GPS locations (tracking) and the calculated display states in encrypted in a local file and tried to transmit these every 60s to the TUM application server over a secured connection (TLS). For encryption a hybrid approach of symmetric and asymmetric cryptography is used to enhance performance. To encrypt the data a random symmetric (AES 128) key is generated. This symmetric key is encrypted with asymmetric cryptography (RSA 2048) for key exchange. Nevertheless, the transmission is also TLS protected. When the car stops, the application immediately sends a notification to the TUM application server. These messages are anonymized by the TUM server, and forwarded to the L4G web service (IK4) to enhance queue length estimations. For the planned field test the application was enhanced with a location based Android background service. When the user enables the service, the background service starts automatically after the smartphone boot and checks the distance to the test area. Indoor the GPS search can timeout and the network location is used. Depending on how far the user is away from the test routes, the check interval is adapted (15s – 15 min), to save battery. The background service automatically can start and stop the visual application, when approaching or leaving the test routes. The implementation also included helpers for debugging. The application also has the function to enable a 'baseline drive'. In this mode the GPS data are tracked and transmitted, but no information is shown to the driver to enable comparisons. The smartphone application was connected (via personalized links) to a LimeSurvey installation. An open source survey system. This system would have been used to collect the users' opinion (System Usability Scale), comments and reports. For the field test also a user management (instruction, verification, blocking) system has been implemented and integrated into the app. To use the app a registration with an email address is needed. The user gets information about the project, the logged data (privacy) and is asked to safely mount the smartphone in the car. It is emphasized that the field test would have been an experiment. The drivers need to be careful. The shown information can be erroneous (errors can also happen in conventional satnav systems). Connections and timing tests showed that the (small) server for this project would have been able to take care of about 1200 users/hour. While the closed loop state had not been achieved, the connections and calculations had been thoroughly checked and evaluated.

The L4G Mobility Product

The *L4G Mobility tool* presented substantial advances, with the significant fuel economy and time travel improvement levels being the boldest ones which enable great business opportunities on modern emerging market areas (e.g. wide spread of GNSS-based navigators) which have recently become "part of our life" as a feature of the widely adopted smartphones.

L4G consortium worked towards developing a more elaborate version of the ***L4G Mobility tool*** in an attempt to commercially exploit it, by enhancing standard off-the shelf GNSS-based navigators (stand alone or as part of a smartphone) ***assisting drivers to achieve significant fuel consumption in the range of 20-40% (thus saving 400€/year)*** through improving the preview of the traffic situation ahead in order to determine the most economical route or way of driving.

A speed-recommendation driver assistance application was simulated in a road network controlled by a Cooperative Traffic Management & Control System, since these two systems were conceived as an integrated system. This simulation showed that, during off-peak hours, the vehicles receiving driving assistance had their delay time reduced by 9% and their number of stops reduced by 10%. During the peak hours, improvements are still made with the driver assistance.

Average Values per Vehicle: Off-Peak Hours		
	Delay Time [s]	**Number of Stops**
Without C2X	193	5.5
With C2X	176	4.9
% Changed	-9%	-10%

Table 6. Average Values per Vehicle: Off-Peak Hours

Average Values per Vehicle: Peak Hours		
	Delay Time [s]	**Number of Stops**
Without C2X	220	6.4
With C2X	207	5.9
% Changed	-6%	-8%

Table 7. Average Values per Vehicle: Peak Hours

Based on the evaluation summarized in the above two Tables, the L4G Mobility tool containing only the speed navigator can lead to improvements in terms of vehicle speeds and fuel consumption of about 10%, Given, however, the facts that (a) the traffic network does not contain any complex geometry (it is an arterial with low curvatures and slopes and, most importantly, with quite simple junction signaling structure) and (b) a highly efficient traffic signaling strategy is implemented simultaneously to the speed navigator implementation, the expected improvements in other traffic networks should be expected significantly higher than 10%.

Moreover, there's ***no need for installing within the vehicles extra equipment and - most importantly - the drivers aren't required to get involved into extra activities other than their usual are***. Using the GIS/GNSS information provided within the GNSS-navigator as well as additional GIS information, weather conditions (available either through the internet or stored offline) , traffic lights information and/or traffic conditions (from a traffic management centre), the *L4G Mobility tool* provides to the driver speed profiling commands which assist them to significantly reduce fuel consumption. ***These speed profiling commands are provided to the driver in an extremely safe, non-distractive, easy-to-follow manner and are tailored to his/her particular driving style.*** Last, but not least, the *L4G Mobility tool* addresses the needs of all different types of vehicles' drivers, professionals or not, everywhere in the world who cover several kilometers daily in either suburban or urban areas and use either a smartphone or a GNSS-based navigator.

The reduction of fuel consumption is a high important issue for the drivers everywhere in the world while the related applications seem to be a continuous growing market. In parallel, institutions like the EC funds research towards this direction along with the vehicle manufacturers who also spend big amount of money for the development of products and applications.

Possible strategies to reduce fuel consumption are via vehicle technology, fuel technology, travel activity and vehicle and traffic system operations:

- ***Vehicle technology*** concerns the improvement of energy efficiency of the vehicle fleet by implementing more advanced engine technologies.
- ***Fuel technology*** targets to reduce the carbon content of fuels through the use of alternative fuels like natural gas, biofuels or hydrogen.

A driver, in order to be benefited from the first two strategies, has to spend a lot of money for buying a car with a new efficient powertrain or to carry out mechanical modifications, which besides the related costs have also a negative impact on engine's lifetime.

- ***Travel activity*** aims to reduce the number of kilometres travelled by vehicles, or shift those kilometres to more efficient modes of transportation. Although there have been important steps in this direction in the EU-28, most EU Member States have reported an increase in the motorisation rates of passenger cars over the last ten years .
- ***Vehicle and traffic system operations*** deals with improving the efficiency of the transportation network so that a larger share of vehicle operations occur in favourable conditions, with respect to speed and smoothness of traffic flow, resulting in more fuel efficient vehicle operations.

Figure 10. L4G Mobility Tool Concept

The *L4G Mobility tool* goes further with driver's economy since it does not require any additional sensor to be plugged into the vehicle as it can operate as an additional application to standard GNSS-navigators (as long as they are interface-able). Most importantly, the *L4G Mobility tool* is able to calculate the speed commands to the vehicle transmitting them in a *user friendly manner and highly-safe*, so as to provide with significant savings in fuel consumption.

Operational algorithm of *L4G Mobility tool*

1. The driver enters the total petrol litters whenever he/she fills the vehicle with petrol.
2. Vehicle's location from GNSS navigator enhanced with additional 3D GIS, weather, traffic lights information and/or traffic conditions are received by the mobile application.
3. Real time calculation of the recommended speed is provided to the driver as a speed carpet which he/she has to reach.
4. Taking into account the various factors affecting fuel consumption and travel times (road geometry and characteristics, driving style of the particular driver, weather and traffic conditions) *L4G Mobility tool* plans continuously the optimal speed profiling strategy for the particular driver and vehicle.

1.6.4. Building TSoS use case: main results

The concept of smart buildings was created to bring the benefits of modern technological developments to the everyday life of people through their experience of indoor environments such as homes, offices, shopping malls, etc. Smart buildings are engineered to meet the, possibly time-varying, comfort criteria of their occupants by taking into account the weather conditions and the number and the behaviour of the occupants. The changing conditions are often not known accurately in advance, which makes the engineering and operation of smart buildings a challenging task. Buildings are among the high priority energy management topics in the EU. The building sector consumes around 40% of the energy used in Europe and is responsible for nearly 40% of greenhouse gas emissions. A smart building represents a system where its environment, the power grid with its subsystems, as well as other external material and energy networks (e.g. gas and water) interact by exchanging energy while providing comfort services to humans.

The goal is to establish a reliable and sustainable technology for deploying green and zero-energy buildings that use all the available sources of energy efficiently and that, even proactively, assist to stabilize the resource and energy networks (in particular the electric power grid).

Similar to the Traffic case the L4G consortium worked on the ***AdaptEEng clima – Energy Efficiency tool.***

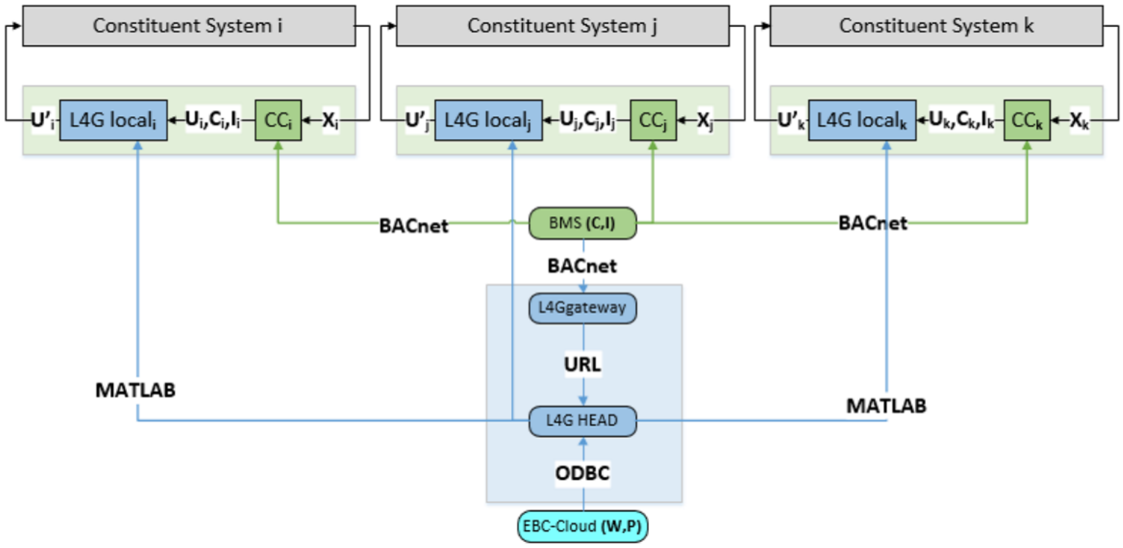


Figure 11. AdaptEEng clima – Energy Efficiency tool: functional view

An overview on the functional implementation of L4G in the BUC test bed is given in Figure 11. In the origin, the TSoS is controlled by the BMS (green data flow), which consists of the central software and a control logic block (CAF-file) for each constituent. Currently, the control logic block contains only the current control algorithm *CC*. The CC receives the sensor vector ***X*** that contains the measurements in the particular constituent, the command vector ***C*** that contains centrally defined parameters or supervisory control decisions (e.g. manual control, emergency control), and an information vector ***I*** that contains additional information used within the CC like schedules, feedback or global information. Based on this information, the control actions vector ***U*** is determined and send back to the actuators in the particular constituent.

In the test case, L4G variables are embedded within the CAF-files, thus the BMS automation and field infrastructure is not changed. For the embedding, the controller configuration is changed and expanded with the additional data exchange for L4G. Therein, the vectors U, C and I are input for L4G, the same input as the CC is aware of. In addition to that, there are a few information given to L4G, namely the current weather condition vector ***W*** and the weather prediction vector ***P*** (this information are not conventional in building technology, but, however, the refurbishment is easy and doesn`t require much effort as they deliver global information, usable in all constituents at once). Based on the vectors ***X***, ***C***, ***I***, ***W*** and ***P***, L4G rectifies control action vector ***U'*** as output to the CAF-file, wherein these commands are directly send to the actuators of the constituent.

The partners considered that there is a general framework that is positively influencing the adoption of Energy Efficiency Tool solutions derived mostly by the maturity of access technologies and the simplification of interfaces and the need for reducing home energy consumption at a global scale.

The reduced thermal resistance as well as many other highly uncertain factors can have a significant impact on the whole building energy performance. Uncertainty about the thermal performance of the building envelope can lead to inefficient design of HVAC systems, building operation inefficiencies and compromised occupant comfort. Unlike conventional rule based control strategies which rely on tedious field tests and cannot always guarantee energy efficiency due to highly uncertain factors affecting the building envelope performance form a large market gap for exploiting ADAPTEENG-CLIMA L4G Energy Management Tool which enables (i) easy and cheap field installation,(ii) easy and straightforward interfacing,(iii) no preparatory tedious research activities and investigations necessary,(iv) minimum required sensing infrastructure,(v) automatized control law maintenance and calibration,(vi) cheap global data exchange costs, (vii) short transient payback period to achieve satisfying performance and tangible savings (energy, environmental footprints, fossil fuel dependence).

Evaluation Results

The building use case (BUC) is one of two use cases for real implementation of the L4G algorithm (L4GPCAO). The test site is the E.ON ERC main building (ERC) in Aachen, Germany. ERC is a modern non-residential building constructed in 2011 and equipped with a conventional building management system (BMS) that has been upgraded to a scientific demonstration building for research in building technology. The core element of this upgrade is the monitoring, control and information system (MCIS) that facilitates to develop, test and demonstrate all kind of advanced control methodologies e.g. L4GPCAO.

Within L4G (L4G) project, an ambitious control and optimization methodology for building technology is developed, applicable on generic technical system-of-systems (TSoS). During the project work in BUC, three methodological assets are developed that improve the possibilities of research in the field of building automation:

First, the TSoS theory is explored as a new perspective on building technology. Based on this, TSoS are identifiable in buildings that fulfil the TSoS characteristics and allow the transfer of TSoS theory into building technology. Based on this work, the L4G BUC TSoS is defined inside the ERC as test bed suitable for the implementation of L4GPCAO.

Second, as the algorithm is meant to control the thermal conditions in everyday working places for about 200 occupants, a pre-analysis takes place to ensure keeping appropriate conditions for the occupants. Therefore, a simulation model of the L4G BUC TSoS is developed for the simulation environment DYMOLA/Modelica containing the physical behaviour of the controlled systems. Taking the transient response of this model, a co-simulation with MATLAB/Simulink via TISC allows modelling the control framework. The developed simulation framework allows the comparisons of the conventional control strategy (as realized in the BMS) with any other (advanced) control methodology, here with L4GPCAO.

Third, five conference constituents are prepared for the experiments three as test case and two as base case rooms by expanding the sensor equipment and developing the software framework for the experiments (L4G BUC framework). The rooms represent the TSoS constituent systems as they are autonomously controlled systems that are commonly supplied by the same distributions systems and the same central (energy) supply systems (CSS). The optimization objective in the BUC is a minimization of non-renewable energy consumption (NREC) constraint by keeping the required thermal comfort. The room controller, which contains the control methodology under investigation, effects the optimization objectives by shifting the heating and cooling loads among the available heating and cooling devices within the constituent system. Thereby, the allocation of energy loads on the particular distribution paths effects the energy conversion system and therewith it`s efficiency and the energy source used by keeping the thermal comfort within the required boundaries.

The project specific findings of the project work are twofold. First, there are the experiment results as KPI, generated by the evaluation of the data acquired with the MCIS that contain all sensor values and actuator control signals during the experiments. Second, there are experienced gathered which are not possible to be expressed in numbers. These results are the lessons learned during the implementation work.

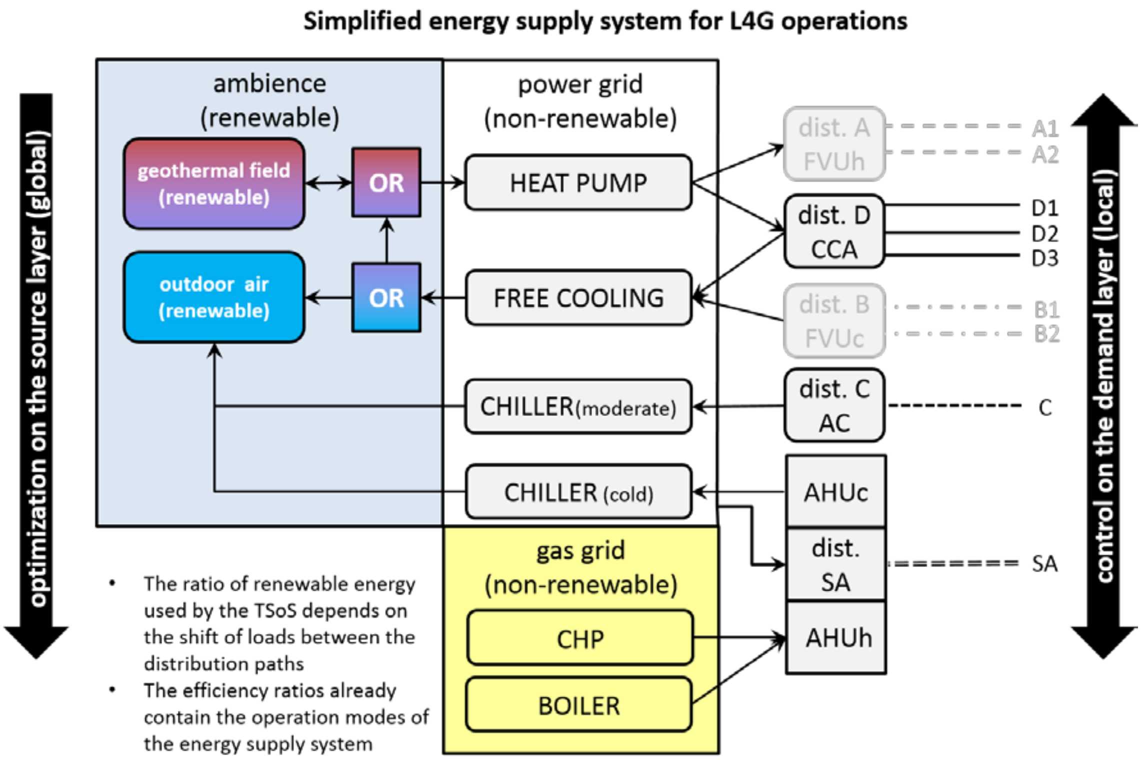


Figure 12: Virtual plant (approximation) for L4G NREC calculation

The evaluation in numbers bases on the results of simulative pre-analysis and fine-tuning (made by RWTH and CERTH), and in two real experiments (of further more), that result in an evaluable data base.

Table 8: List of Experiments

N°.	Start	End	Evolution
2	18.08.2016 10:00	24.08.2016 10:00	L4G-PCAO v1.0; Modified framework with L4G gateway
6	19.11.2016 13:00	24.11.2016 15:00	L4G-PCAO v1.1 – debugged

The major KPI for comparison is the reduction of non-renewable energy (NRES) as the reduction of non-renewable energy consumption (NREC) considering the coincident thermal comfort. As uncertainties like occupancy, weather and user behaviour affect the absolute values, the efficiency, calculated as the fraction of net energy consumption (NEC) generated by non-renewable energy consumption, is even meaningful when the impact of L4GPCAO is assessed.

The overall KPI are determined as given in the Table below. Therein the KPIs of the three data sets are determined. Note that the efficiency was not calculated for the simulation results, thus the average is taken from the two real implementation experiments. The comfort costs of the real implementation experiments are both zero, thus they are within the required boundaries.

Table 9: BUC evaluation and KPI

Data Set	Energy Costs (NREC)	Comfort Costs	Total Costs	Efficiency
Development & Fine Tuning	-5,2 %	-21,4 %	-13,3 %	*
Experiment 2	-17 %	0 %	-17 %	57 %
Experiment 6	-38 %	0 %	-38 %	57 %
Average, real	*-27,5%*	*0 %*	*-27,5%*	*57 %*

The BUC KPI are generated as the average of all available data sets to have a representative result. The impact of L4GPCAO is a reduction of NREC of 27.5 % with no sacrifice on the indoor comfort conditions.

$GKPI_{BUC}$ = 27.5 %

Note that average value neglects the run time of the experiments and all uncertain circumstances and incidents during the experiments. More reliable numbers require further long term experiments. Note that the KPI base only on a single application of L4GPCAO within building technology. They raise no claim to generality regarding the impact of L4GPCAO in building technology. Further applications are necessary to generate more general numbers.

The L4G ADAPTEENG-CLIMA product for Energy Efficient Management

Global contribution from buildings in energy consumption, both residential and commercial, has steadily increased reaching levels between 20% and 40% in developed countries and has overpassed the other major sectors of industry and transportation. Among the most energy intensive domains in the buildings is thermal comfort. Energy consumption for thermal comfort (space heating/cooling) can be considered as the most energy intensive domain in buildings with annual energy demand values consumption of around 80-100[i] kWh/m^2. Recently, there has been a tremendous effort towards improving the energy use for thermal comfort through **Building Automation (BA)**. As sensors and communications become more and more inexpensive, reliable and easier to deploy, BA systems can be used as a cost-effective solution to curb energy consumption, without the need to rip out and replace existing equipment or go through an expensive, laborious retrofit project: according to the European standard “EN15232 Energy Performance of Buildings-Impact of Building Automation", BA systems have the potential of substantial energy savings such as 31% in restaurants, 25% in hotels, 39% in offices, 49% in shopping centres, 18% in hospitals, 34% in schools/universities and 27% in residential buildings[ii].

However, despite the enormous potential of modern BA systems in reducing energy consumption for thermal comfort, they are currently very far from offering such a potential. ***The realization of such a potential requires control decisions that modify many times during the day, in a very intelligent and delicate manner ("at the right time and with the right amount") the operation of the different HVAC elements of the building.*** Existing businesses and services that employ ***BA systems are not able to provide such decisions unless a very consuming and expensive procedure is employed.*** They have been proven poor in fully exploiting BA technologies for maximized energy savings, mainly due to inefficient feedback design which results in a long term money “leaking”. This is because (i) either over-simplifications are adopted that enable building case clustering/grouping so as to apply off-the-shelf library strategies tuned for similar building envelope characteristics and climatic zones (ii) or an expensive and time-consuming manual tuning is performed by hired experts.

L4G overcomes the above-mentioned problems:

L4G main feature is its ***"plug-n-play" nature***. Thanks to this feature, it can provide the optimal control decisions by requiring ***minimum-installation-costs*** and ***minimum-operational-costs*** for ***minimizing energy bills*** without compromising user comfort and satisfaction.

Due to its "plug-n-play" nature:

- it can be plugged to the BA system by requiring ***minimum installation effort*** without the need to perform any analysis of the building/energetic system characteristics or to get involved into cumbersome activities for tuning the IEMS control logic. Moreover,
- as soon as it is plugged to the BA system and thanks to its ***self-calibration/self-learning*** characteristics, the L4G ***fully-automatically takes over*** so as to ***optimally control*** all different HVAC elements and minimize energy bills without compromising building occupants comfort and satisfaction.

In such a way, it requires ***both minimum installation and minimum operational costs*** and, most importantly, it ***does not require the involvement of highly skilled and paid personnel*** as it is typical in most existing solutions.

By suitably exploiting the attributes of L4G, *ADAPTNEENG-CLIMA* is a ***low-purchase-cost***, ***low-operational-cost*** (affordable by the everyday home owner) product for ***automatically minimizing energy bills without compromising user comfort and satisfaction***.

The main modules/components of the *ADAPTNEENG-CLIMA* product are the following:

1. A middleware platform enabling the straightforward and easy interfacing of the *ADAPTNEENG-CLIMA* product with the building sensing infrastructure.
2. A user-interface enabling the user to provide their preferences and requirements as well as to provide energy-related analytics.
3. The L4G system which automatically calculates the optimal real-time control decisions for the different building energy affecting elements (e.g., HVAC set points). These real-time control decisions are* then automatically implemented (e.g., by automatically altering the HVAC set points during the day) through the *ADAPTNEENG-CLIMA* platform.

The overall *ADAPTNEENG-CLIMA* product can be delivered in a miniPC (e.g. RaspberryPi 3 Model B) compatible form, able to be installed and configured easily through a step-by-step guide implemented in a compact, comprehensive and user-friendly format as a free Android application for mobile devices.

Figure 13. ADAPTEENG-CLIMA components

The main economic benefit from ADAPTNEENG-CLIMA product for the building users is the significant reduction of energy consumption for heating/cooling in the range of 20-50%. This is equivalent to average annual energy savings of 20-50 kWh/m^2, which can be translated[iii] **into annual savings of 4.42-11.02€/m^2**, while the customer costs for purchasing and operating the A***DAPTNEENG-CLIMA*** product are

- around 100€ initial investment plus 25€/year/climating device, if the building has already a BA system.
- around 200€+50€/climating device initial investment plus 25€/year/climating device, if the building does not have a BA system.

It has to be strongly underlined that for ***an average European household*** of 70m^2 with 2 controllable climating devices (1 thermostat, 1 AC) ***the expected savings in energy bills will vary between 309.4-771.4€/year*** and thus ***the payback period is expected to be 3 to 6 months if the building is equipped with a BA system and 6 to 12 months if the building is not equipped with a BA system.***

Specific and detailed exploitation and business plans have been made towards the full exploitation of the ADAPTNEENG-CLIMA product.

1.6.5. Other applications: main results

In addition with the building and traffic networks use cases, the L4G tools were tested and used in various ***smart grid/micro grid test cases***, including multiple building transactions, renewable energy resources and storage integration, as well as Electric Vehicle charging stations. Distributed decisions were required in both multiple building cases and charging stations with the integration of renewable energy resources. The L4G approach offers significant improvements with respect to rule-based controllers (based on user decisions) and other well-known open loop approaches. Most important is the capability of ***L4G to successfully attack very-large-scale problems*** where other, state-of-the-art approaches - ***especially centralized ones - totally fail***.

Moreover, a modified version of L4G has been proposed and evaluated as a general methodology for dealing with ***multi-robots problems***, where the mission objectives can be translated to an optimization of a cost function, has been proposed. In both cases, the proposed approach has the following key advantages:

- it does not require any knowledge of the dynamics of the overall system of multi-robots;
- it can incorporate any kind of operational constraint or physical limitation;
- it has a distributed nature and the overall complexity is low allowing real-time implementations;
- it converges rapidly to the (locally) optimal decision variables set, especially in cases with many robots;
- it has fault tolerant characteristics and it can appropriately tackle time-varying cost functions;

Conclusively, we expect that many important tasks in mobile robotics can be approached by the proposed scheme. This is basically due to the fact that the proposed approach does not require an a priori knowledge of the dynamics of overall multi-robots' system and it has a distributed nature. Furthermore, the proposed approach can be appealing in many real-life applications due to its fault-tolerant characteristics, without an explicitly designed fault-detection mechanism. All the above issues are considered of paramount importance in multi-robots' applications.

1.7. Availability of results

The project's outcomes/results have been reported within the foreseen deliverables according to the description of work, ethics and IPR principles agreed and signed under the respective contract. Moreover, during the project's lifespan dissemination material has been produced and published on social media platforms, scientific conferences and journals as well as on YouTube. The list containing all project's results can be found in the respective website: http://local4global-fp7.eu/key-facts/project-resources/.

1.8. Potential Impact of the Results

Cyber-physical systems (CPS) and especially Systems-of-CPS (=TSoS), enable the physical world to merge with the virtual. This intimate coupling between the cyber and physical can be manifested from the nano-world to large-scale wide-area Systems of Systems. Moreover, as the physical and embedded world meets the Internet world there is an increasing number of interacting - possibly highly heterogeneous - cyber-physical systems with strong connectivity utilised in both society and in industry. The core ICT devices that have been traditionally confined to boxes (PCs, smart phones, tablets, etc.) as well as advanced CPS/TSoS technologies like robots are increasingly embedded in all types of artefacts making our homes, offices, factories, cars, trains, public spaces and cities "smarter". Advances in CPS/TSoS can enable capability, adaptability, scalability, resiliency, safety, security, and usability that can far exceed the simple embedded systems of today. CPS/TSoS technology can transform the way people interact with engineered systems - just as the Internet has transformed the way people interact with information. New smart CPS/TSoS are expected to drive innovation and competition in sectors such as energy, transportation, monitoring, building design and automation, healthcare, agriculture, and manufacturing. Indeed, it is clear that CPS/TSoS technologies are central to achieving the vision of Smart & Connected Communities (S&CC), including "Smart Cities", "Smart Manufacturing" and "Smart Ecosystems" which spans these multiple sectors and includes the important attributes of efficiency, safety, and security. Cisco predicts that the Global market size related to Internet of Things (IoT) and cyber-physical systems (CPS) is expected to surpass the amount of $14.4T (i.e. **12.5 trillion euros!)** by year 2022 according to Forbes. Within the following four years the market share growing rate will reach 6%. Additional areas of investment including reducing the time-to-market ($3T), improving supply chain and logistics ($2.7T), cost reduction strategies ($2.5T) and increasing employee productivity ($2.5T). Moreover it can be extracted that 50% of IoT/CPS activity today is in manufacturing, transformation, smart cities and consumer markets.

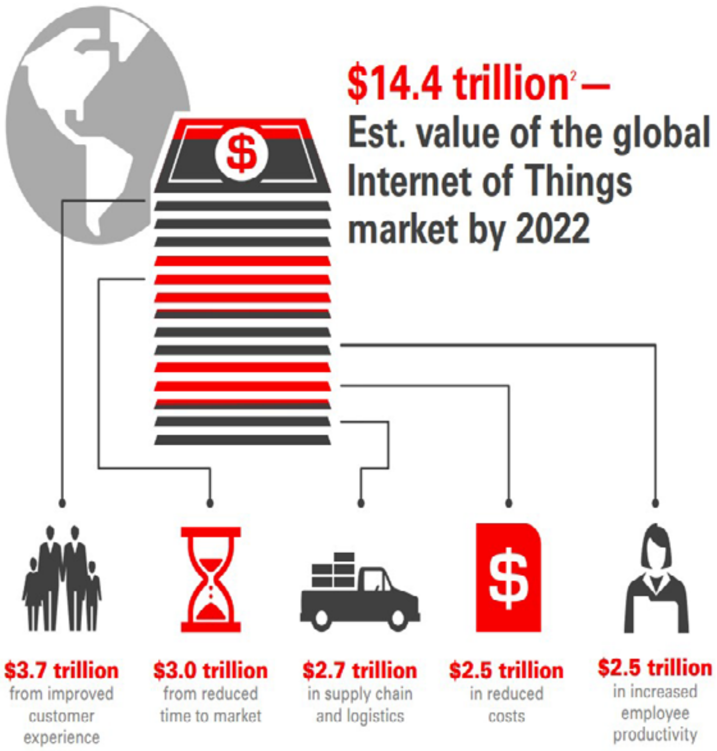


Figure 14: IoT/CPS emerging areas (source: Oracle)

L4G can be used towards the development of new systems that can enable new, or boost existing, added value business models towards reinventing the way that IoT/CPS related processes are executed, increasing furthermore the expected IoT/CPS devices penetration rate in daily operations under specific application domains, as discussed above.

There are two prerequisites for realizing such a vision: the first of them is that large-scale CPS/IoT become easy-to-deploy and easy-to-operate. The second of them is that they must be able to achieve significant improvements in terms of efficiency. Existing CPS tools, technologies and methodologies are far from being able to meet these two prerequisites. The purpose of L4G is to significantly contribute towards rendering existing CPS capable of meeting these two prerequisites: ***L4G can render CPS easy-to-deploy and easy-to-operate while maximizing to their full extended their efficiency and safety capabilities***. This can lead to ***significant improvements in terms of performance and cost-efficiency*** as well as to boosting ***a new generation of significantly more cost-efficient and attractive businesses and services***: smart CPS that ***autonomously and optimally coordinate and control their actions***.

The impact and benefits can be numerous and are related to literally any application area of CPS. To start with the most obvious benefit, L4G can lead towards the ***significant improvement of the performance, productivity and efficiency*** of existing CPS/TSoS. It must be emphasized that the improvements from using L4G are not made possible at the expense of increased operational or other costs. On the contrary, such improvements come together with the ***significant reduction of costs for deployment, operation and maintenance***. This is especially true in applications that involve ***large-scale ecosystems (Systems-of-CPS)*** comprising of different CPS with a very complex interaction with the rest of the ecosystem, such as traffic and transport management systems, robotics and manufacturing and other industrial systems. In all these cases, a highly costly deployment procedure is currently required for programming, verifying and calibrating each and every of the CPS so as to develop all the appropriate decision-making logics. This involves typically a very tedious, highly centralized, off-line and time-consuming procedure which, in many cases, may require months to render the System-of-CPS ready to operate. Even when, however, the System-of-CPS is fully functional and operational, it is more likely to still require a highly costly operation and maintenance procedure: the frequent changes together with the complexity of its operations, call for a frequent or continuous re-programming and re-verification of the CPS operations. What is, however, most important is the fact that there is no guarantee that such a costly deployment and operation can lead to the optimal or, at least, to an efficient performance for the System-of-CPS: in both the initial deployment and during the CPS operation, human operators and users are called to "play with and tune" an extremely large number of parameters in a highly **heuristic** and ad-hoc manner, with all these parameters affecting the System-of-CPS performance in a very complex and "difficult-to-understand/assess" manner. The complexity of the problem renders the success of such a "play and tune" procedure highly dubious. Moreover, due to all the above reasons, the impact and consequences of the availability of a system with the L4G attributes can be tremendous and not only limited to areas and systems where sophisticated CPS are already in place or it is planned to be deployed. It can be also of great significance to areas and systems, where the respective authorities or users are hesitant to deploy a CPS infrastructure as they are not convinced that such a deployment can have a significant impact or because the deployment and operation of the CPS is very costly. In a nutshell, L4G can have a significant impact towards ***removing the barriers that hinder the market penetration*** of CPS-related businesses and services.

Most importantly, embedding CPS with the L4G attributes can greatly contribute ***towards extending CPS to new domains*** as well as ***generating new CPS-related products***. This will at the same time act as a boost for market areas and jobs in the CPS domain. The robotics application is a prominent example of such an effect of L4G: without the existence of a system with the L4G attributes the deployment of such a system and the products, businesses and services resulting from it will not be possible. Needless to mention that in this particular application, L4G can be called to facilitate a number of many different services, demonstrating the ability of L4G to provide ***multiple services***. On the other hand, in Smart City applications, L4G did not only demonstrate its multi-service attributes but demonstrated its ability to ***coordinate and inter-operate highly heterogeneous CPS***, render them capable not only to "talk to each other" but most importantly to optimally cooperate their actions towards ***jointly optimizing their performance***.

We also notice that the Use Cases of L4G strengthen our main argument that L4G is truly applicable in a variety of application areas, involving extremely complex, large-scale and heterogeneous applications. This attests to the fact that with minimal effort the L4G system can be adapted and efficiently utilized in other applications, including, but not limited to: all different areas of transportation and energy management systems, water management systems, emergency response systems, communications and computer networks, the manufacturing sector and beyond. The deployment and operational costs are expected to be minimal as there is no need for large teams of operators and engineers to be constantly involved with "playing" with the many of CPS parameters in a heuristic and ad-hoc manner that reflects today’s standard practice. Moreover, the improved performance through the availability of L4G is expected to increase the demand for the deployment of such systems and lead *directly* to ***strengthened competitiveness of the CPS-related industry and related technologies.***

1.8.1. ADAPTEENG-CLIMA

The need for a cost-effective and straightforward solution to curb building energy consumption, without the need to rip out and replace existing equipment or go through an expensive, intrusive, laborious retrofitting or BA programming is not only a national topic but is strongly related to the European Market in general. While living and working in a building is an absolute necessity to every European citizen, building energy consumption constitutes a major economic drain on household and commercial level. Taking into account the need for reducing energy cost and the market tendency of using renewable energy sources in forthcoming years, the solid commercialization for *ADAPTEENG-CLIMA* application becomes more than obvious.

The implementation of *ADAPTEENG-CLIMA* considers the creation of a **"plug-n-play" application** for optimizing building energy efficiency and **reducing to the minimum energy bills by requiring minimum installation/operation efforts and costs**. The application, using an intelligent energy saving mechanism, is tailored to user **energy management preferences,** targeting to translate innovative technologies into societal needs for energy efficiency. The expected impact of the tool enables the implementation of industrial technologies for societal (and other) challenges, accelerating the commercialization process, by providing an excellent opportunity for the European Market. The introduction of new technologies and concepts is also one of *ADAPTEENG-CLIMA* main priorities and more than that, targets to leverage more private investment into innovation.

The application leads to the generation of important key exploitable results and the novel knowledge produced pave the way for the enhancement of existing Building Automation Systems, Building Management Systems and Energy Management Systems. The benefits generated guarantee the establishment of more holistic and energy efficient approaches at the sectors of residential and commercial buildings. Data generated during *ADAPTEENG-CLIMA* implementation has been studied and elaborated which leads to useful conclusions and directives, as a pool of knowledge of huge importance has been created. Future energy management related research and innovation actions will be able to use this knowledge leading in long term to more improved, affordable, plug-n-play solutions supporting private investment into research and/or innovation. It should be also underlined that the application follows the introduction the 2010 Energy Performance of Buildings Directive and the 2012 Energy Efficiency Directive, as EU's main legislation when it comes to reducing the energy consumption of buildings.

ADAPTEENG-CLIMA aiming to assist occupants in order to elevate HVAC energy savings and improve comfort conditions in an environmental friendly and cost-efficient way: *ADAPTEENG-CLIMA basic ingredient (AGILE-IMS) has already been extensively tested, resulting huge improvements without requiring large efforts and costs for obtaining these improvements.* It should be also noted that the application exploits personalized information and provides building user in a friendly and satisfactory manner, the necessary energy saving schemes according to their specifications and preferences. As a result the solution boosts efficiency and permanently saves costs while providing sustainable comfort improvements.

Apart from the potential of providing a huge benefit on global environment and economy, what is most important is the fact that *ADAPTEENG-CLIMA* represents a commercial attractive opportunity: *without the need to get involved into large investments or into tedious procedures and without degrading comfort conditions in order to curb energy consumption, building users will have the advantage to minimize their energy bills without compromising their comfort and satisfaction*.

ADAPTEENG-CLIMA main economic benefits from for the building owners are the significant savings in energy bills, which are equivalent to ***average annual energy savings of 309.4-771.4€/year for an average household***, resulting in **a payback period of 3 to 6 months (if BA system is available) or 6 to 12 months (if not).**

Moreover, the *ADAPTEENG-CLIMA* illustrates an excellent business opportunity since it blends the advantages of the wide spread BA systems that can be further increased with the introduction of a highly efficient, "plug-n-play" tool for minimizing energy bills. *ADAPTEENG-CLIMA* includes flexible programming, scalability and modular design, simplifies the control, monitoring and optimization of the building. It can be installed and operated in any type of building: *It can operate in any already installed BA infrastructure without any additional addendum and can co-operate with any pre-installed BA system. In case there is not a BA system operating in the building, the tool can still offer its advantages by requiring a quite affordable - to the "everyday" home owner - installation of basic sensing equipment.* It needs to be emphasized that the application keeps all the benefits of the existing BA systems used for Energy Efficiency while ads "on top of those benefits", the advantages of reduced energy consumption and improved comfort conditions.

ADAPTEENG-CLIMA commercialization, concerns the exploitation of its significant market advantages (low-cost of the application and no need for purchasing elaborate hardware) and the use of these unique features as product of unique selling points. An opportunity that supports the applications market position and promises its success is the global market trend of utilizing renewable energy.

Thanks to its usability and effectiveness, *ADAPTEENG-CLIMA* is market-ready for a holistic adoption by European Building sector bridging the gap that conventional systems represent. It demonstrates an efficient and low-cost solution for improving energy savings and user comfort in buildings to its customers, enhancing competitiveness and growth of business opportunities.

The commercial success of *ADAPTEENG-CLIMA* is of course not just based on the economy trend of the market that is promoting such systems, but mainly on the unique benefits of the system as compared with other systems of the same type: *easy to deploy, "Plug-n-Play", inter-operable, flexible, easy upgradeable with low cost installation and operation, responsive and user friendly with long-Term operation, the solution comes to eliminate the problems of modern BA systems by introducing a successfully tried out - in several sites of different kind - new approach in energy management*. *ADAPTEENG-CLIMA* exceeds the effect of the modern conventional BA applications since state-of-the-art technologies cannot handle in an optimal way the complex energy control problem and thus, are not able to provide the same cost-saving advantages.

European and international market size and growth rate/Addressing transnational value-chains and/or EU-wide or global markets

The use of **BA systems for Energy Efficiency (BA-EEC)** has enlarged dramatically the last few years while this trend will continue to increase in the coming years. While the period of 2010–2014 was led by the appearance of BA-EEC start-ups and acquisition strategies among large industry players, the next decade will likely follow a dissimilar market progress path. Recent research predict a new pattern of associations, the development of BA-EEC offerings from proximate markets, and new business models: *BA-EEC intelligent solutions that are suitable for smaller structures are expected to see swift growth in adoption as the pipeline of pilots demonstrates the economic effects of energy effectiveness and maintenance optimization over these building portfolios*. Moreover, the connection and data flow associated with the Internet of Things (IoT) and the Software as a service (SaaS) delivery model will continue to aid the wider adoption of BA-EEC to buyers outside the fractions that have traditionally benefited from building control and automation. The advantage to incorporate smart devices for data acquisition, analytics and control will support flexible and cost-effective solutions that meet the needs of an ever-growing attendance of building management stakeholders [iv].

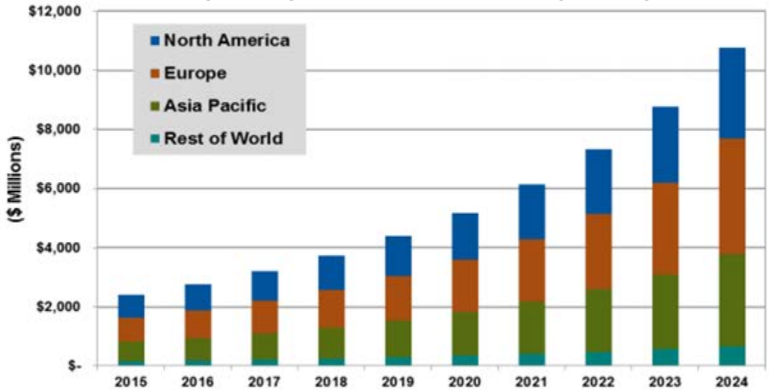


Figure 15. Building Automation for Energy Efficient Climating (BA-EEC) Systems Revenue by Region, 2015-2024[v]

In accordance with recent research, BA-EEC revenue is presumed to grow at $10.8 billion by 2024 at compound annual growth rate (CAGR)[6] of 18.2% [v]. Increasing regulatory pressure due to growing energy wastage in building is predicted to lead the industry over the next years [vi]. Rising awareness concerning the efficient use of energy at corporate and government levels is expected to propel building energy management systems market demand in commercial as well as residential areas. The building sector is mainly responsible

[6] CARG stands for Compound Annual Rate Growth that is more often abbreviated as CAGR. CAGR typically represents an annual rate of the investment growth calculated over several years. It is also used to characterize the growth of other elements of business such as a number of clients or product sales. CAGR is computed with the formula CAGR=[(Ending Value/ Starting Value)^(1/ Number of years)]-1.

for global greenhouse gas emission as well as energy consumption. Rising energy prices and controlling energy costs for commercial as well as residential buildings is expected to raise building energy management systems market size: *The International Market for building Energy Management systems is considered to reach more than $5.5 billion by 2020 driven by the increasing regulatory influence to lower the energy loss in building structures*[vii]. These sectors have been adopting various appropriate technologies for controlling, conserving, and monitoring energy. Although North America and Europe are projected to continue leading in BA-EEC demand in the near term, research actions increasing investment in Asia Pacific in the mid and long term. Furthermore, forecast demand will grow at differing rates by customer segment as the BA-EEC market continues to grow.

Europe, which currently accounts for almost half the current BA-EEC market, is enlarging at almost 10% yearly and according to another research (BRSIA) global BA market will likely double, to more than $6.8 billion by the year of 2020. This remarkable market enlargement is set to occur in spite of several barriers. This is partly because the factors leading this enlargement differ from one region to another: In Western Europe, gas prices almost doubled between 2005 and 2013, while at the same time a lot of European economies became progressively dependent on import of gas from politically sensitive countries, fostering the spectre of uncertain supplies.

While the increase in electricity costs has been less dramatic, lot of European provinces face the huge task of accomplishing their obligation to shut down all nuclear power generation by 2022, while other face analogous challenges as its ageing, coal-consuming and CO_2-spewing power energy production hit the ends of their lives, with the fear of black-outs rising haunting business and political worlds. This and progressively aggressive environmental targets, at national and EU level, mean that even a EU which has been in or near regression for more than five years continues to invest in energy efficiency. At the same time, there are evidences that companies at all levels are starting to realize the full potential of BA-EEC to decrease costs and save money. Besides, as virtually every device of a building becomes capable of generating and communicating data, the approach of big building data has opened great chances both to enterprise data and IT suppliers and to a huge number of smaller newer suppliers of advanced analytics, allowing building managers to forecast and pre-empt issues that degrade a building's energy performance. The reward is most likely to go to solutions that can combine innovation in new technologies and understanding of how building users interact with the structures, with a deep-seated insight of how buildings operate [iv].

Commercial market competitive solutions and the ADAPTEENG-CLIMA solution

Based on the above analysis, there is a big market gap for *ADAPTEENG-CLIMA*'s market viability in BA for energy efficient intelligent online control able to smoothly adapt itself in a real-time automatized manner towards a constantly converging energy efficient building management concept. Annual sales and market penetration levels are expected, based on conservative analysis, quite high due to the uniqueness of the smart energy efficient automatic control feature together with the low cost price of the gateway (around 100€) and the small annual fees foreseen (expected around 50€ per case) in contrast with current market competitive services and products which cost annually in average 180€. The competence analysis is based on four main pillars as described in the following table, alongside with the identified commercially available solutions.

Competitive Commercial Solutions Practise	***ADAPTEENG-CLIMA* Proposition Added Value**
- Manual actuation of energy efficient actions by the user requiring user physical presence indoors. - Competitors: *Wattics, eSight, digitalenergy, ePortal, eco|Driver, enerchart, ENMAT Energy Management, Incenergy, RtEMIS, e-Energy by Cosmote, SAP, etc.*	+ Automated closed loop actuation feature available
- Informed user actions involving energy/building consultants with expensive and long-term dependencies. - Competitors: *EnergyDeck, EnergyLogicIQ, Energinet, Cylon, Utilities Direct, Credit 360, C3, etc.*	+ Actions in an automatized adaptive manner ensuring constant supervisory of the available Building Automation infrastructure with guaranteed energy efficiency and thermal comfort.
- Deficient fine-tuning process of manual actions through long-term customer tutoring and advising	+ Automatized fine-tuning enabled by self-learning model free properties.

based on off-the-shelf solutions and expensive simulation models. - Competitors: *JouleX by CISCO, ETAP, etc.*	
- Simplified control rules (employed by special building automation infrastructure) and advices (provided by energy/building consultants) based on general experience in cases where buildings with different construction and climate characteristics are involved cannot exploit energy savings potential at acceptable level. - Competitors: *Events2HVAC, TREND, Schneider Electric, SIEMENS Desigo, Honeywell Building Solutions, Climax, ELRO, Microsemi, etc.*	+ Delicate automatic closed control loop tuned by an online adaptive algorithm allows specific case tailoring in an automated manner.

Key stakeholders and impact to job creation, turn-over and investment for R&I

The ADAPTEENG-CLIMA application addresses the needs of all building and structures, commercial or not. Therefore, application's targeted users are all kind of building users everywhere in the world. The first users to reach will be the European customers with a solid commercialization plan, which will be defined in detail during next steps of the tools realization and mainly through large market players who can distribute the application through their own customer networks.

The ADAPTEENG-CLIMA does not have any important market barriers to overcome in order to enter the market. However, an important factor that can strengthen its commercialization potential is the agreement conclusion with an important market player who will be in the position to put the product in the market massively and through its own channels.

Apart from building users and vendors of BA systems, BMS, BEMS, HEMS, the following are also significant key stakeholders for the *ADAPTEENG-CLIMA* product:

Energy Service Companies (ESCOs): Energy service companies (ESCOs) offer their customers consumption optimization solutions. Traditionally, ESCOs have offered their customers two types of solutions: *Auditing and equipment sales and Energy services*. Nowadays, they are increasingly focused on a model in which, rather than selling equipment to improve energy efficiency, they offer services to improve energy consumption through consumption measurement and control systems, as well as energy efficient equipment. One of the main barriers for this model is the "expensive" tuning and calibration required, a barrier that will be removed through the *ADAPTEENG-CLIMA* solution.

Smart Grid Companies/DSOs/TSOs: *ADAPTEENG-CLIMA* can significantly contribute towards efficient Demand Response solutions, which are becoming necessary for the operation of all these companies.

District operators: District Energy management System can be supported by *ADAPTEENG-CLIMA* application as they treat the neighbourhood - a group of buildings and energy systems – as a system of system. Thereby, *ADAPTEENG-CLIMA* application overtakes the supervisory control for these energy systems and optimizes their interaction with view on a superordinate objective, regarding the constraints of each constituent.

ICT and BAS developers/planners: Information and solutions that can improve their products/services in the form of opening of a market for ICT-based district/community energy management systems.

It must be emphasized, that the potential of the *ADAPTEENG-CLIMA* solution for a wide penetration into the Building Users sector will have a significant market impact in terms of its turnover. The fact that the *ADAPTEENG-CLIMA* solution "eases" the operation of many other businesses and services (especially ESCOs, city operators and demand-response services for Smart Grid operators, DSOs and TSOs) and removes the barriers hindering their wide penetration, will not only increase their turnover and boost new jobs but it will, moreover, motivate the primary stakeholders of these businesses to invest in future versions of the *ADAPTEENG-CLIMA* tool. Such future versions will incorporate energy efficiency and demand response at the large-scale level (e.g. at the district or city level or for specific group of people such as the elderly or people with special needs) through e.g., social media platforms. The already-decided private investment of several city authorities and operators in Sweden to ingredients used by the *ADAPTEENG-CLIMA* solution can serve as a roadmap towards such a purpose.

1.8.2. L4G Mobility tool

The need for safe and economical travelling and transportation is not only a national topic but concerns also the whole European market. While keeping a car on the road is an absolute necessity for millions of families and professionals across Europe, sadly it is also a wallet-busting drain on household or company finances. Taking into account the expected increase in the volume of travel and moving vehicles in coming years, it is obvious the solid commercialization concept for the *L4G Mobility tool*.

Apart from the potential of providing a huge impact on global economy, what is most important is the fact that the *L4G Mobility tool* is going to be an extremely attractive product: without the need for the driver to get involved into large investments or to change her/his habits and way of driving, it provides the every-day driver with a very safe and user-friendly manner for significant fuel savings. Moreover, the *L4G Mobility tool* has excellent business opportunities since it take advantages of the wide spread of GNSS-based navigators and will be further increased with the introduction of the European advanced GNSS system, Galileo.

The main economic benefits for the users of the *L4G Mobility tool* is a significant reduction in vehicle's fuel consumption in the range of 20-40% (equivalent to 400€/year savings) with the purchase of the proposed low-cost application (operation cost less than 10€/month or 25% surcharge on savings) and without any additional hardware (except a conventional GNSS-based navigator or a smartphone).

European and international market size and growth rate/Addressing transnational value-chains and/or EU-wide or global markets

The use of vehicles has increased dramatically the last decades while this trend will continue to grow in the coming years. It is estimated that the number of 590 million passengers' vehicles in 2002 will explode to 1.7 billion in 2035, with the strongest growth taking place in Asia (India +600%, China +221%, Rest of Asia: +110%) and the Middle East (+161%) according to International Energy Agency[viii] studies. In EU-27, growth is also predicted for the aforementioned period with the number of vehicles to increase from 275 million vehicles in 2010 to 360 million in 2030.

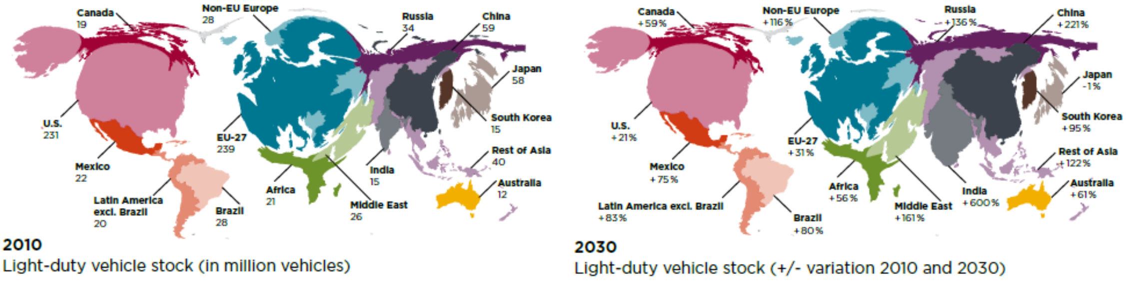


Figure 16. Light – duty vehicle stock 2010 – 2030 evolution

Along with the increase of vehicles numbers the use of GNSS-based navigators (in-car or mobile devices mainly smartphones) has also increased the last years. The numbers show that GNSS market for road applications has grown by approximately 50% per annum in terms of shipments. As a result in 2010, 32% of road vehicles in the EU had a GNSS device on board. According to a survey published by the European GNSS Agency[ix], the global annual shipments of vehicle navigation devices is expected to reach 1800 million units by the end of 2016 whereas the installed base would be consisted of 5 billion units. These numbers are predicted to grow by around 40% in 2020 (i.e. 2400 million and 7.5 billion units respectively) supported by the introduction of European GNSS system Galileo.

Besides, an interesting fact is the huge increase of smartphones units globally. According to IDC[x], a record 1.43 billion smartphones were shipped globally in 2015, an increase of 10.1% over last year's number. For the Q4 of 2015, shipments hit 399.5 million units, a rise of 5.7% from the final three month period of 2014, thus leading to the estimation of achieving a total number of 2.1 billion smartphone users by the end of 2016[xi].

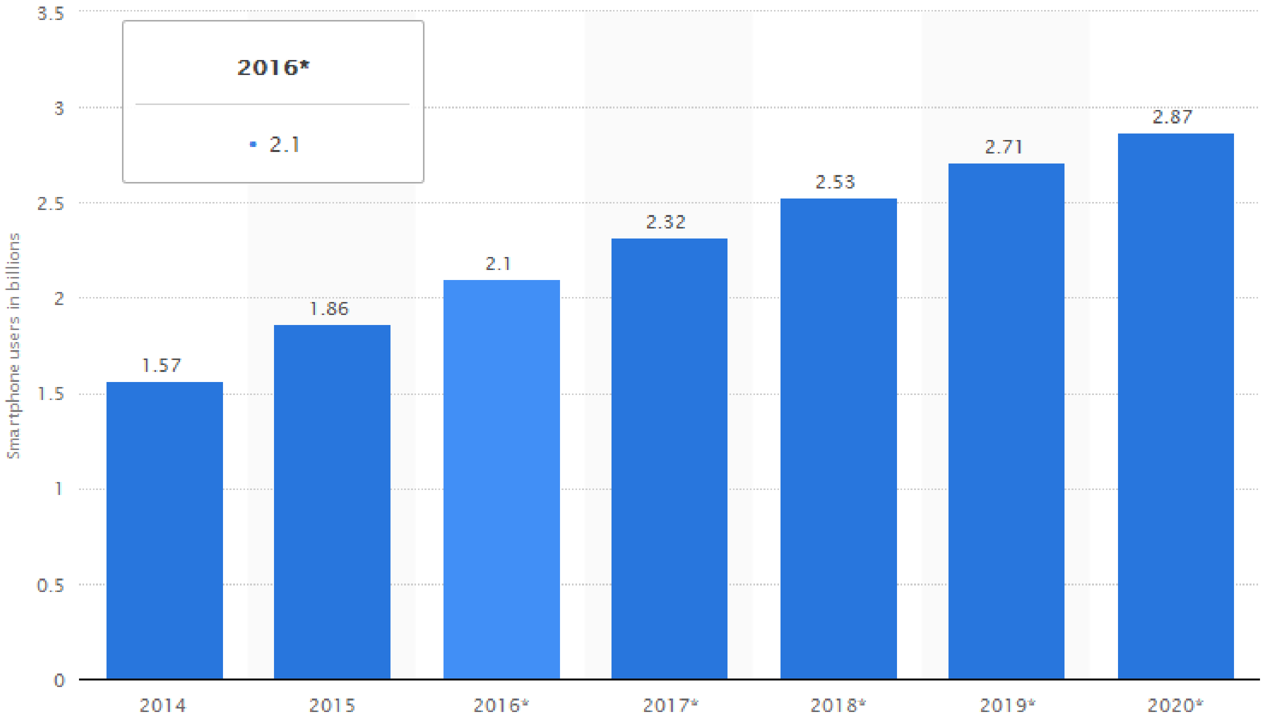


Figure 17. Smartphone users in billions

Yet another study claims that while in 2012 about a quarter of all mobile users were smartphone users[xii], by 2018 this number is expected to double, reaching 50%. The number of smartphone users worldwide is expected to grow by one billion in a time span of five years; from 1.5 billion in 2014 to around 2.5 billion in 2019.

With smartphone penetration rates increasing as well, over 36% of the world's population is projected to use a smartphone by 2018, up from about 10 percent in 2011.This creates a huge market opportunity for vendors of units and developers of applications. Noteworthy is that smartphone based applications are gaining momentum all over the world, mainly displacing sales of other platforms and enabling rapid growth outside of EU and US. In 2010, 10% of all GNSS enabled smartphones sold, are used for the purposes of vehicle navigation. By 2020, this figure is expected to rise to 30%.

The market, which *L4G Mobility tool* addresses, is not saturated given the fact that both the number of vehicles and of smartphone units, along with new applications related to them, will increase rapidly in the coming years.

In EU-28 with a number of 252 million passenger vehicles the number of amateur drivers reached in mid-2015 approximately 180 million. Besides, with a fleet of more than 34 million commercial vehicles the number of professional drivers estimated at 52 million people. By end of 2014, 52% of road vehicles in the EU had a GNSS device on-board. During the Q3 of 2015 the top 50 mobile network operators in Europe reported 960 million of mobile subscribers. In Q3 2015 the smartphone units sold in Europe was 55 million. Therefore, by taking into account the above numbers, *L4G Mobility tool* potential users are estimated at 100 million and *L4G Mobility tool* Total Available Market is estimated (assuming 100€ fee per user) around 10B€ in Europe.

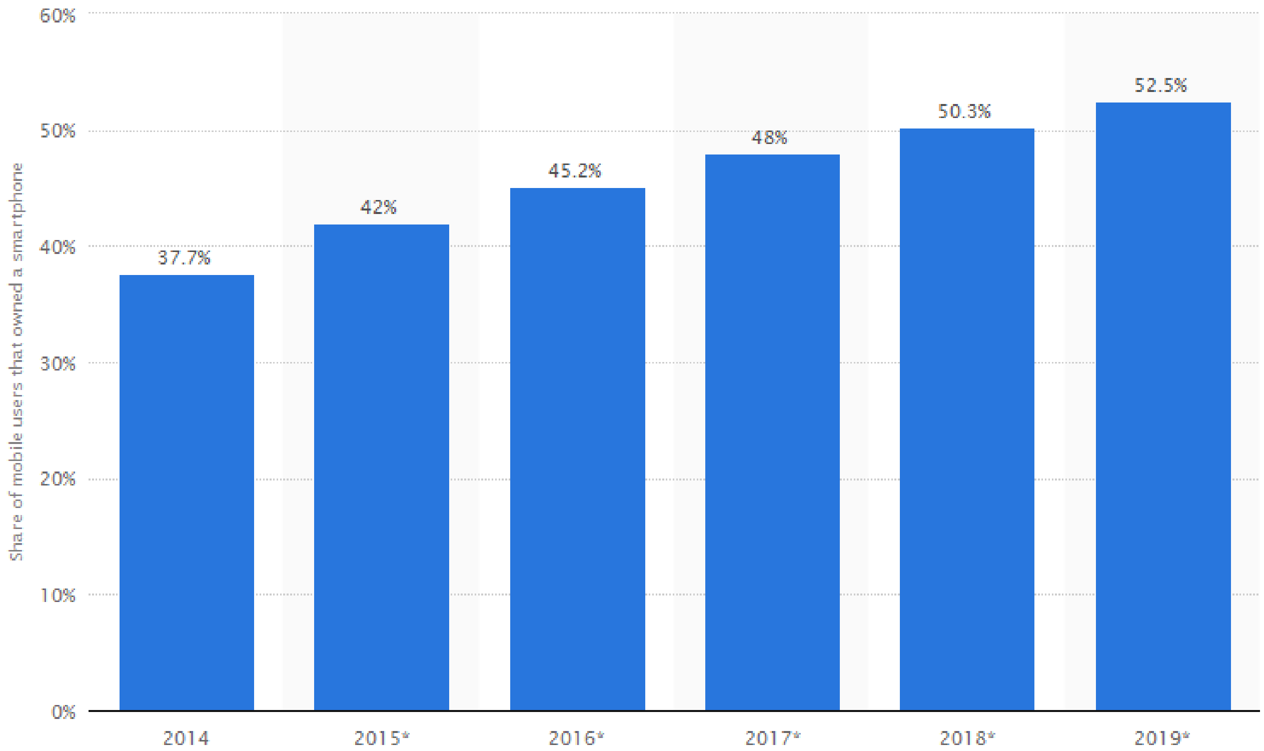


Figure 18. Share of mobile users owning a smartphone

Commercial market competitive solutions and the L4G Mobility tool solution

The "heart" of the proposed *L4G Mobility tool* is an intelligent, learning algorithm which by taking into account the various factors affecting fuel consumption and travel times (type of the road, slope, driving style of the particular driver, weather conditions, etc.), it learns the optimal speed profiling strategy for the particular driver (and apparently for the particular vehicle). Not all drivers drive and respond the same to external commands or instructions and the same driver may have different driving characteristics depending on the type of vehicle he/she is driving. These diverse characteristics of individual drivers and driver/ vehicle combinations have to be taken into account in order to come up with speed instructions which will make driving more efficient, more safe, more comfortable for the driver but also for the overall traffic network.

The competition for *L4G Mobility tool* can be broadly divided into the following groups (see Table 10 for details):

- *Systems supporting the driver to drive the vehicle in a fuel-efficient way*, such as Ford ECOmode, Garmin EcoRoute HD, FIAT EcoDrive, Ford Econocheck. Competitors in this group develop systems for specific vehicle navigation devices either built 'in or portable that indirectly could provide certain support for fuel consumption reduction.
- *ecoRouting systems supporting drivers to choose the route with lower fuel consumption*, such as ecoRouting. Competitors in this group develop systems that don't take into account the actual fuel consumption of the vehicle under certain conditions (weather, road geometry, etc.).
- *Tour planning systems* such as portatour. Competitors in this group develop systems that miss information that may lead to deviations from their prediction (e.g. current weather conditions).
- *Traffic management and control systems* such as InSync. Competitors in this group develop systems either for emergency situations or in order to assist the driver to smoothly slow-down/speed-up the vehicle because of a forthcoming congestion.
- *Cooperative systems V2V or V2I* (that are still subject of research) such as DriveC2X. Competitors in this group develop systems that with extra equipment installed in the vehicle can enable intelligent information exchange to help improve the driving style.

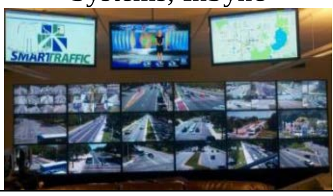
Competitive solution based on:	Vendors/ Products	Competitive analysis
Vehicle technology (by implementing more advanced engine technologies)	Ford EcoBoost 	Less cost-efficient than *L4G Mobility tool*. The adoption of the constantly improving internal combustion engines or change to a hybrid vehicle is a significant investment.
Fuel technology (through the use of alternative fuels)	Natural gas, biofuels, hydrogen 	Less cost-efficient than *L4G Mobility tool*. The introduction of alternative to the petroleum fuel implies for a significant cost while in several cases has a negative impact on engine's lifetime.
Systems for fuel-efficient driving (integrated in the vehicle or available on nomadic devices)	Ford ECOmode, Garmin EcoRoute HD 	Less helpful than *L4G Mobility tool.* These systems are based mainly on driver's behaviour without taking into account important external factors as road geometry.
Several OEMs offer a post trip analysis to their customers (either directly in the vehicle or off-board)	FIAT EcoDrive, Ford Econocheck 	Less useful than *L4G Mobility tool*. Such systems miss the information about the driving environment. Therefore the systems can only monitor and evaluate driver behaviour without putting it in a context.
Systems supporting drivers to choose the route with lower fuel consumption	ecoRouting 	Less useful than *L4G Mobility tool.* These systems offer dynamic adjustment of routes based on traffic information that is broadcasted or transmitted via mobile phone connections.
Tour planning systems	portatour, LFS 	Less helpful than *L4G Mobility tool.* These planning tools incorporate historic traffic information to forecast travel time but miss information that may lead to deviations from their prediction (e.g. weather).
Traffic management and control systems	Transportation Control Systems, InSync 	Less efficient than *L4G Mobility tool.* These are systems designed for accessibility reasons like (dynamic) green waves, parking guidance and traffic information that have been evaluated on their environmental impact and proved to be also successful in reducing fuel consumption in the order of 5%.
Cooperative systems V2V or V2I (*that are still subject of research*)	sim-ID, DriveC2X, eCoMove	Less cost-efficient than *L4G Mobility tool*. Such systems enable intelligent information exchange to help improve the driving style but they require that the vehicle is equipped with expensive "extra" sensors not typically used in everyday vehicles.

Table 10: Competing Solutions and Technologies

The unique selling proposition of *L4G Mobility tool* is that it guarantees to its users significant fuel costs reduction without installing extra equipment in the vehicle or on the road. The necessary for achieving the reduction speed information is personalised (based on his/ her personal driving style) and will be provided to the user in a not distractive manner. The price of *L4G Mobility tool* will be very competitive thus making the application a real "Value for money" solution. Lastly, given *L4G Mobility tool* innovative architecture, any new technological advances that can improve its performance - e.g. an improved GNSS-based sensor - can be easily exploited by appropriately upgrading its software modules. The following table summarises the added value of *L4G Mobility tool.*

Feature	Added value leading to high impact
Efficiency	Significant reduction in the range of 20-40%
Simplicity	Easy-to-use application on the smartphone without extra installations
Personalisation	Personalized to driver's particular driving style and current road and weather conditions
Economy	Low cost of purchase

Table 11: Added value of *L4G Mobility tool*

Key stakeholders and impact to job creation, turn-over and investment for R&I

The *L4G Mobility tool* addresses the needs of all different types of vehicles' drivers, professionals or not, everywhere in the world who cover several kilometres daily with small or big vehicles in either suburban or urban areas, using either a smartphone or a GNSS-based navigator and are interested in economy commuting.

The European market will be fundamental to trigger a successful global commercialization, since Europe represents a significant share of the global market. The first sales, will leverage the interest of European customers and will influence quickly them, as many relevant for *L4G Mobility tool* companies either are connected to European players or are affiliates of them.

The proposed *L4G Mobility tool,* which is an independent from hardware application, does not have any important market barriers to overcome in order to come to the market. However, an important factor that can strengthen its commercialisation potential is the agreement conclusion with an important market player who will be in the position to put the product in the market massively and through its own channels (as mentioned a good partner is the terrestrial mobile phone network operators).

A promising channel for *L4G Mobility tool* initial introduction should be terrestrial mobile phone network operators. In order to make a successful commercial exploitation of *L4G Mobility tool* the following technology and business key stakeholders should (also) get involved:

- <u>Terrestrial mobile phone network operators</u>: they are a good diffusion to the market channel. They could provide *L4G Mobility tool* either as stand-alone application or as service to their customers. In case of services they can among others, distribute directly to the users personalised meteorological or traffic data.
- <u>Mass media e.g. newspapers and magazines</u>: they can distribute *L4G Mobility tool* directly to their customers as an offer for initial introduction or testing.
- <u>Vehicles manufacturers and automotive suppliers</u>: such as VW, Bosch, Metasystems, etc. They could be direct buyers of the application for installation in the provided in-car units.
- <u>Navigation services providers</u>: such as TomTom, Nokia Here, Google Maps, etc. (same role as car manufacturers: buy the licence and the service).
- <u>GNSS manufacturers/ distributors:</u> such as GARMIN, Qualcomm, MLS, etc. (same role as car manufacturers: buy the licence and the service)
- <u>Automobile clubs/ road users/ professional drivers organisations</u>
- <u>Fleet operators and Logistics companies</u>

1.9. Lessons learned during the project

A highly promising system which can be deployed in generic TSoS applications has been developed, analyzed, tested and evaluated within the project L4G. Theoretical analysis, extensive simulations as well as real-life demonstrations have exhibited that the L4G system is capable of globally optimizing TSoS performance by requiring minimum-infrastructure deployments and, most importantly, by requiring no human tedious involvement in modelling, programming and tuning the system operations. The areas where L4G can be applied are numerous and its potential is tremendous. The basic and more promising L4G products have been identified and analyzed towards such a purpose. Moreover, both simulations and real-life demonstrations have exhibited that the L4G system is quite straightforward to implement.

However, there are several steps towards the full exploitation and commercialization of the L4G system. As a matter of fact, this is the main lesson learned during the project: having a system/product with the powerful and attractive features of L4G is not enough: significant steps are needed so as not to "waste" the very valuable achievements of the project.

To start with, the first of these steps requires that the L4G system must become "more convincing" to the potential customers. This can be only made possible if several real-life demonstrations of the system are made available. This was the main feedback from all different stakeholders (listed in section 4.2) the L4G consortium have discussions with so as to identify what the market needs so as to adopt the L4G product. A second step would require shielding the L4G system with attributes necessary for becoming a fully-commercial product: security and privacy, user trustiness, easy maintenance and guaranteed proper operation in long-term applications are some of these attributes. The last, but by no means least, step would require that significant commercialization activities including certification and "packaging the L4G products with an attractive wrap" are required.

Three different ways for accomplishing the first step have been identified and are pursued. The first of them is to seek for funding of the different L4G products through national or international agencies. A first attempt - not successful but promising - have been made through the EC's Fast Track Innovation instrument. The second way is through already established agreements and contacts. The agreement of implementing the system in a pilot in Sweden which - if successful and convincing - can lead to large deployments, is probably the most promising path for such a goal. Another path for achieving the large deployments needed is through two dynamic SMEs with a well-established network of customers (including many public buildings). These two SMEs - which have been engaged in the aforementioned Fast Track Innovation proposal - and are willing to deploy L4G as part of retrofitting projects they are currently negotiating with the local authorities, as L4G provides a comparative advantage over their competitors. The third way is also linked to the accomplishment of steps two and three mentioned above: today there exists a plethora of fully-commercial products that - although they don't have the nice attributes of L4G of optimizing performance in a plug-n-play manner - they successfully deal with all the properties required in a commercial product: security, privacy, trustiness, easy maintenance, guaranteed long-term proper operation, certification and attractiveness are all properties embedded and guaranteed in these products. The L4G consortium policy is to contact the owners of such products - the L4G brochures can be used for this purpose - so as to discuss the possibility of enhancing their products with the L4G attributes. In other words, L4G can be used not as a competitor of existing products but as an add-on which will overcome some of the significant limitations of these products (e.g., limited ability to produce significant savings) - rendering it, thus, more attractive to the customer - while retain all of the customer acceptance/trustiness and attractiveness-to-the-user attributes of the product. For instance, in the building automation sector, there is a number of different, quite attractive products - see e.g., section 1.8.1 - which enable the home users to easily monitor and control their energy-consuming equipment. Although, these products allow the users to program the equipment "intelligence", they are typically used by the users so as to implement simplistic, rules-of-thumb (e.g., "turn air-conditioning on, half an hour before I arrive at home"). This is because it is practically infeasible for the users to program highly intelligent functions. The L4G product can be used as a powerful add-on in these products which will automatically control the equipment and achieve significant energy savings without the need the user to "worry" about how this is done. Similarly, there exists a plethora of products for advising drivers on how/where to drive (see e.g., section 1.8.2 for a list of such products): the L4G product can be used as an add-on in these products to additionally advise the drivers on their speeds towards achieving significant fuel savings as compared to the ones achieved using these products.

1.10. Partners & Contact

	Participants	Contact Channels
1.	CERTH – Centre for Research and Technology – Hellas	Project Coordinator:
2.	ETHZ – Eidgenössische Technische Hochschule Zürich	Pf. Elias Kosmatopoulos (CERTH)
3.	RWTH – RWTH Aachen University	kosmatop@iti.gr
4.	IK4 – IK4 TEKNIKER	Project’s Website:
5.	TRV – TRANSVER GmbH	http://local4global-fp7.eu/contact/
6.	TUC – Technical University of Crete	Facebook: @Local4Global
7.	TUM – Technische Universtität Munchen	Twitter: @Local_4_Global

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[x] http://www.idc.com/getdoc.jsp?containerId=prUS41882816

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[xii] https://www.statista.com/statistics/285596/forecast-smartphone-penetration-amongst-mobile-users-worldwide/