

FOURIER COMPONENTS OF  
DC COMPONENT = 5.000E+00  
HARMONIC FREQUENCY NO (HZ) COMPO

# Information technology Applications

# APLIKÁCIE informačných technológií

1 2020

TOTAL HARMONIC DISTORTION = 5.096E+01 PERCENT

FOURIER COMPONENTS OF TRANSIENT RESPONSE I(t)

DC COMPONENT = 3.999834E+00

FREQUENCY HARMONIC NORMALIZED PHASE

NO	FREQUENCY (HZ)	MAGNITUDE	PHASE
1	5.000E+01	1.000E+00	0.000E+00
2	1.000E+02	1.78E-01	1.245E+01
3	1.500E+02	2.7541E-01	7.803E-02
4	2.000E+02	3.553E-01	2.210E-02
5	2.500E+02	4.1489E-01	3.252E-03
6	3.000E+02	4.6097E-01	3.369E-04
7	3.500E+02	4.927E-02	1.513E-02
8	4.000E+02	5.303E-02	1.014E-02
9	4.500E+02	5.625E-02	1.206E-02

TOTAL HARMONIC DISTORTION = 2.030103E+01 PERCENT





# International Journal of Information Technology Applications (ITA)

Volume 9, Number 1, September 2020

## AIMS AND SCOPE OF ITA

The primary aim of the International Journal of Information Technology Applications (ITA) is to publish high-quality papers of new development and trends, novel techniques, approaches and innovative methodologies of information technology applications in the broad areas. The International Journal of ITA is published twice a year. Each paper is refereed by two international reviewers. Accepted papers will be available online with no publication fee for authors. The journal is listed in the database of the Russian Science Citation Index (RSCI). The International Journal of ITA is being prepared for the bibliographic scientific database Scopus.

### Editor-in-Chief

prof. RNDr. Frank Schindler, PhD. Faculty of Informatics, Pan-European University in Bratislava  
frank.schindler@paneurouni.com

### Executive Editor

Ing. Juraj Štefanovič, PhD., Faculty of Informatics, Pan-European University in Bratislava  
juraj.stefanovic@paneurouni.com

### Editorial Board

Ladislav Andrášik, *Slovakia*

Mikhail A. Basarab, *Russia*

Ivan Brezina, *Slovakia*

Yakhua G. Buchaev, *Russia*

Oleg Choporov, *Russia*

Silvester Czanner, *United Kingdom*

Andrej Ferko, *Slovakia*

Vladimír S. Galayev, *Russia*

Ladislav Hudec, *Slovakia*

Jozef Kelemen, *Czech Republic*

Sergey Kirsanov, *Russia*

Vladimir I. Kolesnikov, *Russia*

Štefan Kozák, *Slovakia*

Vladimír Krajčík, *Czech Republic*

Ján Lacko, *Slovakia*

Igor Lvovich, *Russia*

Eva Mihaliková, *Slovakia*

Branislav Mišota, *Slovakia*

Martin Potančok, *Czech Republic*

Eugen Ružický, *Slovakia*

Václav Řepa, *Czech Republic*

Jiří Voříšek, *Czech Republic*

# International Journal of Information Technology Applications (ITA)

Published with support from



SLOVENSKÁ SPOLOČNOSŤ PRE KYBERNETIKU A INFORMATIKU PRI SAV  
SLOVAK SOCIETY FOR CYBERNETICS AND INFORMATICS

## Instructions for authors

The International Journal of Information Technology Applications is welcoming contributions related with the journal's scope. Scientific articles in the range approximately 10 standard pages are reviewed by two international reviewers. Reports up to 5 standard pages and information notices in range approximately 1 standard page are accepted after the decision of editorial board. Contributions should be submitted via e-mail to the editorial office. The language of contributions is English. Text design should preserve the layout of the template file, which may be downloaded from the webpage of journal. Contributions submitted to this journal are under the author's copyright responsibility and they are supposed not being published in the past.

## Deadlines of two standard issues per year

paper submission deadline	– end of May/end of October
review deadline	– continuous process
camera ready deadline	– end of June/end of November
release date	– Summer/Winter

## Editorial office address

Faculty of Informatics, Pan-European University, Tematínska 10, 851 05 Bratislava, Slovakia  
juraj.stefanovic@paneurouni.com

## Published by

Pan-European University, Slovakia, <http://www.paneurouni.com>  
Paneurópska vysoká škola, n.o., Tomášikova 20, 821 02 Bratislava, IČO 36 077 429  
Civil Association EDUCATION-SCIENCE-RESEARCH, Slovakia, <http://www.e-s-r.org>  
OZ VZDELÁVANIE -VEDA-VÝSKUM, Andrusovova 5, 851 01 Bratislava,  
IČO 42 255 180

## Electronic online version of journal

<http://www.paneurouni.com/ITA>  
<http://www.e-s-r.org>

visit Archive and Instructions for authors:

## Print

Multigrafika s.r.o., Rajecká 13, 821 07 Bratislava

## Subscription

Contact the editorial office for details.  
Older print issues are available until they are in stock.



ISSN: 2453-7497 (online)  
ISSN: 1338-6468 (print version)

Registration No.: EV 4528/12



# Contents

## Editorial

## Research papers

▶	<b>CONCEPT OF SMART CITY IN MOSCOW AND IN BRATISLAVA</b> Eva Mihaliková, Sergey Kirsanov, Eugene Istomin .....	3
▶	<b>THE DEVELOPMENT OF A CONTROL MODEL FOR THE “SMART HOME” SYSTEM</b> Igor Lvovich, Emma Lvovich, Yury Preobrazhenski .....	15
▶	<b>THE COMPLEX ECONOMIC NETWORK CREATED IN STELLA SOFTWARE A Contribution to Emerging Theory of Virtual Complex Networks - Part II</b> Ladislav Andrášik .....	31
▶	<b>CONFIGURING IP CONNECTIVITY OVER A CELLULAR NETWORK ON A RASPBERRY PI-BASED IoT NODE</b> Ivan Šimovček, Lukáš Rajkovič, Lukáš Gdovin, Jakub Beňo .....	49
▶	<b>CONFIGURING IPsec-BASED SECURITY FOR VIRTUALIZED NETWORKS</b> Karol Csivre, Dominik Dermek .....	63
▶	<b>MODELING OF NONLINEAR DYNAMIC SYSTEMS USING SOFT COMPUTING METHODS</b> Ján Cigánek, Filip Žemla .....	77
▶	<b>DEMONSTRATIVE MODELING OF DISCRETE DYNAMIC SYSTEMS</b> Juraj Štefanovič .....	89
	<b>List of Reviewers .....</b>	99

## *Editorial*

.....

Dear authors, dear readers,

this issue is dedicated to various topics of theory and applied research in information technology. Published contributions continue the topic of smart home from the previous edition of our journal. This topic is treated on two hierarchical levels - smart home and smart city as a whole. Third contribution continues the analyse of economic networks as part II, from the previous part I in 2/2019 issue, with the description of modeling and simulation outputs.

Other contributions in this journal edition are featuring technical details in networking, dynamic systems modeling and a simulation of discrete systems. Rich development in networking includes internet of things (IoT) they are connected nowadays in large scale, usually wireless. Potential amount of them is huge and hence the security problems are urgent. Continuous simulation of nonlinear dynamic systems is an useful tool for control and evaluation of huge industry machines. A simulation of discrete systems is a basic condition for construction of control and testing by various technical devices and systems, they are working in decision-statement mode.

To the future, we want to keep the main target of this journal in IT applied research, with more connection to the industry applications. Our attempt is to assembly each issue of journal with a sets of collected contributions concentrated around similar topics. Your forthcoming papers and contributions are welcomed around the year.

Juraj Štefanovič  
ITA Editor-in-Chief

## CONCEPT SMART CITY IN MOSCOW AND IN BRATISLAVA

Eva Mihaliková, Sergey Kirsanov, Eugene Istomin

### **Abstract:**

---

*Sustainable development has represented a globally solved subject matter during the last few years, and smart cities are one of the areas supporting it. Smart Cities are currently considered as a very attractive approach towards the development of cities and city regions, their governance and planning. They are typical with application of modern information technologies to city governance and improvement of city life quality, and focused on more effective management aimed at supporting sustainable development of the city. The presented article introduces the Smart City concepts in Russia and in Slovakia, evaluating the Smart City level in Russian and Slovak capital cities through selected indexes. This article highlights problematic areas, and implemented and planned projects that could contribute to effective implementation of the Smart City Concept.*

### **Keywords:**

*Smart cities, smart technologies, smart indexes, smart concept.*

### **ACM Computing Classification System:**

*Applied computing - computers in other domains, human computer interaction.*

## ■ Introduction

Rapid development of information technologies encourages the society to be progressing and respond to contemporary challenges. Cities play an important role in the economy, facing worsening city infrastructures, lack of budgetary sources, increasing pressure on environment, and increasing requirements of citizens and business sector on the city environment. The half of the whole population, i.e. 3.5 billion of people lives nowadays in the cities. Prognoses indicate that as much as 5 billion people will live in city areas till 2030 [1].

Implementation of the Smart City concept could resolve majority of the problems that modern cities currently face. We can speak today of transition to the third generation of the smart cities where the city development has been accompanied by complex digital transformation. In the intelligent digital city, its governance is based on data, i.e. „data – governed city“, which is a key component of the city ecosystem and its parts – smart housing and communal services, smart energy, smart transport, smart healthcare, etc.

Sustainable development should be taken in account during the city governance system improvement. Sustainable development is a broad – spectrum subject matter aimed primarily at ensuring the future for the following generations. The document „*Transformation of Our World: Agenda 2030 for Sustainable Development*“ also points it out, interconnecting three dimensions of sustainable development: the economic, the social, and the environmental dimension. It is an UN development program for period of years 2015 - 2030.

The program comprises total of 17 goals, amongst them also assurance of open approach, safety, resistance and environmental sustainability of cities and villages. Smart city represents one of the concepts of permanently sustainable development of principles and their application.

Caragliu et al. also state that smart city is close to permanently sustainable development [2]. They point out that city can be classified as a smart city when the investment in cybernetic infrastructure is aimed at supporting sustainable economic growth, life standard improvement, and effective management of natural resources.

Smart City is defined in the paper „Mapping Smart Cities in the EU“ dated 2014, as a city „that makes efforts to solve its public issues most effectively through application of information – communication technologies“[3]. According to Fabianová, smart city is capable of providing all services to the citizens in the most effective way, and concurrently creates jobs, supports innovations, research, new ideas, respects the environment and considers the citizens' opinions. It is a city that controls its mobility, energy consumption, buildings, city space and digital information in an energy efficient and sustainable manner in favor of its citizens, employees and tourists [4].

Main idea of the „smart city“ is simple – the citizens should live a comfortable life, business activities should be effective and easy, and the public offices should successfully control it all. In fact, this approach has been materialized in the form of digital ecosystem that joins all components of infrastructure: from transport and social institutions up to the city properties. Such integration is feasible through the Internet of Things (IoT). This term should be interpreted as identification of things and monitoring of their movement in the Internet space. Along with open data, the Internet of Things has been frequently used in the smart city concepts [5][29].

The following components are of high importance for every smart city:

- Digital platform, being a „heart“ of a smart city since it regulates all processes in the city infrastructure.
- Sensors and sensor systems ensuring data collection from the users and various city systems in the digital ecosystem of the smart city,
- Citizens and social institutions that are an integral part of the smart city.

Based on the above stated components, a smart city can control its data, energy, space and information in autonomous and most efficient way in order to improve the citizens' life standard [6]. The term „smart city“ is interpreted in various ways but all of them stipulate the essential role of information and communication technologies (ICT) that help to support current processes of city life in the most efficient way, engaging the citizens, enterprises and institutions. According to Slávik, ICT represents an important tool helping reach the economic and social goals of the smart city [5]. Definition by the European Committee dated 2018 also points it out, considering Smart City as a city using traditional networks and services more effectively thanks to implementation of digital and communication technologies, which positively impact upon the citizens and the business activities as such [7]. Giffinger specified 6 essential characteristics that should be developed in sake of as fast as possible progress in the fulfillment of the Smart Cities concept [8, 3]; see the following picture (Fig.1).

Projects that European and world cities implement in order to get closer to the Smart Cities concept include mostly those associated with transport and environment, for example sustainable commuting system, transport vehicles sharing, transport control, integrated multimodal public commuting system, innovative solutions in the area of lighting, heating, power engineering, and waste management [9].

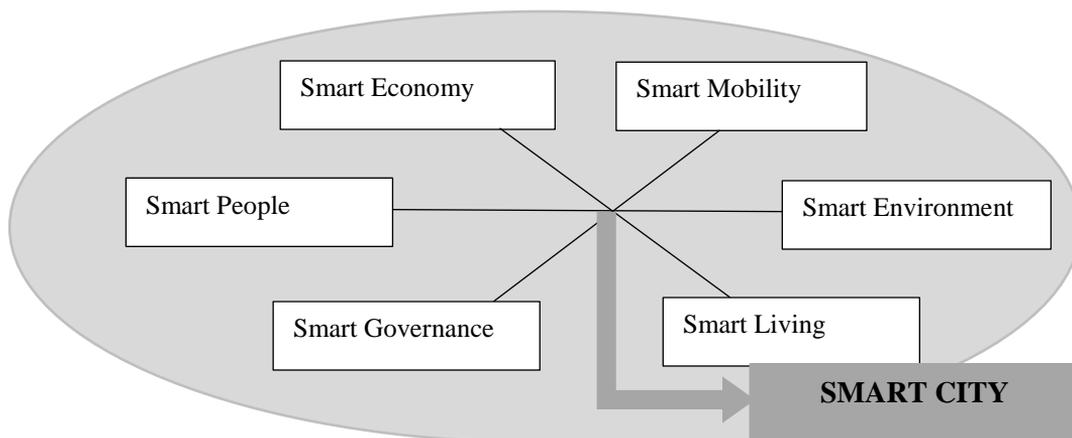


Fig.1. Dimension of Smart City.

## 1 Smart City in Russia

In case of development of smart cities, Russia has been highly subordinated to head economies and projects in progress they are mainly associated with digital and intellectual solutions of particular city services and infrastructures. Russia has generally not ranked on the top positions in the published international ratings of smart cities.

According to a few estimations, the volume of smart city technologies market should reach USD 2.4 billion till 2025. In fact, Russia is not a participant to these markets, which has been to large extent attributable to insufficient readiness of Russian cities for digital transformation. [10]

A few measures have been declared within the program „Digital Economy of the Russian Federation“, adopted by the Russian Government in 2017, which should influence the smart cities development [11].

In 2018, the Russian Ministry of Construction started preparing the Smart City program implementation plan, naming twenty cities that started with the program implementation. Following the global standards, Russian cities will have to acquire the systems of technology control, for example Internet of Things, where every part of the system, every object interacts with the other ones through the Internet.

In the spring 2019, the Russian Ministry of Construction along with the Central Development Center and Competence Center presented the „Smart City“ concept of technology implementation in the Russian cities. The concept was based on the analytic materials prepared by Center for Strategic Development „Northwest“ and published in the form of an expert-analytic report „Priority Paths of Smart City Technology Implementation in Russian Cities“ [12].

Main trends in the document are dedicated to technology solutions and institutional changes whose implementation should ensure development of a modern city governance system. Main principles of Smart City Concept implementation in Russia correspond to: human orientation, technology infrastructure, effective city governance, comfortable city environment, and economic feasibility of the solutions [13].

Requirement of transition to integrated intellectual solutions has been gradually presented in the Russian cities, and smart city concept implementation is perceived as an element of digital society and economy formation in Russia.

Selection of an optimum digital transformation scenario depends to large extent on the goals that the city set forth, and on the initial conditions of digital technology development.

Three models of digital transition can be distinguished for various types of Russian cities:

- decentralized model of digital transition – in Moscow, Petersburg, and in cities with more than 1 million citizens where digital transformation takes place upon participation of high amount of businesses, and in the conditions of significant market capacity for smart city technology implementation;
- centralized model of digital transition – suitable for big and medium size cities where the process of digital transformation is coordinated by the local self – government bodies, mobilizing all available sources and engaging high amount of process participants therein;
- local action model - suitable for big and medium size cities where certain problematic infrastructure sectors are subject to insufficient digital transformation sources.

A complex of the existing barriers will have to be overcome for purpose of successful implementation of any of the above models, including implementation of institutional changes related to the improvement of law regulation and the system of digital transition control on the level of local self- government, as well as mechanisms of coordination of transition to intelligent smart cities on federal level. Such processes could be started up through implementation of smart city pilot projects in special experimental zones. Independent polygons could exist for preparation of priority digital solutions, as well as the whole cities whose control functions allow for testing the concept on the entire site level (for example city Kronstadt) [10].

We have to admit that projects implemented in a Russian smart city are associated especially with digitalization and intellectual solutions for particular services and infrastructure elements.

In the area of transformation to „smart cities“, many Russian cities face problem in the form of insufficient regulation, not enough funds from the budget and necessary infrastructure. Using infrastructure developed as a part of the program Safe City, implemented in many Russian cities in the previous three years, can refer to one of the problem solutions.

„Smart“ potential of a city depends on whether or not there is a place for every citizen with his/her needs and ideas of city development. Involvement of citizens in the active work in this area represents the most important task of the competent authorities, namely in territorial development planning and public control over the implemented decisions. Attention is also paid to education. A new university profile should be opened under the name „Information Sources Management“ (specialization „State and City Government“) for purpose of successful modern city development. Such approach will prepare the experts with complex knowledge and skills, required for high professional smart city information system management. The graduates will be able to find a job in the city governance sector and to successfully communicate with citizens and enterprises, which should ensure permanently sustainable development of Russian smart cities.

Lack of data centers is another major problem of the smart cities, where all information from the city sensors is processed. Analysis of publishing activity indicates that own technology means are missed in Russia in most areas of smart city development [14]. Security problem of personal data and Internet of Things has been also highlighted, indicating not so optimistic future of the smart cities. With the aim to successfully resolve the issues of smart cities development in Russia, the country should be inspired by international experience in the Smart City system implementation in various world cities.

## ▀ 2 Smart City in Slovakia

According to the Slovak Ministry of Economy (guarantor for strategy of innovations creation and implementation including small and medium business support), the term Smart City has been perceived in Slovakia as an innovative approach to the development of cities and city regions, their governance and planning, applying technical and technology innovations including information

and communication technologies. It is an effort for increase of life standard and quality of business environment in cities and regions, increase of their operation effectiveness, aimed at increasing their safety, cleanliness, energy savings, and ability of their response to current and future social, ecological and other challenges and needs [9].

The Slovak Office of the Deputy Prime Minister for Investments and Informatics Solutions (UPVII) is a central coordination body that presented three necessary steps that Slovakia should made in order to support smart cities [15]:

1. Website platform containing all information related to the OP calls, information for self-governments, inspiring projects from Slovakia and abroad, contacts and reference to smart advisors, etc. on a single website.
2. The system of activities aimed at defining OPs (operating programs) that they will be funded from. OPs shall be included in the pilot scheme that offer solutions feasible for smart cities, namely OP Environment, OP Integrated Infrastructure, OP Effective Public Administration, and OP Integrated Regional Operating Program.
3. Publishing the calls for smart city concept support; provided that an advisory call center should be established for smaller cities.

At the end of January 2019, the Office of the Deputy Prime Minister for Investments and Informatics Solutions put into service the internet portal [www.smartcity.gov.sk](http://www.smartcity.gov.sk), where the applicants, cities and villages, and the whole public can find necessary information about the OP calls and the smart city topic. Support has been primarily directed to the area of power engineering, transport, environment, informatics solutions and waste management. The website contains summary of activity funding opportunities in the area of Smart Cities from the EU Structural and Investment Funds but also from other available sources [16].

Furthermore, the website contains contact numbers to established advisory – information centers in all regions, helping with reparation of European projects in the area of smart city free of charge [17].

The document „Support of Innovative Solutions in Slovak Cities“ represents the basis of Smart City projects support in Slovakia. Self-government is a recipient of the innovative solution projects and enterprises with creative and innovative potential representing a driving force (Support of Innovative Solutions in Slovak Cities). Within the latest period, increasing interest in the Smart City concept has been reported from the Slovak self-governments' environment, expressed through the implementation of various projects despite of the absence of Smart City system support. Implementation of the smart solutions offers the new opportunities of self-government control improvement, more effective cooperation between particular departments, as well as possibilities of better interconnection between self-governments and citizens including personnel provision for development of smart solutions and innovations, and their evaluation and implementation [18].

„Smart“ governance is at the beginning of every good idea, exactly defining the areas of required improvement. As an example, it is commuting system in some cities, while in the other ones it is waste management or optimized use of the city energy. Often it is all together at once – cameras, traffic density, available parking lots, air quality, smart lights, and smart containers. All this can be monitored, data summarized in a single place, analyzed and optimized subsequently. Technologies developed currently also in Slovakia serve for this purpose [19].

The Smart City topic represents one of the priorities of Slovakia also during preparation of partner agreement for the new program period 2021 – 2027. Slovakia is interested in the increased utilization of recoverable funding forms in the new program period, and in further development of cooperation with the European Investment Bank that the Memorandum of Cooperation was signed with. The Memorandum will help us effectively spend the EU Structural and Investment Funds during the new program period for sustainable development of cities and regions, based on low-carbon economy [20].

### 3 Analysis of Smart City Evaluation in Moscow and in Bratislava

Fulfillment of the Smart City concept can be evaluated through various indexes. We chose three of them to compare the Russian and the Slovak capital city:

1. IMD Smart City Index (IMD SCI) that is a result of the analysis made by the Smart City Observatory of the Global Competitive Center in cooperation with the Singapore University of Technology and Design.
2. IESE Cities in Motion (CIMI) is a research platform launched jointly by the Center for Globalization and Strategy and IESE Business School's Department of Strategy.
3. Index of Smart Cities developed by the company Easy Park (SCI EP).

The results are presented in the following tables prepared according to evaluation of the above stated companies.

Table 1. Rating of analyzed places according to selected indices.

Country	Capital City	Rating		
		IMD SCI 2019	CIMI 2019	SCI EP 2019
Russia	Moscow	<b>72</b>	86	97
Slovakia	Bratislava	84	<b>70</b>	<b>83</b>
Number of Cities Compared		from 102 Cities	from 100 Cities	from 174 Cities

The results in (Tab.1) indicate that Bratislava ranked on better positions than Moscow within evaluation of CIMI and SCI EP index. On the contrary, Moscow ranked higher than Bratislava in case of IMD SCI index application. In the following section we focused on more detail picture of the areas of evaluation, namely which one of them are more dominant in which city in case of particular indexes.

Index IMD SCI is an index pointing out the Smart City perception through the citizens' opinions set off by economic and technology aspects. (IMD Smart City Index) [21]. It evaluates five key areas (health and security, mobility, activities, opportunities and the public matters administration) in two fundamental pillars (Tab.2). The first pillar is a structure referring to the existing city infrastructure, and the second pillar represents the technologies, namely technological provision and services available to the citizens [22].

Table 2. Comparison IMD SCI in Moscow and in Bratislava

Evaluation area	Structures		Technologies	
	Moscow	Bratislava	Moscow	Bratislava
Health, Safety	48,934	<b>49,536</b>	<b>63,773</b>	48,63
Mobility	<b>42,76</b>	27,525	<b>60,04</b>	46,345
Activities	<b>74,725</b>	53,345	<b>83,47</b>	74,45
Opportunities (Work, School)	59,236	<b>63,88</b>	<b>69,123</b>	56,013
Governance	<b>46,96</b>	44,195	<b>58,605</b>	43,647

Presented data indicate that Moscow dominates over Bratislava especially in evaluation of the second pillar. Bratislava is more dominant in case of the first pillar in the area of health, security and the opportunities. The biggest difference between the two cities was reported in the area of activities and mobility.

IMD Smart City Index is considered the first global index evaluating the city „Smart“ level, evaluating the city municipalities also according to citizens' perception and indicated in the conducted opinion poll.

From a list of 15 indicators, survey respondents were asked to select 5 that they perceived as the most urgent for their city. The higher the percentage of responses per area, the greater the priority for the city (Fig.2).

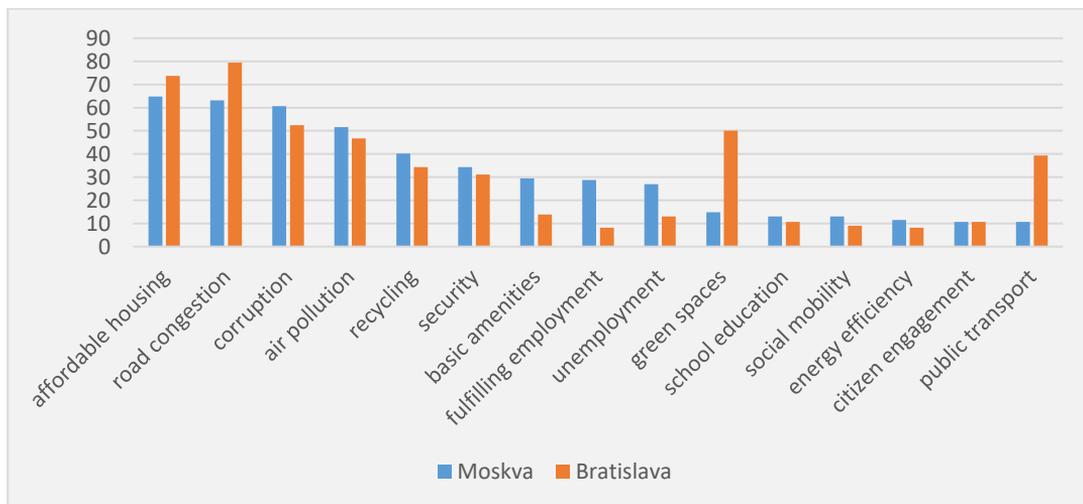


Fig.2. % of respondents who chose the Priority Area: Moscow and Bratislava.

The stated opinion poll indicates that the first three areas are considered most urgent by the citizens of both Moscow and Bratislava. Different opinions were reported on the 4th place where air pollution dominates in Moscow while in Bratislava they are green areas. The analyzed cities didn't show major difference on the fifth place. Comparison showed significant difference in the public commuting system that ranked on the 6th place in Bratislava and on the last position in Moscow in the terms of urgency. This result is associated with the fact that Moscow ranked much higher in the area of mobility.

Index CIMI evaluates (Tab.3) the development level of nine key areas (economy, human capital, social cohesion, environment, public governance, city planning, international influence, technologies, and mobility and transport). Maximum reached Score CIMI refers to 200 points, the higher is the value, the better is ranking. Along with the ranking score, the next table shows the order of analyzed cities in particular areas of evaluation. [23]

Table 3. Comparison CIMI in Moscow and in Bratislava.

Evaluation area	Moskva		Bratislava	
	Ranking	Score CIMI	Ranking	Score CIMI
Mobility and Transportation	<b>65</b>	55,91	85	59,92
Technology	<b>92</b>		113	
International on treach	<b>73</b>		122	
Urban Planning	<b>22</b>		67	
Governance	<b>43</b>		50	
Environment	136		<b>35</b>	
Social Cohesion	163		<b>14</b>	
Human Capital	<b>7</b>		49	
Economy	100		<b>91</b>	

Based on the data, we can state that Bratislava reached score 59,92 and ranked higher than Moscow. Our capital city was better evaluated especially in the area of social cohesion and environment. Moscow ranked much worse in these areas. We should state that Moscow was evaluated very high in the area of human capital which is mainly associated with education.

Index SCI developed by EP considers seven basic criterions that summarize the data of other indicators in the area of transport and mobility (car sharing services, traffic, public transport, e-charge spots and infrastructure investments), sustainability (clean energy, smart building, waste disposal, environmental protection, environmental performance), governance (citizen participation, digitalization of government, urban planning, and education), innovation economy (business ecosystem, blockchain ecosystem), digitalization (4G LTE, Internet speed, Wifi hotspots, smartphone penetration, cyber security), and living standard and expert perception. Each factor is evaluated by score within 1 – 10; the higher is the score, the better is evaluation. (Tab.4) contains calculation of the average score in particular areas of evaluation. [24]

Table 4. Comparison Rank Score in Moscow and in Bratislava according SCI EP.

Evaluation area	Moskva		Bratislava	
Transport and Mobility:	5,015	rank/score 4,29	4,335	rank/score 5
- smart parking	2,78		5,13	
- <b>car sharing services</b>	<b>9,47</b>		3,04	
- traffic	1,45		7,58	
- public transport	1,08		3,87	
- <b>e-charge spots</b>	<b>9,09</b>		4,33	
- infrastructure investments	6,22		2,06	
Sustainability:	2,772		3,97	
- clean energy	4,15		4,31	
- smart building	4,03		1,91	
- waste disposal	2,07		2,3	
- <b>environmental protection</b>	1,08		<b>7,81</b>	
- environmental performance	2,53		3,52	
Governance:	4,6875		5,75	
- citizen participation	1,54	2,86		
- digitalization of government	9,39	5,92		
- urban planning	6,29	7,20		
- education	1,53	7,05		
Innovation Economy:	5,03	6,74		
- business ecosystem	1	6,45		
- blockchain ecosystem	9,06	7,03		
Digitalization:	4,134	4,876		
- 4G LTE	1,68	6,75		
- Internet speed	2,29	7,58		
- <b>Wifi hotspots</b>	<b>10</b>	5,69		
- smartphone penetration	2,6	1,92		
- cyber security	4,1	2,44		
Living Standard	1,68	2,74		
<b>Expert Perception</b>	<b>6,64</b>	<b>9,16</b>		

The table indicates that Bratislava reached better evaluation score. The best results were achieved in the evaluation of Expert Perception (Moscow score 6,64 and Bratislava score 9,16). Of the partial indicators, Bratislava reached the highest value in Sustainability in the indicator of environmental protection (score 7,81). Moscow reported major deviations in particular values. The best results was reached in transport and mobility in the indicators - car sharing services (score 9,47) and e-charge spots (score 9,09). The best rated indicator is wifi hotspots (max. score 10) in digitization.

## 4 Discussion

The presented evaluation results don't show major differences in the ranking of compared cities within the global Smart City ranking. The order of the cities mostly depends on the type of evaluation index and the indicators that are taken in account in determination of Smart City level in particular index. This is why the results differ from one another in the comparison when various indexes are used. Major success of Moscow refers to evaluation according to index CIMI where the city ranked on the 7<sup>th</sup> position in the global ranking in the area of human capital, mostly associated with education quality. Moscow ranked behind London, Los Angeles, New York, Boston, Berlin and Paris. Accordingly, people, their education and increase of digital literacy are considered one of the most important factors of Smart City development in Russia.

Comparing Bratislava and Moscow, we can state that Moscow ranked better in the area mobility in all evaluations. Moscow reached more positive results also in the area of technologies and governance. On the other hand, Bratislava dominates in the area of environment and social cohesion.

Both cities developed the Smart City development concept that has been continuously improved. In Bratislava, it is the concept called Reasonable Bratislava 2030. This concept represents an open intention of the whole city development, aimed at contributing to the life standard improvement. In the document, our capital city decided to seek reasonable solutions in 12 areas, namely in the city governance, mobility, power engineering, environment, circulation economy, undertaking, public space, education, social inclusion, culture, tourism, and sport. The area of environment (79.2 %) and mobility (71.8 %) are considered of key importance according to conducted opinion poll. [25].

Within the support of these areas, Bratislava has implemented a few projects, for example Up! City, Bike sharing, Pilot Project of Semi-Underground Containers, Pilot Project of Public Commuting System Preference, Electronic Solution of Bratislava Self-government Services, Contact Point of Services for Citizens, Bratislava City Card, etc. [26].

In the capital of Russia, work continues on the digital strategy of Moscow, Smart City - 2030. It is proposed to use two indexes as important indicators of the strategy: quality of life and quality of the urban environment.

In general, "Smart City - 2030" is a high-level strategic document that is being developed by the Moscow Department of Information Technologies with the involvement of experts, the business community and citizens. The document defines the goals, objectives and directions of further development of Moscow as an innovative smart city of the future [27].

A unique ecosystem is being created in Moscow - a set of digital services, services and capabilities, platforms for business interaction with the city, consumers and partners, the key element of which is a personal account on the official portal of the mayor mos.ru. With its help, entrepreneurs can receive 90 public services, more than half of them exclusively in electronic form.

Today, the key task of the municipalities of the Russian Federation is the creation of a single IT platform, which should become the basis for the development of smart cities.

The introduction of modern technology requires a major infrastructure upgrade. One of the key projects is the creation of a 3D map of Moscow. In the future, this technology can be used to build routes for unmanned vehicles or aircraft.

For urban planning and city management, it is almost indispensable. For example, it is possible to select a specific point on the map and get all the information about this territory: about accomplishment, urban development, underground utilities, documentation. This function helps the city government to quickly make management decisions and monitor the execution of orders. In the future, all projects implemented in Moscow will initially be “embedded” in a 3D city, where they will evaluate their impact on citizens. It will be possible to calculate the load of the building on the existing infrastructure of the city and, for example, evaluate how much it fits into the architecture of the quarter. [28].

## Conclusion

Innovations and information-communication technologies represent the basis of Smart city. Using the advanced technologies, e.g. „Internet of Things“, „Big Data“, „Machine Learning“ improves the city governance and social-economic city indicators, and increases quality of provided services and quality of the environment. The city is progressing and becomes more attractive for its citizens and visitors. The Smart City concept becomes a fundamental strategic document of cities, implemented in gradual steps.

Active attitude of the cities to the development of smart city concept represents the basis of success and progress in the global rating systems. Many companies, research and education institutions develop and continuously improve the Smart City indexes that determine the position of particular cities, highlighting the quality of their key areas. Results of these ratings map the situation and refer to a good starting point of the system improvement. In this way, the cities can become more comfortable, secure and open to useful innovations in the future; capable to better ensure their competitiveness and sustainability.

## Acknowledgement

This article was prepared upon support of a research project: VEGA number 1/0302/18 Smart cities as a possibility to implementation the concept of sustainable urban development in the Slovak Republic.

## References

- [1] *Цели в области устойчивого развития*. Sustainable development goals. Retrieved online, March 22, 2020, from <https://www.un.org/sustainabledevelopment/en/cities/>
- [2] Caragliu, A., Del Bo, Ch., Nijkamp, P. (2011) Smart Cities in Europe. *J. Urban Technol.*, 18 (2), pp. 65-82.
- [3] *Mapping Smart Cities in the EU*, 2014. Retrieved online, February 20, 2020, from [http://www.europarl.europa.eu/RegData/etudes/etudes/etudes/join/2014/507480/IPOL-ITRE\\_ET\(2014\)507480\\_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf)
- [4] Fabianová, K. *Smart cities – aj mestá môžu byť skutočne inteligentné*. Smart cities - even cities can be really smart. Retrieved online, February 20, 2020, from <https://energieprevas.sk/komentare.php?id=122>
- [5] Slávik, J. (2017). *Smart City v praxi. Smart City in practice*. Praha: Profi Press, s. r. o., ISBN 978-80-86726-80-9
- [6] Petrova, A (2019). *История и будущее умных городов*. History and future of Smart Cities. Retrieved online, March 22, 2020, from <https://hightech.plus/2019/11/26/istoriya-i-budushee-umnih-gorodov>

- [7] European Commission (2019). *Smart Cities*. European Union. Retrieved online, February 20, 2020, from <https://ec.europa.eu/digital-single-market/en/smart-cities>
- [8] Giffinger, R. et al. (2007). *Smart cities. Ranking of European medium-sized cities*. Final Report. Vienna: Centre of Regional Science, Vienna UT. Retrieved online, February 15, 2020, from [http://www.SMART-cities.eu/download/SMART\\_cities\\_final\\_report.pdf](http://www.SMART-cities.eu/download/SMART_cities_final_report.pdf).
- [9] Support of Innovative Solutions in Slovak Cities. *Podpora inovatívnych riešení v slovenských mestách*. Retrieved online, February 20, 2020, from <https://www.mhsr.sk/uploads/files/n5m7duxS.pdf>
- [10] *Smart city в России. Как заставить города поумнеть?* Smart city in Russia. How to force cities to get wise. Retrieved online, March 22, 2020, from <https://www.csr.ru/ru/publications/smart-city-v-rossii-kak-zastavit-goroda-poumnet/>
- [11] Распоряжение от 28 июля 2017 года №1632-р «Об утверждении программы «Цифровая экономика Российской Федерации». Program: Digital Economy of the Russian Federation.
- [12] *Технологии для умных городов* Фонд «Центр стратегических разработок «Северо-Запад». Technologies for Smart Cities. Retrieved online, March 22, 2020, from [http://www.csr-nw.ru/files/publikacie/doklad\\_tehnologii\\_dlya\\_umnyh\\_gorodov.pdf](http://www.csr-nw.ru/files/publikacie/doklad_tehnologii_dlya_umnyh_gorodov.pdf)
- [13] *Концепции умных городов в России*. Concept Smart City in Russia. Retrieved online, March 22, 2020, from <https://www.csr.ru/ru/news/v-rossii-poyavilas-kontseptsiya-razvitiya-umnyh-gorodov>
- [14] *Приоритетные направления внедрения технологий умного города в российских городах* (2018). Priority directions for the implementation of Smart City Technologies in Russian cities. Retrieved online, March 22, 2020, from <https://www.csr.ru/upload/iblock/bdc/bdc711b002e9651fb2763d98c7f7daa6.pdf>
- [15] *ÚPVII predstavil tri základné kroky na podporu Smart Cities*. UPVII presented three fundamental steps of Smart Cities support. (2018). Retrieved online, February 20, 2020, from <https://www.vicepremier.gov.sk/aktuality/cko/upvii-predstavil-tri-zakladne-kroky-na-podporu-smart-cities/index.html>
- [16] The Smart City topic refers to one of the Slovak priorities in the new program period. *Téma Smart City je jednou z priorit Slovenska pre nové programové obdobie*. Retrieved online, May 20, 2020, from <https://www.vicepremier.gov.sk/aktuality/cko/tema-smart-city-je-jednou-z-priorit-slovenska-pre-nove-programove-obdobie/index.html>
- [17] *Na novej webovej stránke samosprávy nájdú všetky smart projekty a výzvy*. All smart projects and OP calls can be found on the self-government website. (2019). Retrieved online, May 10, 2020, from <https://spis.korzar.sme.sk/c/22042836/na-novej-webovej-stranke-samospravy-najdu-vsetky-smart-projekty-a-vyzvy.html>
- [18] Kóňa, A., Kóňa, J. (2020). Implementácia Smart Cities na Slovensku – potreba a východiskový stav. Implementation of Smart Cities in Slovakia - necessity and current state. In: *Trvalo udržateľný rozvoj v krajinách Európskej únie II*. Nekonferenčný zborník vedeckých prác, UPJŠ v Košiciach, pp. 92 – 98. ISBN 978-80-8152-855-2
- [19] *Aj Vaše mesto môže byť smart*. I Want a Smart City. Retrieved online, February 20, 2020, from <https://www.chcemsmartmesto.sk/>
- [20] *Téma Smart City je jednou z priorit Slovenska pre nové programové obdobie*. The Smart City topic represents one of the priorities of Slovakia in the new program period. (2019). Retrieved online, May 20, 2020, from <https://www.vicepremier.gov.sk/aktuality/cko/tema-smart-city-je-jednou-z-priorit-slovenska-pre-nove-programove-obdobie/index.html>
- [21] *IMD Smart City Index 2019*. The IMD World Competitiveness Center's Smart City Observatory, in partnership with Singapore University of Technology and Design (SUTD). Retrieved online, January 10, 2020, from <https://www.imd.org/research-knowledge/reports/imd-smart-city-index-2019/>
- [22] Koreňová, D. (2020). Koncept smart city v podmienkach hlavných miest krajín V4. A smart city concept in the specific conditions of capital cities in V4 countries. In: *Trvalo udržateľný rozvoj v krajinách Európskej únie II*. Nekonferenčný zborník vedeckých prác, UPJŠ v Košiciach, pp. 99 – 114. ISBN 978-80-8152-855-2
- [23] *IESE Cities in Motion Index 2019*. Retrieved online, January 13, 2020, from <https://blog.iese.edu/cities-challenges-and-management/2019/05/10/iese-cities-in-motion-index-2019/> DOI: <https://dx.doi.org/10.15581/018.ST-509>

- [24] *Smart City Index 2019*. Retrieved online, April 25, 2020, from <https://www.easyparkgroup.com/smart-cities-index/>
- [25] *Lepšie miesto pre život*. Better Place for Life. Retrieved online, March 15, 2020, from <https://bratislava.dnes24.sk/mesto-vytvorilo-smart-city-koncepciu-rozumna-bratislava-2030-295767>
- [26] *Koncepcia Smart City Bratislava - rozumné mesto 2030*. Concept Smart City Bratislava, Reasonable City 2030. (2018). Retrieved online, March 15, 2020, from <https://zastupitelstvo.bratislava.sk/data/att/38524.pdf>
- [27] *Moscow - Smart city*. (2019). Information technology in Moscow, Retrieved March 28, 2020, from: <http://www.tadviser.ru/index.php/>
- [28] Kirsanov, S., Safonov, E. (2019). Information technology at the service of city management in Russia. In: *Verejná správa a spoločnosť*. UPJŠ v Košiciach, XX (2), pp. 66-72, ISSN 1335-7182. <https://doi.org/10.33542/VSS2019-2-05>
- [29] Lvovich, I., Choporov, O., Preobrazhenskiy, Y., Štefanovič, J. (2019). Development of a smart home control subsystem. *Information Technology Applications (ITA)*, vol. 8, No. 2., 2019

## ▲ Authors



### **Ing. Eva Mihaliková, PhD.**

University of Pavol Jozef Šafárik, Faculty of Public Administration,  
Popradská 66, Košice, Slovakia  
[eva.mihalikova1@upjs.sk](mailto:eva.mihalikova1@upjs.sk)

Currently at the Faculty of Public Administration, Department of Economics and Management of Public Administration. She has been working at the faculty for 20 years and she has taught an accounting and a financial analysis. Her research interests include environmental and informatization.



### **Prof. Sergey Kirsanov**

Russian State Hydrometeorological University,  
Sankt Petersburg, Russia  
[ksaimr@mail.ru](mailto:ksaimr@mail.ru)

Currently he works at the Institute of Information Systems and Geotechnologies, at the Department of Applied Informatics. Teaching disciplines: Information resources in management, Information technologies in economics and management, Information management and others. His research interests include computerization, economics, and management.



### **Prof. Eugene Istomin**

Russian State Hydrometeorological University,  
Sankt Petersburg, Russia  
[biom@bk.ru](mailto:biom@bk.ru)

Currently he works at the Institute of Information Systems and Geotechnologies, head of the Department of Applied Informatics. Teaching disciplines: Information systems and technologies, Management of geographic information systems, Fundamentals of the theory of reliability of technical systems and others. His research interests include geoinformatics, department management, improving the quality of the educational process.

## THE DEVELOPMENT OF A CONTROL MODEL FOR THE “SMART HOME” SYSTEM

Igor Lvovich, Emma Lvovich, Yury Preobrazhenski

### **Abstract:**

---

*This paper describes the possibilities for the development of smart home systems. In the definition of such a concept, the basic concept is associated with a complex system having a single control panel. The modern concept that describes a smart home is defined as a set of control systems that can respond to the presence of a person and the environment with a subsequent solution, which is aimed at creating favorable and comfortable living conditions. The user preference model includes categories of people that have restrictions on certain factors influencing them, and also includes the priority of profiles. All categories of users are divided into legitimate and illegitimate. The tenants of the house are legitimate, and the guests are illegitimate. The model of the house is described. It includes a house plan, equipment composition and its initial state. A model of the situation is described. It is formed from the following components: those present in the room, the current equipment settings, external factors, the knowledge base. A description of the decision tree is given. On its basis, a methodology for the formation of knowledge structures is implemented, which provides the logic of the operation of the intellectual core of the smart home system. The description of the methodology for assessing the effectiveness of the “Smart House” system is given. It includes rules on how to approach the assessment of the level of comfort and safety, general recommendations, how to calculate intermediate indicators, how to form a scale and calculate the final result. The developed technique can be used to develop various options for implementing smart home systems.*

### **Keywords:**

*Computer network, traffic loading, protocol.*

### **ACM Computing Classification System:**

*Network protocols, network algorithms, network types.*

## ■ Introduction

A smart home is a modern type of residential building, organized for people to live with the help of automation and high-tech devices. A smart home is a system that ensures safety, comfort and resource efficiency for all users.

According to the original idea, “Smart Home” does not imply the implementation of intelligent control of the environment (even the original word smart is understood here in the sense of convenient). The system is controlled by profiles with priorities or in manual mode (from the remote control).

But with the development of artificial intelligence systems and the expansion of the functionality of the equipment, it is the “intelligent” control of the environment that becomes quite feasible and even desirable. In which the “smart home” system is a “thinking building” that independently makes decisions in changing circumstances.

The existing traditional approach to designing a “smart home” is based on profile management. By a profile in work, we mean a set of individual settings that determine within what limits to support certain parameters, depending on the status (with or without a profile, belonging to vulnerable categories or not). Initially, several profiles are created for each user, defining within what limits to maintain certain parameters (air temperature, ventilation, lighting, etc.).

During operation, each user of such a system is forced to manually reconfigure his profile or be content with the parameters of the microclimate of the dominant (higher priority) profile. As long as there is one person in a separate room or there are no vulnerable categories of people, such management pays off. But it does not make the system flexible when in the presence of several people it is necessary to find a compromise between comfort and safety.

The safety of people (not only residents of the “Smart Home” with customized profiles) is an important factor, which cannot be taken into account with a “formal” approach. It defines how the system should react to the presence of certain vulnerable categories of people: infants, preschool children, pregnant women, people with disabilities, etc.

There are specific restrictions for them, regardless of the premises and the people already there.

## 1 The Model of User Preferences in the “Smart Home” (SH) System

The user preference model includes categories of people that have restrictions on certain factors influencing them, and also includes the priority of profiles.

The main aspects are their categories: legitimacy, priorities, interactions with specific types of equipment in specific rooms.

The user preference model is included in the settings. The model describes the main indicators about a person and his preferences (age, profile, etc.).

Profile status:

- Personal profile status (customized);
- Restrictive (required);
- Low priority (advisory);
- High priority.

The classes of people are shown in (Fig.1):

1. Infant - a person aged from birth to one year. Distinguish between the neonatal period (the first 4 weeks after birth) and infancy (from 4 weeks to 1 year). During such a period, the influence of harmful factors on health and the special attention of adults should be taken into account.
2. Child - a person aged 1 to 11 years. Distinguish between the nursery or preschool period (from 1 year to 3 years), preschool period (from 3 to 7 years), primary school age (from 7 to 11 years). During such a period, the influence of harmful factors on the health and attention of adults should be taken into account.
3. A teenager is a person between the ages of 11 and 18. The transitional stage between childhood and adulthood.
4. A pregnant woman is a person who is in a special condition in which a developing embryo or fetus is located in his reproductive organs. In this condition, the influence of harmful factors on health should be taken into account.
5. Elderly - a person between the ages of 75 and 90. The period of life when some functions in his body fail.

6. People with disabilities (only from residents):
  - by movement
  - by manipulation
7. Without special restrictions - people in adolescence, adulthood, mature age who have no restrictions on health.

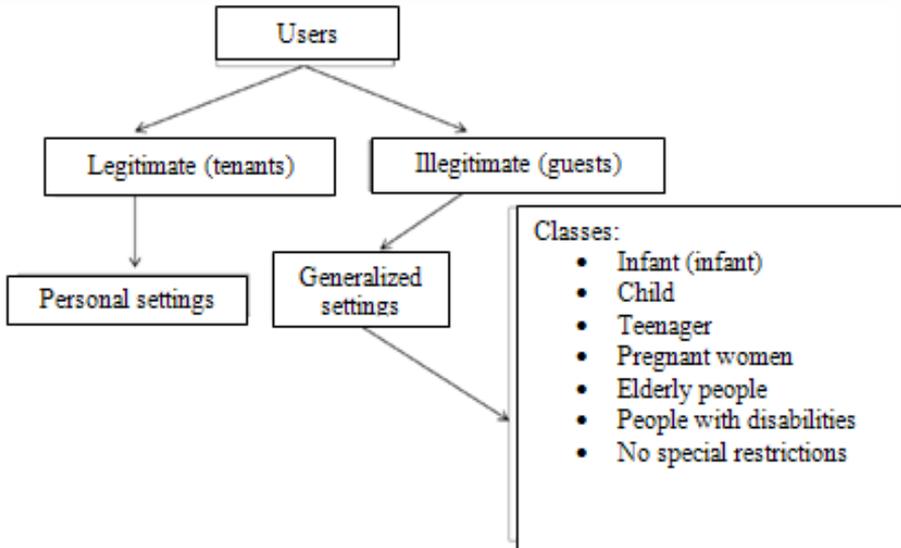


Fig.1. User classes.

Also, all categories of users are divided into legitimate and illegitimate. The tenants of the house are legitimate, and the guests are illegitimate.

Legitimate users have personal settings (profiles) in the SH system. The user adjusts his preferences, and the system adapts to him. And illegitimate users are divided into classes and have generalized settings.

The system affects the object, but its preferences are usually not taken into account. And therefore, as a rule, some of the legitimate and illegitimate users will have the same preferable microclimate settings, some do not, and some may be harmed by the system. This raises the problem that not only residents, but also guests should have user profiles, and since all profiles cannot be made, a compromise must be sought. Therefore, in a specific situation, the compromise profile should be automatically determined in the process of determining a certain number of people and quality in the room. Therefore, we are talking not just about a compromise, but a dynamic synthesis of profile settings.

In conflict situations between profiles of different users, it is necessary to take into account not only the status of the profile, but also to focus on the restrictions for vulnerable categories of users.

Restrictions for certain (vulnerable) categories of citizens:

1. It is harmful for infants, children, pregnant women and the elderly to be in a room where the temperature is below or above the specified norm, so the temperature must be maintained from 20-22 °C.

2. It is harmful for pregnant women and babies to be in a room with loud music, so lower the volume at the upper limit of the noise level.
3. Babies, children and the elderly should not be in a room with open windows and therefore close the windows as appropriate to ensure draft-free conditions.
4. It is not safe for infants and children to be in a room where there are electrical appliances with increased danger, so turn them off if there is no adult in the room. (Fig.1) - User classes.

## 2 A Model House

The house model includes the house plan, equipment composition and its initial state. A room belonging to the “Living room” class should, as a rule, define some equipment:

- temperature sensor;
- a window opened / closed sensor;
- lighting;
- air conditioner;
- control of sockets;
- audio multimedia;
- heating control;
- electrical appliances.

A room belonging to the “Bedroom” class should define the equipment:

- temperature sensor;
- a window opened / closed sensor;
- lighting;
- air conditioner;
- control of sockets;
- heating control;
- electrical appliances.

A room belonging to the “Kitchen” class should define the equipment:

- temperature sensor;
- a window opened / closed sensor;
- lighting;
- air conditioner;
- control of sockets;
- heating control;
- water control sensor;
- electrical appliances.

A room belonging to the class “Bathroom” should define the equipment:

- temperature sensor;
- lighting (general, special);
- air conditioner;
- heating control;
- water control sensor.

The house model also includes data on external factors:

- time of day;
- weather data;
- noise level (outside the window).

When hosts and / or guests appear in one of the rooms, it is necessary to apply an existing profile, or synthesize a new profile.

A situation model is needed in order to see how the system should respond to general vulnerable categories of people.

### 3 Model of the Situation

The situation model consists of the following components:

- those present in the room;
- current equipment settings;
- external factors;
- knowledge base.

The decision making model depends on time, the number of hosts, the number of guests and is set from a subset of hosts and guests:

$$Mdec(time, hosts, guests) = \{h\}\{g\}, \quad (1)$$

where  $Mdec$  is the decision-making matrix; time-time; host - host; state guest. The adjacency matrix depends on the model of the house, the model of external factors and the models of profiles:

$$Ma = (Mh, Mex, Mprof), \quad (2)$$

where  $Ma$  - adjacency matrix;  $Mh$  - house model;  $Mex$  - model of external factors;  $Mprof$  - profile model. The model of the situation can be with or without conflict.

If one person or several with the same requirements appears in the room, then this situation will be considered conflict-free and the system selects an already existing profile. If people appear in the room with conflicting requirements, then the situation will be conflict. Risk situations: - maintain an optimal temperature (especially for babies, children, pregnant women and the elderly); - limit the sound volume; - ensure the absence of drafts; - turn off high-risk electrical appliances (if there is an infant, child, teenager or elderly person in the room). Any deviations from the norm can not only be felt at the physical level, but also lead to a deterioration in well-being, and in some cases to an exacerbation of various chronic diseases.

### 4 Decision Tree

The methodology for the formation of knowledge structures that provide the logic of the work of the intellectual core of the CA system involves the compilation of a knowledge field, its formalization in the form of a structured decision tree, and then identifying a set of rules for logical generalizations. Having such structures, a solver (decision-making kernel) is formed, which provides algorithmic development of situational traversal of the decision tree.

The general decision tree is shown in (Fig.2).

Let's consider each fragment of the tree in more detail. Let us illustrate a fragment of the knowledge field of the expert system, which is responsible for controlling the volume level of multimedia systems, highlighting three levels of generalization:

1. The first level is the categorization of input data that determines the situation of choosing the settings of the multimedia system.
2. The second level is a generalization of the initial data, in the form of a set of hypotheses.
3. The third level is the conclusion of the nature of the control action on the multimedia system.

Let's represent the decision tree in the form of a graph, which is shown in (Fig.2), detailing each level of the composition decision tree. The first level will have six vertices: "Room type", "Current volume level of the multimedia system", "Preferred volume level of the priority (master) profile", "Presence of a child in the room", "Presence of a pregnant woman in the room" and "Presence in room of an elderly person or a person with disabilities".

We detail the first level. The first vertex is "Room type". This vertex can take the following values: "Kitchen"; "Bedroom"; "Bathroom"; "Living room and others".

The second peak is "Current value of the volume level of the multimedia system", which reflects the quantitative value of the current volume level setting for the multimedia system, which after fuzzification will take one of the following states: "Quiet"; "Average volume"; "Loud"; "Very loud". The next vertex is "Preferred volume level of the priority (master) profile", which takes one of the following values: "Quiet"; "Average volume"; "Loud"; "Very loud".

Vertices "The presence of a child / pregnant woman / elderly person or a person with a disability in the room" are discrete and refer exclusively to guests (those who do not have a configured profile in the CA system).

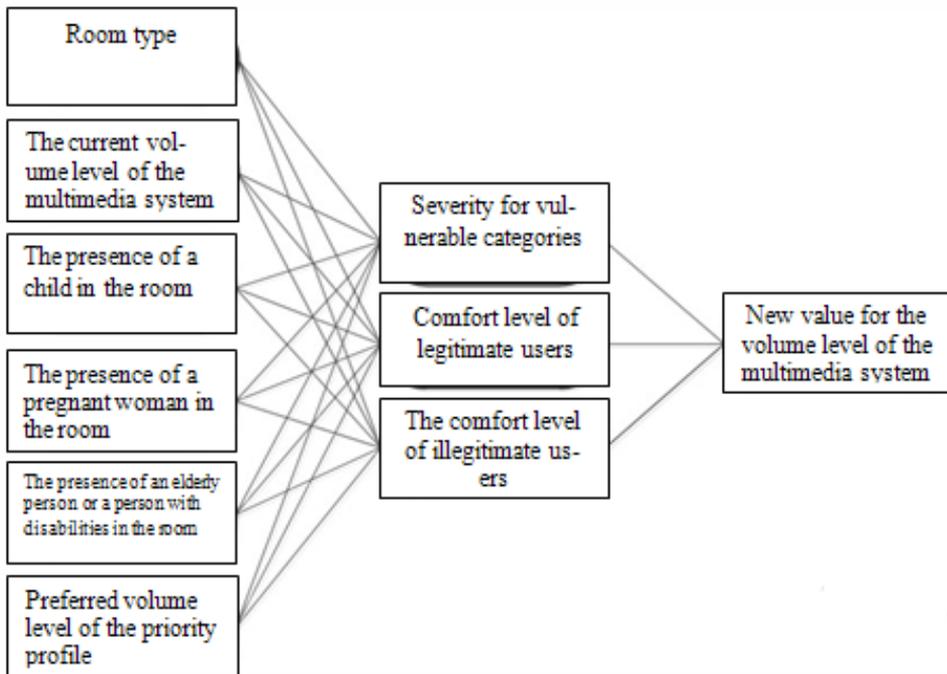


Fig.2. Fragment of the decision tree for controlling the volume level of the multimedia system in the SH.

At the second level of generalization, the following hypotheses will be tested: "The degree of danger for vulnerable categories", "The comfort level of legitimate users" and "The comfort level of illegitimate users". The top "Degree of danger for vulnerable categories" (the possibility of causing harm) is represented by the following states: "Not dangerous"; "Minor"; "Significant". The next peak - "The level of comfort of legitimate users" takes the following values: "Meets expectations"; "Doesn't meet expectations". And the top "Comfort level of illegitimate users" can take on the following values: "Not taken into account"; "Acceptable"; "Not acceptable".

At the third level (pin level) there will be one vertex - this is the "New value of the volume of the multimedia system", which has the following values:

"Leave the volume at the current level"; "Decrease the volume level to the safety margin"; "Increase the volume to the comfort limit". On (Fig.2) it is shown, at the combination of which peaks of the first level, each of the peaks of the second level is obtained. And the totality of all peaks of the second level determines the value of the only peak of the third level. Similarly, consider the part of the decision tree responsible for lighting control, which is shown in (Fig.3), highlighting three levels of generalization:

1. The first level is the categorization of the input data that determines the situation of choosing the lighting settings.
2. The second level is a generalization of the initial data, in the form of a set of hypotheses.
3. The third level is the conclusion of the nature of the control effect on lighting. The first level will have six vertices: "Type of lighting", "Degree of ambient lighting", "Current lighting value", "Preferred lighting level of the priority (master) profile", "Presence of a child in the room", "Presence of a pregnant woman in the room" and "The presence of an elderly person or a person with disabilities in the room", "Room type". We detail the first level.
4. The first vertex is Lighting Type. This vertex can take the following values: "General"; "Special"; "Bathroom". The second vertex is "Ambient Light Degree"; "Dim"; "Light"; "Very light". The following vertices - "Current illumination value" and "Preferred illumination level of the priority master profile", take values: "On"; "Turned off".
5. Vertices "The presence of a child / pregnant woman / elderly person or a person with a disability in the room" are discrete and refer exclusively to guests (those who do not have a configured profile in the CA system).

At the second level of generalization, the following hypotheses will be tested: "Comfort level of legitimate users" and "Comfort level of illegitimate users". Top - "Comfort level of legitimate users" takes the following values: "Meets expectations"; "Doesn't meet expectations". And the top "Comfort level of illegitimate users" can take on the following values: "Not taken into account"; "Acceptable"; "Not acceptable".

At the third level (pin level) there will be one vertex - this is the "New value of the lighting level", which has the following values: "None"; "Reduce lighting level"; "Raise lighting level to the comfort limit". The next fragment of the decision tree, which is responsible for temperature management, shown in (Fig.4), highlighting three levels of generalization:

1. The first level is the categorization of the input data that determine the situation for choosing temperature settings.
2. The second level is a generalization of the initial data, in the form of a set of hypotheses.
3. The third level is the conclusion of the nature of the control action on the temperature.

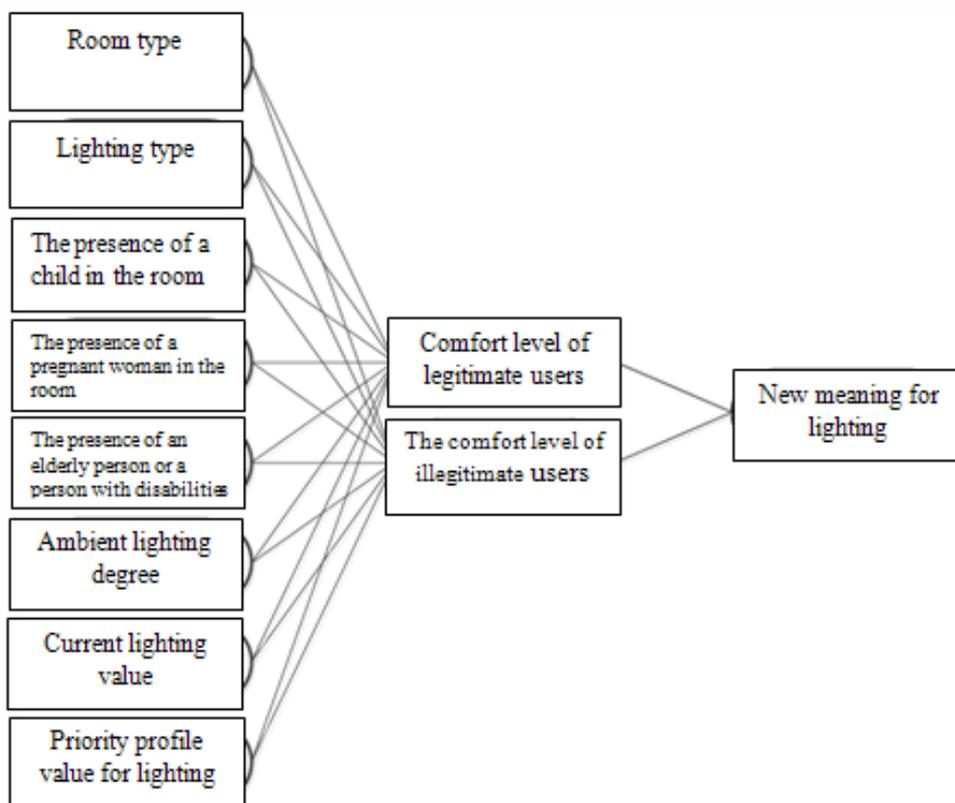


Fig.3. Fragment of a decision tree for controlling the level of lighting in the SH system.

At the first level there is (Fig.4): “Current value of windows”, “Current value of ventilation”, “Current value of air conditioning”, “Current value of heating”, “Preferred level of opening windows of the priority (master) profile”, “Preferred level of ventilation of the priority (master's) profile”, “Preferred level of air conditioning of the priority (master) profile”, “Preferred level of heating of the priority (master) profile”, “Temperature outside”, “Presence of a child in the room”, “Presence of a pregnant woman in the room”, “The presence of an elderly person or a person with disabilities in the room”, “Room type”. We detail the first level.

The first vertex is the “Current value of windows”. This vertex can take the following values: “Open”; “Closed”; “Micro ventilation”. The next peaks are “Current ventilation value”, “Current air conditioning value”, “Current heating value”, “Preferred ventilation operation level of the priority (master) profile”, “Preferred air conditioning operation level of the priority (master) profile”, “Preferred heating operation level priority (master) profile”, take the following values: “Disabled”; “Minimum”; “Maximum”. Top - “Preferred level for opening windows of the priority (master) profile”, takes on the values: “Open”; “Closed”; “Micro ventilation”. And the top - “Temperature outside”, takes on the values: “Heat”; “Cool”; “Coldly”.

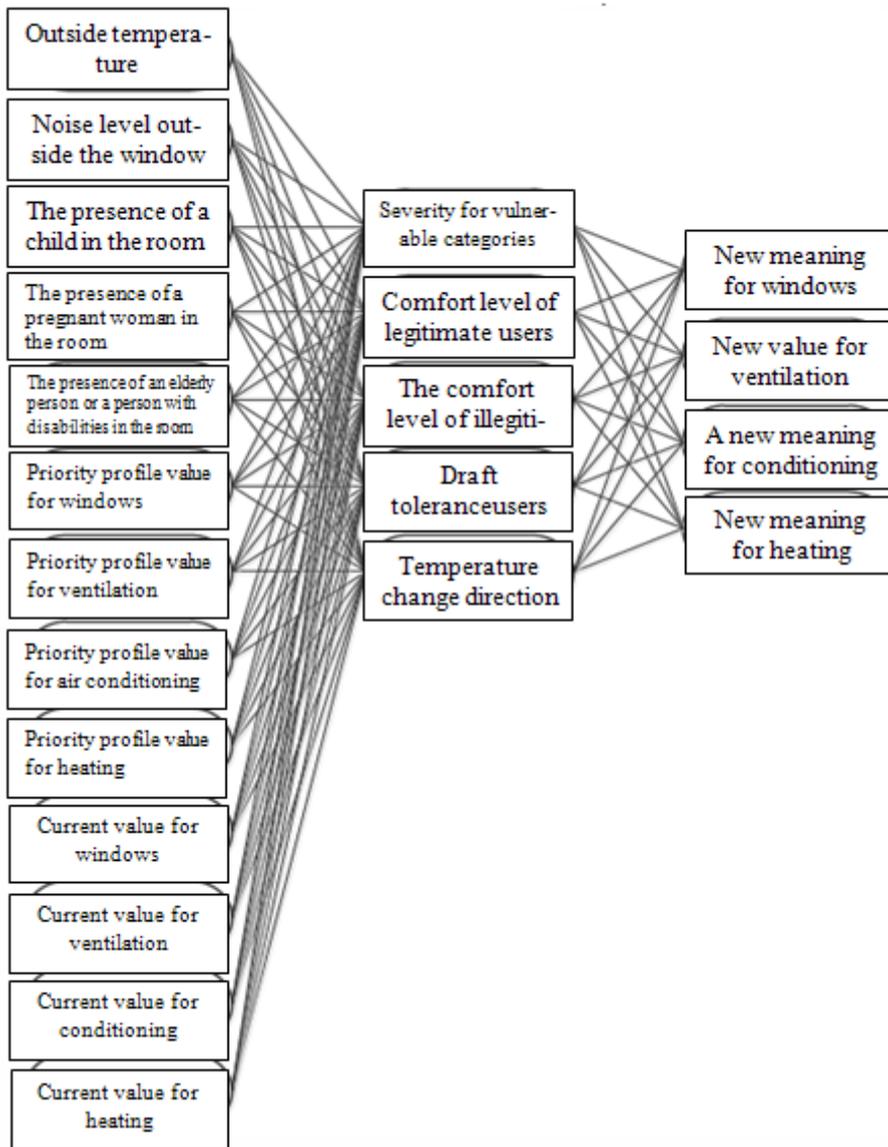


Fig.4. Fragment of a decision tree for temperature control in the SH system.

At the second level of generalization, the following hypotheses will be tested: “Leading hazard category”, “Direction of temperature change”, “Comfort level of legitimate and illegitimate users”, “Leading temperature control” and “Leading air conditioning control”. Vertex - “Leading hazard category”, takes the following values: “None”; “Child”; “Pregnant woman”, “Elderly or disabled person”; The next peak - “The comfort level of legitimate and illegitimate users” takes the following values: “Both are satisfied”; “The first is satisfied, the second is dissatisfied”; “The first is dissatisfied, the second is satisfied”.

And the tops “Leading temperature control” and “Leading air conditioning control” take the values: “Windows”, “Air conditioning”, “Ventilation”, “Heating”. At the third level (output level) there will be tops - “Windows”, “Air conditioning”, “Ventilation”, “Heating”.

The top “Windows” has the following meanings: “Open”; “Closed”; “Micro ventilation”. And the top of “Air Conditioning”, “Ventilation”, “Heating”: “Off”; “Minimum”; “Maximum”. Consider the following fragment of a decision tree responsible for water supply management in the Smart Home system, highlighting three levels of generalization:

- The first level is the categorization of input data that determine the situation of choosing water supply settings.
- The second level is a generalization of the initial data, in the form of a set of hypotheses.
- The third level is the conclusion of the nature of the control impact on water supply.

We represent the decision tree in the form of a graph in (Fig.5), detailing each level of the composition decision tree.

The first level will have six vertices: “Room type”, “Current water supply value”, “Water supply value for the priority (master's) profile”, “Presence of a child in the room”, “Presence of a pregnant woman in the room” and “Presence of an elderly person in the room or a person with disabilities”.

We detail the first level. The first vertex is “Room type”. This vertex can take the following values: “Kitchen”; “Bedroom”; “Bathroom”; “Living room and others”. The second vertex is “Water supply value for the priority (master) profile”, which takes on the following values: “Enabled”; “Turned off”.

And the vertices “Presence of a child / pregnant woman / elderly person or a person with disabilities in the room” are discrete and refer exclusively to guests (those who do not have a configured profile in the CA system).

At the second level of generalization, the following hypotheses will be tested: “The degree of danger for vulnerable categories”, “The comfort level of legitimate users” and “The comfort level of illegitimate users”.

The top “Degree of danger for vulnerable categories” (the possibility of causing harm) is represented by the following states: “Not dangerous”; “Minor”; “Significant”. The next peak - “The level of comfort of legitimate users” takes the following values: “Meets expectations”; “Doesn't meet expectations”.

And the top “Comfort level of illegitimate users” can take on the following values: “Not taken into account”; “Acceptable”; “Not acceptable”.

At the third level (the level of outputs) there will be one vertex - “Water supply”, which has the following values: “Enable”; “Turn off”. Let's consider the last fragment of the decision tree, which is responsible for electricity management in the Smart Home system, shown in (Fig.6), highlighting three levels of generalization:

- The first level is the categorization of input data that determine the situation of choosing electricity settings.
- The second level is a generalization of the initial data, in the form of a set of hypotheses.
- The third level is the conclusion of the nature of the control effect on electricity.

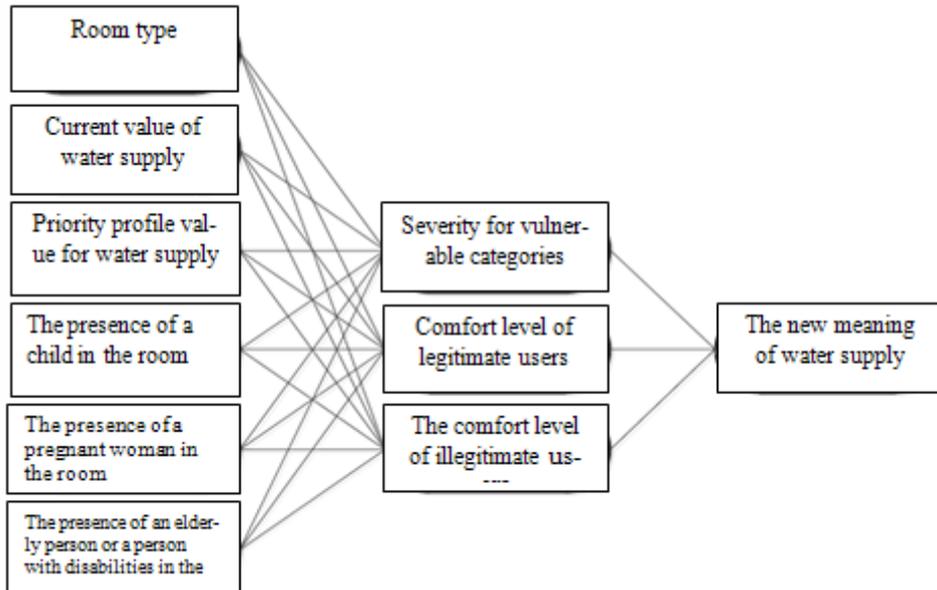


Fig.5. Fragment of a decision tree for water supply management in the management system.

Let's represent the decision tree in the form of a graph shown in (Fig.6), detailing each level of the composition decision tree. The first level will have six vertices: "Room type", "Current electricity value", "Electricity value for the priority (master) profile", "The presence of a child in the room", "The presence of a pregnant woman in the room", "The presence of an elderly person in the room or a disabled person", "Appliance type", and "Age of the oldest person in the room".

We detail the first level. The first vertex is "Room type". This vertex can take the following values: "Kitchen"; "Bedroom"; "Bathroom"; "Living room and others".

The second vertex is "Electricity value for the priority (master) profile", which takes on the following values: "Enabled", "Turned off".

And the vertices "Presence of a child / pregnant woman / elderly person or a person with disabilities in the room" are discrete and refer exclusively to guests (those who do not have a configured profile in the CA system). One more vertex "Device type", which takes the following values: "Free sockets"; "Electrical devices with high danger"; "Low Hazard Electrical Appliances"; "Electrical devices with high SH integration".

At the second level of generalization, the following hypotheses will be tested: "The degree of danger for vulnerable categories", "The comfort level of legitimate users" and "The comfort level of illegitimate users". The top "Degree of danger for vulnerable categories" (the possibility of harm) is represented by the following states:

- "Not dangerous";
- "Minor";
- "Substantial".

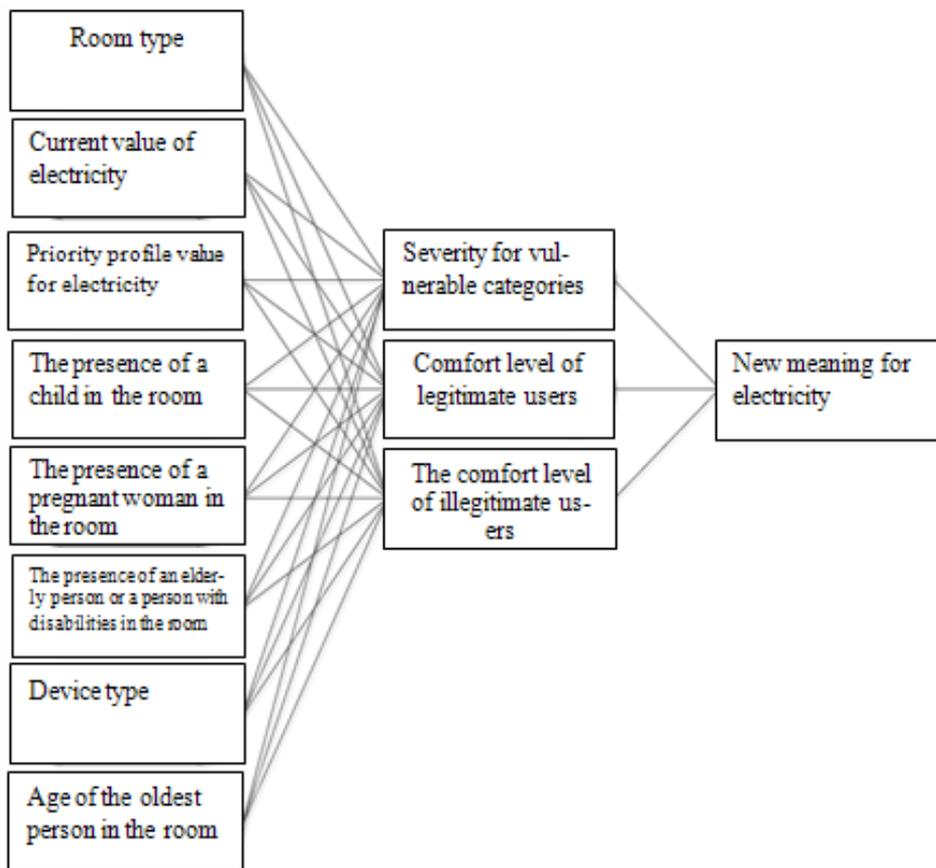


Fig.6. Fragment of a decision tree for electricity management in the SH system.

The next peak - “The level of comfort of legitimate users” takes the following values:

- “Meets expectations”;
- “Doesn't meet expectations”.

And the top “Comfort level of illegitimate users” can take on the following values:

- “Not taken into account”;
- “Acceptable”;
- “Not acceptable”.

At the third level (the level of conclusions) there will be one vertex - “Electricity”, which has the following meanings:

- “Enable”;
- “Turn off”.

The constructed knowledge field is presented as a collection of production rules of the expert system. The FLM\_Build program [7] is used as a shell for the formation of the expert system, and the FLM\_Integrator dynamic link library [8] is used as the module for integration with the kernel of the control system of the SH.

In the program, we transform quantitative indicators into qualitative ones using the fuzzy logic method. For example, for the indicator "Current value of the volume level of the multimedia system". We classify the indicator into groups: "quiet", "medium volume", "loud", "very loud". Then we determine how many lines of code a very small function requires on average, how many - medium and large.

## 5 A Synthesis Technique

The methodological support of the process of managing the settings of the SH system should be based on the formation of a dynamic (situational) profile of the operating modes of active equipment.

Let us note the main stages of the dynamic synthesis of the profile (equipment settings) by the intelligent core of the Smart House control system:

- Stage 1. Loading situational data and knowledge from the knowledge base.
- Stage 2. Conversion of quantitative indicators into qualitative ones using the fuzzy logic method (phasification);
- Stage 3. Decision making by the CA system (a set of production rules from the knowledge base) on the values of the settings for each type of equipment in the room (priority is the safety of vulnerable categories of users);
- Stage 4. Formation and application of a dynamic compromise profile based on the solutions obtained. Filling in all profile parameters with the data that were defined in the previous step and applying for equipment settings.

## 6 Methodology for Assessing the Effectiveness of the "Smart Home" System

The methodology contains rules on how to approach the assessment of the level of comfort and safety, general recommendations, how to calculate intermediate indicators, how to form a scale and calculate the final result. Comfort and safety assessment methodology:

- Stage 1: Scaling custom aspects from a safety and comfort standpoint relative to current values;
- Stage 2: Assessment of security deviations and preferred settings from the proposed methodology;
- Stage 3: Average value for all rooms in one experiment;
- Stage 4: Generalization of assessments of the level of comfort and safety for a series of experiments.

The scoring model depends on the settings and on the adjacency matrix:

$$Mev = (Mdec, Ma), \quad (3)$$

where  $M_{ev}$  is the evaluation model;  $M_{dec}$  - decision-making matrix;  $M_a$  - adjacency matrix. Let's give an example: consider a compromise profile in a room based on two devices (volume and lighting), when the owner is in the room without any special restrictions and a pregnant woman. The scale for devices (volume and lighting) is shown in (Fig.7).

Host and guest priorities (safe) are set - settings for the first device (illumination):

- $Ms1$  = strong; (master settings)
- $Sr1$  = not definite; (safety requirements)
- $Cur1$  = weak. (current settings)

Settings for the second device (volume):

- $Ms2$  = high;
- $Sr2$  = medium;
- $Cur2$  = low.

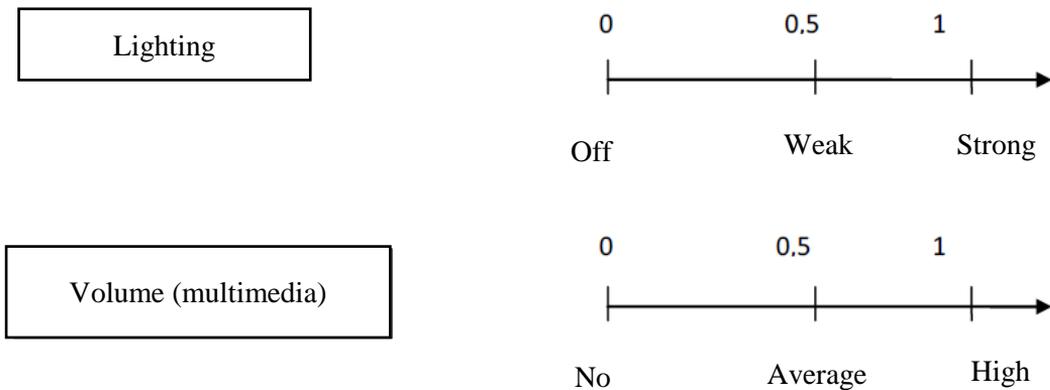


Fig.7. Scaling of tunable devices.

We synthesize a new profile based on the settings (host, security requirements and current settings). Setting resulting for the first device:

$$Res1 = Ms1 \times 1, \tag{4}$$

where  $Res1$  is the resulting setting;  $Ms1$  – master settings for 1 equipment. For the first device, the security is not defined, so we take the master's setting. Setting resulting for the second device:

$$Res2 = Sr2 \times 1, \tag{5}$$

where  $Res2$  is the resulting setting;  $Sr2$  - safe requirements; For the second device, it was determined that the master setting differs from the secure requirements setting and the current setting differs from the secure requirements setting, then we choose the resulting setting towards security.

We assess the degree of satisfaction. We calculate the satisfaction of the host and guest using the formula:

$$y_{h,g} = \sum_n \frac{y_{h,g}}{n} = 0,75 \quad (6)$$

where  $y_h$  is the owner's satisfaction;  $y_g$  - guest satisfaction;  $n$  is the number of devices. The owner's satisfaction for the first device from the example is:

$$y_h 1 = 1 \quad (7)$$

The owner's satisfaction according to the second device is equal to:

$$y_h 2 = 0,5 \quad (8)$$

Guest satisfaction for the first device is:

$$y_g 1 = 1 \quad (9)$$

For the first device, the guest has no requirements, so we take the default settings. Guest satisfaction for the second device is:

$$y_g 2 = 1 \quad (10)$$

For the second device, the guest's secure profile was adopted to the settings.

**Outcome:**

The owner's satisfaction in terms of two indicators is equal to:

$$\sum_i y_x = \frac{1,5}{2} = 0,75 \quad (11)$$

Guest satisfaction by two indicators is equal to:

$$\sum_i y_x = \frac{2}{2} = 1 \quad (12)$$

▀ **Conclusion**

A methodological study was carried out and a knowledge base was compiled, including: a model of a house, a model of a person, a model of a situation and a decision tree.

The house model is presented in the form of a house plan and its composition (types of equipment); The user preference model includes the categories of people who have preferences and restrictions on certain factors influencing them; The situation model consists of the components present in the room, the current equipment settings and external factors. The decision tree consists of aspects: volume control (multimedia) in the control system, lighting control in the control system, water supply control in the control system, electricity control in the control system, heating control in the control system, air conditioning control in the control system. Each aspect involved the development of a fragment of a decision tree. Based on the results of building the knowledge base, a technique was proposed for the dynamic synthesis of a compromise profile using the mechanism of intelligent expert decision making.

As an implementation, we will choose the expert systems tool. To check the adequacy of the work of the intelligent core of the control system of the SH, which carries out the dynamic synthesis of the compromise profile, it is necessary to test the technique on a software simulator.

## References

- [1] Lvovich I., E., Lvovich I., I., Preobrazhenskiy A., P., Golovinov S., O. (2010) Development of a computer-aided design system for wireless communication systems. *Telecommunications*. No. 11. Pp. 2-6.
- [2] Kazakov E., N. (2016) Development and software implementation of the algorithm for estimating the signal level in a wi-fi network. *Modeling, optimization and information technology*. No. 1 (12). Pp. 13.
- [3] Baranov A., B. (2012) Problems in the functioning of mesh networks. *Bulletin of the Voronezh Institute of High Technologies*. No. 9. Pp. 49-50.
- [4] Lvovich I., Ya., Lvovich Ya., E., Preobrazhenskiy A., P., Preobrazhenskiy Yu., P., Choporov O.N. (2019) Modeling of information processing in the internet of things at agricultural enterprises. Collected: IOP Conference Series: Earth and Environmental Science Krasnoyarsk Science and Technology City Hall of the Russian Union of Scientific and Engineering Associations. P. 32029.
- [5] Pustynnik I., E., Preobrazhenskiy Yu., P. (2019) Methods of protecting smart devices using Samsung TV as an example. *Bulletin of the Voronezh Institute of High Technologies*. No. 2 (29). Pp. 84-89.
- [6] Lvovich I., Preobrazhenskiy A., Preobrazhenskiy Y., Lvovich Y., Choporov O. (2019) Managing developing internet of things systems based on models and algorithms of multi-alternative aggregation. In: 2019 International Seminar on Electron Devices Design and Production, SED 2019 - Proceedings 2019. P. 8798413.
- [7] Lvovich I., Ya., Preobrazhenskiy A., P., Preobrazhenskiy Yu., P., Choporov O., N. (2019) Problems of using Internet of things technologies. *Bulletin of the Voronezh Institute of High Technologies*. 2019.No 1 (28). Pp. 73-75.

## Authors



### **Prof. Igor Lvovich**

Doctor of Sciences (Engineering), Professor  
Voronezh Institute of High Technologies, Voronezh, Russia  
E-mail: i\_lvovich@mail.ru



### **Emma Lvovich**

Candidate of Economic Sciences, Associate Professor  
Voronezh Institute of High Technologies, Voronezh, Russia  
E-mail: lvemma@vvt.ru



### **Yury Preobrazhenski**

Candidate of Technical Sciences, Associate Professor,  
Voronezh Institute of High Technologies, Voronezh, Russia  
E-mail: yup@vvt.ru

# THE COMPLEX ECONOMIC NETWORK CREATED IN STELLA SOFTWARE

## A Contribution to Emerging Theory of Virtual Complex Networks - Part II

Ladislav Andrášik

### Abstract:

---

*In the contemporary mainstream economics, there is a persisting reckoning on mathematical apparatus of Newtonian Mechanics or in better case of first (of Clausius) Thermodynamics. However, the economy in objective reality isn't existing as a mechanical system but as such it is living in the form of complex evolving social organism creating a complex network. De facto economy is a spontaneous product of great population of Homo sapiens in a very long historical evolution. Problems and difficulties for economics scholars are consisting in fact that such entities in objective reality are not directly observable and the less they are in whole effectively controlled from separate sole centre. Fortunately the progress in information and communication technologies (ICT) and mainly in computational intelligence (CI) are bringing new possibilities for insight if not directly into objective economies thereabout at least into virtual ones. For such purposes we have constructed a relatively simple software called STELLA. It is a primordial virtual economy which allows to the user directly in computer to observe the behaviour in it. However, only a slide showing of snapshots passed from STELLA is less explanatory. For that reason we must to expend the exposition by voluminous verbal commentaries. On the other hand we must emphasize that "reading" of snapshots from computer simulations is a new very efficient modus of mining knowledge from complex economic process. In the Part I of this essay we have introduced foundations of the theory of complex network economies and elementary virtual economies created in software STELLA. Simulations and deep commentary to behaviour in virtual economy are the purpose of this Part II of our essay.*

### Keywords:

*Complexity, experiment, graph theory, idiosyncrasies, network, neoclassical economy, self-reinforcing complexification, STELLA software, teleonomic selection, virtual environment.*

### ACM Computing Classification System:

*Network economics, network performance evaluation, network modelling, network simulation, network experimentation, network properties.*

## ▀ 1 Graphical results of simulation runs: Sequence A

In Part I of our essay we are trying to set down some elementary bases for creating paradigm of complex network economics. In this Part II we will to show and expose some results of simulation runs in computer using in STELLA constructed virtual economies published in Part I. The process of simulation in STELLA virtual economy is somewhat running as it were actually spontaneous.

It is because we are using built-in regulators which are used for emulating decision making of CEO's in individual firms and households in the four sectors of our virtual economy. We will accede to running the whole model exhibited in (Fig. 11) of Part I. The snapshots of (Fig. 1) to (Fig. 13) are exposed graphs of simulation results with only single series of realised decisions of CEO's to prices and demand, the supplies are untouched. In (Fig. 1) we are showing the process of growth of fixed capital  $Kfix$ , which is stored as four parts in four rooms/containers:  $RoomPi$   $Kfix$  and the sum of all that is called  $Total$   $Kfix$ . These growths are happen because the technical progress  $PIA$  in sector  $P1$  is sufficiently great to fulfilling the needs (demands) of all four sectors in  $Kfix$ . The growth of  $Kfix$  is the lone factor of growth of whole virtual economy, in other words it is depending on  $PIA$ , which is for this case  $=0.99/per\ month$ , consequently the supply of  $Kfix$  for investment is the sum of 12 months product of  $PIQKfix$ , in first year is  $= 16\ units$  accumulated in  $RoomP1$  for  $Kfix$ , (Fig. 11) Part I.

We can directly and clearly see that the process of economic evolution even in this very simple model is behaving more complex than economic growth being in mind of neoclassical economists. The evolution in our simple virtual economy is demonstrating natural properties of complexification<sup>1</sup> in very low level of computer running steps. This is basically different process than abstract computation of neoclassical formulas. In the snapshot of (Fig. 1) we can see the impact of different time step longitude on the quality and quantity of evolution in the case of  $Kfix$ , which is in our model twelve months, whilst in the case of other variables is the step longitudes only one month. During a curse of twelve months of a year the investment product of sector  $P1$  is stockpiles in container  $RoomP1Kfix$  and in next time is realised in the investment good market. On the one hand this is the origin of economic growth and on the other hand this invokes fluctuation if all  $Kfix$  in one year cycle and in other variables in cycle one month. This is demonstrated in the snapshot of (Fig. 2) for other variables. On the snapshot of (Fig. 3) we can see the fluctuations of total supply of  $L$  and the available for using  $L$  in all sectors.

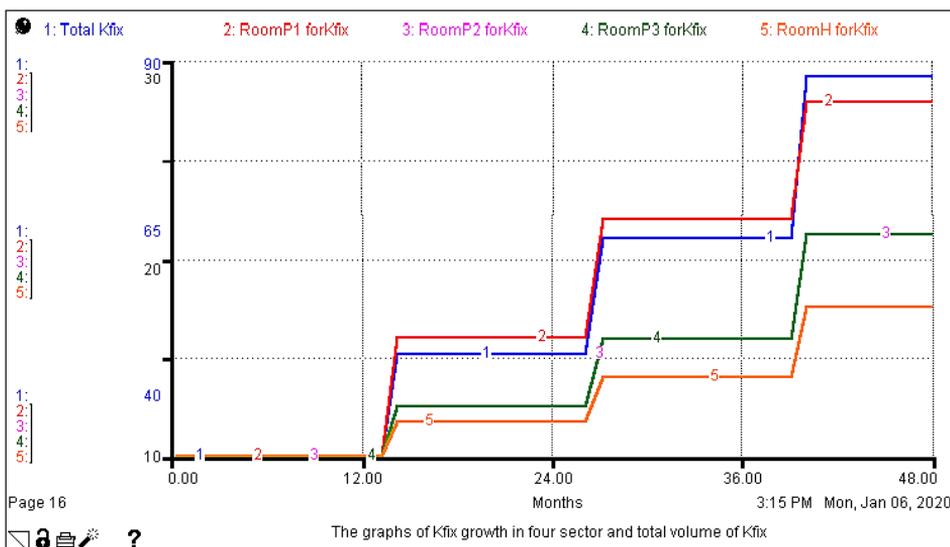


Fig. 1. The graphs of fixed capital  $Kfix^2$  growth in four years interval of time.

<sup>1</sup> By the term *complexification* in this essay we understand a process of evolving parts and mainly the economy as a whole having to be more and more *complex*.

<sup>2</sup> For better clearness of models data built in STELLA is not used depreciation of fixed capital  $Kfix$ .

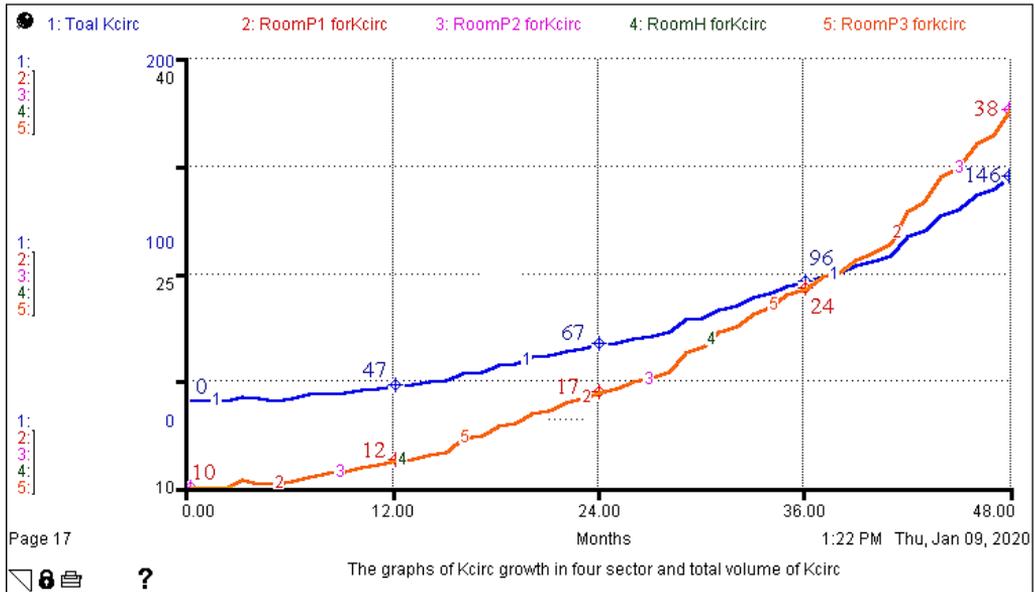


Fig.2. The graphs of circular capital *Kcirc* growth (total is blue) in four years interval of time.

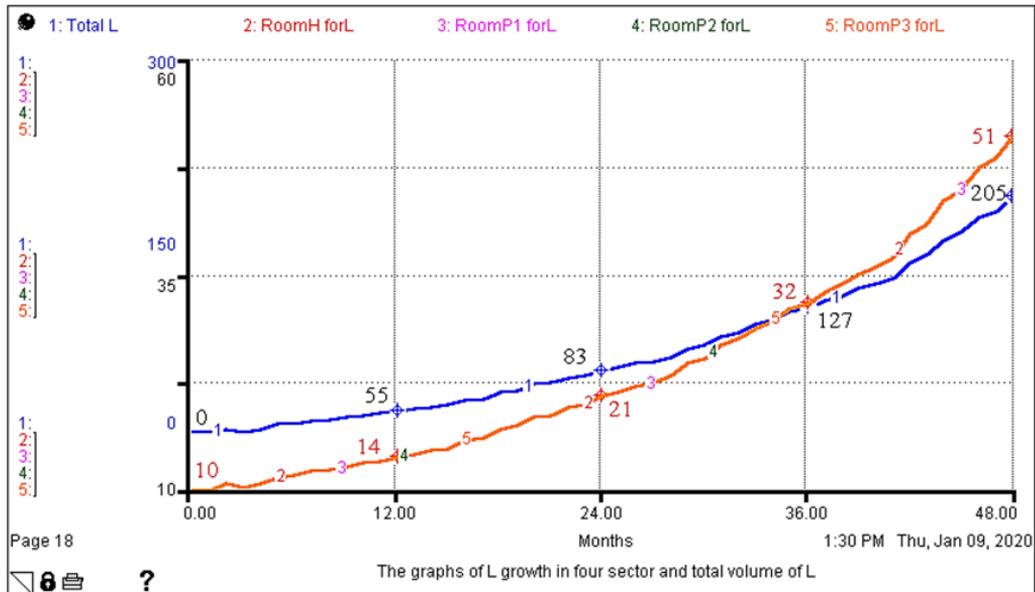


Fig.3. The graphs of labour forces *L* growth in four years interval of time.

In (Fig.1 - 3) it is shown a swamp fluctuation of our virtual economic evolution variables: *Kfix*, *Kcirc*, and *L*. Another picture is shown in the snapshot of (Fig.4) where is depicted a fluctuation of consumption goods *CG*, which is a sole product only for households. The consumption goods are the primary important input to economy, without these no economy moreover any social organism cannot exists.

Because of interplay between Households and  $P3$  sector in quantitative and qualitative volumes and structures of  $CG$  there are emerging strong changes in a type of growth and to loss of structural stability in the  $CG$  production. These all and the inventions in both side that is in demand and supply side of  $CG$  is lead to self-reinforcing the complexity in all economy.

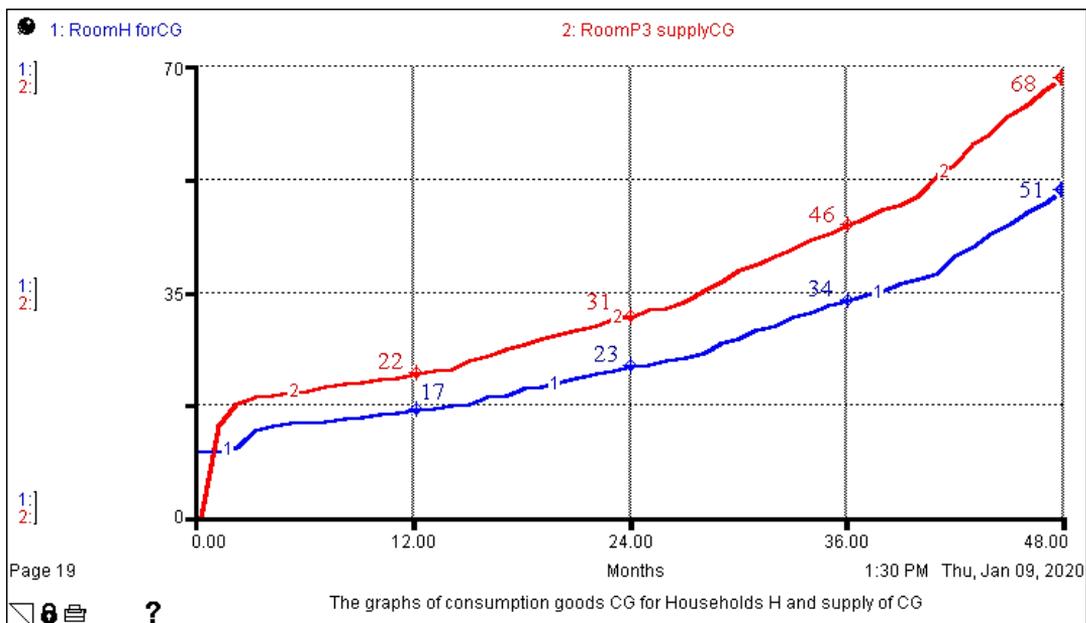


Fig.4. The graphs of consumer goods  $CG$  growth in four years interval of time.

For better and deeper insight into whole structure of model we are introduced summing of three productive factors, which we are not included to Part I of our essay.

In (Fig.7) it is shown the fluctuation of variables:  $L$ ,  $Kcirc$  and  $CG$  in one month steps compared with one year longitude steps of  $Kfix$ .

In (Fig.8 - 11) it is shown the behaviour of sector  $P1$ ,  $P2$ ,  $P3$  and Households  $H$  influenced by mutual multifarious and reciprocal relations in created and further evolving complex network. The new approach is lying in possibility directly to observe evolution in different morphological fields and resonances in evolving multilayer network.

Even our realised simulation runs with relatively simple models in STELLA are showing complexification tendencies, which are in neoclassical models with theirs simple mathematical formulas fully indispensable. The structural and functional complexification of economic evolution is fully natural phenomena, which is realising discretely step by step.

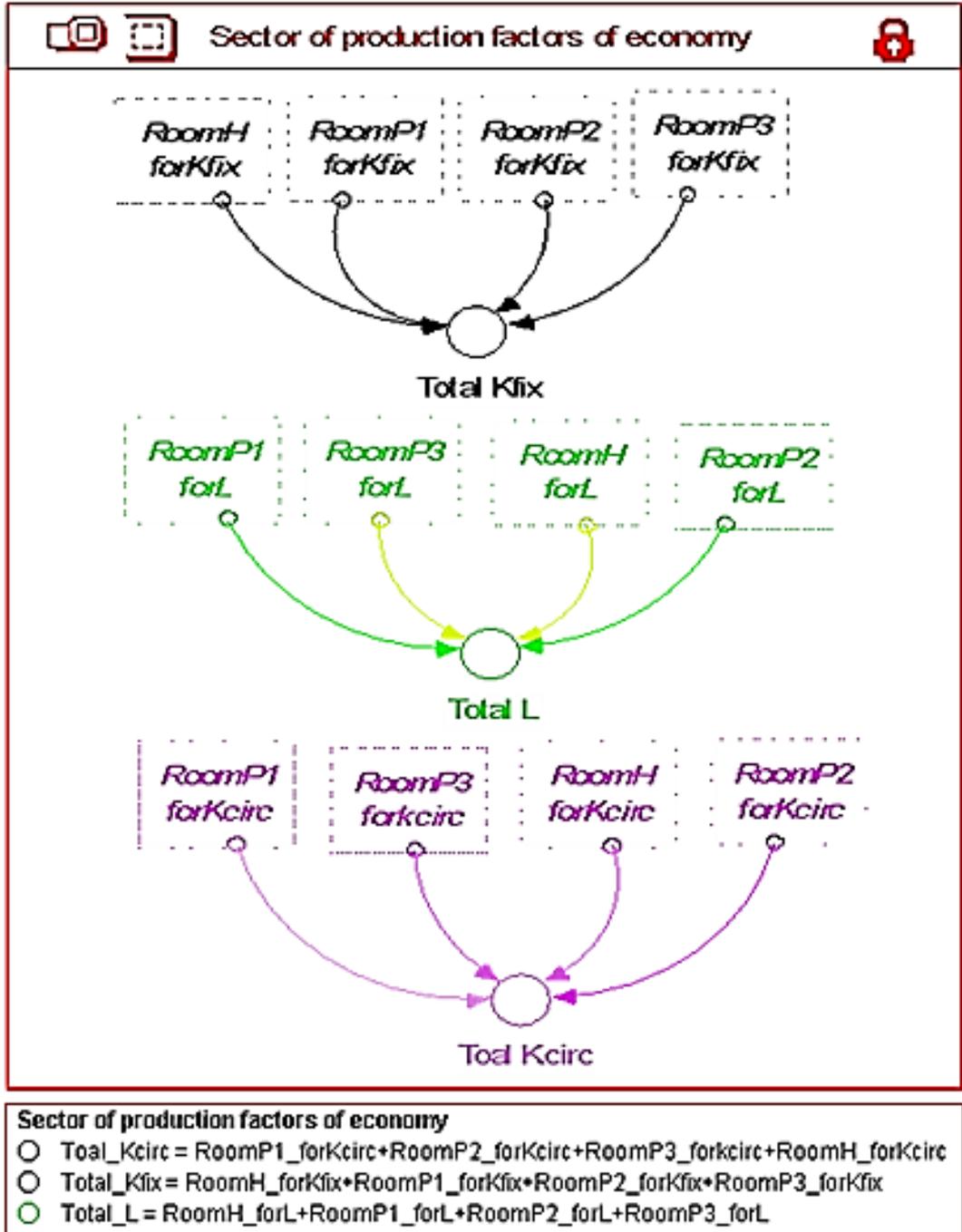


Fig.5. The sums of three productive factors of virtual economy.

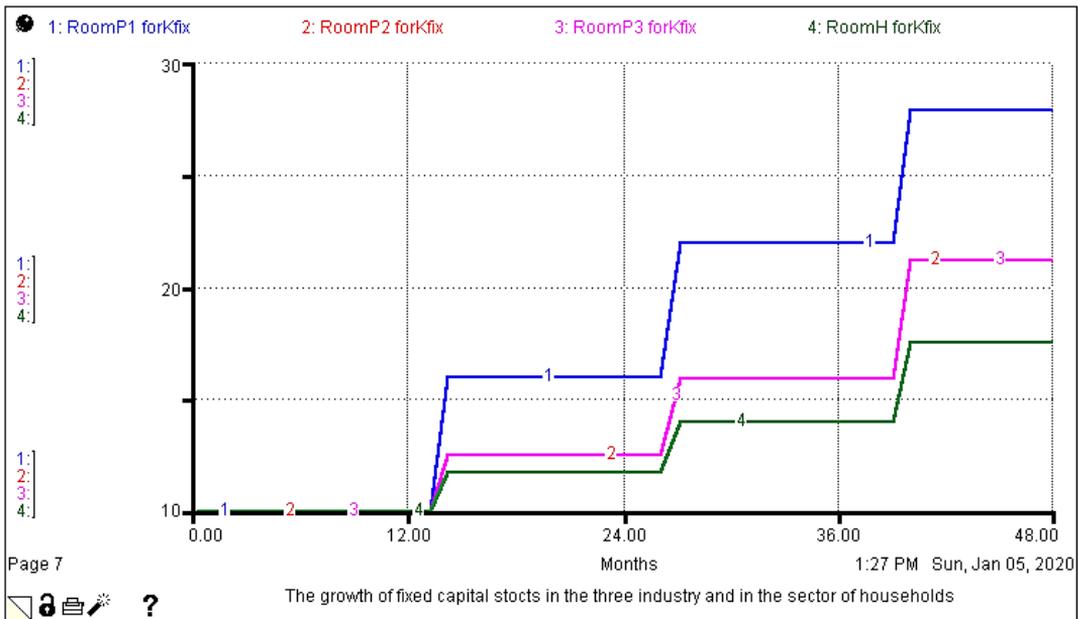


Fig.6. The graphs of fixed capitals growth of four sectors in longitude of four years interval.

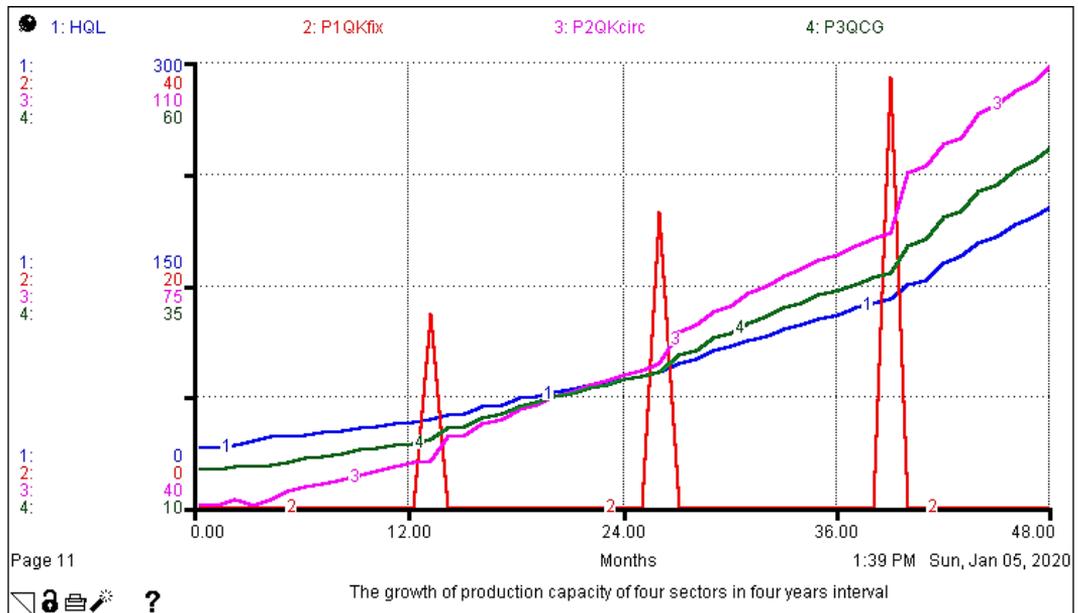


Fig.7. The graphs of production  $L$ ,  $K_{fix}$ ,  $K_{circ}$  and  $CG$  in four years interval.

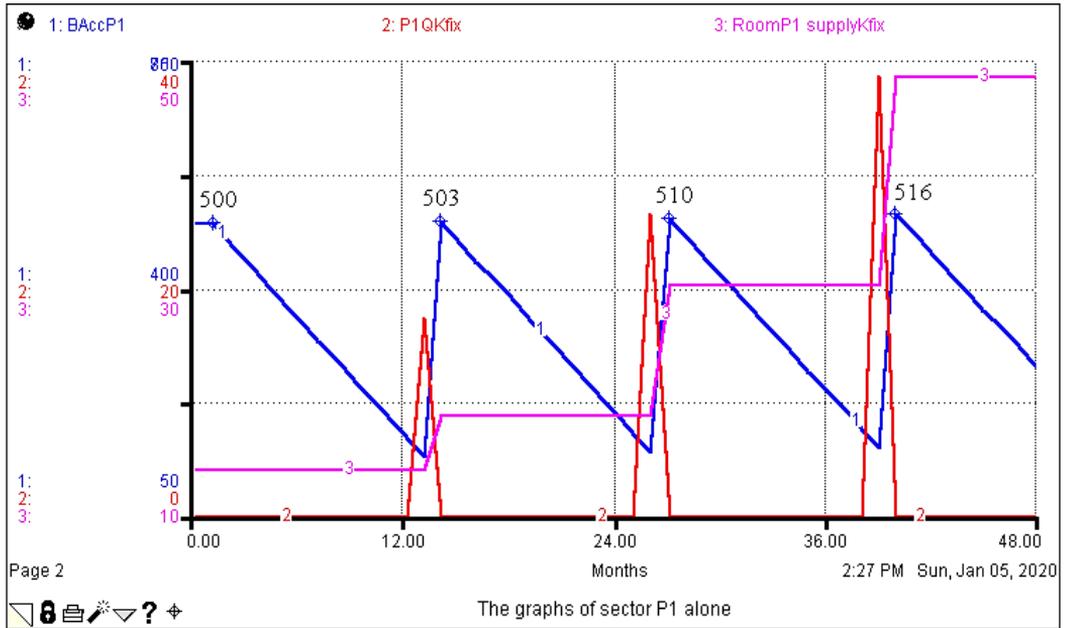


Fig.8. The graphs of sector P1 unit's growth: the values of bank assets.

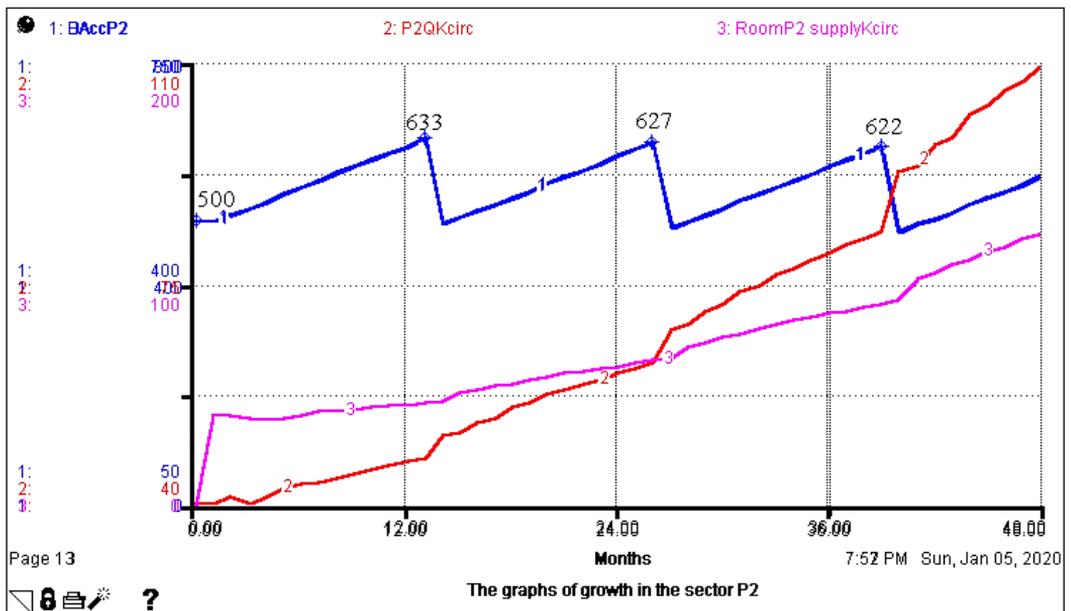


Fig.9. The graphs of sector P2 unit's growth: the values of bank assets.

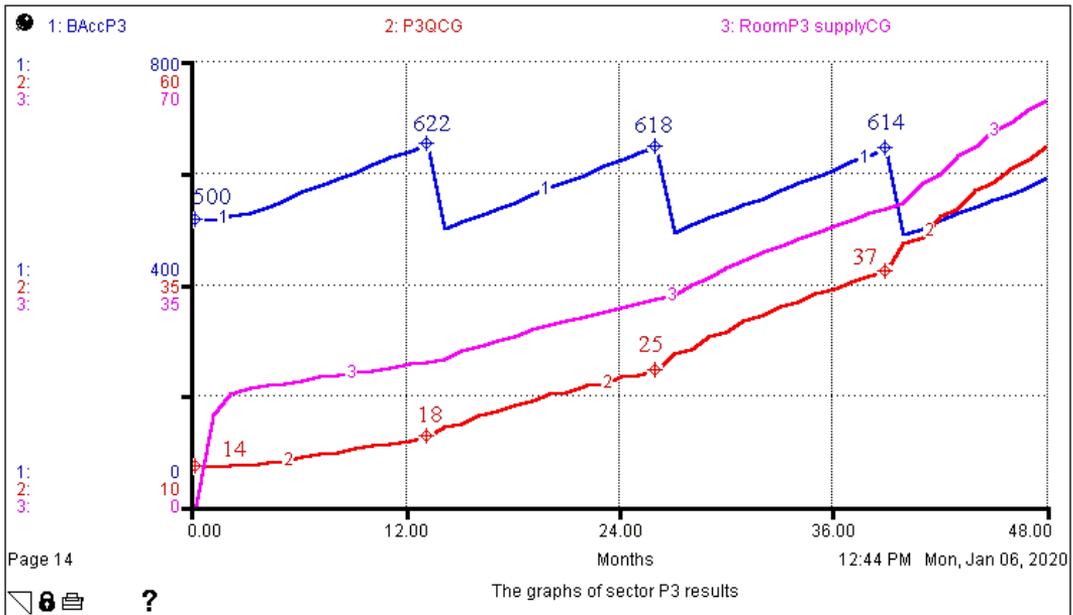


Fig.10. The graphs of sector P3 unit's growth: the values of bank assets and CG.

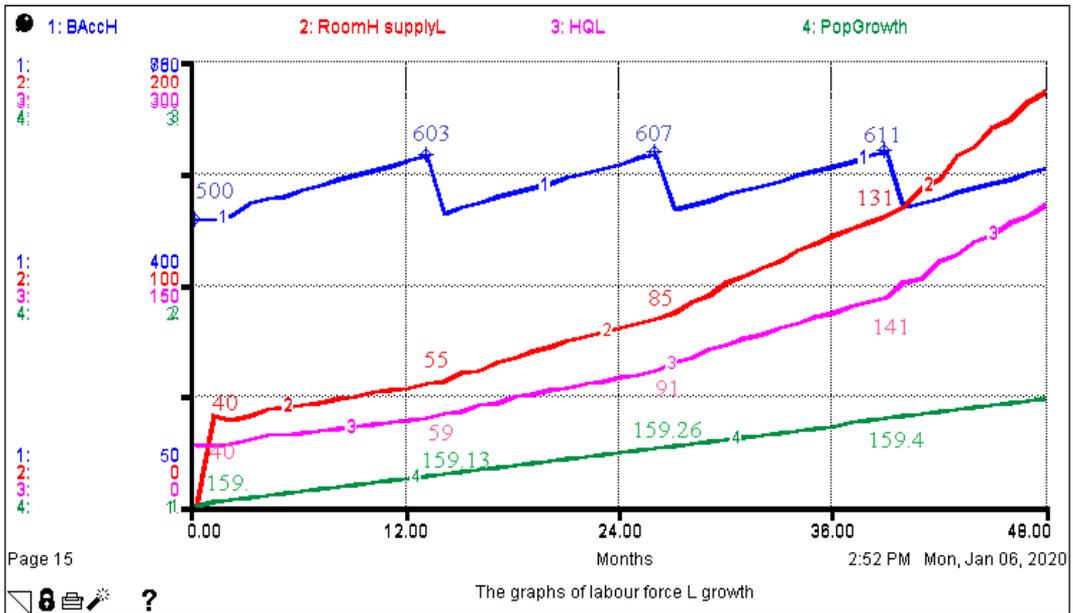


Fig.11. The graphs of household sector H unit's growth: the values of bank assets and L.

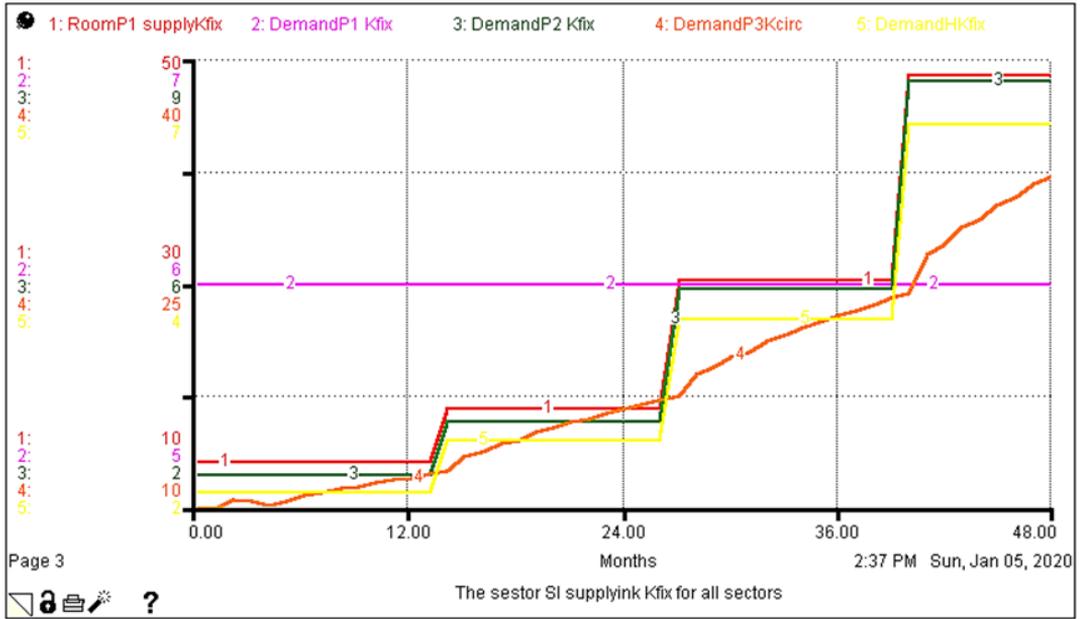


Fig.12. The graphs of investment goods supply and demands.

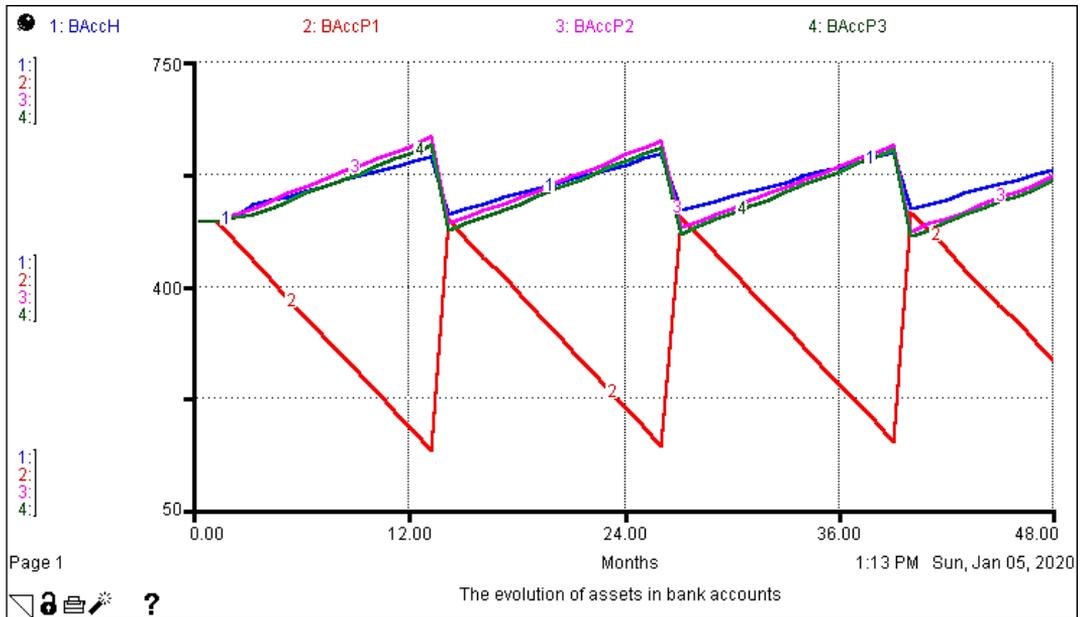


Fig.13. The graphs of four bank accounts: results of four years evolution.

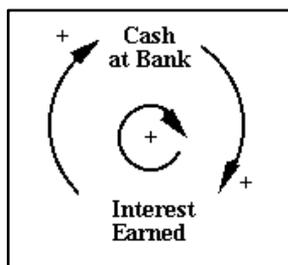


Fig.14. Compound Interest.

The famous scholar of the Center “Leo Apostel” Francis Heylighen in his essay “*The structural and functional complexity during evolution*” [5] is clearly demonstrating the reason of such phenomena. He was writing that “Although the growth of complexity during evolution seems obvious to most observers, it has recently been questioned whether such increase objectively exists” (p.1). In his paper he “tries to clarify the issue by analysing the concept of complexity as a combination of variety and dependency.” He argues “that variation and selection automatically produce differentiation (variety) and integration (dependency), for living as well as non-living systems”. *Structural complexification* is produced by spatial differentiation and the selection of fit linkages between components.

In (Fig.14) there is STELLA visualisation of such but very simple economic issue: *Self-reinforcing (Positive feedback) System Behaviour*. It means a behaviour which reinforces current systems exhibiting which is characteristic of positive feedback, a classic example of which is the process of accumulation of compound interest in a savings account. In this instance, the loop may be simply interpreted by noting that, “... as the amount of cash on deposit at the bank increases, so the amount of interest earned increases, which adds to the amount of cash at the bank, which in turn increases the amount of interest earned”. The process is that of a continually reinforcing process (note the + signs at the arrow-heads) and the loop is conventionally signed as a reinforcing loop with the positively signed arrow at its centre. *Functional complexification* follows from the need to increase the variety of actions in order to cope with more diverse environmental perturbations, and the need to integrate actions into higher-order complexes in order to minimize the difficulty of decision-making. Both processes produce a hierarchy of nested *supersystems* or *metasystems*, and tend to be self-reinforcing (p.1).

More deeply interested reader may, if he/her use much focused “reading” of subsequent snapshots from simulations of our virtual economy, learn completely new information and understandings on complex economic evolution, which conventional economics can't to provide. The newest achieved progresses in ICT, AI and CI allowing economic students and scholars too, to reason in higher level of imagination than on the level of mathematics so suited and approved procedure for tasks in Newtonian mechanics. In longer evolution of economic network there is emerging some special behaviour in the form of *self-reinforcing complexification modus* both of structures and of functionalities too, as Heylighen means. Such tasks are even more challenging ones and conventional economics are not prepared to solve them. The intensity and different modus are also caused by several and frequently obvious economic activities and process, among other we have focused attention on:

1. Relation between and among psychologically different, socio-economic groups:
  - Competition
  - Conflicts in different settings of aggression
  - Symbiosis
  - Cooperation and Collaboration
  - Commensalisms
  - Parasitism (Racketeering) and Parasitisms (Tunneling, Asset stripping), and other black and/or shadow economic activities and so on
  - Dynamic (cobweb) game between producers and consumers in different type of markets

2. Further noticeable socio-economic topics constructed as mental models (used in textbooks, and/or in/of wider purposes):
  - Trade-off possibility frontiers
  - Opportunity cost
  - Monopoly, duopoly and oligopoly
  - Cyclical economic and social growth
  - Competitive scarcity
  - Inconsistencies in resource depletion
  - Renewable resources
  
3. Miscellaneous problems
  - Preferences (social, economic and others)
  - Conflicts between religion groups, communities
  - Conflicts between ethnics, races, and so on

2 Evolution (a.i. development with emergent qualitative changes) of Socioeconomic Network

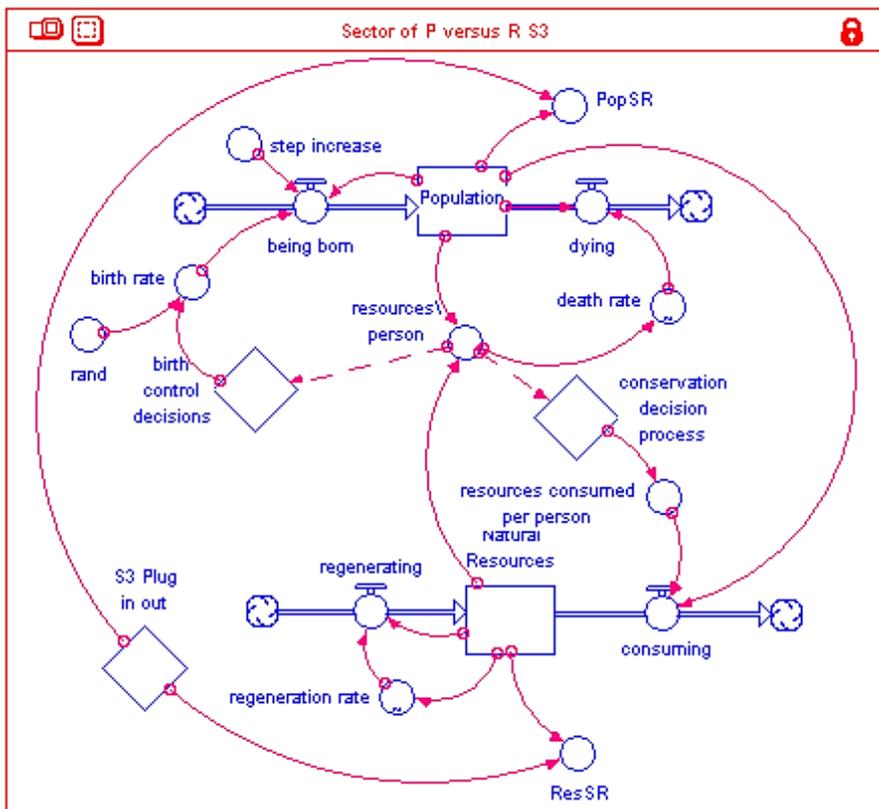


Fig.15. The snapshot of Sector PRS3.

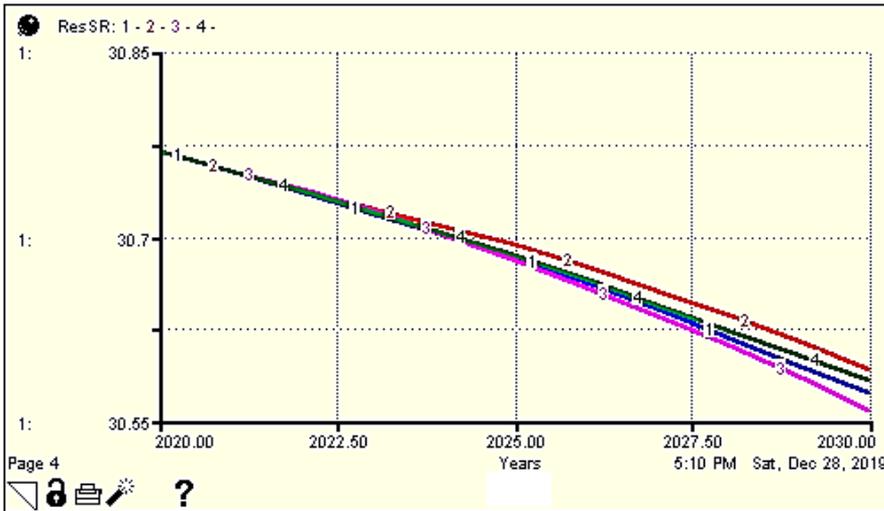


Fig.16. The perturbed evolution of natural resources.

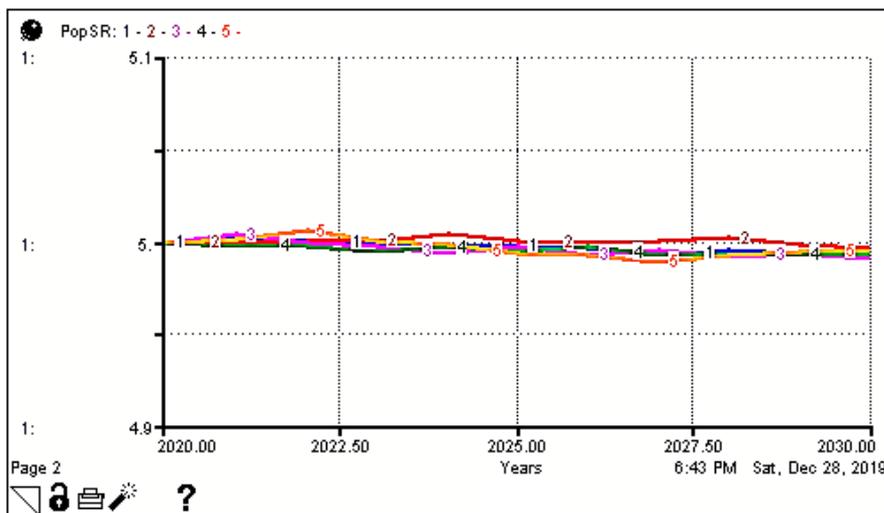


Fig.17. The perturbed evolution of population.

In the snapshot from STELLA it is shown the modified network of banks interaction, which is created by using module Causal Loops from original complex network of bank interaction, see (Fig.18) (that is (Fig.10) in Part I). The difference between two networks that is between complicated and complex entities in sensu stricto is apparent on the first sight.

The qualitative differences in (Fig.21) are hidden.

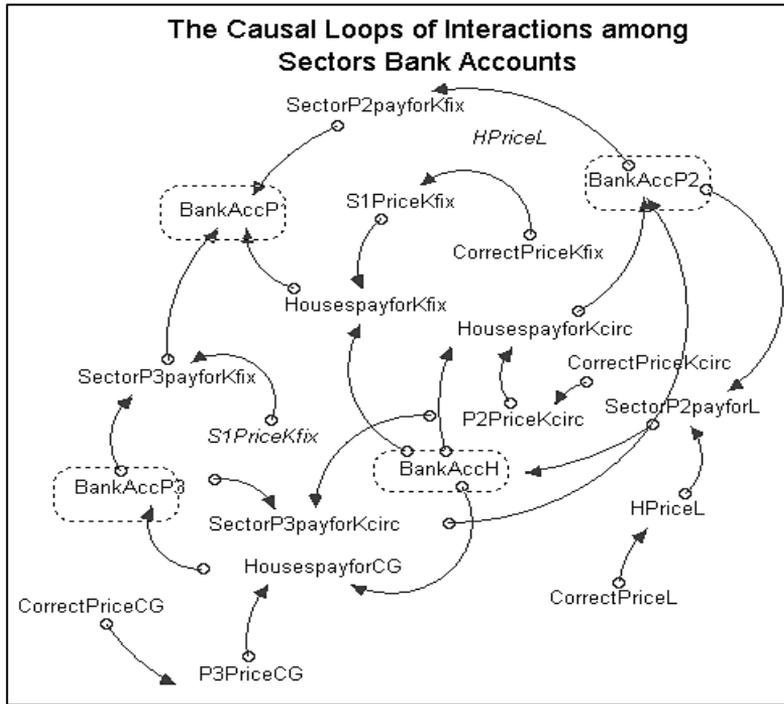


Fig.18. The complicate network of interactions among Bank Accounts.

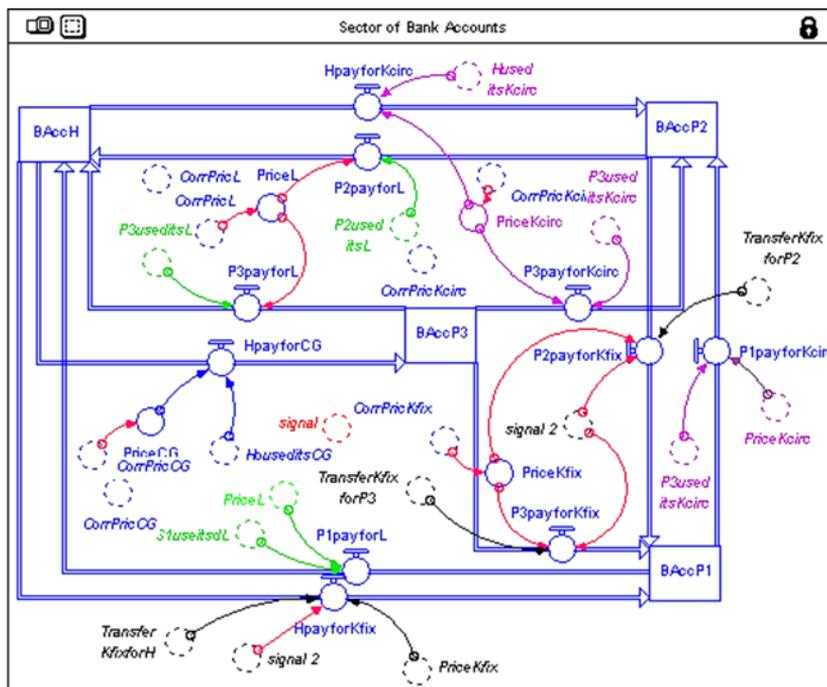


Fig.19. The original complex network of bank accounts published in Part I.

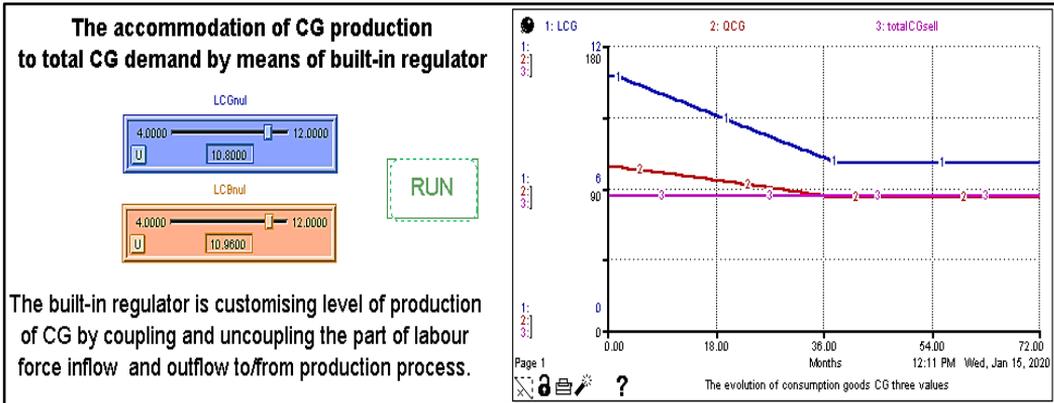


Fig.20. The snapshot of Interface page from STELLA.

### Appendix: The Simple Example of Built-in Regulator

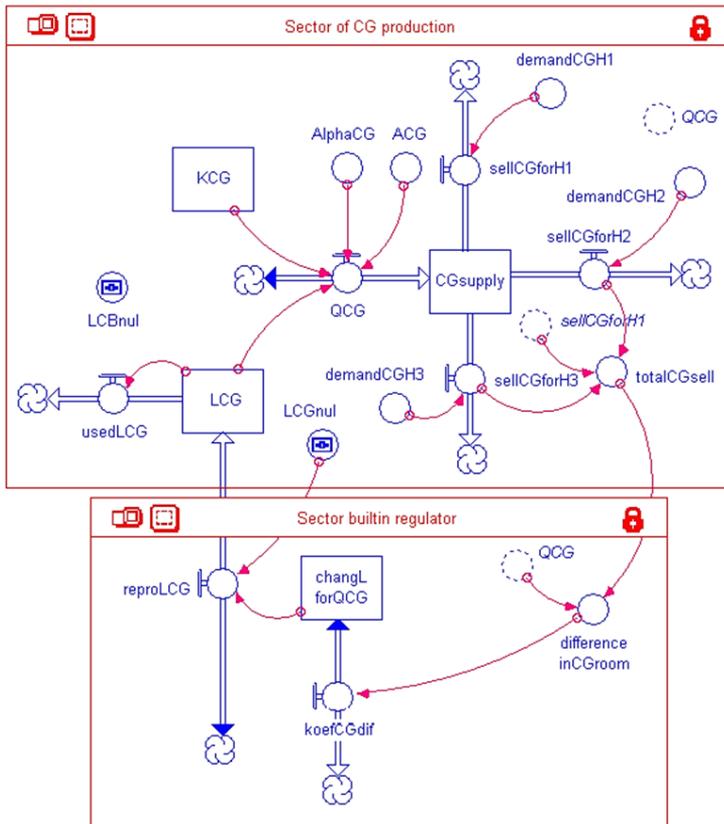


Fig.21. The snapshot of simple model with built-in regulator.

Table 1. The fillings of building boxes of model with built-in regulator.

<p><b>Sector builtin regulator</b></p> <p><input type="checkbox"/> <math>changL\_forQCG(t) = changL\_forQCG(t - dt) + (- koefCGdif) * dt</math>          INIT <math>changL\_forQCG = 0</math>          OUTFLOWS:              <math>koefCGdif = -difference\_inCGroom</math></p> <p><input checked="" type="checkbox"/> <math>reproLCG = LCGnul + changL\_forQCG</math>          INFLOW TO: LCG (IN SECTOR: Sector of CG production)</p> <p><input type="checkbox"/> <math>difference\_inCGroom = IF(QCG &gt; totalCGsell) THEN -0.1 ELSE 0</math></p>	
<p><b>Sector of CG production</b></p> <p><input type="checkbox"/> <math>CGsupply(t) = CGsupply(t - dt) + (QCG - sellCGforH1 - sellCGforH3 - sellCGforH2) * dt</math>          INIT <math>CGsupply = 100</math>          INFLOWS:              <math>QCG = (ACG * KCG * AlphaCG) * LCG^{(1 - AlphaCG)}</math></p> <p>OUTFLOWS:              <math>sellCGforH1 = demandCGH1</math>              <math>sellCGforH3 = demandCGH3</math>              <math>sellCGforH2 = demandCGH2</math></p> <p><input type="checkbox"/> <math>KCG(t) = KCG(t - dt)</math>          INIT <math>KCG = 1000</math></p> <p><input type="checkbox"/> <math>LCG(t) = LCG(t - dt) + (reproLCG - usedLCG) * dt</math>          INIT <math>LCG = LCGnul</math>          INFLOWS:              <math>reproLCG</math> (IN SECTOR: Sector builtin regulator)</p> <p>OUTFLOWS:              <math>usedLCG = LCG</math></p> <p><input type="checkbox"/> <math>ACG = 1</math>  <input type="checkbox"/> <math>AlphaCG = 0.5</math>  <input type="checkbox"/> <math>demandCGH1 = 30</math>  <input type="checkbox"/> <math>demandCGH2 = 30</math>  <input type="checkbox"/> <math>demandCGH3 = 25</math>  <input type="checkbox"/> <math>LCBnul = 12</math>  <input type="checkbox"/> <math>LCGnul = 8</math>  <input type="checkbox"/> <math>totalCGsell = sellCGforH1 + sellCGforH2 + sellCGforH3</math></p>	

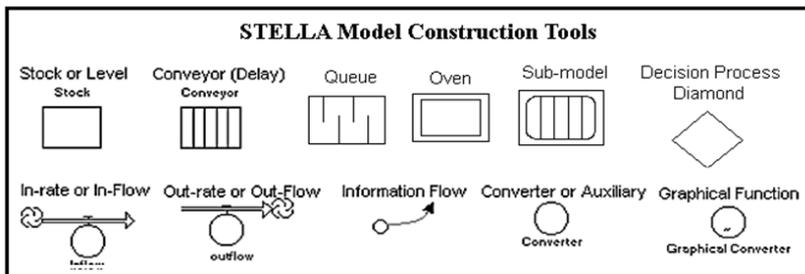
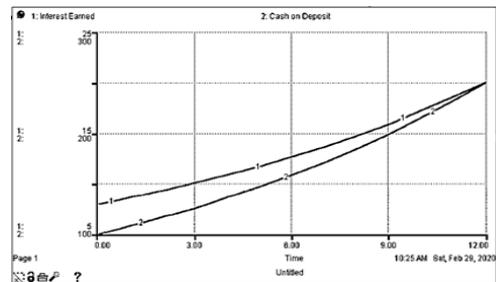
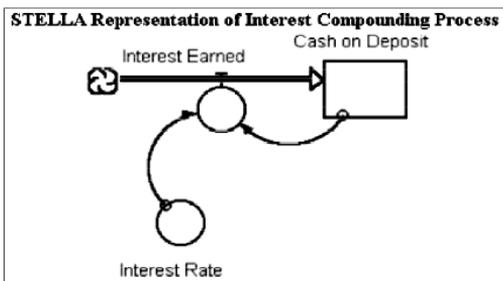


Fig.22. Illustrative snapshots from STELLA.

## Conclusion

The deep reasoning on an economy assisted by contemporary ICT, AI and CI is showing us that this entity is a most complex network in the known world. Actually even the simple models we are collected in this essay (Part I and II) and their simulations running in computer, demonstrate the range of political and economic questions that can be productively addressed with easy-to-use modelling tools of software STELLA. Complex networks, and agent-based models associated with them, are advancing a warranted residence on economic theory and they are, in fact, progressively replacing the standard representative agent paradigm.

We were showing that economy as complex network has very wide forms of nodes, links and other building entities. Among others means of nodes and relations in economic networks it can correspond at least to: • *Directors (CEOs, management)*; • *Firms*; • *Farms*, • *Forests*; • *Mines*; • *Fishing trawlers*; • *Households*; • *Labour forces*; • *Inputs-crude material, energy etc., as Stocks/Flows*; • *Outputs-Products, as Flows*; • *Business Groups*; • *Banks*; • *Investors*; • *Traders*; • *Consumers*; • *Cities*; • *National states*; • *States grouped in integration*; etc. but we are use in our essay only few of them because we want to preserve simplicity for better understanding of this new approaches in economics.

However it is clear that in objective economic reality there are, qualitatively and quantitatively, very different building blocks for defining and building economic networks. We are emphasized in Part I of this essay that the behaviour of economy as a whole in objective reality cannot be examined via the behaviour of isolated individuals (*homo oeconomicus*). Actually the living economy reflects dynamic interactions of a large set of different participants in network. This is the reason why we are coming to imagine on economy using different modelling methods and tools than is usual in mainstream economics and why we applied network approach assisted by ICT, AT and CI. This is corresponding with reasoning of several but non neoclassic economists. For example, it is known that even the economist Friedrich von Hayek interpreted the economic entity as a system governed by spontaneously emerging relations among set of participants. Such term designates the potential of the market relations to be self-organized, thus not requiring any centralized coordination. Self-interested agents, planned and pursuing their own individual goals, will form a spontaneous, hence as a whole not planned, network of relations that scientists need to carefully analyse in order to acquire a panoramic and solid understanding on how the economy as a whole truly works.

So called mainstream economics, if we are concerning the study of network relations, has resisted to adopt a network analysis as a mainstream approach of methods and tools for its research. This happens for several reasons. One of them, perhaps the most striking, is a kind of inertia that prevents economists to escape the straightjacket they themselves have created. Several scholars in this area appear to be fully satisfied with the benchmark model of Economics, and use it to the exhaustion to address every possible issue they are confronted with. Such paradigm is the popular representative agent of intertemporal optimization model.

In this Part II of our essay we made several simulation exercises using STELLA for models created in Part I. By these activities we have learned that plain computing of neoclassical mathematical formulas is not suited for demonstration of economic process in real life because abstract computation isn't corresponding with complex reality. Furthermore, by help of modeling and simulation we have detected several other ontological, methodological and theoretical mistakes of abstract mathematical interpretation of economic phenomena which is caused by tough-minded ones using Newtonian mathematical devices.

Today in the era of supercomputers and multiparallel platforms it is accrued time of possibilities to overstep old paradigms of economic theory and methodology founded on Newtonian mechanical and/or on early thermodynamically (Clausius) imaginations and seeking to create complex economical networks for elaboration them with help of the most advanced information technologies and computational intelligence.

## References

See also References published in Part I.

- [1] Bowles, S. Gintis, H. (1975) The problem with human capital theory – A Marxian critique. *The American Economic Review*, 65(2), pp. 74–82.
- [2] Emmert-Streib, F., Tripathi, Sh., Yli-Harja, O. and Dehmer, M. (2018) Understanding the World Economy in Terms of Networks: A Survey of Data-Based Network Science Approaches on Economic Networks. *Frontiers in Applied Mathematics and Statistics*, 28 <https://doi.org/10.3389/fams.2018.00037>
- [3] Goodwin, R. M. (1947) Dynamical coupling with especial reference to markets having production lags. *Econometrica*, 15(3), pp. 181–204.
- [4] Gräbner, C. H., Torsten Kudic, M. (2017) Network theory and social economics – A promising conjunction? Institute for Institutional and Innovation Economics (IINO), University of Bremen, Bremen, Germany; and, Institute for New Economic Thinking (INET), University of Oxford, Oxford, UK; and, Stifterverband für die Deutsche Wissenschaft, Wissenschaftsstatistik, Essen, Germany.
- [5] Heylighen, F. (1999) The growth of structural and functional complexity during evolution. Center “Leo Apostel”, Free University of Brussels, Pleinlaan 2, B-1050 Brussels, Belgium. Available from: <https://www.researchgate.net/publication/228607447> (september 2020)
- [6] Simon, H. A. (1953) Notes on the observation and measurement of political power. *The Journal of Politics*, 15(4), pp. 500 – 516.
- [7] Schweitzer, F., Fagiolo, G., Sornette, D., Vega-Redondo, F., Vespignani, A., White, D., R. (2009) Economic networks: the new challenges. *Science*, 325(5939):422–425.

## Authors



### **Prof. Ladislav Andrášik, DrSc. (DSc.), PhD., MSc.**

Professor emeritus of Slovak University of Technology

[ladislav.andrasik@gmail.com](mailto:ladislav.andrasik@gmail.com)

The author is specialist in application of Information Technologies into anti-aircraft missiles/guidance systems and scholar in introducing ICT/CI into theory and methodology of socio-economic sciences. He is graduated of different military schools and alumni of Economic University. Its brown jobs in Army persist 35 years (ten years he occupied roles in anti-aircraft brigade and 25 years in Military Academies an in General Staffs of Army). After he reached statutory retirement age in army he works in Academy of Science as chief scientific worker and as a department chief in Faculty of Electrical Engineering and Information Technology of Slovak University of Technology. He is author, editor and contributor of several monographs, textbooks for Military Academy and for Slovak University of Technology and for Economic University. He published more than 100 scientific essays, articles and papers for scientific conferences organized in several European countries.



# CONFIGURING IP CONNECTIVITY OVER A CELLULAR NETWORK ON A RASPBERRY PI - BASED IoT NODE

Ivan Šimovček, Lukáš Rajkovič, Lukáš Gdovin, Jakub Beňo

## **Abstract:**

---

*Connecting smart devices using the ubiquitous WiFi radio interface has been very straightforward even for non-technical users for some time now. This paper deals with complementary wireless communication technologies, which are relatively less widely configured manually on PC or Raspberry Pi, and from the perspective of a home user they are not trivially configured within a Linux-like system. 3GPP standardized cellular network-based radio WAN communication interfaces complementary to WLAN provide the desired IP connectivity. Detailed practical instructions on how to configure connectivity over existing high-throughput 4G network along with the legacy 2G-based backup and alert SMS channel on the Raspberry Pi platform using a GPIO and USB connected external modem are provided. The cellular-connected node is then tested in an Arduino-based IoT network where various low-power nodes offload the complex processing and data analytics to a high-performance central computer.*

## **Keywords:**

*Internet of Things, cellular WAN uplink, 4G modem, QMI.*

## **ACM Computing Classification System:**

*Networks, network components, end nodes, network adapters.*

## ■ **Introduction**

Connecting smart devices to the Internet has been very popular recently. Small constrained, often microcontroller-based devices are typically connected using Low-Power and Low-Rate radio communication technologies, such as IEEE 802.15.4 in PAN/LAN context, while time-proven but proprietary radios LoRa and SigFox provide WAN coverage. More recently the 3GPP specifications for LTE-M and NB-IoT, which can operate within the existing 4G (LTE) infrastructure [1] started to appear in actual networks. The EC-GSM-IoT specification brings further IoT capabilities to legacy 2G (GSM). Relatively high-throughput LAN standards, such as even the old IEEE 802.11n, are now common even in the simple Arduino devices [2][3].

This paper deals with a relatively more expensive, and from the perspective of user not trivially configured, cellular network-based radio communication interfaces GPRS and LTE. Despite the hype surrounding the coming rollout of the fifth generation (5G), the most practical currently available WAN network with IP connectivity is still the 4G LTE. The 3G networks infrastructure in the European Union is still in place, but starting in 2020, it is being slowly phased out, while, interestingly, the legacy 2G networks are continuing operation [4] in the EU. This is motivated i.a. by the low cost of operation and extremely large footprint coverage of these long-existing networks.

The M2M/IoT application do not usually require high throughput or low latency, so even the lowest-rate 2G GPRS mode with 9.6/8 kbps is often sufficient for simple sensor readout or actuator application. This paper describes the configuration of one experimental network with simple sensor-equipped IoT nodes with limited processing power, that connect using different, complementary radio-link standards to a central server, that can implement advanced processing and data analytics with great computational power. Such an approach has been tried and described in literature for some time [5], and is now regularly use in the IoT+cloud context, with worldwide operational networks examples including: The Things Network [6] or the Mathworks' ThingSpeak [7].

The nontrivial configuration of a IP connectivity using a 4G cellular modem with 2G backup/alert link on Linux/Raspbian platform is described in detail, providing important practical information, based on our hands-on experience. Such information is often missing from manuals, or is provided in an incomplete form.

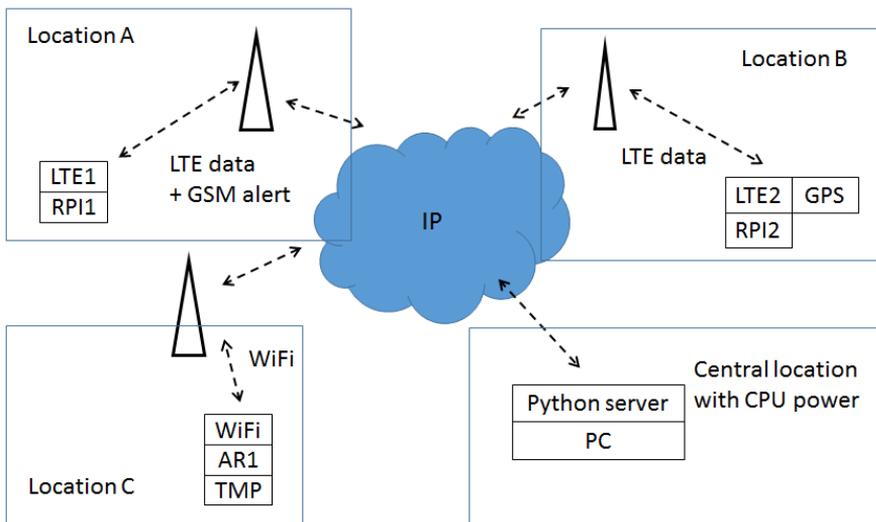


Fig.1. Experimental topology: RaspberryPi and Arduino platforms implemented as the IoT nodes with temperature and GPS sensors, while a central node has enough power for advanced processing and data analytics. Three different radio communication links are configured: IEEE 802.11n for WLAN and LTE and GPRS for WAN access. A non-IP GSM-based SMS alert channel serves for error notification.

As shown in (Fig.1), two complementary Platforms: Arduino and RaspberryPi and three different radio interfaces are used to implement the IoT sensor-carrying nodes. Both platforms need no special introduction. More recent Arduino MKR family of devices is used. These are all SAMD boards based on a 32-bit ARM Cortex-M0+ MCU. Broad selection of integrated radio connectivity is available, starting with MKR WiFi 1010 utilizing the ubiquitous LAN standard IEEE 802.11. More exotic low-rate low-power WAN options include the MKR FOX 1200 and MKR WAN 1300 with a SigFox and LoRa radio link for true IoT application. These are both time-proven and easy to use technologies [8]. The proprietary nature and absence of end-to-end IP connectivity may, however, limit the usability of IoT nodes implementing such radio link.

The MKR GSM 1400 cellular 2G/3G network connectivity presents an interesting option with GSM signal coverage unparalleled by any other radio, providing more than sufficient data rates for an IoT application, even in the lowest-rate GPRS mode, along with a desired IP connectivity. Detailed analysis and measurement of real-world throughput and latency parameters of a live 4G network can be found in [9].

On the other hand, regarding the security aspects, over time, the 3GPP accumulated tremendous amount of experience in securing the radio interface. The original 2G specifications security flaws were thoroughly analyzed in literature [10][11]. Flaws were addressed and advanced security mechanisms were incorporated in later specifications and even implemented in networks. The 4G radio layer therefore provides one of the most secure wireless communication option. Sophisticated denial of service DoS attacks were, however, described in literature [12][13].

The obvious drawback of the 2G connectivity is the monthly payment, that limits the use case for applications where only several nodes are needed. With massive IoT node set deployment, even the truly modest monthly payment of 1 Euro per node [14] may be too expensive.

Furthermore, care must be taken with such integrated devices since a radio-link-specific device must be purchased, and when the radio is updated, the whole device must be replaced. This is an approach complementary to a programmable Software-Defined Radio (SDR) design, where even the PHY-layer parameters of modulation can be updated by SW [15]. The analysis and implementation utilizing such tools is, however, out of the scope of this paper.

The paper is organized as follows: the next section gives the brief recap of platforms and libraries used to implement cellular connectivity. The second section provides a detailed step-by-step configuration of a modem for cellular network connectivity for IP connectivity. The third section provides information on configuring of an SMS backup/alert channel along with suggestions for its practical usage. The next section then summarizes the practical experimental setup. The final section concludes the paper.

## 1 Platforms, Libraries and Tools

### SIM7600X overview

The SIM7600X is a series of multiband cellular modems with explicit support for PC, RaspberryPi, Jetson Nano and Arduino platforms. The Europe, Middle East and Africa (EMEA) variant – SIM7600E-H 4G support includes LTE-FDD, 3G covers UMTS/HSPA+ and 2G includes GSM/GPRS/EDGE [16][17].

The module implements a CAT4 modem with peak UL/DL data rates of up to 50/150 Mbps and a 2G GPRS UL/DL up to 85.6Kbps. It also contains an integrated GPS/ GLONASS/ Beidou/ Galileo receiver and provides a wide set of interfaces: USB2.0 for connection to the host computer, along with UART, GPIO plus a digital PCM audio. To connect to cellular network, a SIM card is necessary to be inserted into the on-board (U)SIM card slot, while optional flash memory can be attached by MMC/SD card slot. Very detailed parameters description can be found in [18]. The USB drivers supports also legacy versions of Windows starting with Windows 2000, while Linux OS is supported since kernel at least 3.2, with support also for older kernels indicated by [19]. The Radio Interface Layer (RIL) support for Android starting with version 2.4 is also present. The Linux OS will be in the primary focus of this paper.

The Qualcomm MSM Interface (QMI) a modern but proprietary Qualcomm interface for Qualcomm baseband processors, replacing the legacy Hayes commands and PPP session establishment, is the primary means of configuration to be accessed either by the proprietary GobiNet

driver [20] or preferably by the community-maintained `qmi-wwan` upstream kernel driver. On Ubuntu based distributions, such as the Raspbian OS for Raspberry Pi, the later driver is then in turn utilized in the `libqmi` package [21]. While the legacy Hayes AT command set is supposed to be replaced by the QMI, the manufacturers' AT command set manual [22] indicates that it is in fact still alive and well. The classic serial port-based modem control and terminal emulation package `minicom` comes handy for Hayes-based access. In Raspbian, the `busybox` package contains many handy utilities to be used in configuration. While the SIM7600 model comes also with Arduino compatibility, the Arduino MKR 1010 WiFi with IEEE 802.11n radio was used for the sake of variety.

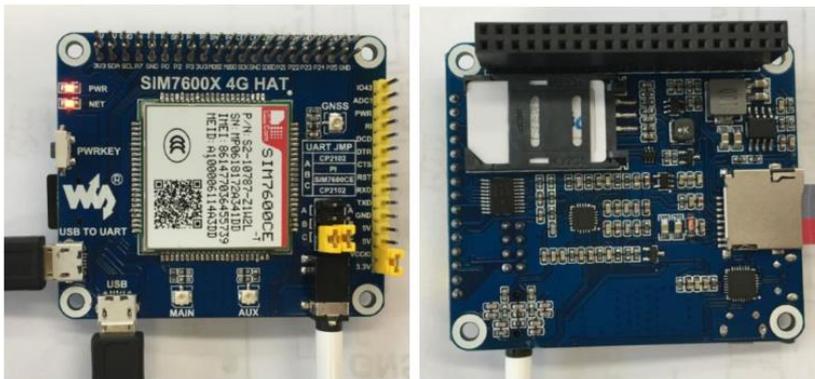


Fig.2. The SIM7600 multiband 4G/3G/2G modem with integrated GNSS receiver [16].

## 2 Configuring Cellular Network IP Connectivity

In our experiments, we have configured Raspberry Pi 3 (RPI) with the SIM7600E module. The OS used were the Ubuntu-derived Raspbian Buster. First, a SIM card needs to be inserted into the modem, which has to be connected to the RPI using the GPIO and also using one USB port. After the module is connected to both, two device files are created by the OS:

```
/dev/cdc-wdm0 - the QMI control interface
/dev/ttyUSB2  - generic USB device
```

To use the cellular network, the module must be properly configured. First, the test of the device connection to RPI is performed by the `minicom`, followed by the AT command within `minicom` prompt, which should return an OK confirmation:

```
root@rpi:minicom -D /dev/ttyUSB2
Minicom>AT
Minicom>OK
```

Note that the `Minicom` program doesn't really show a prompt, so the prompt string is added here for clarity. At minimum, four important modem parameters need to be set: the SIM-card specific Personal Identification Number (PIN), the Access Point Network (APN) specifying which of the available cellular networks (providers) to connect to, the type of the IP connection within the

providers' network, and the Packet Data Protocol (PDP) context identification. All these parameters are set using two AT commands [22]:

```
Minicom>AT+CPIN=<PIN>
Minicom>AT+CGDCONT=<ContextID>,<Type>,<APN>
```

In our experiments the Slovak O2 operator was tested with a SIM card with generic PIN equal to 1111 and the following parameters were used:

```
Minicom>AT+CPIN=1111
Minicom>AT+CGDCONT=1,"IPV4V6","o2internet"
```

If not sure the user can use the ? character which can be used to query for status, first a correct PIN for the SIM card was tested:

```
AT+CPIN?
+CPIN: READY
```

Then the correct parameters of the packet data protocol were evaluated, the first value was used in our experiments:

```
AT+CGDCONT?
+CGDCONT: 1,"IPV4V6","o2internet","0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0",0,0,0,0
+CGDCONT: 2,"IPV4V6","ims","0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0",0,0,0,0
+CGDCONT: 3,"IPV4V6","", "0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0",0,0,0,1
+CGDCONT: 6,"IPV4V6","o2internet","0.0.0.0.0.0.0.0.0.0.0.0.0.0.0.0",0,0,0,0
+CGDCONT: 7,"IP","o2internet","0.0.0.0",0,0,0,0
```

Fig.3. Available PDP contexts for the “O2” operator in Slovakia.

Note that there are additional optional parameters, that need not be specified manually. When connected to an operators' cellular network, it is sometimes important to distinguish between the generations of available networks. If for instance 2G, 3G and 4G networks are available, the network with the most suitable link attributes can be automatically selected. Since we would like to have precise control over the specific network generation selection, another AT command [22] is useful:

```
Minicom>AT+CNMP=<Mode>
```

It provides the user with identification value of the mode of currently connected cellular network. It is important to understand the mapping of mode numbers to network generations. All possible values supported by the modem HW are defined in [22], while the most practical for our experiments are summarized in (Tab.1):

Table 1. Integer values selecting the mode by AT+CNMP command [22].

Mode Nr.	Mode
2	Automatic
13	GSM only (2G)
14	WCDMA only (3G)
19	GSM + WCDMA (2G + 3G)
38	LTE only (4G)
39	GSM + WDMA + LTE (2G + 3G+ 4G)

For practically useful network performance, the LTE network was selected:

```
Minicom>AT+CNMP=38
```

After successful modem configuration, it is necessary to test IP connectivity using the ping command. This can be done directly from `minicom` using an AT command:

```
Minicom>AT+CPING=<IPaddress>,<AddressType>
```

Where, according to [22], the `AddressType` value of 1 indicate the use of IPv4 and value 2 specifies IPv6. The convenient actual parameter for testing is the IP address of the Google public DNS server:

```
Minicom>AT+CPING="8.8.8.8",1
```

After successful modem configuration, it is necessary to configure it's usage in the host RPI. This can be done using the `qmicli` command line tool for configuring QMI devices. First, the package `libqmi-utils` must be installed:

```
root@rpi:~# apt-get install libqmi-utils
```

this will install the most important tools: `qmicli` and the `qmi-network` helper script. With `qmicli` it is necessary first to check the modem status [21]:

```
root@rpi:~# qmicli -d /dev/cdc-wdm0 --dms-get-operating-mode
```

if the device status is not online, it is necessary to set the operating mode by:

```
root@rpi:~# qmicli -d /dev/cdc-wdm0 --dms-set-operating-mode='online'
```

Other useful parameters provide the user with information on the connected network:

```
root@rpi:~# qmicli -d /dev/cdc-wdm0 --nas-get-home-network
```

As shown in the output, the Mobile Country Code (MCC) and Mobile Network Code (MNC) together specify which carrier the modem is using:

```
[/dev/cdc-wdm0] Successfully got home network:
Home network:
MCC: '231'
MNC: '6'
Description: '02 - SK'
```

Fig.4. The MCC and MNC values truly identify the cellular operator, which the modem is connected to.

The MCC and MNC codes can be looked up in the online database of countries and service providers [23], that indeed confirms the O2 service provider in Slovakia. Other important values are summarized in (Tab.2).

Table 2. Integer values of MCC and MNC numbers for cellular operators in Slovakia [23].

MCC	MNC	Operator
231	03	4Ka
231	06	O2
231	01	Orange
231	05	Orange
231	15	Orange
231	02	T-Mobile
231	04	T-Mobile
231	99	ZSR

Furthermore, detailed info on PHY-layer signal parameters, such as the Received Signal Strength Indicator (RSSI), Signal to (Interference and) Noise Ratio (SINR/SNR), Reference Signals Received Power (RSRP) and Reference Signal Received Quality (RSRQ) can also be obtained:

```
root@rpi:qmicli -d /dev/cdc-wdm0 --nas-get-signal-strength
```

Output:

```
[/dev/cdc-wdm0] Successfully got
Current:
Network 'lte': '-54 dBm' RSRQ:
RSSI: Network 'lte': '-54 dBm' SNR: Network 'lte': '-8 dB'
ECIO: Network 'lte': '-2.5 dBm' RSRP: Network 'lte': '21.2 dB'
IO: '-106 dBm' RSRP: Network 'lte': '-85 dBm'
SINR (8): '9.0 dB'
```

Fig.5. Example PHY-layer signal parameters output for the LTE network.

For the interested reader, the significance of these PHY-layer parameters is further explained in [24][25]. These values may be of high interest for a more in-depth analysis.

The USB-connected modem exposes a standard networking interface to the user in the form of a wwan identifier usable with the ip (or legacy ifconfig) command. The wwan0 interface is usually set with 802.3 protocol. However, for the SIM7600 module, raw-ip needs to be set. To do this, we use the following commands:

```
root@rpi: ip link set wwan0 down
root@rpi: echo 'Y' > /sys/class/net/wwan0/qmi/raw_ip
root@rpi: ip link set wwan0 up
```

After that, to enable transmission the qmicli utility for QMI protocol is used:

```
root@rpi:qmicli -p -d /dev/cdc-wdm0 \
--device-open-net='net-raw-ip|net-no-qos-header' \
--wds-start-network="apn='o2internet',ip-type=4" \
--client-no-release-cid
```

The output of this command provides the user with the Cell ID (CID), uniquely identifying the base station (or eNodeB) the modem is currently connected to:

```
[/dev/cdc-wdm0] Network started
Packet data handle: '2264561904'
[/dev/cdc-wdm0] Client ID not released:
Service: 'wds'
CID: '20'
```

Fig.6. Cell ID uniquely identifies the base station (eNodeB) to which the modem is connected.

The next step is to set up a DHCP client. That can be done on interface `wan0` using `udhcpc` command which is part of the `busybox` [26] package:

```
root@rpi:udhcpc -i wan0
```

From the command output, the user can see the IP address obtained for the `wan0` interface, along with other DHCP parameters:

```
udhcpc: started, v1.30.1
No resolv.conf for interface wan0.udhcpc
udhcpc: sending discover
udhcpc: sending discover
udhcpc: sending discover
udhcpc: sending select for 10.70.108.234
udhcpc: lease of 10.70.108.234 obtained, lease time 7200

default via 10.70.108.233 dev wan0
10.70.108.232/30 dev wan0 proto kernel scope link src 10.70.108.234
```

Fig.7. The output of the `udhcpc` and `ip` commands show important network-layer parameters: the IP address assigned to the `wan0` interface, and the default gateway IP address (assigned to modem).

To verify the successful configuration of the `wan0` interface and the default gateway, the standard `ip` command comes handy:

```
root@rpi:ip r s
```

where the user can see that two IP addresses were actually assigned, one for the `wan0` interface of the RPI and the other one for the USB-attached modem, that is logically a separate device, even though may be physically enclosed together, and provides a default gateway for the RPI. As demonstrated by the output and in (Fig.7 and 8), where the point-to-point link between two devices is at the IP layer visible as a private-scoped subnet:

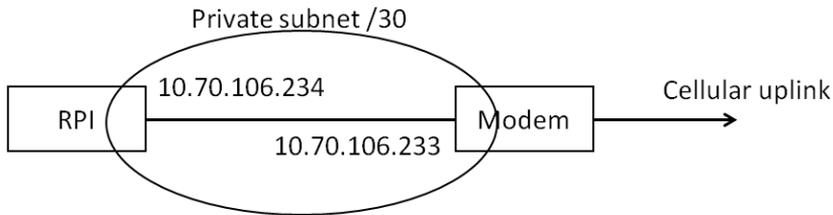


Fig.8. The private subnet for a point-to-point link between modem and RPI.

Finally the connection should be tested by ping (this time directly from the RPI shell):

```

PING 8.8.8.8 (8.8.8.8) 56(84) bytes of data.
64 bytes from 8.8.8.8: icmp_seq=1 ttl=56 time=119 ms
64 bytes from 8.8.8.8: icmp_seq=2 ttl=56 time=37.7 ms
64 bytes from 8.8.8.8: icmp_seq=3 ttl=56 time=34.3 ms
^C
--- 8.8.8.8 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 5ms
  
```

Fig.9. The IP connectivity is fully operational at the RPI.

It is only now, that the RPI has full Internet connectivity over the `wan0` interface and can be used in practical application.

### 3 Using 2G SMS Service for an Error-Reporting Side Channel

Once the cellular connection is working, sending SMS messages is straightforward. While the AT command manual [22] defines a wide selection of AT commands to fine tune many aspect of SMS sending, format, storage and service options, only very few commands are needed.

First, it is necessary to specify the input and output format of the short messages, the two possible format-specifier values are 0 for PDU mode and 1 for text mode, which is the simple format selection AT command:

```
AT+CMGF=1
```

Then the actual text message can be sent to a specific phone number:

```
AT+CMGS="<PhoneNumber>"<CR>MessageText
```

For receiving of text messages, the preferred message storage must first be set. Several options are available here with “ME” mad “MT” values specifying flash memory storage while “SM” indicating storing of the message directly on the SIM card, and finally value “SR” defining Status report storage [22]. Since the modem in question didn’t come with any on board flash memory, we chose the most straightforward approach – storing the SMS messages on the SIM card. The command takes three argument to define storage for: reading (of received messages) , writing (and sending messages), and third memory for stored messages.

```
AT+CPMS="SM","SM","SM"
```

The SIM card typically has only limited user-writable data capacity of around 128 – 256 kB [27] so in an application, when messages must be stored for longer term, extra micro SD card storage can be used. However, in our application, where messages are archived on the central server, or are intended for human operator for immediate consumption, the storage limit at the modem is irrelevant.

Finally, a received message is read in selected format from selected storage. Messages are integer-indexed with value of `MessageIndex` starting at 1:

```
AT+CMGR=<MessageIndex>
```

Similarly, the received message is then deleted by the `CMGD` command:

```
AT+CMGD=<MessageIndex>
```

These commands may be manually entered by the user within the `minicom` application or, more practically, incorporated into various scripts. For our application of periodic reporting of measured sensor value, integration into a Python script was selected, the important code snippet is shown in (Fig.10) where Python-default Unicode strings are first converted to 8-bit character strings to be sent as SMS messages.

```
def SendShortMessage(phone_number, text_message):
    send_at("AT+CMGF=1", "OK", 1)
    answer = send_at("AT+CMGS=\""+phone_number+"\"", ">", 2)
    if 1 == answer:
        ser.write(text_message.encode())
        ser.write(b'\x1A')
        answer = send_at('', 'OK', 20)
        if 1 == answer:
            print('send successfully')
        else:
            print('error')
    else:
        print('error%d'%answer)
```

Fig.10. Python function for sending SMS text messages over the SIM7600 modem.

Since there is no IP connectivity when using the legacy SMS service, such Python function is not primarily used for sending regular sensor data updates. It can be, but its practical purpose is somewhat different: the SMS messaging represents a service side channel for informing the operator of unusual events, potentially requesting operators' attention. The most interesting of such alerts is reporting of Internet connection problems: the modem can be configured to simultaneously be connected to the legacy 2G (GSM) and 4G (LTE) networks where the fast Internet connection is provided by the 4G network. Since the 2G and 4G networks are separate technologies, it is a good chance, that even if the 4G network experiences connection problems, the 2G SMS service will still be operational. Therefore the SMS link can serve as an important alert and error reporting channel.

## 4 Putting It All Together

Once the IP protocol is up and running, it is a relatively straightforward task to connect different type of nodes (RPI and Arduino-based or other) to a central server, collecting all the measured data. This can be implemented in C or preferably in Python utilizing the Socket API, with overall design shown in (Fig.1). The implementation of sending and receiving short ASCII-character messages over UDP cannot directly utilize non-IP technologies, such as the SMS service. These were configured in this context as a complementary backup channel alerting the human operator.

The Python UDP server running on the central computer is then concentrating various messages from different sources. Since the network and transport layer communication hides the link layer details, the server processes messages from both RPI and Arduino based nodes, connected at the link layer by IEEE 802.11 or 3GPP LTE. All IP-compatible radio links are supported by the server. This excludes the SMS messaging running within the legacy 2G network, where communication endpoints are identified using phone numbers and no IP protocol is available.

```

UDP server up and listening
[22:37:53, 62.197.243.28:50000]: 3001,Lukas Gdovin posielala Teplotu: 32.03
[22:37:57, 46.34.235.179:13409]: 2008,Jakub Beno posielala cas: 21:37:55
[22:38:00, 194.154.240.95:54654]: 1007,Lukas Rajkovic posielala GPS: 1,1,20200519203753.000,48.109819,17.113505
[22:38:03, 62.197.243.28:50000]: 3002,Lukas Gdovin posielala Teplotu: 31.95
[22:38:10, 194.154.240.95:49245]: 1008,Lukas Rajkovic posielala GPS: 1,1,20200519203803.000,48.109819,17.113504
[22:38:13, 62.197.243.28:50000]: 3003,Lukas Gdovin posielala Teplotu: 31.90
[22:38:18, 46.34.235.179:13426]: 2010,Jakub Beno posielala cas: 21:38:17
[22:38:21, 194.154.240.95:52344]: 1009,Lukas Rajkovic posielala GPS: 1,1,20200519203814.000,48.109818,17.113504
[22:38:23, 62.197.243.28:50000]: 3004,Lukas Gdovin posielala Teplotu: 31.86
[22:38:28, 46.34.235.179:13396]: 2011,Jakub Beno posielala cas: 21:38:27
[22:38:31, 194.154.240.95:52437]: 1010,Lukas Rajkovic posielala GPS: 1,1,20200519203824.000,48.109818,17.113505
[22:38:33, 62.197.243.28:50000]: 3005,Lukas Gdovin posielala Teplotu: 31.88
[22:38:39, 46.34.235.179:13522]: 2012,Jakub Beno posielala cas: 21:38:37
[22:38:42, 194.154.240.95:46312]: 1011,Lukas Rajkovic posielala GPS: 1,1,20200519203835.000,48.109818,17.113505
[22:38:43, 62.197.243.28:50000]: 3006,Lukas Gdovin posielala Teplotu: 31.90

```

Fig. 11. UDP central server output is collecting the messages  
*“username sends temperature/time/GPS”*  
 and measured values from different nodes.

(Fig.11) presents a shortened output of the server. It's output consists of the a timestamp identifying arrival of the message, source IP address and port of the sending node, message serial number local to each transmitting node, a user-customized message, along with the value of the measured sensor node. As shown in (Fig.1), some nodes send their position coordinates measured by a GPS module, while other send the values of their temperature sensor.

## Conclusion

In this paper, we have implemented a network consisting of nodes based on the RaspberryPi and Arduino platforms, uploading various sensor data over two complementary WLAN and WAN radio links. The cellular-connected RPI nodes and WiFi connected Arduino nodes together create an IoT network where various low-power nodes offload the complex processing and data analytics to a high-performance central computer. A step-by-step description, compiling the often incomplete technical documentation of a non-trivial configuration of a 4G cellular WAN network with 2G backup link used by a RaspberryPi board for IP uplink is given.

## Acknowledgement

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-19-0436 and it was also supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and Slovak Academy of Sciences (grant VEGA 1/0477/18) and by the Tatra bank foundation programme Quality of Education, within the project "SDRLab 2.0 – technologies of 5G networks and IoT in classroom".

## References

- [1] 3GPP Release 13, LTE-Advanced Pro [Available: <https://www.3gpp.org/release-13> ]
- [2] Arduino MKR WiFi [Available: <https://store.arduino.cc/arduino-mkr-wifi-1010> ]
- [3] u-blox NINA-W102: NINA-W10 series: Stand-alone Multiradio modules, Data sheet [Available: [https://content.arduino.cc/assets/Arduino\\_NINA-W10\\_DataSheet\\_%28UBX-17065507%29.pdf](https://content.arduino.cc/assets/Arduino_NINA-W10_DataSheet_%28UBX-17065507%29.pdf) ]
- [4] westbase.io: 3G Sunset in Europe: Planning Your Next Steps, 2019 [Available: <https://www.westbase.io/3g-sunset-in-europe-planning-your-next-steps/>]
- [5] Dobos J., Ruzicky, E., Tseng, Y.C., Vidacs, A., et al. The smoke in the Chimney - Internation cooperation at Paneuropean University. In proc.of Current Issues of Science and Research in the Global World. Taylor & Francis, Vienna, 2014, ISBN 9781138027398.
- [6] LoRa Alliance: The Things network[Available: <https://www.thethingsnetwork.org/>]
- [7] MathWorks:ThingSpeak: Data collection in the cloud with advanced data analysis using MATLAB [Available: <https://thingspeak.com/>]
- [8] Mekkia,K., Bajica,E., Chaxela, F. Meyer, F. A comparative study of LPWAN technologies for large-scale IoT deployment. Research Centre for Automatic Control of Nancy, France, 2018 [Available: <https://www.sciencedirect.com/science/article/pii/S2405959517302953> ]
- [9] Fresolone, F., Kloibhofer, R. et al. Throughput and One-Way Latency Measurements in a 3G/4G Live-Network Hi-Mobility Uplink. In TSP 2016 : 39th International Conference on Telecommunications and Signal Processing. Vienna, Austria, June 27-29, 2016. Vienna : IEEE, 2016, S. 44-49. ISSN 1805-5435. ISBN 978-1-5090-1288-6.
- [10] J. Cao, M. Ma, H. Li, Y. Zhang and Z. Luo, "A Survey on Security Aspects for LTE and LTE-A Networks," in IEEE Communications Surveys & Tutorials, vol. 16, no. 1, pp. 283-302, First Quarter 2014, doi: 10.1109/SURV.2013.041513.00174.
- [11] F. Tian, P. Zhang and Z. Yan, "A Survey on C-RAN Security," in IEEE Access, vol. 5, pp. 13372-13386, 2017, doi: 10.1109/ACCESS.2017.2717852.
- [12] M. Lichtman, R. P. Jover, M. Labib, R. Rao, V. Marojevic and J. H. Reed, "LTE/LTE-A jamming, spoofing, and sniffing: threat assessment and mitigation," in IEEE Communications Magazine, vol. 54, no. 4, pp. 54-61, April 2016, doi: 10.1109/MCOM.2016.7452266.
- [13] Silva, A., Rupp, M. Rakus, M. et al. Intelligent Interferer in LTE and LTE-A. In proc.of Current Issues of Science and Research in the Global World. CRC Press, Taylor & Francis Group, Vienna, 2014, ISBN 9781138027398.
- [14] orange.sk catalogue online [Available: <https://www.orange.sk/produkty-a-sluzby/volania/volania-s-kreditom/sikovna-volba> ]
- [15] Glossner, J., Iancu, D., Moudgill, M., Jinturkar, S., et al. Implementing Communications Systems on an SDR SoC. In ICASSP 2008. IEEE International Conference on Acoustics, Speech & Signal Processing : Las Vegas, USA, 2008. ISBN 1/4244-1484-9.
- [16] SIM7600CE-T/E-H/A-H/G-H 4G Modules resources page [Available: [https://www.waveshare.com/wiki/SIM7600E-H\\_4G\\_HAT](https://www.waveshare.com/wiki/SIM7600E-H_4G_HAT) ]
- [17] SIM7600E-H 4G HAT catalogue by SIMCOM [Available: <https://www.waveshare.com/catalog/product/view/id/3576/s/sim7600e-h-4g-hat/category/348/> ]

- [18] SIM7600 Series\_Hardware Design\_V1.02  
[Available: [https://www.waveshare.com/wiki/File:SIM7600\\_Series\\_Hardware\\_Design\\_V1.02.pdf](https://www.waveshare.com/wiki/File:SIM7600_Series_Hardware_Design_V1.02.pdf)]
- [19] SIM7500\_SIM7600 Linux NDIS User Guide V2.01 [Available:  
[http://www.microchip.ua/simcom/LTE/SIM7500\\_7600/Application%20Notes/SIM7500\\_SIM7600%20Linux%20NDIS%20User%20Guide\\_V2.01.pdf](http://www.microchip.ua/simcom/LTE/SIM7500_7600/Application%20Notes/SIM7500_SIM7600%20Linux%20NDIS%20User%20Guide_V2.01.pdf)]
- [20] Morgado, A. Qualcomm Gobi devices in Linux based systems. 2013, Osmocom.org. [Available:  
[//osmocom.org/attachments/download/3303/Qualcomm%20Gobi%20devices%20on%20Linux.pdf](http://osmocom.org/attachments/download/3303/Qualcomm%20Gobi%20devices%20on%20Linux.pdf)]
- [21] libqmi manual page [Available: <https://www.freedesktop.org/wiki/Software/libqmi>]
- [22] Shanghai SIMCom Wireless Solutions Ltd, SIM7500\_SIM7600 Series\_AT Command Manual\_V1.01, 2016. [Available: [https://simcom.ee/documents/SIM7600C/SIM7500\\_SIM7600%20Series\\_AT%20Command%20Manual\\_V1.01.pdf](https://simcom.ee/documents/SIM7600C/SIM7500_SIM7600%20Series_AT%20Command%20Manual_V1.01.pdf)]
- [23] Mobile Country Codes (MCC) and Mobile Network Codes (MNC) number database  
[Available: <https://www.mcc-mnc.com>]
- [24] L. Pedrini. What is Ec/Io (and Eb/No)?  
[ Available: <https://www.telecomhall.net/t/what-is-ec-io-and-eb-no/6271> ]
- [25] Teltonica: RSRP and RSRQ  
[Available: [https://wiki.teltonika-networks.com/view/RSRP\\_and\\_RSRQ](https://wiki.teltonika-networks.com/view/RSRP_and_RSRQ)]
- [26] udhcpc busybox manual page [Available: <https://manpages.debian.org/stretch/udhcpc/udhcpc.8>]
- [27] Warycka A. SIM Card Storage Capacity  
[Available: <https://www.techwalla.com/articles/the-difference-between-2g-3g-sim-cards>]

## ▲ Authors



**Bc. Ivan Šimovček**  
Slovak University of Technology  
Faculty of Electrical Engineering and Information Technology  
Bratislava, Slovakia  
[xsimovcek@stuba.sk](mailto:xsimovcek@stuba.sk)



**Bc. Lukáš Rajkovič**  
Slovak University of Technology  
Faculty of Electrical Engineering and Information Technology  
Bratislava, Slovakia  
[xrajkovicl@stuba.sk](mailto:xrajkovicl@stuba.sk)



**Bc. Lukáš Gdovin**  
Slovak University of Technology  
Faculty of Electrical Engineering and Information Technology  
Bratislava, Slovakia  
[xgdovin@stuba.sk](mailto:xgdovin@stuba.sk)



**Bc. Jakub Beňo**  
Slovak University of Technology  
Faculty of Electrical Engineering and Information Technology  
Bratislava, Slovakia  
[xbenoj2@stuba.sk](mailto:xbenoj2@stuba.sk)



# CONFIGURING IPSEC-BASED SECURITY FOR VIRTUALIZED NETWORKS

**Karol Csivre, Dominik Dermek**

**Abstract:**

---

*In this paper we focus on the latest trends in computer network virtualization. The evolution of data-center networks from L2 Virtual Local Area Networks (VLAN) to more advanced L4-tunnelled Virtual Extensible LANs (VXLAN), necessary for elastic provisioning of overlay networks in a multi-tenant data-center environment, is described. The L3 security implemented by IPsec is identified as a promising method for securing such overlay networks and a complete configuration of tunneling mode IPsec-v3 including IKE-v2 within the Cisco IOS is given. Furthermore, quantitative results regarding the effects of various cryptographic algorithms with selected parameter combinations obtained using measurements on an example virtualized topology are presented.*

**Keywords:**

*Virtual networks, overlay networks, IPsec, tunneling.*

**ACM Computing Classification System:**

*Networks, network components, end nodes, network adapters, network protocols, session protocols.*

## Introduction

Several current networking trends play an important role in future networks design development. Stacking of several individual active networking boxes, such as the Cisco Catalyst switches, into a single logical device simplifies network configuration and provides substantial network bandwidth improvement [1]. Encryption directly at the MAC layer improves security. The seamless integration of wireless connectivity and management of wireless access points directly from an on-switch built-in controller is now also feasible [2]. The new Linux-kernel based Cisco Open IOS XE [2] brings custom LXC type IOx applications using Docker containers [3], facilitating unprecedented level of programmability directly on the switch, along with standard Linux applications, such a Wireshark.

One of the important trends guiding the design of future networks is massive virtualization. The classic concepts of L2 Virtual LAN (VLAN) is extended to a much more flexible Virtual Extensible LAN (VXLAN) [4] tunneling L2 frames within UDP and the enterprise network topology design, show in (Fig.1) is being slowly replaced by a fully virtualized network design, shown in (Fig.2).

In the classic design, groups of computers are separated into VLANs and the mapping between L2 VLANs and L3 subnets is implemented at the aggregation layer, both for IPv4 and the rising IPv6, which comes with its own challenges (The interested reader can find more details on IPv6 and IPv4/IPv6 interoperability in [5][6]). The venerable Spanning Tree Protocol (STP) and its update Rapid STP (RSTP) [7] are used to prevent loops in topology.

The more modern design emphasizes the use of a switched fabric with traffic spread between multiple physical links and a complete elimination of STP, replacing it usually with a variety of Shortest Path Bridging (SPB)[8].

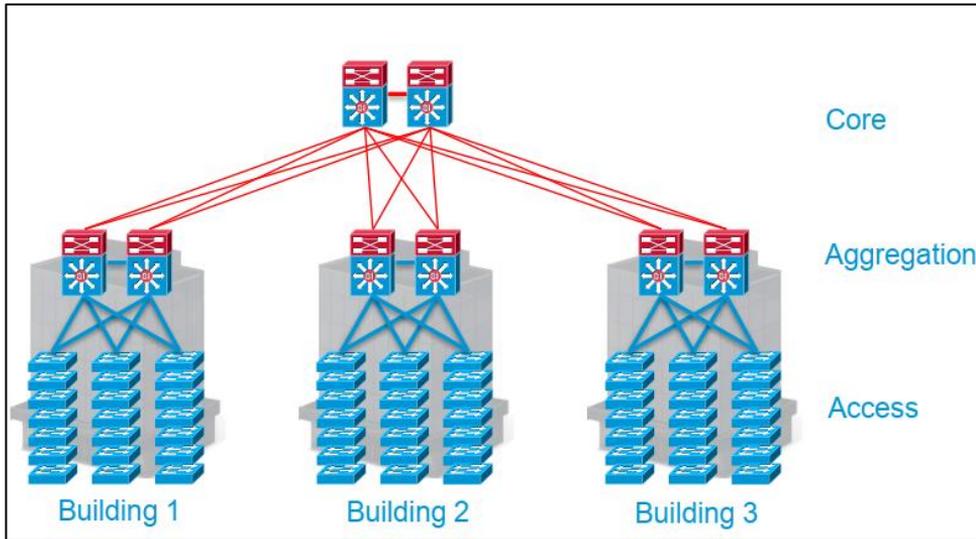


Fig.1. Classic three-tier enterprise network architecture with redundancy [9].

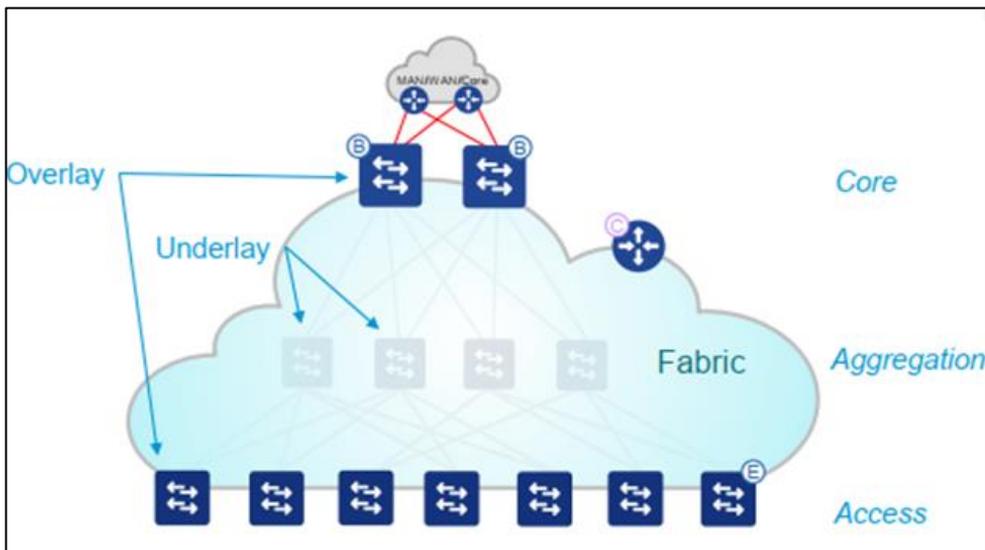


Fig.2. Future enterprise networks with switching fabric and virtualized set of overlay networks [9].

There are several layers, where security in the form of encryption and authentication can be provided. MACsec has been standardized in 802.1AE [10] and 802.1X-2010 [11] and provides security directly at the link layer, while the venerable IPsec set of standards, dating back to 1995, is extremely mature and widely supported, even in affordable consumer devices.

The utilization of IPsec lies in the focus of this paper and an excellent overview of various IPsec RFCs is provided in RFC6071 [12], bringing a comprehensive information to the interested reader. As demonstrated by [13], the development in this area does not end with the conclusion of the IPsec Working Group, and a new working group dedicated to IPsec is already setting a standardization roadmap.

The challenges of implementing reliable IPsec protection within the context of mobile cellular networks where a moving user equipment (UE) undergoes a handover process when moving between areas covered by different base stations are addresses in [14] and [15], while [16] provides a detailed analysis of the effects of handover latency on IPsec security and suggest a cross-layer L2/L3 security mechanism. [17] then gives realistic values of latency to be expected in cellular networks based on practical measurements.

As described in the IETF charter for the working group: IP Security Maintenance and Extensions (ipsecme) [18] the potential use of IPsec for resource constrained IoT nodes is finally gaining attention of the standardization bodies. Method for reducing ESP and IKEv2 overhead by compressing selected header fields are discussed in several draft RFCs [19][20][21], to be published in 2020.

The paper is organized in the following way: Section one brings a brief recap of the principles of IPsec and GRE. Section two with the help of appendices then gives a full configuration guide for implementing IPsec tunneling on Cisco devices to facilitate the VPN establishment. The next section discusses implementation of the GRE tunneling mode. Section IV then gives quantitative results on the performance of various encryption and hashing algorithm configurations within the GNS3-based virtualized environment. The last section then concludes the paper.

## 1 IPsec and GRE Overview

Complementary to other transport-layer and application-layer security protocols, such as TLS and SSH, the IPsec provides security directly within the network layer, with implementation built-in the operating system. The advantage of such a design is that an application utilizing the Socket API [22] doesn't need to be modified at all to be protected. The IPsec operates on a per-packet/datagram bases and consists of two slightly different security protocols: Authentication header (AH) and Encryption Security Payload (ESP). Both can operate in transport, or tunneling mode. Since the tunneling mode hides the whole original packet, including its header (and therefore protect also the source and destination IP addresses), it is in the focus of this paper. This is consistent with current data center trends of overlay networks implemented using tunneling, such as VXLAN [23].

Tunneling is a way that is used when it is desired to make connection between the source client somewhere on the Internet or in private network and the destination node or network. IPSec protocol it is one of the tunneling protocol open standards, that provides authentication, encryption and data integrity between the source and destination hosts.

The definition of the current version: IPsec-v3 is given primarily in RFC 4301[24], while many other RFCs amend the basic specification and provide further information. [25] provides an excellent overview of the many RFCs involved along with their status. This protocol provides three main functionalities:

1. Authentication (verification) – it means that the data was not modified during its transmission (it uses and extended authentication header – AH – RFC4302 [26]).
2. Encryption (confidentiality) of transmitted data – this provides protocol Encapsulation Security Payload (ESP), in addition to encryption, it also provides authentication (more information see [27]).
3. Key exchange between the entities – this functionality provide Internet Key Exchange Protocol defined in a much newer RFC [28] that obsoletes previous specifications. Despite its separation to different RFC, motivated by its reuse also out of the scope of IPsec, for all practical purposes IKE must be considered an integral part of successful IPsec deployment.

IPSec use to ensure the secure transmission of data, voice, and data between sites (Site-to-Site). We create a VPN tunnel over a public Internet and the communication among the tunnel encrypted using encryption algorithms that ensure the confidentiality of transmitted data. A key mechanism for authentication and securing confidentiality within the IPsec protocol is the creation of a Security Association (SA), which is stored in the Security Association Database (SAD). A security association is a one-way logical connection (for bidirectional communication two SAs are created own for each direction). The SAs are applied according to security policies, that are stored in the Security Policy Database (SPD).

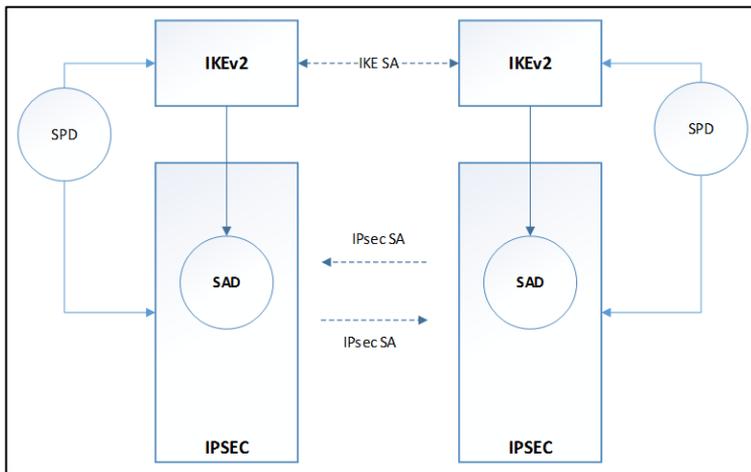


Fig.3. Schematics of IPsec operation:

in phase one the Security Association (SA) parameters are configured by IKE. These are than used on a per-packet basis for communication securing.

The negotiations of the security association in IKEv1 consisted of two parts. The aim of the first part in IKEv1 was to establish a security association for the exchange of IKE SA keys, and the aim of the second part of IKEv1 is to establish a security association for the transfer data of IPsec SA.

The IKEv2 simplifies the negotiation process of the security association. It uses two exchanges (4 messages in total) to create the IKE SA security association and a pair of messages for the IPsec SA security association. IPsec SA is based on the mutual exchange of messages in pairs.

- The first pair of messages (temporary exchange) - information about cryptographic algorithms and other security parameters. The result is the creation of a special security association (IKE SA). After that, the exchanged messages protect by encryption and authentication.
- During the second exchange, the communicating entities authenticate to each other and create the first IPsec Security Association (IPsec SA), which is used to ensure normal operation between the communicating entities. To creating a security, association requires the exchange of two pairs of messages. The security association is stored in the database of security associations (SAD)

The Generic Routing Encapsulation (GRE) is a tunneling protocol developed to address the shortcomings of basic IP-in-IP tunneling, such as the inability to tunnel multicast traffic. Similarly to IPsec, it can be used to establish a tunneled connection between network nodes. Definition of the GRE is given in [29] and [30]. The GRE protocol is unsecure that means this communication in the tunnel is not encrypted. To implement a secure transmit multicast communication over the internet (for example transmit routing information via OSPF protocol which is the multicast communication) it is common practices to secure the communication with combination of GRE and IPsec protocol.

## 2 IPsec Implementation Within Cisco IOS

(Fig.4) gives an overview of the example topology to implement a VPN using an IPsec tunnel: the IP traffic is securely tunneled between branch offices at their security gateways RouterA and RouterB, while the middle ISP router models an unsecured Internet connection between the branch offices. The advantage of this approach is that the computers in branch offices' local networks do not even need to implement IPsec – its operation is transparent to them, thus saving precious computing resources.

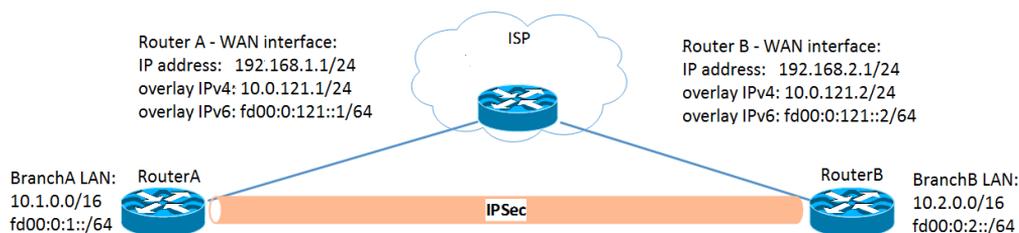


Fig.4. IPsec tunnel between two branch offices over an unsecured Internet modelled by the top ISP router. Tunnel may be configured to carry IPv4 in IPv4 (IP-IP) or IPv6 in IPv4 (6in4) with or without GRE for tunneling multicast traffic.

Before an IPsec tunnel is configured, the IKE configuration should take place. The configuration of IKEv2 consists of the several configuration steps (Note: In all tables, the prompt RouterA/B indicates this command is set on both routers with the same arguments.):

IKEv2 Keyring - create the configuration in case if we want to use the shared secret key for authentication. Creating the IKEv2 keyring consist of pre-shared keys associated with the IKEv2 profile as shown in (Tab.1):

Table 1. Configuration of IKEv2 keyring within Cisco IOS.

Step	Command	Description
1	RouterA(config)# crypto ikev2 keyring KEYRING-RA RouterB(config)# crypto ikev2 keyring KEYRING-RB	Define the name of the IKEv2 Keyring and enter into configuration mode.
2	RouterA(config-ikev2-keyring)#peer RouterB RouterB(config-ikev2-keyring)#peer RouterA	Define the name for the opposite side of the future tunnel.
3	RouterA(config-ikev2-keyring-peer)# address 192.168.2.1 RouterB(config-ikev2-keyring-peer)# address 192.168.1.1	Specify the IPv4 or IPv6 address on the remote peer – the other end of the IPsec tunnel (the delivery protocol).
4	RouterA/B(config-ikev2-keyring-peer)# pre-shared-key Passw0rd2020	Specify the shared secret key.

IKEv2 Proposal - consists of definitions of transformations and defines parameters such as the encryption algorithm, the algorithm of the data integrity, pseudorandom functions and the choice of Diffie-Hellman group.

Table 2. Configuration of IKEv2 proposal within Cisco IOS.

Step	Command	Description
1	RouterA(config)# crypto ikev2 proposal PROP-RA RouterB(config)# crypto ikev2 proposal PROP-RB	Define the name of the IKEv2 Proposal and enter into configuration mode.
2	RouterA/B(config-ikev2-proposal)# encryption aes-cbc-256	(Optional) Define one or more transformation for the encryption.
3	RouterA/B(config-ikev2-proposal)# integrity sha512	(Optional) Define one or more transformation for the integrity.
4	RouterA/B(config-ikev2-proposal)#group 14	(Optional) Define one or more transformation for the Diffie-Hellman group

IKEv2 Policy – define the name of the IKEv2 Policy and interlinking with the IKEv2 Proposal that the IPsec will to use in the negotiation of the IKE SA security association in the exchange of IKE\_SA\_INIT messages.

Table 3. Configuration of IKEv2 policy within Cisco IOS.

Step	Command	Description
1	RouterA(config)# crypto ikev2 policy POLICY-BRANCHA RouterB(config)# crypto ikev2 policy POLICY-BRANCHA	Define the name of the IKEv2 Policy and enter into configuration mode.
2	RouterA(config-ikev2-policy)# proposal PROP-RA RouterB(config-ikev2-policy)# proposal PROP-RB	Specify the name of the IKEv2 Proposal that will be interlinking with the IKEv2 Policy.

IKEv2 Profile – define the IP address of the remote peer, specify the local and remote authentication mode.

Table 4. Configuration of IKEv2 profile within Cisco IOS.

Step	Command	Description
1	RouterA(config)# crypto ikev2 profile PROF-RA-TO-RB RouterB(config)# crypto ikev2 profile PROF-RB-TO-RA	Define the name of the IKEv2 Profile and enter into configuration mode.
2	RouterA(config-ikev2-profile)# match identity remote address 192.168.2.1 255.255.255.255 RouterB(config-ikev2-profile)# match identity remote address 192.168.1.1 255.255.255.255	Select the profile based on the remote IP address
3	RouterA/B(config-ikev2-profile)# authentication local pre-share	Specify the local authentication method.
4	RouterA/B(config-ikev2-profile)# authentication remote pre-share	Specify the remote authentication method.
5	RouterA(config-ikev2-profile)# keyring local KEYRING-RA RouterB(config-ikev2-profile)# keyring local KEYRING-RB	Specify the name of the IKEv2 Keyring for this profile.

An Access Control List (ACL) must be created to specify, which packets are to be sent to the tunnel and secured using IPsec:

Table 5. Configuration of ACL within Cisco IOS.

Step	Command	Description
1	RouterA(config)# ip access-list extended VPN-RA-TO-RB RouterB(config)# ip access-list extended VPN-RB-TO-RA	Define the name of the extended ACL and enter into configuration mode.
2	RouterA(config-ext-nacl)# permit ip 10.1.0.0 0.0.255.255 RouterB(config-ext-nacl)# permit ip 10.2.0.0 0.0.255.255	Permit all packets that meets the conditions.

Set the transformation set that defines how the data is protected:

```
RouterA(config)#
crypto ipsec transform-set TS-RA-TO-RB esp-aes 128 esp-sha512-hmac
RouterB(config)#
crypto ipsec transform-set TS-RB-TO-RA esp-aes 128 esp-sha512-hmac
```

Crypto map – this configuration joins the previous parts of the IPSec configuration (ACL, transformation set, IP address of the remote peer, lifetime of the data connection, etc.).

Table 6. Configuration of crypto map within Cisco IOS.

Step	Command	Description
1	RouterA(config)# crypto map CRYPTO-MAP-RA-RB 10 ... ipsec-isakmp RouterB(config)# crypto map CRYPTO-MAP-RB-RA 10 ... ipsec-isakmp	Create or change the crypto map
2	RouterA(config-crypto-map)# set peer 192.168.2.1 RouterB(config-crypto-map)# set peer 192.168.1.1	Specify the hostname or IP address of the remote peer.
3	RouterA(config-crypto-map)# set transform-set TS-RA-TO-RB RouterB(config-crypto-map)# set transform-set TS-RB-TO-RA	Specify the transformation set.
4	RouterA(config-crypto-map)# match address VPN-RA-TO-RB RouterB(config-crypto-map)# match address VPN-RB-TO-RA	Specify the name of the extended ACL.
5	RouterA(config-crypto-map)#set pfs group14 RouterB(config-crypto-map)#set pfs group14	Optional – define for IPSec, that should request password confidentiality when requesting new SA.
6	RouterA(config-crypto-map)# set ikev2-profile PROF-RA-TO-RB RouterB(config-crypto-map)# set ikev2-profile PROF-RB-TO-RA	Specify the name of the IKEv2 Profile
7	RouterA(config-crypto-map)# set security-association lifetime seconds 3600 RouterB(config-crypto-map)# set security-association lifetime seconds 3600	Optional – specify the lifetime of the Security Association

And finally, the crypto map must be activated on the WAN interface on the both routers.

Table 7. Activation of crypto map within Cisco IOS.

Step	Command	Description
1	RouterA(config)#int e0/0 RouterB(config)#int e0/0	WAN Interface selection.
2	RouterA(config-if)# crypto map CRYPTO-MAP-RA-RB RouterB(config-if)# crypto map CRYPTO-MAP-RB-RA	Applying crypto map on the interface..

Table 8. Creating virtual interface for the tunnel.

Step	Command	Description
1	RouterA(config)#interface tunnel 1 RouterB(config)#interface tunnel 1	Create virtual interface for the tunnel and enter into the configuration mode.
2	RouterA(config-if)#tunnel source 192.168.1.1 RouterB(config-if)#tunnel source 192.168.2.1	Specify the outside source IP address for the virtual interface.
3	RouterA(config-if)# tunnel destination 192.168.2.1 RouterB(config-if)# tunnel destination 192.168.1.1	Specify the destination IP address of the delivery protocol.
4a	RouterA(config-if)# ip address 10.0.121.1 255.255.255.0 RouterB(config-if)# ip address 10.0.121.2 255.255.255.0	For IPv4-in-IPv4 tunnel. Assign the IP address into virtual interface tunnel 1.
4b	RouterA(config-if)# ipv6 address FD00:0:121:0:0:0:0:1/64 RouterB(config-if)# ipv6 address FD00:0:121:0:0:0:0:2/64	For IPv6-in-IPv4 (6in4) tunnel. Assign the IPv6 address into virtual interface tunnel 1.

Further configuration steps regarding routing (static or OSPF) must also be taken, but since they aren't really part of IPsec, are omitted here. The successful configuration is then tested using the classic integrated ping command from within the router's IOS command line interface. In a virtualized, GNS3-based topology however, it is straightforward to test the encryption using the Wireshark packet analyzer, as show in (Fig.5).

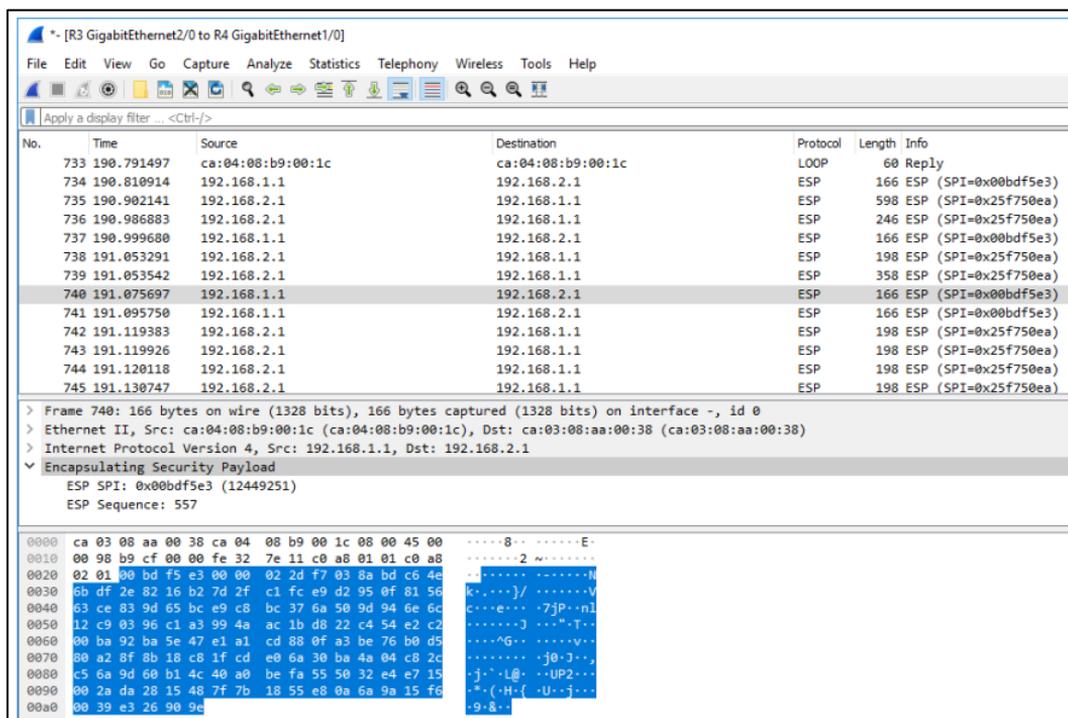


Fig.5. Wireshark analysis at ISP link shows the traffic is indeed encrypted and therefore protected.

### 3 Measurements on Virtualized Topology

Since the virtualization of computer networks becomes ever more important, interesting questions regarding the throughput and latency parameters of such virtualized design, and their effect on CPU-utilization when simulating network operation arise. These have to be measured by affordable, or better free and open tools, such as `iperf`. For a simple topology show in (Fig.4), the throughput and latency were measured in a virtualized GNS3-based topology along with the CPU utilization on a Intel(R) Core(TM)-i7-8650U CPU 1.90 GHz processor.

Table 9. Results of measurements.

Protection parameters	Throughput [Mbps]	CPU utilization [%]	Average latency [ms]
None	59	61-66	3
DES with MD5	35	61-66	3
DES with SHA1	34	62-67	4
DES with SHA256	32	60-64	3
DES with SHA384	28	61-64	3
DES with SHA512	28	62-66	3
3DES with MD5	29	59-65	2
3DES with SHA1	28	60-65	4
3DES with SHA256	27	59-64	3
3DES with SHA384	24	60-65	3
3DES with SHA512	23	60-67	3
AES-CBC128 with MD5	43	60-65	4
AES-CBC128 with SHA1	42	60-65	4
AES-CBC128 with SHA256	38	60-66	2
AES-CBC128 with SHA384	33	60-67	3
AES-CBC128 with SHA512	32	61-68	3
AES-CBC192 with MD5	42	59-63	4
AES-CBC192 with SHA1	40	59-63	3
AES-CBC192 with SHA256	37	58-63-	4
AES-CBC192 with SHA384	33	59-63	4
AES-CBC192 with SHA512	32	59-62	5
AES-CBC256 with MD5	41	58-63	3
AES-CBC256 with SHA1	40	59-64	3
AES-CBC256 with SHA256	37	61-65	4
AES-CBC256 with SHA384	33	58-63	5
AES-CBC256 with SHA512	31	58-64	4

As shown in the (Tab.9) the CPU utilization and average latency played no major role on virtual environment. CPU utilization without running the test was at the level of 15% on the physical machine, during data transfer using the `iperf` tool, CPU utilization was at the level of 58-66% for all encryption algorithms. These parameters did not change even when we increased the number of cores on end workstations. Network latency can play a significant role in large networks and CPU utilization in turn can be affected based on the HW equipment of the router e.g. whether the encryption is performed on the basis of the operating system on the router (SW) or the given HW has a special chip which provides encryption at the motherboard level.

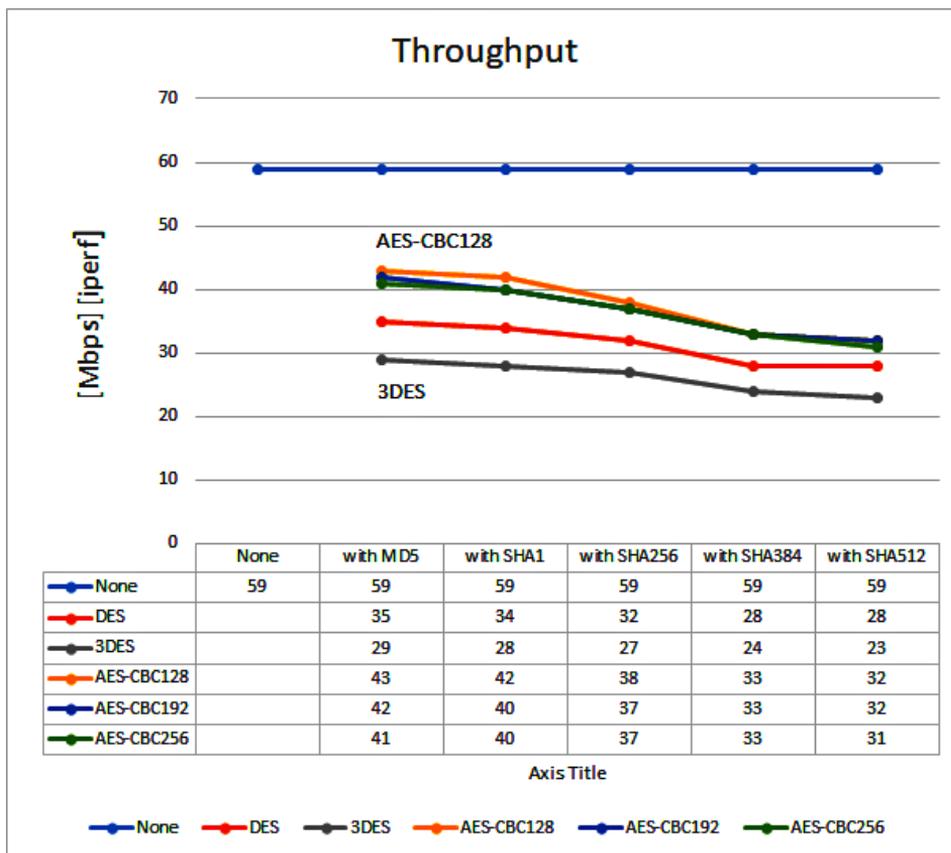


Fig.6. Comparison of measured throughput values of selected encryption and hash algorithms. (to distinguish color lines, see the online version of journal)

However, it can be seen from the experiment that turning on encryption reduces data transmission throughput by 27% for the best result using AES-CBC128 with a legacy (and therefore not practical) MD5, to for a more realistic AES-CBC256 with SHA256 with a 37% performance penalty. Older legacy encryption algorithms such as DES and 3DES performed worse in the measurement than newer AES encryption algorithms which gives one more reason, apart from their know weaknesses, not to use them.

## Conclusion

In this paper we have focused on the latest trends in the evolution of data-center networks from L2 based VLANs to more advanced L4-tunnelled VXLANs, necessary for elastic provisioning of overlay networks in a multi-tenant data-center environment. The L3 security implemented by IPsec was identified as a promising method for securing such overlay networks and a complete configuration of tunneling mode IPsec-v3 including IKE-v2 within the Cisco IOS was given along with a simple example topology. Quantitative results regarding the effects of various cryptographic algorithms on throughput, latency and CPU utilization were presented.

## ▲ Acknowledgement

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-19-0436 and it was also supported by the Scientific Grant Agency of the Ministry of Education of Slovak Republic and Slovak Academy of Sciences (grant VEGA 1/0477/18) and and by the Tatra bank foundation programme Quality of Education, within the project "SDRLab 2.0 – technologies of 5G networks and IoT in classroom".

## ▲ References

- [1] Catalyst 3750-X and 3560-X Switch Software Configuration Guide, Release 12.2(55)SE [Available: [https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst3750x\\_3560x/software/release/12-2\\_55\\_se/configuration/guide/3750xscg/swstack.html](https://www.cisco.com/c/en/us/td/docs/switches/lan/catalyst3750x_3560x/software/release/12-2_55_se/configuration/guide/3750xscg/swstack.html) ]
- [2] Cisco IOS XE [Available: <https://www.cisco.com/c/en/us/products/ios-nx-os-software/ios-xe/index.html>]
- [3] Cisco devnet Tutorial: Build sample LXC type IOx app using Docker toolchain [Available: <https://developer.cisco.com/docs/iox/#!lxc-workflow/tutorial-build-sample-lxc-type-iox-app-using-docker-toolchain>]
- [4] M. Mahalingam et al. RFC 7348: Virtual eXtensible Local Area Network (VXLAN): A Framework for Overlaying Virtualized Layer 2 Networks over Layer 3 Networks, Aug 2014,IETF [Available: <https://tools.ietf.org/html/rfc7348>]
- [5] Palenik, T.: Computer Networks. ForPress, Slovakia 2014, ISBN 978-80-89731-13-8.
- [6] Stas F., Palenik T.: Mechanism of interoperability between IPv4 and IPv6 Protocols. In proc of Redzur 2016: 10th anniversary International Workshop on Multimedia and Signal Processing, Bratislava, Slovakia, May 2016, ISBN: 978-80-227-4560-4.
- [7] IEEE Standard for Local and metropolitan area networks: Media Access Control (MAC) Bridges, in IEEE Std 802.1D-2004 (Revision of IEEE Std 802.1D-1998) , vol., no., pp.1-281, 9 June 2004, doi: 10.1109/IEEESTD.2004.94569.
- [8] IEEE Standard for Local and Metropolitan Area Network--Bridges and Bridged Networks, in IEEE Std 802.1Q-2018 (Revision of IEEE Std 802.1Q-2014) , vol., no., pp.1-1993, 6 July 2018, doi: 10.1109/IEEESTD.2018.8403927.
- [9] J. Pilař, P. Křížanovský, Z. Roubal, R. Boch: Připravte si infrastrukturu na novou realitu – Přepínané síťe. webinar Cisco Engage 25.6.2019
- [10] IEEE Standard for Local and metropolitan area networks-Media Access Control (MAC) Security, in IEEE Std 802.1AE-2018 (Revision of IEEE Std 802.1AE-2006) , vol., no., pp.1-239, 26 Dec. 2018, doi: 10.1109/IEEESTD.2018.8585421
- [11] IEEE Standard for Local and metropolitan area networks--Port-Based Network Access Control, in IEEE Std 802.1X-2010 (Revision of IEEE Std 802.1X-2004) , vol., no., pp.1-205, 5 Feb. 2010, doi: 10.1109/IEEESTD.2010.5409813.
- [12] S. Frankel, S. Krishnan: RFC 6071: IP Security (IPsec) and Internet Key Exchange (IKE) Document Roadmap, Feb 2011, IETF [Available: <https://tools.ietf.org/html/rfc6071>]
- [13] T. Pauly, S. Touati, R. Mantha: RFC8229: TCP Encapsulation of IKE and IPsec Packets, Aug 2017, IETF. [Available: <https://tools.ietf.org/html/rfc8229>]
- [14] S. Smaoui, F. Zarai and L. Kamoun: IPSec tunnel establishment for 3GPP-WLAN interworking, 8th International Conference on Informatics and Systems (INFOS), Cairo, 2012, pp. NW-74-NW-80.
- [15] A. Hussein, I. H. Elhaji, A. Chehab and A. Kayssi: Securing Diameter: Comparing TLS, DTLS, and IPSec, 2016 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET), Beirut, 2016, pp. 1-8, doi: 10.1109/IMCET.2016.7777417.
- [16] F. Leu, Y. Huang and C. Chen: The IPSec Security Problems and a Cross-layer Security Mechanism for PMIPv6 Handover when an IPSec Security Association is Established on an L2 Direct Link, 2012 Seventh International Conference on Broadband, Wireless Computing, Communication and Applications, Victoria, BC, 2012, pp. 452-457, doi: 10.1109/BWCCA.2012.80.

- [17] Kloibhofer R., Fresolone F. et al.: Throughput and One-Way Latency Measurements in a 3G/4G Live-Network Hi-Mobility Uplink.  
In proc. TSP 2016 – 39th International Conference on Telecommunications and Signal Processing, Vienna, Austria, June 2016, ISBN: 978-1-5090-1287-9, ISSN: 1805-5435.
- [18] IETF Datatracker: IP Security Maintenance and Extensions (ipsecme) Working Group: Charter for Working Group [Available: <https://datatracker.ietf.org/wg/ipsecme/about/>]
- [19] D. Migault, T. Guggemos, C. Bormann, D. Schinazi: draft-mglt-ipsecme-diet-esp: ESP Header Compression and Diet-ESP, March 2019, IETF [Available: <https://tools.ietf.org/html/draft-mglt-ipsecme-diet-esp-07>]
- [20] V. Smysov: draft-smyslov-ipsecme-ikev2-compression: Using compression in the Internet Key Exchange Protocol Version 2 (IKEv2). March 2020, IETF  
[Available: <https://tools.ietf.org/html/draft-smyslov-ipsecme-ikev2-compression-08> ]
- [21] V. Smysov: draft-smyslov-ipsecme-ikev2-compact: Compact Format of IKEv2 Payloads. March 2020, IETF [Available: <https://datatracker.ietf.org/doc/draft-smyslov-ipsecme-ikev2-compact/>]
- [22] Linux programmer's Manual, socket(2). Linux man-pages v5.07, 2020  
[Available: <https://man7.org/linux/man-pages/man2/socket.2.html>]
- [23] IETF, RFC7348: Virtual eXtensible Local Area Network (VXLAN): A Framework for Overlaying Virtualized Layer 2 Networks over Layer 3 Networks, 2014, ISSN: 2070-1721,  
[Available: <https://tools.ietf.org/html/rfc7348> ]
- [24] IETF, RFC4301: Security Architecture for the Internet Protocol, 2005  
[Available: <https://tools.ietf.org/html/rfc4301>]
- [25] IETF, RFC6071: IP Security (IPsec) and Internet Key Exchange (IKE) Document Roadmap  
[Available: <https://tools.ietf.org/html/rfc6071> ]
- [26] IETF, RFC4302: IP Authentication Header, 2005 [Available: <https://tools.ietf.org/html/rfc4302>]
- [27] IETF, RFC4303: IP Encapsulating Security Payload (ESP), 2005  
[Available: <https://tools.ietf.org/html/rfc4303>]
- [28] IETF, RFC7296: Internet Key Exchange Protocol Version 2 (IKEv2), 2014  
[Available: <https://tools.ietf.org/html/rfc7296> ]
- [29] IETF RFC2784: Generic Routing Encapsulation (GRE), 2000  
[Available: <https://tools.ietf.org/html/rfc2784>]
- [30] IETF, RFC2890: Key and Sequence Number Extensions to GRE, 2000  
[Available: <https://tools.ietf.org/html/rfc2890>]

## ▲ Authors



### **Bc. Karol Csivre**

Allianz Technology  
karol.csivre@gmail.com

Works at the middle-tier IT process management, leading projects and manages a team of people who take care of information systems (hardware, software, network infrastructure LAN, MAN, SAN, WAN, firewall, DB). Has 25 years of experience with operating and building systems in a corporate data center environment.



### **Bc. Dominik Dermek**

Slovak University of Technology  
Faculty of Electrical Engineering and Information Technology  
Bratislava, Slovakia  
xdermekd@stuba.sk



# MODELING OF NONLINEAR DYNAMIC SYSTEMS USING SOFT COMPUTING METHODS

Ján Cigánek, Filip Žemla

**Abstract:**

---

*The presented paper deals with the modeling principles of nonlinear dynamic systems and with the design of optimal model structures created by artificial neural networks and fuzzy theory. Four models were created for modeling of selected system: a neural network model, an adaptive neuro-fuzzy model and two neural networks with optimal structure obtained using Optimal Brain Damage and Optimal Brain Surgeon algorithms. The quality of proposed solutions were compared and verified on a real system of steam turbine in thermal power plant and in nuclear power plant.*

**Keywords:**

*Modeling, artificial neural networks, Optimal brain damage, Optimal brain surgeon, pruning methods, dynamic system.*

**ACM Computing Classification System:**

*Computing methodologies,  
modeling and simulation,  
model development and analysis,  
modeling methodologies.*

## ■ Introduction

Presently, several methods for modeling of dynamic systems are known.

The latest techniques use artificial intelligence, which is able to approximate the behavior of complex nonlinear processes with a high degree of accuracy. One of the options for processing such information is represented by neural networks using fuzzy logic. The main advantage of this combination is their ability to learn.

Modern methods for the structure optimization of neural networks can more effectively exploit their properties by identification and modeling of dynamic systems.

Models have an important position by simulation, analysis and system design. The first step in modeling is to create a mathematical model.

Models typically arise from the understanding of physical patterns and interactions in the studied system. The complexity of the model depends on the given requirements of the model accuracy.

There is a lot of model information that can be difficult to write in the form of algebraic or differential equations, but there are several progressive methods that can introduce this information into the model.

## 1 Neural Networks

Artificial Neural Networks (ANNs) are widely used to development of empirical models for a broad class of scientific, engineering and business activities. In the area of decision-making and control, the ANNs are used to modeling linear and non-linear processes [6]. The basis of systems modeling using ANNs are their very good approximation properties.

Principly, the neural network consists of 3 base layers (input, hidden and output) with a different numbers of neurons, whereby only the neurons from different layers can be connected together (Fig.1).

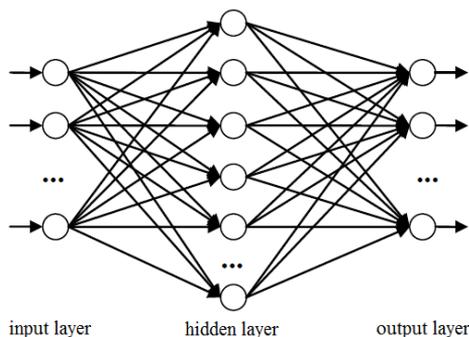


Fig.1. Neural network with 3 layers.

Neurons and neural network connections are rated by real numbers. Each neuron  $v_i$  is evaluated by the threshold  $x_i$ . Similarly, each joint between two neurons ( $v_j, v_i$ ) is evaluated by the weighting factor  $w_{ji}$  (weight).

The target of the adaptive process in ANN is to find such thresholds and weights to minimize the difference between required real output vector and simulated output vector from ANN.

According to the direction of transmitted signals, the ANNs are divided into two main groups: feed-forward and recurrent ANNs.

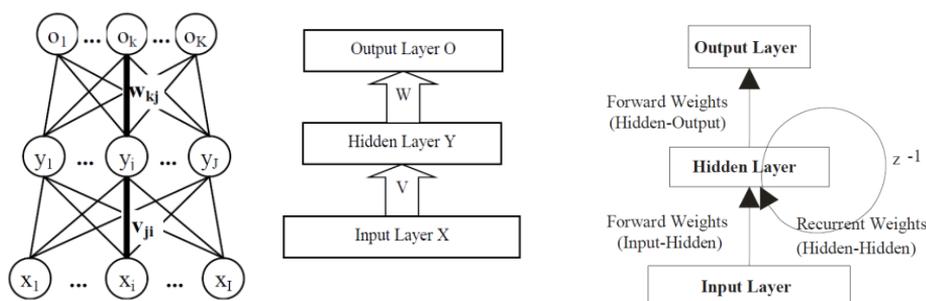


Fig.2. a) Feed-forward ANN, b) Recurrent ANN.

**Feed-forward ANNs** (Fig.2a) are those in which the signal spreads only from the input neurons through hidden neurons (any types of ANNs do not have hidden layer) to the output neurons. Input and output patterns do not depend on time.

The most widely used learning algorithm is the so-called Backpropagation algorithm – consists of calculating and redistributing of the error signal. While the target output on the output layer of the network is known, there can be easily calculated deviations of the actual output of the network from the required one. This difference is an error signal in the output layer. Then the error signal proceeds in the opposite direction, and the error signal propagates with a force adequate to the weight of the individual connections. Thus, at the output of the neuron in the hidden layer arrives the sum of the error signals from all neurons of output layer (transmitted by the weight of the individual connections).

In **recurrent ANNs** (Fig.2b) can also the signal be moved from the output layer to the hidden parts, or even to the input layer. Recurrent ANNs are an extension of feed-forward multilayer perceptron networks. The memory is realized by weight-delayed interconnections.

Both types of ANNs are the universal approximator, theoretically they can approximate arbitrary nonlinear projection with required accuracy.

## 2 Fuzzy Models

The mathematical model, created using fuzzy sets, is called a fuzzy model. In such a model, relations between variables are represented by "IF-THEN" rules. The aim of fuzzy modeling is to model and to control processes based on empirical knowledge. The basic advantage of fuzzy logic is the ability to mathematically represent the information expressed verbally.

The design of the shape, type and number of membership functions (MFs) is usually the most complex part of the design of each fuzzy system. Usually a triangular or trapezoidal MFs is used. The number of linguistic values for one fuzzy variable is different. Usually it is used 3 to 5 MFs for input variable and up to 7 MFs for output variable [6].

The basic principle of fuzzy modeling is the combination of input and output values and their formalization by means of rules [6]. The basic scheme of fuzzy system is shown in (Fig.3).

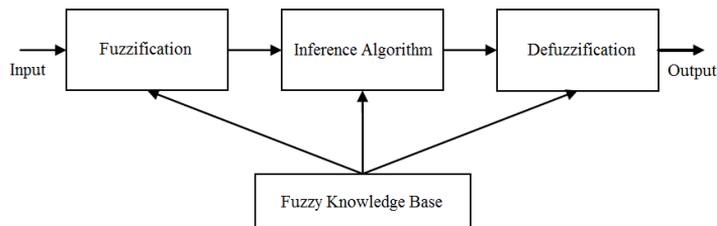


Fig.3. Basic scheme of fuzzy system.

Fuzzification - is the first step in the fuzzy inferencing process. This involves a domain transformation where crisp inputs are transformed into fuzzy inputs. Crisp inputs are exact inputs measured by sensors and passed into the fuzzy system for processing.

Fuzzy inference algorithm is the process of formulating the mapping from a given input to an output using fuzzy logic. The output values of all enabled rules for each linguistic variable are merged into one fuzzy set.

Defuzzification is the process of producing a quantifiable result of output value in Crisp logic, given fuzzy sets and corresponding membership degrees.

Fuzzy Knowledge Base - represents the facts of the rules and linguistic variables based on the fuzzy set theory so that the knowledge base systems will allow approximate reasoning.

### 3 Hybrid Models

It is possible to upgrade the properties of ANNs and fuzzy systems by their combination in hybrid systems [1]. (Tab.1) summarizes all the advantages and disadvantages of these two technologies. Hybrid systems are trying to combine these features so that the new system has maximum of advantages and minimum of disadvantages.

Table 1. Properties of ANNs and fuzzy systems.

	Advantages	Disadvantages
<b>ANNs</b>	<ul style="list-style-type: none"> <li>- function approximation of various data</li> <li>- learning ANNs and their adaptability</li> <li>- parallelism of ANNs</li> <li>- hardware implementation</li> </ul>	<ul style="list-style-type: none"> <li>- learning time is relatively long</li> <li>- we can not precisely determine the topology</li> <li>- impossible implementation of a priori knowledge</li> </ul>
<b>Fuzzy systems</b>	<ul style="list-style-type: none"> <li>- possible implementation of a priori knowledge</li> <li>- manipulation of fuzzy sets</li> </ul>	<ul style="list-style-type: none"> <li>- no learning</li> <li>- knowledge base has to be designed by an expert</li> </ul>

A typical example of hybrid models is ANFIS (Adaptive Neuro-Fuzzy Inference System). ANFIS realizes a fuzzy system of Takagi-Sugeno type using ANN. The methodology includes controlled learning of nodes in ANN by input data. In (Fig.4), adaptive nodes are marked with a square, while non-adaptive nodes are marked with a circle.

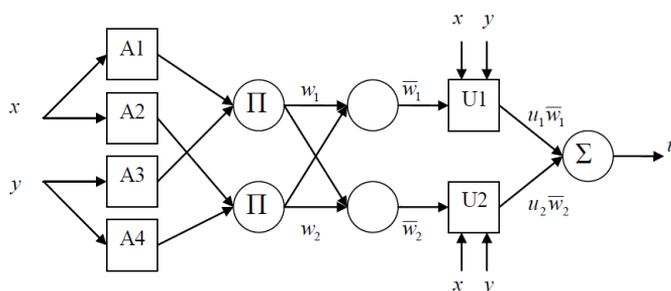


Fig.4. Example of ANFIS model.

The presented ANFIS model (Fig.4) contains two inputs  $x$  and  $y$  and one output  $u$ . The knowledge base consists of two IF - THEN fuzzy rules. The crisp value of the output is given by:

$$u = \frac{u_1 w_1 + u_2 w_2}{w_1 + w_2} = \bar{w}_1 u_1 + \bar{w}_2 u_2 \tag{1}$$

The network consists of five layers. The nodes of each layer have the same nodal functions.

Layer 1: Each node of this layer is adaptive and its output is the membership value of the input  $x$  to the level  $A_i$  of the linguistic variable. Usually, we select the function  $\mu_{A_i}$  with values in interval  $(0; 1)$ , i.e. in form (2):

$$\mu_{A_i} = \frac{1}{1 + \left(\frac{x - c_i}{a_i}\right)^{b_i}}, \quad i = 1, \dots, 4 \quad (2)$$

where  $a_i, b_i, c_i$  are premise parameters changing the shape and placement of membership functions.

Layer 2: It represents the power of the rule. Each node of this layer is non-adaptive, labeled with a sign  $II$  that multiplies input signals and transmits their product to next layer.

Layer 3: Each node of this layer is non-adaptive and calculates the power of the  $i$ -th rule to the power of all rules.

$$\bar{w}_i = \frac{w_i}{w_1 + w_2}, \quad i = 1, 2 \quad (3)$$

Layer 4: Each node of this layer is adaptive, with consequent parameters  $p_i, q_i, r_i$ :

$$\bar{w}_i \bar{u}_i = \bar{w}_i (p_i x + q_i y + r_i) \quad (4)$$

Layer 5: Non-adaptive node filling the summing function of input signals (1).

By the feed-forward, the signals propagate up to layer 4, the consequent parameters are identified by the least squares method. By back-propagation, the error signal is moving in reverse direction with updating the premise parameters.

## 4 Pruning Methods

One of the most important problems encountered in the practical application of ANNs is to find a suitable or ideally minimal ANN topology. Some of the main reasons are that an unsuitable topology increases the training time or even causes nonconvergence, thus it usually decreases the generalization capability of ANN [7].

The principle of pruning algorithms starts with a large ANN that is gradually decreasing [3]. The following methods represent various ways of removing connections and neurons. The pruning algorithm attempts to reduce ANN by eliminating unnecessary connections and neurons.

Sensitivity-based algorithms (requiring ANN convergence status) work according to the following procedure:

1. appropriate ANN is selected,
2. learning with back-propagation or similar algorithm is performed until ANN achieves a minimal error,
3. the importance of each element is calculated (connection or neuron) in terms of network performance,
4. the element of least importance shall be deleted,
5. re-learning of ANN (until a minimum of error function),
6. if the error is too high, return to point 3,
7. (optional) reinsert the last cut off element to obtain a lower error.

The simplest heuristic variant of pruning - after each learning step, the neural connection with the smallest weight is removed. The absolute value of the connection weight is therefore the only measure for the usefulness of the connection. Although this method is very simple, it rarely achieves worse results than more sophisticated algorithms.

**Optimal Brain Damage** (OBD) algorithm reduces the number of connections to prevent learning. The algorithm is designed to remove connections that will have the least impact on the network's error function  $E(w)$ , where  $w$  is the weight vector.

Under assumption that the original network is too large, after removing these connections new learning can improve the generalization capability of ANN. The OBD approximates the error function at the local minimum by Taylor's polynomial:

$$\delta E = \left( \frac{\delta E(w)}{\delta w} \right)^T \delta w + \frac{1}{2} \delta w^T H \delta w + F(\|\delta w\|^3) \quad (5)$$

where  $H$  is Hessian matrix of second partial derivatives.

To simplify the calculation, it is assumed that ANN has come the local minimum of error function  $E$  so that the first equation member of the right side can be ignored. Also third order and higher derivatives can be dismissed. By the Hessian approximation, only the diagonal elements are counted. After the neural connection removing, it is assumed that the effect on the error function will not depend on the settings of the other connections. The result of these simplifications is the equation:

$$\delta E = \frac{1}{2} \sum_{1 \leq i, j \leq n_k} h_{(i,j)} \delta w(ij)^2 \quad (6)$$

The importance of the line is inversely proportional to  $\delta E$ . The weight elimination procedure organizes the neural connections by importance. One or more of the least important connections is removed, ANN is re-learned and this cycle is repeated for the required number of times or till required accuracy of ANN model is reached.

Procedure steps of OBD algorithm:

1. The classical "reasonably large" feed-forward neural network is created, all neurons in neighbour layers are connected each with other.
2. Learning of ANN by selected algorithm until the minimum of error function is reached.
3. Evaluation of ANN on test data, storage of actual results (mean quadratic error for test data, network structure, values of weights and thresholds).
4. Elimination of weights that have the least impact on the error function (elimination of more weights are recommended, in our case study 5%).  
If there is nothing to be removed, then step 5 follows, otherwise go back to step 2.
5. The ANN structure with the smallest error was found (resulting in the optimal NN structure).

**Optimal Brain Surgeon** (OBS) algorithm is an improvement of the OBD algorithm. The benefits of OBS over OBD include that it does not require slow re-learning of ANN after connection withdrawal.

The approximation of the error function uses the same equation (5). The meaning of symbols is the same as for OBD. The first and third members of the Taylor's polynomial are ignored for the same reasons.

The first step of algorithm is to set one of the weights to zero ( $w_q$ ) to minimize the increase in error function (5). The elimination of the weight  $w_q$  can be expressed by equation (7):

$$\delta w_q + w_q = 0 \quad \text{or} \quad e_q^T \cdot \delta w + w_q = 0 \quad (7)$$

where  $e_q^T$  is the unit vector in the weight space, which also includes (scalar) weight  $w_q$ .

The task is to solve:

$$\text{Min}_q \left\{ \text{Min}_{\delta w} \left( \frac{1}{2} \delta w^T H \delta w \right) \right\} \tag{8}$$

under restriction (7). This leads to Lagrangian equation (9):

$$L = \frac{1}{2} \delta w^T H \delta w + \lambda (e_q^T \cdot \delta w + w_q) \tag{9}$$

Thus, the resulting optimal weight change  $\delta w$  and resulting change in error  $L$  are:

$$\delta w = -\frac{w_q}{[H^{-1}]_{qq}} H^{-1} \cdot e_q, \quad L_q = \frac{1}{2} \frac{w_q^2}{[H^{-1}]_{qq}} \tag{10}$$

Note: neither Hessian matrix  $H$  nor  $H^{-1}$  need to be diagonal [8]. Moreover, this method recalculates the magnitude of all the weights in ANN.  $L_q$  is called “saliency” of weight  $q$  – the increase in error after the weight elimination.

Procedure steps of OBS algorithm:

1. The classical “reasonably large” feed-forward neural network is created, all neurons in neighbour layers are connected each with other.
2. Learning of ANN by selected algorithm until the minimum of error function is reached.
3. Computation of inverted Hessian matrix  $H^{-1}$ .
4. Find such  $q$  that gives the minimal saliency  $L_q$ . If this candidate error increase is much smaller than  $E$ , then the  $q$ th weight  $w_q$  should be deleted and we proceed to step 5, otherwise go to step 6. (Other stopping criteria can be used too.)
5. Use  $q$  from step 4 to update all weights  $\delta w$  (10). Go to step 3.
6. No more weights can be deleted without large increase of  $E$ . The ANN structure with the smallest error was found (resulting in the optimal NN structure).

## 5 Case Study

The dynamic system represents the steam turbine in the second block of the thermal power plant in Nováky, Slovak republic. Data for modeling were obtained by two measurements (Fig.5). The first measurement contains 4501 samples and the second measurement 3601 samples. The following variables were observed by the measurements:  $y(t)$  - steam pressure,  $u(t)$  - fuel supply,  $ff(t)$  - required active power.

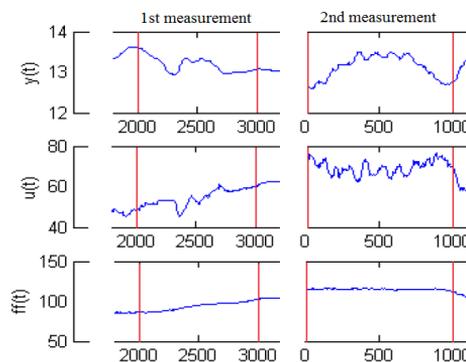


Fig.5. Training data with 2000 samples.

The target of the modeling will be to approximate the output variable - steam pressure  $y(t)$ . We consider that a nonlinear dynamic system is described by a differential equation in form (11):

$$y(t) = f[y(t-1), \dots, y(t-P), u(t), \dots, u(t-Q), ff(t), \dots, ff(t-R)] \quad (11)$$

where  $P, Q, R$  are numbers of previous values. In order not to have large computational demands, the maximum number of past values was determined:

$$1 \leq P \leq 5; \quad 0 \leq Q \leq 5; \quad 0 \leq R \leq 5 \quad (12)$$

where 180 different combinations of inputs into ANN model is possible to create from the  $P, Q, R$  values. The simplest input combination is  $P=1, Q=0, R=0$  with differential equation  $y(t)=ff[y(t-1),u(t),ff(t)]$ , and the largest input combination is  $P=5, Q=5, R=5$ .

Usually, the more inputs into ANN are connected, the more accurate the model is. After few experiments, the combination with  $P=5, Q=3, R=5$  was selected.

As training data were selected two subsets of samples from both measurements (Fig.6) so that the complete training set contains 2000 samples to best characterize the dynamics of the system. The first set of data (from the first measurement) contains all samples between 2001 and 3000 and the second set of data (the second measurement) between 1 and 1000. These two subsets were merged into one training set.

For testing of each model, a whole set of data (both measurements separately) will be used to evaluate the model accuracy by the mean square error (MSE):

$$MSE = \frac{1}{N} \sum_{i=1}^N (X_i - Y_i)^2 \quad (13)$$

where  $N$  is number of samples,  $X_i$  is required model value,  $Y_i$  is output model value.

Based on (12), the ANN (Fig.6) was created using Neural Network Toolbox in Matlab-Simulink. It is a feed-forward ANN with back-propagation error. Created ANN consists of 15 inputs, where the input layer only distributes the input signals, the hidden layer contains 10 neurons, and the output layer contains one output neuron. Each neuron is connected to all other neurons in neighbor layers and each neuron has a threshold. The transfer function on the hidden layer is sigmoid (tansig) and the transfer function on the output layer is linear (purelin). The Nguyen-Widrow algorithm [2] is used to initialize weights and thresholds.

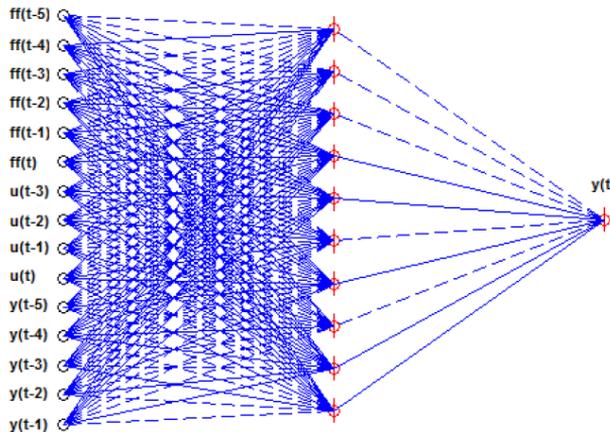


Fig.6. ANN structure.

Four learning algorithms [5] (all implemented in MATLAB-Simulink) were used to train:

1. Gradient descent with momentum backpropagation (traingdm).
2. Gradient descent with adaptive learning rate backpropagation (traingda).
3. BFGS quasi-Newton backpropagation (trainbfg).
4. Levenberg-Marquardt backpropagation (trainlm).

For each method, 10 training sessions were run, with the maximum number of epochs set to 1000. The average MSE for 10 sets of test data was used to evaluate (Tab.2) with the best rating for Levenberg-Marquardt backpropagation algorithm.

Table 2. Comparison of learning algorithms.

Algorithm	Average MSE for test data 1	Average MSE for test data 2
<b>Traingdm</b>	0.01395	0.00791
<b>Traingda</b>	0.00947	0.00582
<b>Trainbf</b>	0.00161	0.00066
<b>Trainlm</b>	0.00035	0.00011

The results obtained by ANN are acceptable, created models are able to approximate the current output value of the steam pressure for both measurements.

### A. ANFIS Model

This model was created using Fuzzy logic Toolbox [4]. For network training is used ANFIS hybrid learning method. Parameters in the antecedent of a rule (determining the input variability attributes) are optimized by a gradient method, the subsequence parameters (constants or linear function coefficients) are counted using the least squares (backpropagation) method. The number of inputs for this model has been reduced to five, due to the simplification of the ANFIS model (by experimenting, it was found to be unsuitable to have many inputs for this model).

Selected dynamic system is identified by function  $y(t) = f[y(t-1), u(t), u(t-1), ff(t), ff(t-1)]$ , that will be approximated by ANFIS structure.

The fuzzy system has to be initialized; Takagi-Sugeno method was chosen. The genfis3 method [4] was used to create the fuzzy model using the clustering technique. The number of clusters is adjustable and determines the number of rules and the number of membership functions. The best results were obtained by 3 clusters.

The next step is to define the learning parameters. The number of iteration is 100 and the tolerance (error) is  $10^{-6}$ . The last step is the learning process and the evaluation of the model accuracy on test data.

ANFIS model was tested for both test sets (first and second measurements). The red color is the ANFIS output and the blue color actual steam pressure value of the steam turbine (Fig.7).

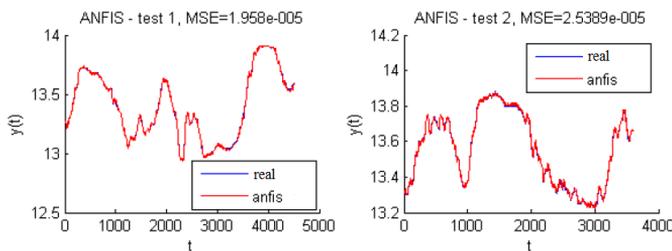


Fig.7. Comparison of ANFIS model with test data.

### B. Optimal Brain Damage

The Levenberg-Marquardt backpropagation method was used to train the ANN. After successfully performing of OBD algorithm (by removing the connection), the simplified network structure was obtained (Tab.3) as it is shown in (Fig.8).

The blue dotted line represents the negative weight value, the plain blue line means the positive value, the red circle is the neuron (if it is checked, its threshold has a nonzero value) and the individual inputs are represented by black circles.

The optimal ANN structure was obtained after 56 iterations.

Table 3. Comparison of ANN with OBD algorithm.

	ANN before optimization	ANN after optimization
<b>Number of connections</b>	160	17
<b>Number of inputs</b>	15	11
<b>Number of hidden neurons</b>	10	4
<b>Number of nonzero thresholds</b>	11	4

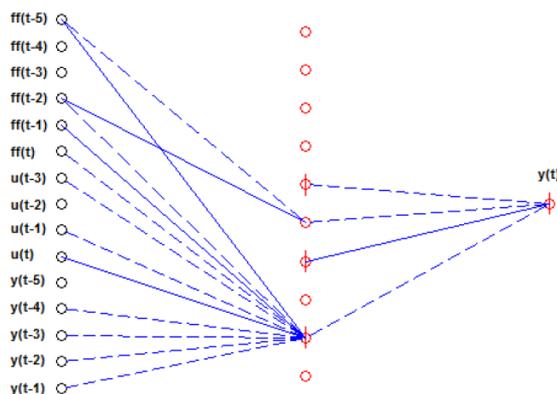


Fig.8. ANN structure after OBD algorithm.

### C. Optimal Brain Surgeon

After successfully performing of OBS algorithm (by removing the connection), the simplified network structure was obtained (Tab.4) as it is shown in (Fig.9).

The optimal ANN structure was obtained after 60 iterations and it is even simpler than the above-mentioned ANN, optimized by OBD algorithm.

Table 4. Comparison of ANN with OBS algorithm.

	ANN before optimization	ANN after optimization
<b>Number of connections</b>	160	17
<b>Number of inputs</b>	15	7
<b>Number of hidden neurons</b>	10	2
<b>Number of nonzero thresholds</b>	11	1

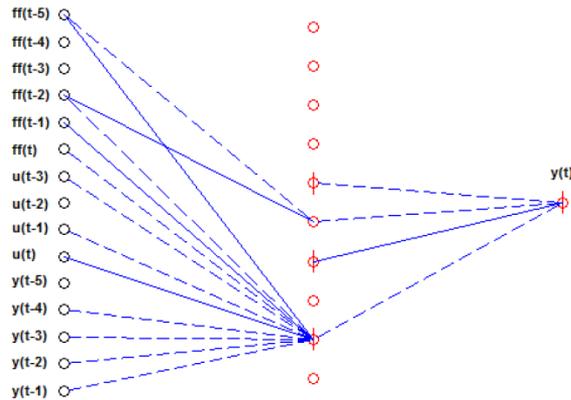


Fig.9. ANN structure after OBS algorithm.

#### D. Results

For a particular dynamic system, the steam turbine of the thermal power plant, four models were created. Each model is based on ANN.

The first model is a classical feed-forward ANN, the second one is an adaptive neuro-fuzzy model, and optimal structures of ANN were designed using two pruning methods (Optimal Brain Damage and Optimal Brain Surgeon). It has been confirmed that the proposed models are able to approximate the dynamic system, in our case study the output variable of steam pressure.

Obtained results are compared in (Tab.5). It is shown that the model accuracy is almost the same for all methods. However, the ANN model after OBS algorithm counts the lowest number of neurons and connections, this model obtained the best values of the model accuracy. These numbers are proof that ANN with optimal and incomplete structure can learn on a given set of data.

Table 5. Comparison of model accuracy.

Model	MSE 1 <sup>st</sup> test set	MSE 2 <sup>nd</sup> test set
ANN	$3.524 \cdot 10^{-4}$	$1.0698 \cdot 10^{-4}$
ANFIS	$1.958 \cdot 10^{-5}$	$2.5389 \cdot 10^{-5}$
ANN + OBD	$2.256 \cdot 10^{-5}$	$2.227 \cdot 10^{-5}$
ANN + OBS	$1.7896 \cdot 10^{-5}$	$1.7013 \cdot 10^{-5}$

#### Conclusion

Problems with a large number of neurons and connections in ANNs are huge; computational demands are high and a lot of time is needed to train the network. Conversely, if the number of connections in the network is too low, it does not have the power to provide the correct results for test examples. Therefore, the task is to find the correct relationship between network error and its complexity. Presented pruning methods for ANN optimization were used for approximation of any real dynamic system in energetics, e.g. for modeling a nuclear power plant in Jaslovské Bohunice. The result of these procedures is the exact model of a real dynamic system.

## ▲ Acknowledgement

This paper was supported by the Slovak Grant Agency VEGA 1/0819/17, and by the Scientific Grants APVV-17-0190 and SEMOD-79-2/2019.

## ▲ References

- [1] Babjak, J. (2003). *Hybrid inteligency* (In Czech) <http://www.root.cz/clanky/hybridna-inteligencia/>
- [2] Demuth, H., Beale, M. and Hagan, M. (2009). *Neural Network Toolbox™ User's Guide*. The MathWorks, Inc..
- [3] Bundzel, M. (2001). *Neural networks with adaptive topology*. University of technology, Kosice, Slovak republic.
- [4] Jang, R., Gulley, N. (2009). *Fuzzy Logic Toolbox™ User's Guide*. The MathWorks, Inc.
- [5] Norgaard, M. (2000). *Neural Network Based System Identification Toolbox*. Technical University of Denmark
- [6] Cigánek, J., Noge, F. (2014). *Fuzzy Logic Control of Mechatronic Systems*. In IEEE Int. conference on Process Control, Strbske Pleso, Slovak Republic.
- [7] Ghosh, J., Tumer, K. (1994). *Structural adaptation and generalization in supervised feed-forward networks*. In Journal of Artificial Neural Networks, vol. 1, no. 4, pp. 431-458.
- [8] Le Cun, Y., Denker, J. S. and Solla, S. A. (1990). *Optimal Brain Damage*. In Proceedings of Neural Information Processing Systems, pp. 598-605.

## ▲ Authors



### **Ing. Ján Cigánek, PhD.**

Faculty of Electrical Engineering and Information Technology,  
Slovak University of Technology in Bratislava, Slovakia  
[jan.ciganek@stuba.sk](mailto:jan.ciganek@stuba.sk)

He was born in 1981 in Malacky, Slovakia. He received the diploma and PhD. degree in Automatic Control from the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology (FEI STU) in Bratislava, in 2005 and 2010, respectively. He is now Assistant Professor at Institute of Automotive Mechatronics FEI STU in Bratislava. His research interests include optimization, robust control design, computational tools, SCADA systems, big data, and hybrid systems.



### **Ing. Filip Žemla**

Faculty of Electrical Engineering and Information Technology,  
Slovak University of Technology in Bratislava, Slovakia  
[filip.zemla@icloud.com](mailto:filip.zemla@icloud.com)

He is currently a student of doctoral studies at Slovak University of Technology in Bratislava. The main focus of his studies is oriented to virtualization and optimization of modern manufacture processes. His main skills are SCADA systems, database systems and front-end programming.

# DEMONSTRATIVE MODELING OF DISCRETE DYNAMIC SYSTEMS

Juraj Štefanovič

## Abstract:

---

*Modeling and simulation of discrete dynamic systems includes several basic principles. Here the principles of event-driven graphs, queueing systems and Petri-nets were chosen. Three simple implemented models for study and experimental purposes were created. These models are implemented as a short source code in C-language, including the simulation engine without any black-box parts for simple overview of everything from abstract principle to the bottom code. Simulation models can be extended but these simple examples can already produce complex behavior.*

## Keywords:

*Event driven graphs, queueing systems, Petri nets, discrete dynamic systems, practices in C-language.*

## ACM Computing Classification System:

*Modeling and simulation.*

## Introduction

Discrete dynamic systems are subject of study for many diverse purposes in technology of control systems and production management. Our intention was to create not too complicated models of discrete dynamic systems for study and education. First model is based on the principle of event-driven graphs, they were introduced by classical work [1] and explained in various sources, as for example [2], [4]. In our region is to mention the interactive graphic tool [3] which was based on the open-source C++ library “Tiny”. This library was created for study purposes, with relative rich content including event-driven structures, queues, simulation control modules, random number generators, etc. Second model here is an extension of the first one, including the principle of queueing systems. Queueing system is an abstract model with many practical representations and explanations wherever [5]. The third presented model is a simple representation of production line as an example of control with external events, they are given from the user and/or from automatic control which is constructed by Petri-net. Control systems based on Petri-nets are well known and studied, for example [6]. Our result here is the creation of easy to understand implementations of simulation examples, they are suitable for study and experimental purposes.

## 1 Event-Driven Model with Basic Implementation

To start with event-driven model, there is some very basic example of dynamic system: people are coming into entrance hall and a lift operates to take them away. Two different events occur in parallel, when model is running, see (Fig.1). **Event1** is that another person comes and increments the amount of waiting people. **Event2** is the operation of lift, which takes several people with and decrements the amount of people. Both events are scheduled itself repeatedly to run after some random number of timesteps. This model contains **event0** which runs only once at the very start of simulation to make first scheduling of events 1 and 2.

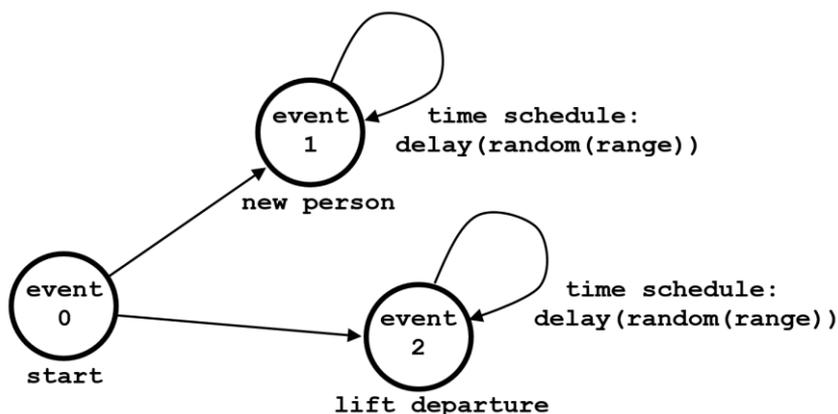


Fig.1. Event-driven system: persons are coming into entrance hall and lift operates.

An event-driven model as shown above can be implemented with the use of usual programming language, when the event-calendar is prepared. Event-calendar is a simple list of records {time, event}. Time is a number of simulation timestep when event (an identification number of event) is scheduled to run.

We use examples in C-language. Optimal implementation of the event calendar is some object in C++ with private data and public methods to enter and remove these data. For the purposes of basic C-language training, we can write each method as an individual function and the calendar data is some global structure of variables, static allocated in the easiest case:

```

void calendar_initialise(void);
// make empty queue of records in the calendar data structure

void calendar_print(void);
// dump contents of calendar records for debugging purposes

void event_schedule(int delay, int event)
// add the record {current_time + delay, event} to calendar

int event_cause(void)
// proceed the simulation_time to the next record {time, event}
// delete this record from queue and return the number event

```

The simulation loop is some kind of decision switch, what event is to execute at the next simulation step. This basic implementation can be extended deliberately with another events and more complicated behavior.

```

event_schedule(1,1); // first events must be scheduled
event_schedule(1,2);
while(simtime < maxtime) // simulation loop with some constraint
{
    event = event_cause(); // next event?
    printf("\ntime: %2d event: %d ", simtime, event);
    if(event==0) break; // empty calendar: stop
    if(event==1) event1();
    if(event==2) event2();
}

```

Having prepared the functionality of the event calendar, the model of entrance hall and a lift can be implemented in some first version as follows:

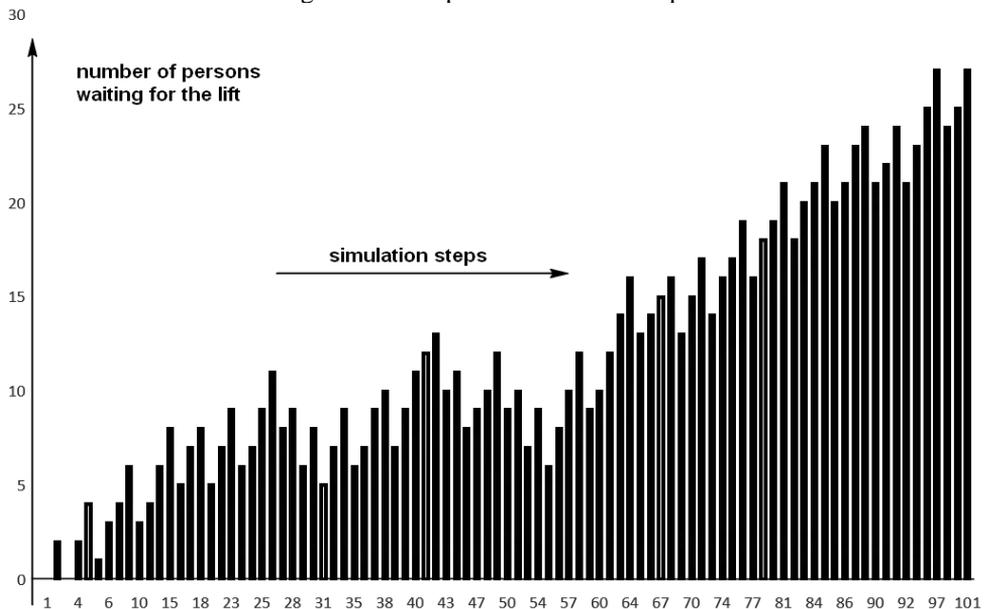
```

void event1(void)                // people are coming to the hall
{
    int i;
    i = get_random_number(1,3); // 1 - 3 persons come
    printf("persons came: %d", i);
    persons = persons + i;
    event_schedule(get_random_number(2,5),1);
    // this event 1 (next persons) returns after 2.- 5 timesteps
    return;
}

void event2(void)                // lift departures from the hall
{
    persons = persons - 3;
    if(persons < 0) persons = 0; // max 3 people enter the lift
    printf("lift is left, waiting persons: %d", persons);
    event_schedule(get_random_number(3,5),2);
    // this event 2 (lift) returns after 3 - 5 timesteps
    return;
}
    
```

Even though this mentioned model is simple with two not complicated events, the behavior might be interesting as well. On (Fig.2) there is an example of simulation run, which shows some sensitivity to random deviations. The number of waiting people can be relatively stable in some range of time, but an overflow may blow without prevision. Changing parameters of model with study of its stable and unstable behavior is possible.

Fig.2. An example of simulation output.



## 2 Model Extension with Queueing System

Previous model contained one queue of waiting persons, but that queue was interpreted in easy way as a set, containing only a number of persons without their ordering. The next model is extended with the implementation of queues. In (Fig.3) some *transactions* (persons, products, administration letters, data packets, etc.) are coming by **event1** and placed in order into first waiting **queueA**. Each transaction is represented as a unique integer. **Event2** is the activity of first service place, where some decision is made to what queue the current transaction is placed next. In this model, several parameters must be set in advance: arrivals of transactions, time of each service and the decision policy between **queueB** and **queueX**.

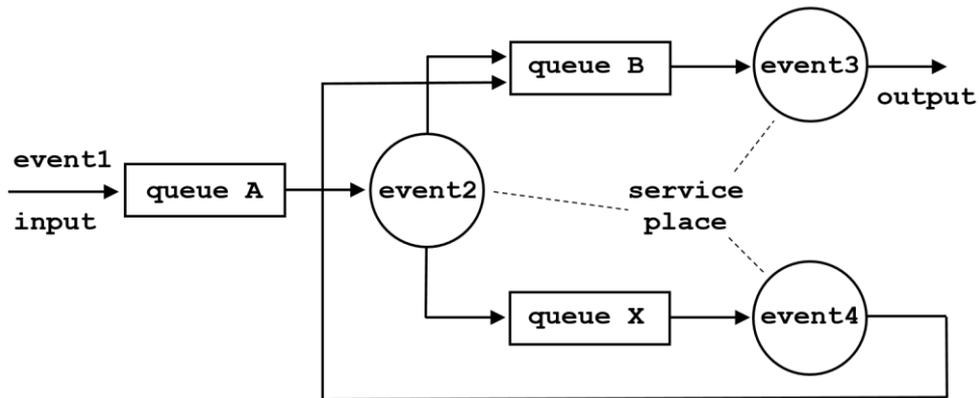


Fig.3. Queueing system with three queues and three service places.

Four events are implemented in similar way with scheduling statements as in previous model example. The **event2** makes some trivial decision where to put current transaction: if the number is even or odd.

```

void event1(void)           // transactions are coming to the queueA
{
    static int item = 0; item++; // each transaction as unique number
    (void)queueA(item);         // insert number into queueA
    event_schedule(10,1);      // next event1 in 10 timesteps
}

void event2(void)          // transactions are taken from queueA
{
    int item;
    item = queueA(-1);       // take an item from queueA
    if(item >= 0)            // if the queue is not empty
    {
        if(item % 2 == 0) (void)queueB(item); // put into queueB
        else               (void)queueX(item); // put into queueX
    }
    event_schedule(10,2);    // next event2 in 10 timesteps
}

```

```

void event3(void) // transactions are taken from queueB to output
{
    int item;
    item = queueB(-1); // take an item from queueB
    if(item >= 0) // not empty queue
        printf(" %d from B to out", item); // give some info
    event_schedule(10,3); // next event3 in 10 timesteps
}

void event4(void) {... // from queueX to queueB in similar way

```

An easiest way to implement queue (when somebody starts with C-programming) is to write a function with static array inside (`static int qu[]`) and with input and output using the function parameters and return statement. Negative numbers as parameters represent control input, positive numbers and zero are transactions being added into the queue.

```

int queueA(int insert)
// insert: 0..N insert a transaction as a number,
// -1 remove transaction and return it, -2 print, -3 initialize
{
    static int qu[LENGTH]; // queue as an array of numbers
    if(insert >= 0) ... // add transaction to the queue
    if(insert == (-1)) ... // remove transaction from queue
    if(insert == (-2)) ... // print the contents of queue
    if(insert == (-3)) ... // initialize (reset) the queue
    return(...); // transaction number or other information
}

```

Certainly, each queue must be implemented this way as a separate function. In C++, separate object instances will implement this task more effective. The simulation loop is similar as in the previous model:

```

while(simulation_time < maximal_time) // simulation loop
{
    event = event_cause(); // get event and shift time
    if(event==0) break; // empty calendar, stop
    if(event==1) event1();
    if(event==2) event2();
    if(event==3) event3();
    if(event==4) event4();
}

```

Behavior of this model is more complicated with more parameters then the previous model in the first part of paper. Experimental change of parameters allows to observe and study various effects. An example of observation, when parameters were setup as follows:

next event 1, 2, 3 and 4 were scheduled after 5, 6, 14 and 30 timesteps  
a decision in `event2: if(get_random_number(1,100) > 50)` put into `queueB`

Here is a state of queues **A**, **X**, **B** with waiting transactions in some simulation timestep. Some transactions are randomly selected to make delayed bypass around `queueX`.

```

queue A: 39,38,37,36,35,34 >>>
queue X: 33,32,31,28,23,22,21,19,18,16 >>>
queue B: 15,30,29,27,26,12,25,24,10 >>>

```

### 3 Production Line with Petri Net Control

The next model is event-driven with events generated from outside, by manual control and/or automatic control. Production line (Fig.4) consists from seven machines they can be switched on and off by commands. Two transporters and two operation places have predefined time duration to complete their action. Three feeders move objects from place to place and their action is completed instantly in one current timestep of simulation. Six sensors return binary information, whether an object is present/absent at given place.

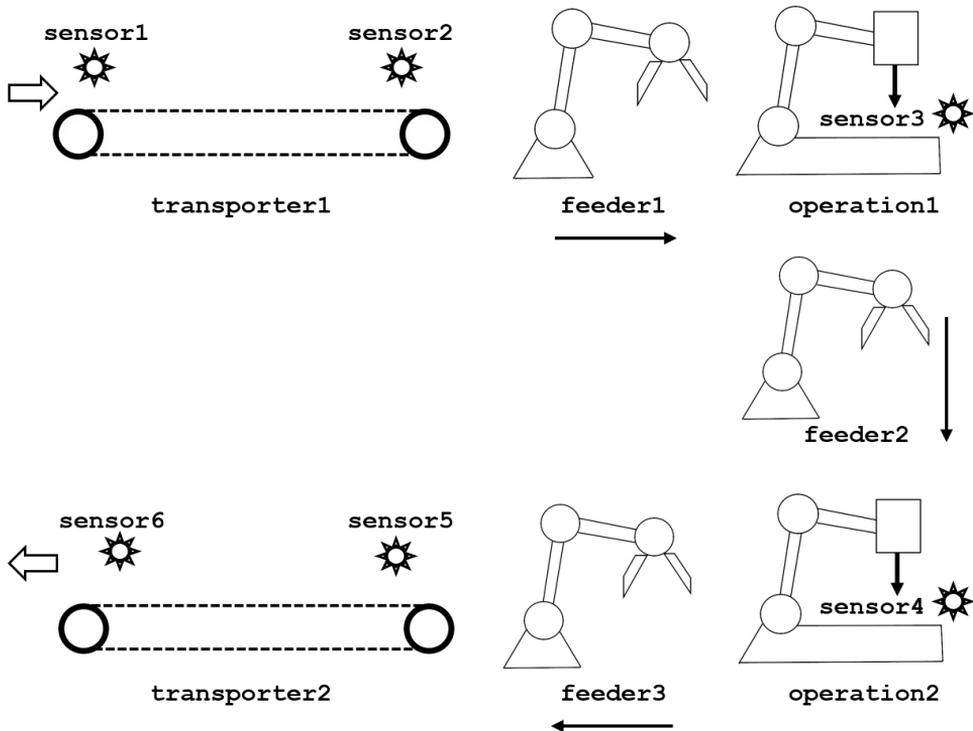


Fig.4. A production line model with 6 binary sensors and 7 machines under control.

This is the simulation loop:

```

link_reset();           // setup the data structure
while(1)
{
    link_timestep();    // decrement all counters of work
    printf("\n\n step %d: ", step++ );
    gets(line);        // read Enter key and command if any
    if(line[0]=='e') break; // the end, if command 'e'
    manual_control(line); // intervention of person if command
    automatic_control(); // intervention of automatic control
    sensors_output();
    link_print();      // show state (Fig.5)
}

```

On (Fig.5) there is a simple terminal-like visualisation of the state of production line. **Transporter1** is in state running, where **T1** denotes that an object (if the object was placed there) has finished his route on transporter. **Sensor2** confirms that there is an object at the end of transporter. **Transporter2** is running, **T4** means that an object (if the object was placed there) must move three timesteps of simulation, to reach the state **T1** being at the end of transporter. **Sensor5** and **sensor6** are placed at both edges of transporter, not any object is there. **Operation2** contains an object, **sensor4** gives confirmation and **T3** means that two timesteps of operation are needed to complete the work and reach the state **T1** = work completed, object present. When the **feeder3** takes this object away, **operation2** comes to the state **T0**.

```

step 0:
control tokens: 1 0 0 0

  sensor1  transporter1  sensor2
  ( ) =====> T1 >===== (*)
  empty    running      present

                        v
                        v
feeder1 > > > operation1  sensor3
              (T0) ----- ( )
              stop         empty

                        v
                        v
                        feeder2

                        v
                        v
feeder3 < < < operation2  sensor4
              (T3) ----- (*)
              running      present

                        v
                        v
sensor6  transporter2  sensor5
  ( ) =====> T4 >===== ( )
  empty    running      empty

step 1: (insert command here if needed, press Enter)
    
```

Fig.5. State of production line model as shown on text output.

Using this terminal-like interface, the production line can be controlled by these commands. At any timestep of simulation, only one command can be entered via terminal.

```
void manual_control(char *line)
{
    if(line[0]=='i') insert_object();// to the first transporter
    if(line[0]=='t') take_object(); // from the second transporter
    if(line[0]=='p' && line[1]=='1') action_feeder1();
    if(line[0]=='p' && line[1]=='2') action_feeder2();
    if(line[0]=='p' && line[1]=='3') action_feeder3();
    if(line[0]=='d' && line[1]=='1') transporter1_on-off();
    if(line[0]=='d' && line[1]=='2') transporter2_on-off();
    if(line[0]=='o' && line[1]=='1') operation1_on-off();
    if(line[0]=='o' && line[1]=='2') operation2_on-off();
}
```

A data structure contains the whole state information of the production line:

```
struct production_line
{
    // sensors in state: object present/empty
    int sensor1; ...

    // transporters in state: stop/run
    int transporter1; ...

    // object on transporter:
    // 0 - absent, 1 - at the end, N - at the start,
    // N = decremented number of transport steps until 1 (finished)
    int transporter1_object; ...

    // operation in state: stop/run
    int operation1; ...

    // the operation place contains object:
    // 0 - absent, 1 - present, operation finished,
    // N = decremented number of operation steps until 1 (finished)
    int operation1_object; ...
} link;
```

An example of action: feeder takes and inserts the object. Some error-detection is included into the code.

```
void action_feeder1(void)
// feeder completes his action at current simulation step
{
    if(link.transporter1_object != 1)
        { printf("\n error: object not found at the end"); return; }
    if(link.operation1_object > 0)
        { printf("\n error: feeder1 disturbs operation1"); return(); }
    link.transporter1_object = 0; // take object from transporter
    link.operation1_object = N; // insert into operation for N steps
}
```

An automatic control is constructed with the scheme of Petri net. On (Fig.6) there is a part of control scheme related to first transporter and feeder. When this example is used by practice lessons, students have to complete the control scheme to get some consistent solution. Using basic programming in C, the presence of tokens at all places of Petri net is saved into static array `place[4]`.

```

void automatic_control(void)
{
    static int place[4] = { 1, 0, 0, 0 };
    // initial number of tokens in Petri net places

    if(place[0] == 1) // if token at place1
        if(link.sensor1 == 1) // if condition is true - object present
        {
            action_transporter1(); // transporter on
            place[0] = 0; // get token from previous place
            place[1] = 1; // put token to the next place
        }

    if(place[1] == 1) // if token at place2
        if(link.sensor2 == 1) // if condition is true - object present
        {
            action_transporter1(); // transporter off
            place[1] = 0; // get token from previous place
            place[2] = 1; // put token to the next place
        }

    etc...
}

```

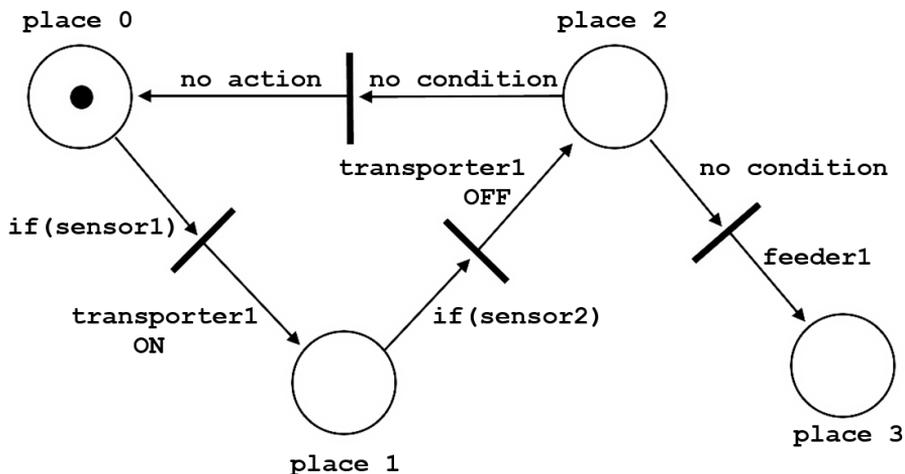


Fig.6. Petri net which controls first two machines from the model above.

## Conclusion

Three examples of simple modeling with discrete event systems are presented. They were created for teaching and study purposes with following features:

- the whole model including the simulation engine is written in relative short source code using C-language, students can see the complete connection between an idea on the top (event-graphs, queue schemes, Petri-net) and the code on the bottom,
- there is not any black box inside, not only abstract training how to setup items on the screen and to press button to get simulation results,
- these models can be extended in any way, the code permits any change and extension
- despite of simplicity, small models are able to manifest complex or less predictable behavior, which is very instructive.

## References

- [1] Schruben, L.: Simulation Modeling with Event Graphs. *Communications of the ACM*, Volume 26, Number 11, November 1983, pp. 957-963. <https://doi.org/10.1145/182.358460>
- [2] Leemis, L. M., Park, S. K.: *Discrete-Event Simulation: A First Course*. Upper Saddle River: Pearson Prentice Hall, 2006. 604 s. ISBN 0-13-142917-5.
- [3] Šafařík, J., Netri, A., Solčány, V.: EGRET - Event Graph Editor and Simulator. 16th European Simulation Multiconference, ESM 2002, Darmstadt, Germany. In: *Proceedings of the 16th European Simulation Multiconference on Modeling and Simulation 2002*, ISBN 978-90-77039-07-6.
- [4] MathWorks®, Help Center, *Create a Discrete-Event Model*. Online 8.2020. <https://www.mathworks.com/help/simevents/gs/create-a-discrete-event-model.html>
- [5] *Queueing Systems, Theory and Applications*. Springer. ISSN 1572-9443/0257-0130. Online 8.2020 <https://www.springer.com/journal/11134>
- [6] Giua, A., Seatzu, C.: Petri nets for the control of discrete event systems. Springer, *Software & Systems Modeling* 14, 693–701 (2015). <https://doi.org/10.1007/s10270-014-0425-1>

## Authors



**Ing. Juraj Štefanovič, PhD.**

Faculty of Informatics, Pan-European University, Bratislava, Slovakia  
[juraj.stefanovic@paneurouni.com](mailto:juraj.stefanovic@paneurouni.com)

## List of Reviewers

### Issue 1/2020, in alphabetic order

Cigánek, J. - Slovak University of Technology in Bratislava, Slovakia

Képešiová, Z. - Slovak University of Technology in Bratislava, Slovakia

Kozáková, A. - Slovak University of Technology in Bratislava, Slovakia

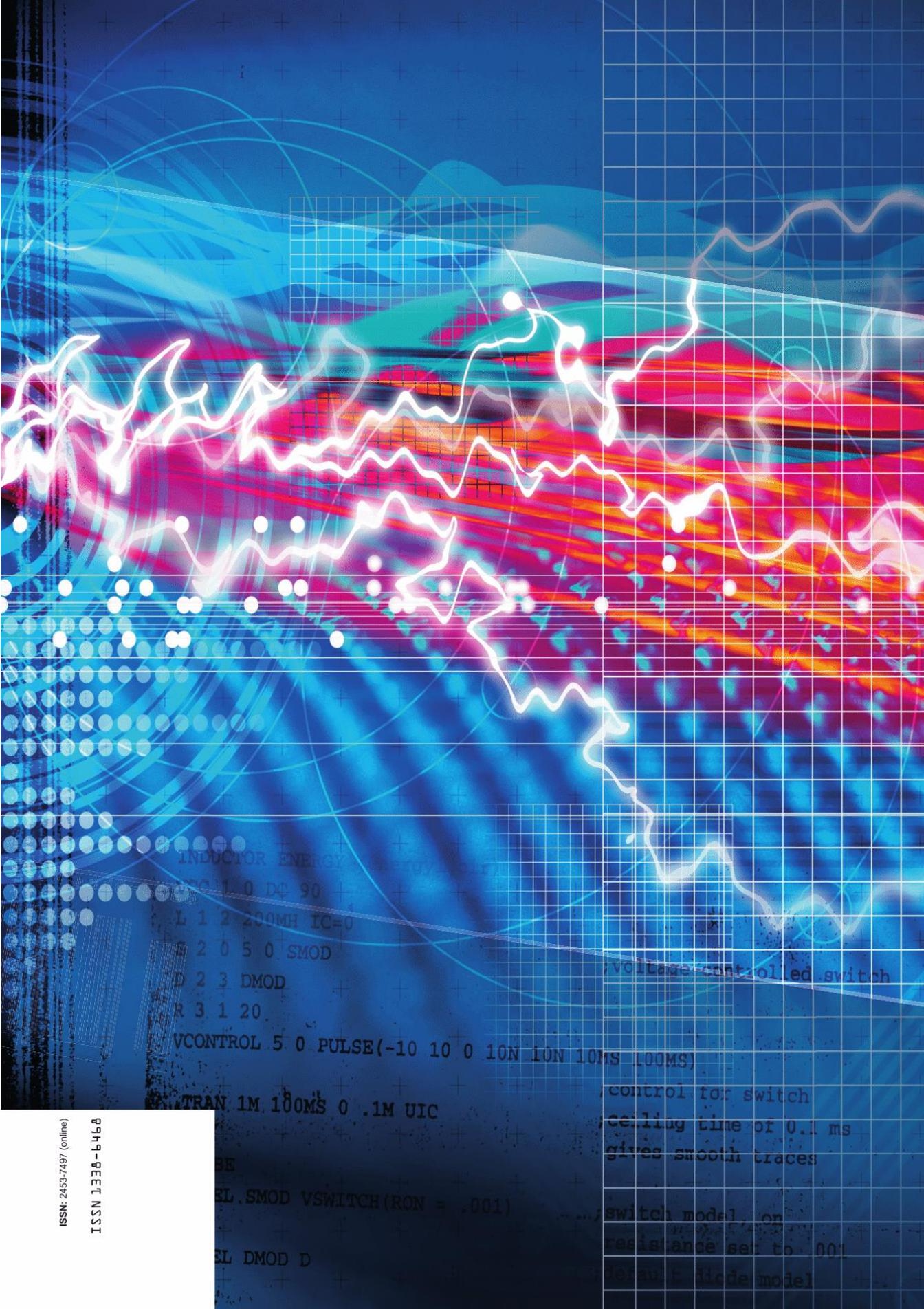
Kozák, Š. - Pan-European University, Bratislava, Slovakia

Lacko, J. - Pan-European University, Bratislava, Slovakia

Grellneth, I. - Student Technology Center, Cisco Netacad, Slovakia

Rosinová, D. - Slovak University of Technology in Bratislava, Slovakia

Ružický, E. - Pan-European University, Bratislava, Slovakia



INDUCTOR ENERGY

Q 1 0 D1 90

L 1 2 200MH IC=0

R 2 0 5 0 SMOD

D 2 3 DMOD

R 3 1 20

VCONTROL 5 0 PULSE(-10 10 0 10N 10N 10MS 100MS)

TRAN 1M 100MS 0 .1M UIC

voltage-controlled switch

control for switch

falling time of 0.1 ms  
gives smooth traces

switch model, on  
resistance set to .001

default diode model