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Autonomic Properties in Traffic Control

Krasimira Stoilova, Todor Stoilov, Konstantin Nikolov

Institute of Information and Communication Technologies, 1113 Sofia
Email: todor@hsi.iccs.bas.bg

Abstract: *The operation of a complex system like a transportation network is considered with respect to the opportunities to identify the application of autonomic properties. The autonomic features of self-properties are analyzed. A multilevel approach is suggested for the formalization of the transport operation. The integration of relevant optimization problems is also considered in the framework of a multilevel, hierarchical scheme of control. The application of bi-level formalism in the transportation systems gives quantitative assessment of the control processes in the traffic control system. The multilevel approach allows the increase of the solution space of a complex optimization problem with an additional traffic control variable, which in the classical optimal formalization participates with fixed parameters in the optimization problem. The benefit of the multilevel control approach is tested in a real network of crossroad sections.*

Keywords: *Traffic control, autonomic computing, multilevel systems, bi-level optimization, computer systems.*

1. Introduction

The Information Technologies (IT) have significant progress nowadays. This fact together with the development of Internet leads to propagation of information and communication technologies in nearly all areas of life. However, the information technologies require competent influence of IT specialists. As the variety of proposed information services increases very fast, the IT specialists will not be able to maintain these IT services and their interaction fast which leads to impossibility for servicing all these systems, computers, communications and customers. The IT and their wide propagated spectrum stay behind the maintenance of IT specialists. In the near future since the technologies' development and their variety has higher speed than their maintenance, a shortage of corresponding IT specialists is expected and the system "customer-services" will not be able to work. To overcome this negative tendency Paul Horn, vice-president of IBM, alarmed the scientific society in 2001 and proposed to the scientists some directions for thinking and research [10]. His idea is based on the creation of new opportunities for decision making and essential calculation, and communication operations without human participation, i.e., development of automatic systems. The efforts have to be directed to the development of computer systems, which are self-controlled in the same manner as the human nervous system – it regulates and protects our body. As the human nervous system controls and protects our body, the idea of the autonomic computing is to develop computer systems in a manner, allowing their adaptation, control, reaction, protection and interaction with other systems automatically, without or with little human participation. These systems are named autonomic computing systems. Today, the existing technologies allow particular realization of a self-controlling approach concerning separate components. The goal is to develop and implement self-controlling systems which have possibilities for adaptation with respect to the existing changeable conditions and can allocate efficiently their resources.

The following eight characteristics of autonomic computing systems are proposed by IBM [10]:

1. The autonomic computing systems have to know themselves – their components have to present the system's identity. Since the system can exist in many layers, detailed knowledge is necessary of the state of all its components, their capacity, final states, and relations to other systems in order to be controlled.

2. The autonomic computing systems must change their structure under some conditions and be self-configured. This pre-structuring must be automatically realized by dynamical adaptation to the changing environment.

3. The autonomic computing systems have to optimize their work. They have to observe their consisting elements and working flows in order to reach the preliminary put goals.

4. The autonomic computing systems must be able to self-heal themselves from usual or unusual events which can damage some system's elements. They have to find problems or potential problems and discover alternative ways for using resources or for reconstruction of the system in order to keep its normal operation.

5. The autonomic computing systems must be able to protect themselves. They must find, identify and protect against different attacks, in order to maintain the system safety.

6. The autonomic computing system has to know its environment and act according to it. It has to find and generate rules how to interact with the neighbour systems. It has to use the most appropriate resources and if they are not available, to negotiate with other systems so that take them from these systems. It has to change itself and the environment or it has to be able to adapt it.

7. The autonomic computing systems cannot exist in closed environment. They have to act in various environments and apply open standards. They do not perform preliminary done decisions. They have to continuously make decisions.

8. The autonomic computing system has to predict the necessary optimal resources for accomplishing the current tasks. The system has to satisfy the quality of services and arrange the information-technological resources in a manner to

decrease the distance between the business and personal goals of the customer and IT instruments.

The concept of autonomic computing can be decomposed in connection with four main aspects of self-regulation, presented in Table 1 according to [12]. The stress of the autonomic computing properties is the term “self-“, applied for the configuration, optimization, healing and system’s protecting.

Table 1. Four aspects of self-controlling today and later [12]

Concept	Current computing	Autonomic computing
Self-configuration	Corporate data centers have multiple vendors and platforms. Installing, configuring, and integrating systems are time consuming and error prone.	Automated configuration of components and systems follows high-level policies. The rest of the system adjusts automatically and seamlessly.
Self-optimization	Systems have hundreds of manually set, nonlinear tuning parameters, and their number increases with each release.	Components and systems continually seek opportunities to improve their own performance and efficiency.
Self-healing	Problem determination in large, complex systems can require team programmers’ weeks.	The system automatically detects, diagnoses, and repairs localized software and hardware problems.
Self-protection	Detection of and recovery from attacks and cascading failures is manual.	The system automatically defends against malicious attacks or cascading failures. It uses early warning to anticipate and prevent system wide failures.

The concept of autonomic computing has propagated for other domains of complex systems and an attempt for autonomic computing application is considered in this paper. The scientific problem, developed here, is in searching manners of application of the paradigm of autonomic computing in a kind of a complex system like the transportation control system. This system has to monitor the current state of the transport network, to watch planned or statistical data, to analyze and to identify its states in order to take control decisions in different aspects which can have a fluctuating character. However, the transportation system will have a better integral state and its functionality will be better in comparison with the current state, controlled by only one criterion.

The necessity of researches in autonomic computing in the transportation domain is of great importance because of the traffic increase in the city and intercity transport networks. As the infrastructure changes are difficult, slow and expensive, it is obligatory to search decisions for optimal traffic control. Some algorithms and models applying the paradigm of autonomy in the transport systems by traffic lights control, density traffic control, integration of transport and ecological targets, are presented in the paper. The autonomic concept is considered like a manner for realization and control of the transport systems in direction of self-control by realization of direct control, optimization, adaptation and self-configuration. These functionalities have to be integrated in a common architecture of the traffic control system. A class of formal models allowing the development of integral control problems is determined.

2. Autonomic properties in transportation systems

There are not known many publications about the application of the autonomic paradigm for the real time traffic control nowadays. This paradigm is raised for the control of distributed computer infrastructure [18]. The elements of the computer infrastructure – web servers, data bases, and mobile devices are managed by the corresponding autonomic controller which observes the current state of the unit and the environment influence. On this basis it plans the necessary actions and fulfils control influences. This can be illustrated for a transport system, presented in Fig. 1.

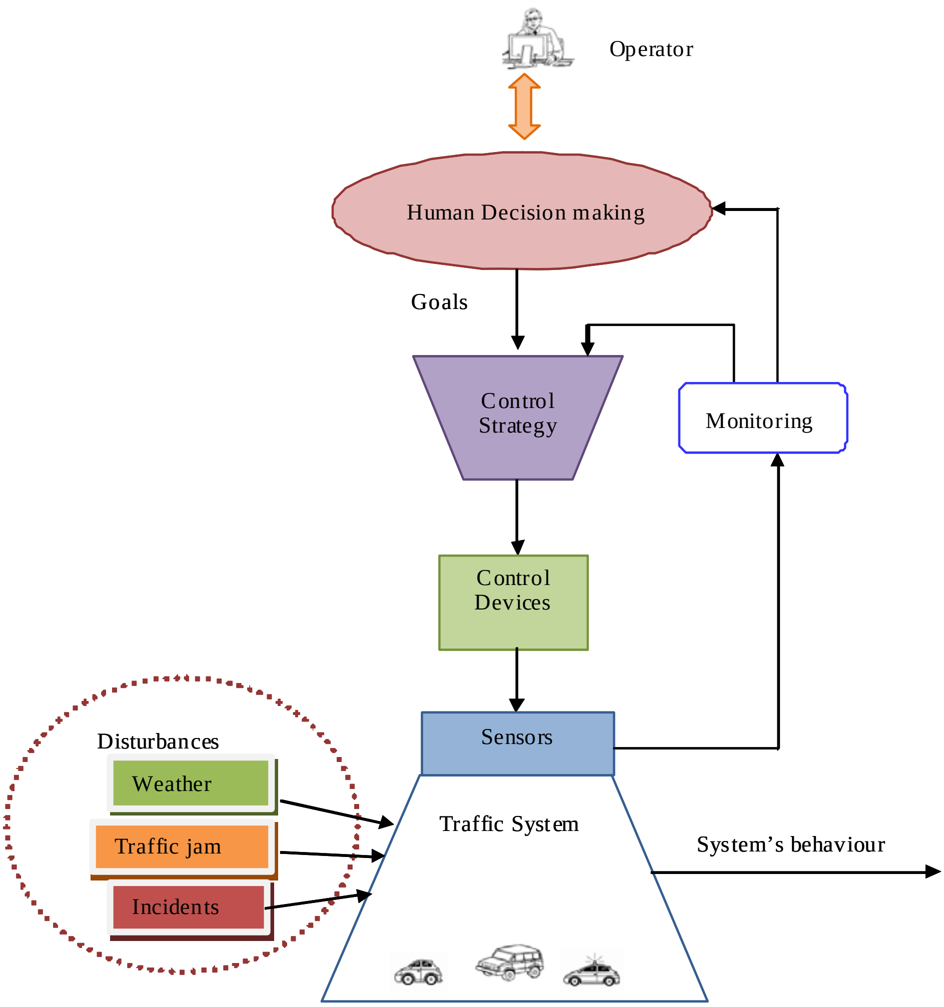

Fig. 1. Closed-loop traffic control

At the lowest level the local control devices are located, which maintain their parameters and control influences according to the authority of the controlled subsystem. They measure the changes in the transportation system and fulfil individual control for subsystems without taking into account the links with other control subsystems. The controllers from the lowest level are coordinated and dynamically configured from the upper autonomic control (control strategy). The control hierarchy can be increased with human interaction level and decision making (Human Decision making). This hierarchical traffic control system represents the autonomic character of the human system and regulation. The local controllers are the devices in regard to the direct system's influence and control. The upper levels' control includes additional arguments and constraints in the realization of more common parameters and targets of the system.

As a consequence of the limits of the extensive development of the transport infrastructure, the researches about the control of the transport systems were directed to find solutions for Intelligent Transportation Systems (ITS) where functions on information systems for travellers are included; for control of the transport networks and flows; control of the city traffic systems. These intelligent control strategies have been realized by three types of control systems: centralized, decentralized and hierarchical, shown in Fig. 2. The centralized structure assumes that all data and solutions are centralized in one controller. The last has information of the whole transport system.

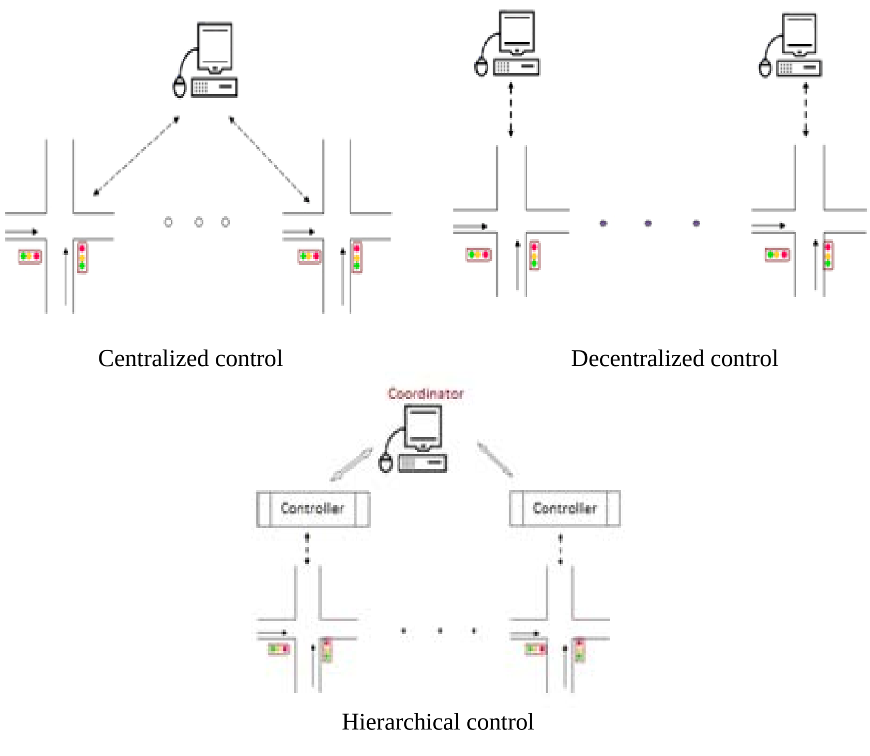

Fig. 2. Control systems architectures

The controller implements functions for predicting future transport events; it develops optimal control strategy, including optimal routing and optimal signalization [16]. The decentralized system applies local control of multiple controllers on separate transport areas [9]. The local controllers use the local measured data. The controller does not have such information about the outside control areas or he/she applies data which is not really measured. This is the reason for the appearance of lack of coordination and contradiction during the control of the whole system. The hierarchical control applies coordination in the work of the local controllers [2, 3]. The disadvantages of each system are presented in [16]. The centralized architecture requires enormous computer and communication capacity. Otherwise, the opportunity of real time control is lost. The decentralized system leads to suboptimal solutions and can cause inconsistency and overloading/traffic jams in different parts of the network. The hierarchical architecture aims to integrate the positive properties of the previous structures. However, here exist certain problems about real time coordination of numerous local controllers.

A perspective manner for applying the autonomic traffic control is the implementation of multilevel hierarchical control. The autonomic functioning of several local controllers and their coordination in real time can be applied like the architecture of an autonomic control system. Every local controller will act according to its local goals, resources, limits and measured data. The challenge of autonomic computing is to realize the opportunities of self- functioning and creation of a common integration control strategy which integrates the opportunities of the independent subsystems taking into account their influences. In this manner a common control strategy can be realized for adaptation of the whole system to outside influences and disturbances.

The formalization of the autonomic systems' action can be found in applying the principles of multilevel hierarchical systems. The global autonomic problem can be defined like a problem of interconnected local optimization problems with fewer dimensions. The manner of the functioning of the autonomic system will follow the sequence of determination and solving the local and global optimization problems. The hierarchical arrangement of the optimization problems allows the realization as a common process the control, optimization, adaptation and self-organization, Fig. 3.

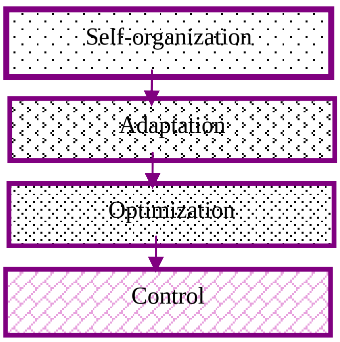

Fig. 3. Hierarchical control

The hierarchical organization of Fig. 3 can be formalized as a system of interconnected optimization problems, $k > 1$,

(1) $$\min_{x^k} f_k(x^1, x^2, \dots, x^k), \qquad g_k(x^1, x^2, \dots, x^k) \le 0,$$

where x^1 solves the local problem

(2) $$\min_{x^1} f_1(x^1, x^2, ..., x^k), \quad g_1(x^1, x^2, ..., x^k) \le 0.$$

Problem (1) is solved by the coordinator, situated at the top of the hierarchical system. It observes and determines the control influence x^k minimizing its goal function f_k, taking into account its constraints g_k. However, both these functions depend on the solutions x^i, i = 1, k–1, of the other optimization problems. In this manner a hierarchical interconnected optimization problem is determined. These problems are difficult for solving even in the simplest case of bi-level hierarchical problems [4, 14].

The short analysis of the formalization of autonomic functioning like a hierarchical control system shows the potential formalization like hierarchical interconnected optimization problems.

3. Transportation systems modeling

The common model for preservation of a material flow is applied because of its simplicity for modeling and control of transport flows. The model is introduced by G a z i s and P o t t s [7] and it is actively used by researchers. The engineering meaning of this model refers to continuity of a flow which allows determining the dynamics of changes of the automobile queues in traffic lights crossroads. This model allows determining and solving the optimization problems for finding the optimal control of transport flows. Researches for reducing the calculations using this model have been done for realizing on-line calculations in an open or closed loop [5, 6]. These researches aim to reduce the traffic jams which have secondary favorable influences for reducing emissions, noise, time for travelling, reduction of fuel consumption, etc. Analysis of different kinds of optimization problems is done in [15].

The control strategies are classified as control of a fixed time interval [17] and controls taking into account the traffic intensity on the roads [11]. These models lead to determining the linear dynamical problems of the state space, which do not reflect the nonlinear relations of the traffic jams dynamics and the effect of reverse traffic jams propagation during the road length. Examples of these nonlinear phenomena are analyzed in [15] where manners for their reflecting in linear dynamical problems are proposed. In particular, additional inequality constraints are introduced. The vector of the state space and control has to accept extreme values in preliminary determined limits. Usually, the system’s state x is the flow of cars which exits from the queue of the waiting traffic. The control influence is the relative duration g_i of the green traffic light in a given direction or the common duration of the green light in all directions of the crossroad, $G = \Sigma g_i$. The time cycle c_i of the traffic light is assumed as unknown parameter which also has to be determined by the optimization problem. The common equation about the flow continuity in differential form is

(3) $$\frac{\partial q}{\partial t} + \mathrm{V}(q,\rho)\frac{\partial \rho}{\partial x} = 0,$$

where q is the car flow [car numbers for a time unit], ρ is the flow density [car numbers for a distance unit], $V(q, \rho)$ is the velocity of the flow movement. This equation is used for all macroscopic traffic control models. This relation in an integral form becomes $q = V\rho$. To be solved, analytical relation between V, q, and ρ is searched. This relation gives a fundamental movement diagram. This relation is most often approximated in a linear form [8]

(4) $$V=V_{\text{free}}\,(1-\rho/\rho_{\max}),$$

where V_{free} is the free movement flow velocity in zero density; $\rho_{\max}$ is the maximum density in which the flow movement stops. Replacing V in (4), a quadratic relationship between q and ρ is obtained:

$$q = V_{\text{free}}\,\rho - \rho^2\, V_{\text{free}}/\rho_{\max}.$$

The flow density ρ can be expressed like variation of the number of cars x for the control road with a length L. Thus the quadratic integral relationship is achieved:

$$q=x\, V_{\text{free}}/L \;- x^2\, V_{\text{free}}/L^2\, \rho_{\max}.$$

This relationship can be used as a goal function of the control problem, in which the maximum flow of cars for the control transport stretch road has to be obtained. An equality system reflecting the cars variation through the stretch road in time is a system of constraints:

$$x(k+1)= x(k) + x_{\text{inflow}} - x_{\text{outflow}},$$

where $x_{\text{inflow}} = s_{\text{i}}\, g_{\text{i}}\, c_{\text{i}}$, $x_{\text{outflow}} = s_o\, g_o\, c_o$; g is the duration of the green traffic light for the corresponding input and output, c is the cycle of the traffic light, s – the coefficients. In this way for a given transport network, a system of equations is defined where g and c have to be calculated.

The solution of this class of control problems in real time is searched in the class of closed control systems with feedback. Applying the autonomic paradigm, the control system is designed like a hierarchical multilevel system. An optimization problem is solved on each hierarchical level where the problem's solution influences the problem of the lower level and vise versa, Fig. 3. For instance, for the above case the lower control layer determines the duration of the green light g in given time cycles c. The upper layer determines the traffic light's cycle having in mind the solutions of the lower layers. In this manner connected optimization problems are determined hierarchically, that formalize the autonomic control model. From practical considerations most often nowadays bi-level hierarchical models with two levels are determined, known as bi-level optimization problems [4, 14] Fig. 4,

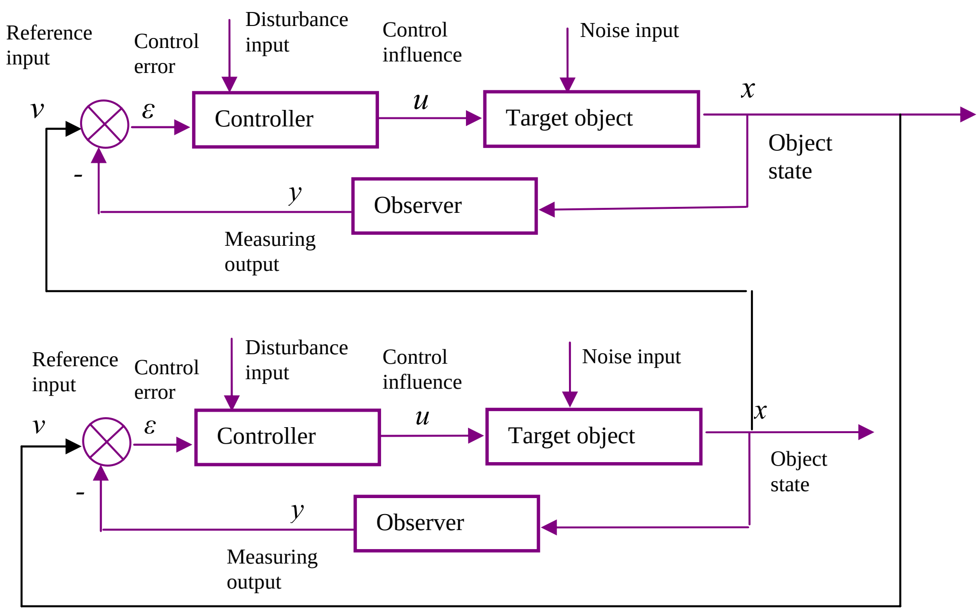

Fig. 4. Bi-level control system

4. Case study of the autonomic behavior of a transportation system

The autonomic behaviour of the transportation systems is inspired mainly by the complex nature of the traffic phenomena and the necessity to resolve the associated decision making problems by the road operators. The complexity of the traffic management comes from the requirements to solve a set of management traffic tasks and the technical devices and systems, which can provide parts of the needed functionality of the traffic control system. The basic structure of a road control system is equipped with sets of sensors of different types, which have to make measurements, needed for the traffic management. Additionally, the traffic processes are subjected to a number of noisy inputs, like weather conditions, subjective driver decisions, incidents which cannot be predicted neither controlled in the traffic management system. Thus, the traffic management is strongly influenced by a human traffic manager, who decides how to manage the traffic according to his competence about the traffic needs. The traffic operators receive a lot of information from various sets of resources and thus they are suffering from information overload. To solve efficiently the traffic problem, the traffic management cannot rely only on the experience of the human operators. A prospective way to tackle the complexity of the problem for traffic management is to apply the concept for the autonomic behaviour of several local control subsystems and to coordinate their functionalities in a multilevel control system. Since the traffic management system is a distributed system with local subsystems, each operating with its own goal and functionality, the challenge is to provide self-properties to each subsystem and to create a cohesive management policy that will integrate the subsystems' capabilities taking into account the subsystems' interactions. This will allow the control policies and local control influences to adapt the overall traffic control accordingly.

An application of a bi-level optimization model [4, 14] for implementation of the autonomic properties in traffic light control is illustrated below. The idea of the modeling is to increase the scale of the arguments in the optimization problem. Thus, in a bi-level formulation the solution of the problem is not only the relative duration of the green lights, but the durations of the cycles of the traffic lights as well. In this way, in a common control process the transport system autonomically turns to optimal values both important parameters of the transport crossroads.

The practical case concerns crossroad sections in the centre of Sofia (between Eagle Bridge and Sofia University). Two crossroad sections interrupt the main stream of the traffic flow (Fig. 5). The formal model, presenting the dynamics of the waiting vehicles in front of the traffic lights, is related to the conservation law:

$$x(k+1) = x(k) + q_{\text{in}}(k) - q_{\text{out}},$$

where $x_i(k)$ is the number of waiting vehicles, q_{in} and q_{out} are the inflow and the outflow of vehicles of the crossroad section, k is the control discrete period termed later a “cycle”.

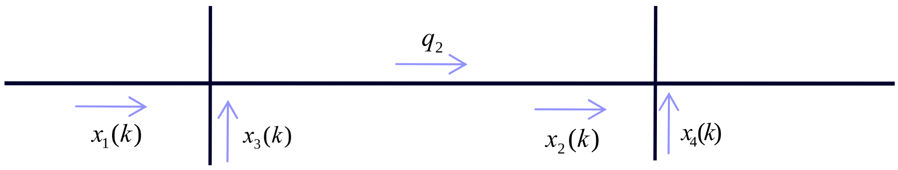

Fig. 5. Arterial road traffic flow

Following the notations in Fig. 5, the optimization problem for finding the relative duration u_l of the green lights is:

(5) $$\min_{u_1,u_2}(a_1x_1^2 + a_2x_2^2 + a_3x_3^2 + a_4x_4^2 + r_1u_1^2 + r_2u_2^2),$$

$$x_1(k+1) = x_1(k) + q_{1\text{in}}(k) - s_1u_1c,$$

$$x_2(k+1) = x_2(k) + s_1u_1c_1 - s_2u_2c_2,$$

$$x_3(k+1) = x_3(k) + q_{3\text{in}}(k) - (L_1c_1 - u_1c_1)s_1,$$

$$x_4(k+1) = x_4(k) + q_{4\text{in}}(k) - (L_2c_2 - u_2c_2)s_2,$$

where $x_{i_0} = x_i(0), i = 1, 4,$ are the initial known values; c_l, $l = 1, 2,$ are the time cycles of the traffic lights (constant values); u_p, $p = 1, 2,$ are the relative durations of the green lights for the two sections; s_j, $j = 1, 2,$ are the capacities of the crossroad sections; $L_m, m = 1, 2,$ is the relative duration of the amber light.

This problem is widely used to evaluate the optimal relative durations $u_p, p = 1, 2,$ assuming that the time cycles c_l are known, according to predefined reference plans. The idea of this work is that according to the autonomic considerations of self-adaptation and self-optimization, the traffic light cycles c_l have to be adapted to the transport behaviour. Thus, c_l, l = 1, 2, have to be defined as solutions of an appropriate optimization problem instead of using them like predefined parameters. In this manner the autonomic functionalities of the transportation system will be practically implemented. Here a bi-level optimal problem is introduced, which results in increasing the solution space of the optimization. Thus both the relative duration of the green lights up and the time cycles c_l will be evaluated like solutions of a common optimization problem. This autonomic framework is implemented by the following bi-level problem formulation.

By solving the classical problem (5) with different values of c_l , the solutions $u_p(c_l)$, l, p = 1, 2, are inexplicit functions of the time cycles c_l. For optimal durations of c_l, l = 1, 2, an additional optimization problem is defined, Fig. 5. For the particular case of Sofia crossroad sections, the upper level optimization problem is defined to maximize the traffic flow on the arterial road. This is noted as traffic flow q_2 between the two crossroad sections in Fig. 6.

Following the flow modeling, the traffic flow q_2 is proportional to the average speed v and the density ρ_2 of the flow,

$$q_2 = v\rho_2.$$

Applying Greenshield approximations [8] for the relation $v(\rho)$, Fig. 7, it follows that

$$v = v_{\text{free}}\left(\frac{1-\rho_2}{\rho_{\max}}\right),$$

which applies values for the free speed v_{free} and critical density $\rho_{\max}$.

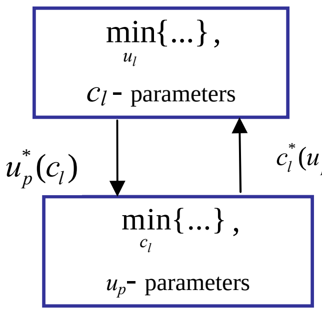

Fig. 6. Bi-level formalization

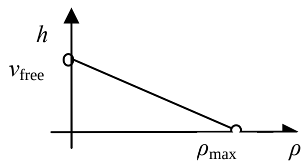

Fig. 7. Linearity of the optimization problem approximation

Using these physical considerations, the traffic flow q_2 is

$$q_2 = v(\rho_2) = v_{\text{free}}\rho_2 - \frac{\rho_2^2 v_{\text{free}}}{\rho_{\max}}.$$

The flow density ρ_2 is evaluated as the number of vehicles x_2 on the road with length L_2, or

$$\rho_2(x_2) = \frac{x_2}{L_2}.$$

Finally, the traffic flow $q_2(x_2)$ is

$$q_2(x_2) = \frac{v_{\text{free}}}{L_2} x_2 - \frac{v_{\text{free}}}{\rho_{\max} L^2} x_2^2$$

and it can be used for the bi-level problem definition.

Thus the upper level optimization problem has engineering meaning of maximization of the traffic flow $q_2(x_2)$, or

$$\max_{c_1,c_2} \{q_2(x_2(c_1,c_2)\} = \max_{c_1,c_2} \left\{ \frac{v_{\text{free}}}{L_2} x_2(c_1,c_2) - \frac{v_{\text{free}}}{\rho_{\max} L^2} x_2^2(c_1,c_2) \right\},$$

where the problem solutions are the time cycles $c_l, l = 1, 2.$

(6) $$\max_{c_l, l=1,2} \left\{ H(c_l) = q_2(x_2(c_l)) - c_l^{\mathrm{T}} h c_l \right\}.$$

Using $x_2(c_1,c_2)$ from (5), the upper level optimization problem becomes

(7) $$\max_{c_1,c_2} \left\{ x_2(c_1,c_2) - \frac{1}{\rho_{\max} L} x_2^2(c_1,c_2) - h(c_1^2 - h_2 c_2^2) \right\}.$$

$$x_2 = x_{20} + u_1 s_1 c_1 - u_2 s_2 c_2.$$

The particular form of the optimization problem (5) allows the solutions to be derived as analytical functions with respect to c_l , or

(8) $$u_1(c_1,c_2) = \frac{2x_{10} - x_{20} - 2x_{30} - x_{40}}{5 s_1 c_1} + \frac{s_2 c_2}{5 s_1 c_1} + \frac{2}{5},$$

$$u_2(c_1,c_2) = \frac{x_{10} + 2x_{20} - x_{30} - 3x_{40}}{5 s_2 c_2} + \frac{s_1 c_1}{5 s_2 c_2} + \frac{2}{5},$$

where $c_1 \neq 0$, $c_2 \neq 0$.

Using (8), the upper level optimization problem (6) is

(9) $$\max_{c_1,c_2} \left\{ H(c_1,c_2) = x_2(c_1,c_2) - \frac{1}{\rho_{\max} L} x_2^2(c_1,c_2) - c_1^2 - c_2^2 \right\},$$

$$x_2 = x_{20} + u_1 s_1 c_1 - u_2 s_2 c_2,$$

$$c_1, c_2 \geq 0,$$

where u_p are derived from (8).

The experiments provided for the traffic network, use the following initial data:

$$x_{10} = 50; \quad s_1 = 21 \text{veh/m},$$

$$x_{20} = 60; \quad s_2 = 25 \text{ veh/m},$$

$$x_{30} = 45; \quad s_3 = 24 \text{ veh/m},$$

$$x_{40} = 40; \quad s_4 = 18 \text{ veh/m},$$

$$L = 800 \text{ m}; \quad \rho_{\max} = 0.175 \text{ veh/m}.$$

The experimental results of the bi-level optimization have been compared with the green lights durations u_l with constant values of $c_l, l = 1, 2$ (dashed red lines). For the queue lengths of the arterial directions x_1, x_2, x_3, x_4 in front of the crossroad section, comparisons between constant (dashed line) and controlled time cycles have been performed. It can be seen that the queue lengths for the arterial directions x_2 and x_4 decrease faster applying the bi-level model in comparison with the optimization problem with constant time cycles c_l. The time cycle changes c_1, and c_2 are given in Fig. 12, where c_1 varies while c_2 is kept constant. The relative values of the green lights u_1 and u_2 are given in Fig. 13. In the classical case these values are constants. Here they are solutions of the optimization problem of the upper hierarchical level.

An integral assessment of the bi-level control policy is presented in Fig. 14 by evaluating the total queue length x_2 for the overall control horizon. The application of the bi-level model leads to decreasing the total queue length (q_2) in comparison with the case of one-level optimization with constant time cycles c_l = const, l = 1, 2.

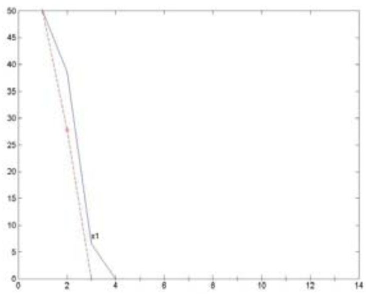

Fig. 8. Queue length x_1 towards cycle k

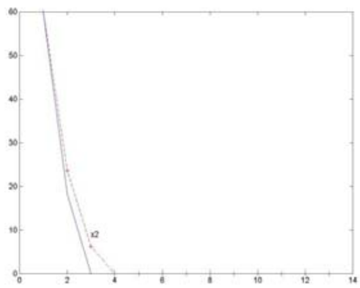

Fig. 9. Queue length x_2 towards cycle k

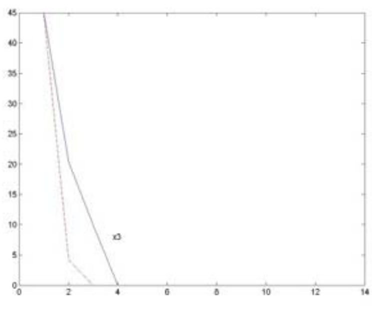

Fig. 10. Queue length x_3 towards cycle k

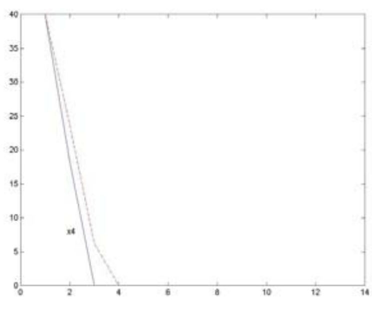

Fig. 11. Queue length x_4 towards cycle k

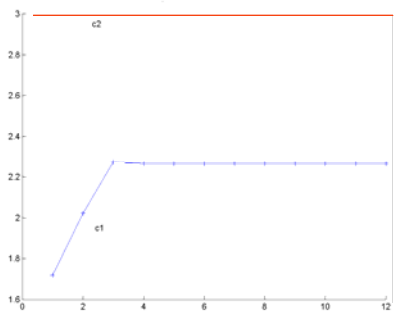

Fig. 12. Time cycles changes

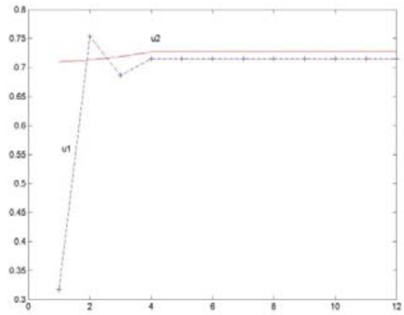

Fig. 13. u_1 and u_2 changes towards k

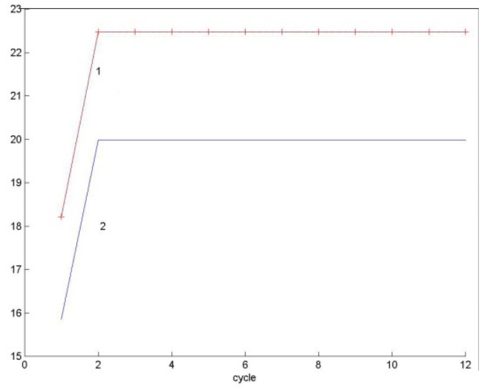

Fig. 14. Integral queue length q_2 towards the cycle: 1 – q_2, c_i=const; 2 – q_2

Thus, the autonomic concept for integration of more components and requirements in the control process benefits the transport behaviour.

5. Conclusions

The paper presents a case study about applying the paradigm of autonomic computing to the object of transportation systems on the example of a road transport stretch in Sofia. The class of formal models appropriate for this object is analyzed. As a consequence of the architecture principles of traffic flows, a hierarchical model is proposed. Because of the complexity of coordination in hierarchical systems, a bi-level one is proposed for modelling. In this manner the interconnections among the different subsystems can be taken into account. This allows extending the number of control parameters which are solutions of the interconnected optimization problems. These problems belong to different levels of the hierarchical management system. This model allows integrating different functions in a common management system which is the target of the autonomic systems. It is shown that by integrating in a hierarchical relation two optimization problems, there are more integrated solutions of the transportation system.

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