

TRAFFIC CONTROL IN URBAN JUNCTIONS – PLANNING AND COMMUNICATIONS

Ana Maria Nicoleta MOCOFAN

Urban traffic control systems (UTC) are a key element of intelligent transportation systems (ITS), as they represent the answer to users' needs of increased road network capacity through reducing delays, stops and travel times. The present paper describes the planning phase of a hybrid UTC system and solutions related to its communication architecture. It is important to know the traffic parameters within the system, so that neighbouring junctions can cooperate to produce optimal control strategies. This paper aims to present the outcomes of the research work related to high availability and quality of services in a fully adaptive UTC system.

Keywords: control, architecture, distributed system, adaptive operation, traffic parameter, communication, quality of services

1. Introduction

UTC systems can be employed for achieving improved performance of an urban road network by reducing the impact of delays and stops. They can also be used for obtaining equilibrium of the network's capacity by distributing traffic flows in selected areas or prioritizing certain categories of vehicles, like public transport or emergency cars [1].

According to specific needs and city size, local authorities can choose to implement a particular type of urban traffic control in order to meet the expected level of optimization for the overall traffic context.

In time, various types of UTC systems have been developed, starting with fixed times control strategies, unable to react to spontaneous changes in traffic progress or incidents, to fully adaptive approaches (centralized or distributed), based on communication with traffic detectors in the field and real time computation of signalling times [2] [3]. The most popular systems already in place in many urban centres throughout the world are [4]:

- SCOOT (Split, Cycle and Offset Optimization Techniques) – centralized approach;
- SCATS (Sydney Coordinated Adaptive Traffic System) – centralized as well;
- UTOPIA/SPOT (Urban Traffic Optimization by Integrated Automation/ System for Priority and Optimization of Traffic) – a

hybrid model, with SPOT being the locally distributed component and UTOPIA the supervising level in the traffic control centre.

The optimal way of ensuring scalability and performances of a modern UTC system consists of modularity and efficient communication between its various components, especially if we talk about a wide system (from a geographical point of view) or a complex traffic management system integrating UTC as a subsystem.

This can be achieved through following a basic system architecture.

This paper presents the UTC communication architecture, a conceptual plan introduced by the author as a first step of the research, based on a broader framework developed by the Federal Highway Administration of the United States, the so called “National ITS Architecture”.

A solution for a wide area UTC system is proposed, combining the 2 existing approaches (centralized and distributed) within an unique system. The resulting hybrid approach would implement 2 layers of decision and control:

- A local level, where traffic control is achieved in a cooperative manner between directly connected junctions;
- A central level, acting as supervisor for the local level and able to intervene in order to change the reference strategy and improve traffic progress in some particular conditions.

The proposed hybrid system is based on a hierarchical model and is suited for a regional deployment, by using the distributed model in the cities and building a traffic control centre at a regional level. Its purpose is to gather data from the cities, to supervise the local systems’ operation and to perform event driven macro-regulation functions. The system can be further enhanced for operation at a national level or to be integrated within a cross border traffic monitoring strategy desired in the future by European decision factors.

In order to obtain an optimal control strategy both at the local and area level, the fully responsive UTC systems employ a series of variables measured by field sensors disposing nowadays of several detection technologies.

The main traffic parameters defined in the traffic flow theory and evaluated through modern detection methods are [5]:

- Vehicle presence;
- Flow rate (number of vehicles reaching the stop line within 1 hour);
- Traffic intensity (number of vehicles on time unit);
- Speed;
- Occupancy (the amount of time a road spot is occupied with vehicles);
- Density (number of vehicles on distance unit);
- Headway;

- Vehicle type (traffic classification).

There is a high level of cooperation that needs to be ensured within a distributed UTC system in order to achieve an efficient operation of traffic signals. This can only be done through continuous exchange of traffic information (flow, speed, etc.) and coordination of junctions included in a certain area, trying to prioritize traffic on main links and reduce congestion for the entire network [6].

The author's entire research is built around fully adaptive, traffic responsive UTC systems. Their performance against the fixed-times signalling strategies has been demonstrated through a traffic analysis conducted in Synchro Studio 7 simulation environment. The traffic network used for the demonstrations consisted of 5 successive intersections in the southern area of Bucharest, Romania, included today into a modern urban traffic management system with adaptive control operation.

Several analyses have been done to study the importance of traffic parameters and their variability. In the simulations, different values of traffic parameters have been applied. Measures of effectiveness such as delays, stops, fuel consumption and performance index - PI (linear combination of the first three, and, optionally, excessive queuing) have been analysed. The results and conclusions allowed the definition of a classification scheme for the main traffic parameters [7].

Starting the end of the 1990s, the quality of services (QoS) has come to the attention of many researchers and network engineers as a necessity for ensuring end-to-end efficient communication. The fast evolution of information technology applications and increasing Internet usage have driven to the analysis of various issues and study of different architectures and frameworks in order to improve the services' availability [8].

In the last section of the paper, a QoS solution was tested, aiming to ensure that critical traffic information is exchanged between the UTC distributed system's entities in order to maintain fully adaptive operation and cooperation even in difficult conditions of congested communication channels. The solution has been tested in a network simulation environment and the results prove that this is an option to be considered within any modern UTC system for maintaining a high level of availability and performance.

2. UTC Communication Architecture

An Intelligent Transportation System (ITS) architecture is a conceptual plan that defines the structure and/or the behaviour of an integrated ITS system. The architecture defines the system's components or its functional blocks and

gives a basic view that can be used for developing the desired intelligent transportation system [9]. The ITS architecture defines:

- The specific functions of an ITS system;
- The physical entities or subsystems that perform the system's functions;
- The information flow that interconnects and integrates these functions and physical subsystems into a system [9].

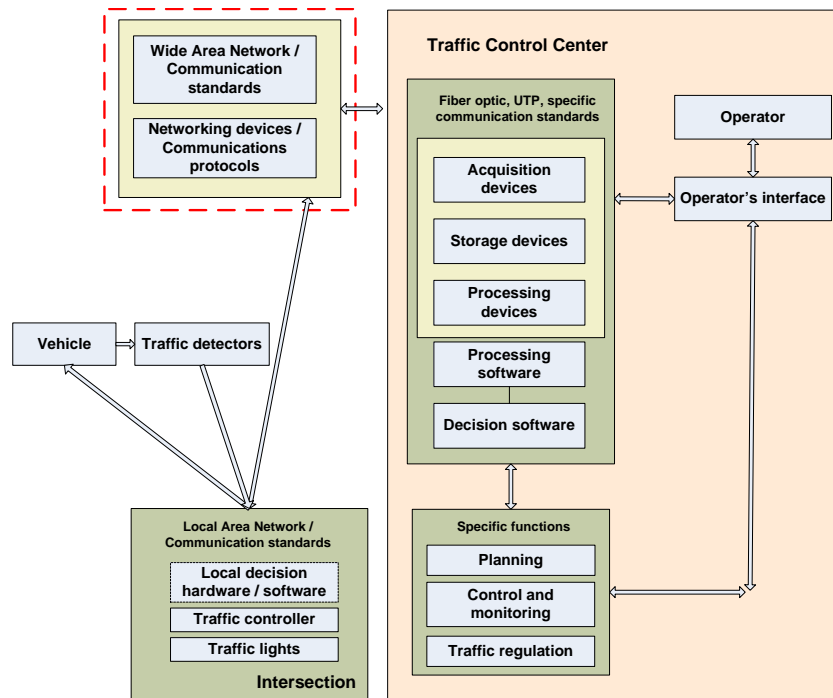


Fig. 1. UTC communication architecture

Based on the general ITS architecture studies and framework, the author applied specific concepts and knowledge to design the UTC systems set of architectures that can be used within the planning and implementation phase of any kind of UTC system, as well as for future developments of existing ones.

The communication architecture in Fig.1 describes the physical components of the system, at a detailed level of elements that are communicating with each other through data transmission networks based on international open standards, well defined and documented [10].

The traffic control centre is equipped with modern, high performance computing devices, capable of working with big quantities of data.

The equipment in the traffic control centre and those installed in the field in charge with the linkage of the 2 subsystems (local and central) are networking devices, meant to physically interconnect the junctions and to make the information available in the control centre, by managing the traffic data transfer using dedicated communication protocols [10].

The networking component (red quadrant in Fig.1) represents the main focus of the following sections, as being the core of the entire system by enabling the efficient data transfer between the local and central control levels.

3. Hybrid UTC system for regional implementation

A cooperative (distributive) system is a collection of independent computers that can work together as a consolidated system [11]. The concept does not require these equipment to be identical or even have the same technical performances; it is achieved through the way they are collaborating and exchanging information with each other [12].

The proposed approach is based on a hierarchical model, aiming to ensure the scalability, performance and maintenance of the system. This is extremely important for a wide area implementation of an UTC system or a more complex integrated management system, including different types of ITS solutions.

The proposed solution for a wide area UTC system involves the combination of both distributed and centralized approaches within a complex hybrid system, which is more efficient in achieving its purpose, namely performing advanced urban traffic control. The solution for stakeholders would be to use a distributed adaptive sub-systems in smaller cities and a centralized supervising subsystem on top of the first one, in big cities.

The smaller cities subsystems would basically be subordinated to the central level available in the closest big city or to the regional one, if it is decided to use a limited number of central sub-systems (for instance one for each important region in the country).

The communication architecture of the proposed system offers the possibility to take advantage of cutting edge resources and technologies in parallel with obtaining significant financial benefits (savings, cost reductions).

The cloud computing concept involves the access to an informatics infrastructure provided as a service through a communication network (usually the Internet or, for specific customers, a private dedicated solution). Due to its main advantages (service at request, location independent, transfer of responsibilities and risks from client to service provider), cloud computing is seen as the informatics model of the future [13].

The development of this new phenomenon represents a fundamental change in the way information technology is used, scaled, upgraded and invoiced [14].

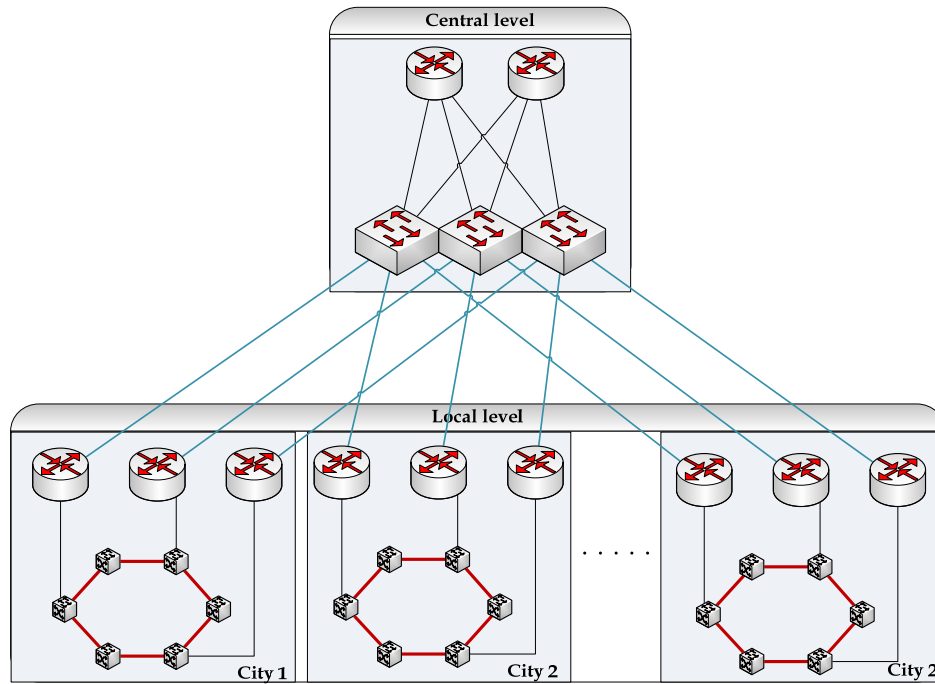


Fig. 2. Physical architecture of the communication network within the proposed UTC system

The proposed solution for the local network topology is based on physical rings of Multilayer switches. Each ring can contain up to 6 devices in order to ensure the optimal operation of the Spanning Tree Protocol (STP). STP is employed for avoiding the occurrence of switching loops that can overwhelm the network and stop the communication between the system's entities [7].

In order to build the system's topology for the entire city, the ring pattern can be employed to cover all the desired junctions (Fig.2). Using a full mesh topology for the local network would result in a more expensive solution and would also increase the configuration and maintenance tasks. Therefore, the proposed solution is a partial mesh organized as a star of rings. For achieving a fault tolerant topology, the solution uses 2 common nodes for every 2 consecutive rings. This is a method to increase availability of the UTC system, as the structure allows in certain conditions 2, 3 or even 4 simultaneous failures of switches located on the same branch and still, there would be no additional isolated junction prevented to perform in a fully adaptive mode [7].

4. Traffic parameters and quality of services for the proposed UTC system

Using Synchro 7 simulation program, the network has been modelled and several analyses have been performed to study the importance of traffic parameters and their variability. In the simulations, different values of traffic parameters have been applied. Measures of effectiveness such as delays, stops, fuel consumption and performance index - PI (linear combination of the first three, and, optionally, excessive queuing) have been analysed.

Synchro 7 allows a particular set of parameters to be used as input values for the simulations. They are:

- Traffic flow for each link;
- Average hourly speed for a link or the entire network;
- Vehicle type (classification) as heavy and light vehicles percentages (also on a link or at a network level);
- Headway (through variation of ideal saturation flow, on a link or network).

Synchro then automatically calculates other traffic parameters, such as occupancy or control parameters (cycle length, split and offset).

After performing the simulations with various values for the aforementioned traffic variables, including the absence of one or more of them, it was concluded that traffic parameters decisively impact the high level decisions within an UTC system. Their availability in real time is the determining factor for achieving efficient signalling plans for improving the traffic process for a controlled area [7].

The chart in Fig.3 sustains this last statement. The optimal values were achieved when all traffic parameters were known and employed at every step by the decision units (represented by the dotted line at the bottom of the chart). The optimal value of the performance index is the smallest one, meaning reduced values for the traffic delays and stops [7].

Each of the studied scenarios aimed to obtain the optimal control strategy for the simulated network based on the available traffic information. Therefore, the chart in Fig.3 shows the connection between the performance index achieved at each step and the optimal cycle length determined with Synchro [7].

The results of the analysis show that the UTC decision making components are able to produce improved signalling plans if they have available as many traffic information they can get from the field detectors [7].

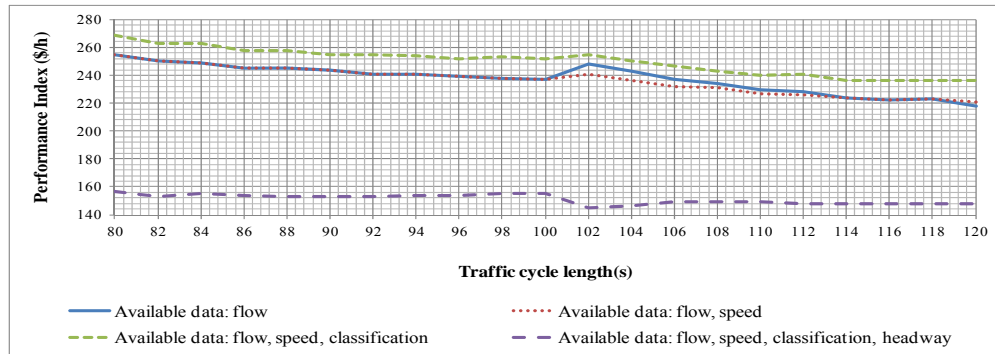


Fig. 3. Performance values for the simulated UTC system depending on availability of traffic parameters [7]

Nowadays, the availability of UTC systems is critical for managing traffic variations that produce congestions and delays.

By developing and implementing a quality of services method for handling the available bandwidth for traffic information exchange within an UTC system, the developers can ensure that critical data will always reach the intended destination.

In order to maintain a high level of quality for the transmissions, priorities must be set between different types of messages. It is important to establish the critical data that must be sent to the destination, even with the price of sacrificing other information [15].

The distributed approach is the main operating mode within a hybrid UTC system; the central component is commonly deployed as a supervising entity only.

Information commonly exchanged within a distributed UTC system is the following:

- Signalling plans;
- Traffic flow values;
- Speed information;
- Classification information;
- Headway information as a measure of the ideal saturation flow;
- Link occupancy;
- Turning percentage;
- Diagnoses and control information.

In order to perform a correct design and dimensioning of the communication network, the size and frequency of the data packets expected to travel through the physical media has to be estimated. This will allow the

calculation of the bandwidth required to produce an optimal data transfer and choice of the physical media type (wired or wireless).

The required bandwidth needed to accommodate the afore identified UTC packets and the surplus employed by advance routing protocols such as OSPF (Open Shortest Path First) is calculated using expression (1) [16].

$$\text{Bandwidth [kpbs]} = \text{Total packet size [kb]} \cdot \text{Packet rate [pps]} \quad (1)$$

OSPF sends 136 Bytes notifications to all the network devices at every 30 minutes plus short "Hello" messages between neighbouring equipment at every 10 seconds, in order to signalize their presence [17]. Therefore, considering a system with 45 cities per region and 232 junctions included in the system per city, the OSPF required bandwidth is:

$$\text{City OSPF bandwidth [kpbs]} = \left(\frac{136 \cdot 8}{30 \cdot 60} + \frac{36 \cdot 4 \cdot 8}{10} \cdot 232 \right) \cdot 10^{-3} = (0.604 + 26726) \cdot 10^{-3} \approx 26.73 \text{ kpbs} \quad (2)$$

The maximum UTC data packet including headers added in the TCP/IP encapsulation process is 1570 Bytes.

$$\text{City UTC bandwidth [kpbs]} = \left(\frac{1570 \cdot 8 \cdot 7 \cdot 4}{2} + \frac{1570 \cdot 8 \cdot 4}{60} \right) \cdot 232 \cdot 10^{-3} \approx 40989 \text{ kpbs} \quad (3)$$

Adding the 2 pieces of bandwidth determined with expressions (2) and (3), the maximum bandwidth required for a city is determined:

$$\text{City total bandwidth} \approx 40989 + 28 = 41017 \text{ kpbs} \approx 41 \text{ Mbps} \quad (4)$$

Finally, the estimation of the backbone media (used for connecting the local and central sub systems) is presented using expression (5):

$$\text{Backbone bandwidth} = 45 \cdot \text{City total bandwidth} = 45 \cdot 41 = 1845 \text{ Mbps} = 1.845 \text{ Gbps} \quad (5)$$

In conclusion, 100 Mbps links are sufficient to interconnect the local junctions within the distributed adaptive system; for transmitting the data towards the regional control centre, the system should employ higher capacity media such as 10 Gbps links. The media can be proprietary or leased from a service provider.

An informatics attack aiming to produce the denial of services (DoS) is an attempt of turning the network unavailable for its legitimate users, for a specific or

undefined period. Under normal operation, the packets are marked according to the QoS policy applied on each equipment. The transmission runs smoothly and no data loss occurs.

The author tested a second and more relevant scenario by injecting malicious packets into the network, to show the improvements offered by the QoS solution in the event of a DoS attack. Therefore, corrupted or oversized packets of data were sent throughout the simulated network. The simulations have been run for 5 minutes in order to evaluate the bandwidth consumption and data traffic behaviour.

If quality of services was not configured within an UTC system, there would be no guarantee that the legitimate information would reach its destination in the event of an excessively loaded communication channel. But, with a suited QoS solution in place, it can be ensured that a specified amount of bandwidth will always remain available for UTC packets.

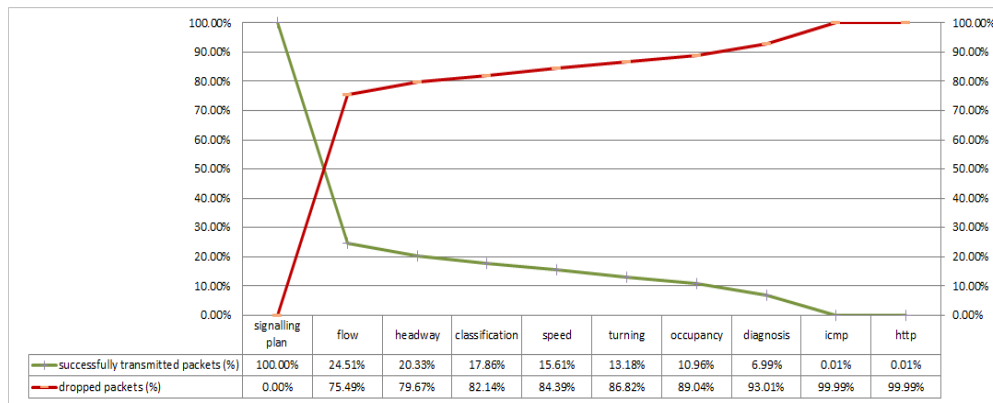


Fig. 4. Successful and unsuccessful transmissions on a highly congested simulated channel

Fig. 4 shows the transmitting percentage of UTC data packets between 2 junctions. The signalling plans reach their destination with 0% losses according to their highest priority and transmission actions in place. Because the other UTC information is not critical for the system to operate in an adaptive mode, it has been sacrificed in order to ensure the signalling plans are being transmitted. Their drop percentage is high, up to 93% for diagnoses packets. For what concerns the illegitimate data traffic (ICMP and HTTP), it was 99.99% dropped.

5. Conclusions

Intelligent transportation systems represent the best option for achieving an efficient road infrastructure management, reduced number of accidents, minimized impact of traffic congestions and environmental effects, increased comfort and safety of travelers.

In this paper, the author presents a hybrid UTC system that can be implemented at a country or regional level in order to achieve a reliable and efficient urban traffic control.

The importance of traffic parameters within such an UTC system has been shown in this paper with the aid of Synchro 7 simulation environment. Having all this information available in real time enables the efficient generation of optimal signalling plans, able to improve the overall urban traffic context.

Some information is more important than other as it produces considerable variations of the computed signalling times and consequently affects the traffic progress in the area. Therefore, a meticulous analysis of the data transmitted within any type of urban traffic control system is recommended.

Safety measures must be deployed in order to guarantee the availability of critical parameters ensuring the fully adaptive operation of the system.

The outcomes of a test performed for proving the utility of the aforementioned measures have been presented in this paper. A scenario of saturating the communication link of a distributed UTC system has been created, showing how implementing a quality of services solution can bring substantial benefits for what concerns the traffic control operation.

Not only does it allow a higher flexibility and control over the available bandwidth, but it also ensures that packets containing the signalling plans will successfully reach their intended destination even in difficult, saturated conditions.

The presented results represent the outcomes of the author's research conducted during the PhD study period.

Acknowledgements

The work has been funded by the Sectorial Operational Program Human Resources Development 2007-2013 of the Romanian Ministry of Labour, Family and Social Protection through the Financial Agreement POSDRU/107/1.5/S/76813.

REFERENCES

- [1] *Papacostas, C. S., Prevedouros, P. D.* Transportation Engineering and Planning – Second edition, cap. 6. New Jersey, SUA, 1993
- [2] *KonSULT.* The Knowledgebase on Sustainable Urban Land use and Transport, Leeds, England, 2005;
http://www.konsult.leeds.ac.uk/private/level2/instruments/instrument014/l2_014a.htm
[accessed in December 2012]
- [3] *Koonce, P. et al, US Department of Transportation, Federal Highway Administration.* Traffic Signal Timing, chapter 5. Washington, USA, 2008
- [4] *Slager, G. and Milano, M.* Urban Traffic Control System using Self-organization. Paper presented at the 13th International IEEE, Annual Conference on Intelligent Transportation Systems, Madeira Island, Portugal, 2010
- [5] *Hall, F. L.* Traffic stream characteristics (chap. 2 of Traffic Flow Theory - A State-of-the-Art Report), USA, 2001
- [6] *Li, S.* A survey of urban traffic coordination controls in intelligent transportation systems. Paper presented at the IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), 2012
- [7] *Mocofan, A. M. N., Ghiță, R., Tomás López, V. R., Nemțanu, F. C.* A Comparative Assessment of Traffic Control Parameters within an UTC Distributed System. Article accepted for publication in „Journal of Transportation Engineering (ASCE)”, USA, 2013
- [8] *Jin, J., Gubbi, J., Luo, T. and Palaniswami, M.* Network Architecture and QoS Issues in the Internet of Things for a Smart City, 2012 International Symposium on Communications and Information Technologies (ISCIT), Koh Samui, Thailand, 2012
- [9] *M. Minea, F. D. Grafiu, M. C. Surugiu,* Sisteme inteligente de transport - aplicații (Intelligent transportation systems – applications), Matrixrom, Bucharest, 2007
- [10] *Mocofan, A. M. N., Ghiță, R., Bătroș, I.* Urban Traffic Control systems specifics and architectures. Article published in „Scientific Bulletin” C series, volume 75, nr 3, 2013, Romania
- [11] *Tanenbaum, A. S., Van Steen, M.* Distributed Systems Principles and Paradigms, Second Edition, chapter. 1, 2. New Jersey, USA, Prentice Hall, 2006
- [12] *Coulouris, G., Dollimore, J., Kindberg, T., Blair, G.* Distributed systems – Concepts and Design, Fifth Edition, chapter 1, 2, 3. USA, Addison-Wesley, 2012
- [13] *Hayes, B.* Cloud Computing. Article published in “Communications of the ACM”, vol. 51, nr. 7, USA, 2008
- [14] *Mell, T., Grance, T. - NIST* (National Institute of Standards and Technology, 2009). The NIST Definition of cloud computing v15, NIST. <http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf> [accessed in October 2012]
- [15] *Szigeti, T. and Hattingh, C.* End-to-End QoS Network Design: Quality of Service in LANs, WANs and VPNs, Indianapolis: Cisco Press, IN, USA, 2004
- [16] *Cisco Systems, Inc.* CCNP Optimizing converged Cisco networks, Student Guide, Version 1, vol. 1, chapter 3, 4
- [17] International standard „RFC1245”, OSPF protocol analysis (1991)
<http://tools.ietf.org/html/rfc1245>