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RESEARCH ARTICLE

BME VIK Annual Research Report on Electrical Engineering and Computer Science 2015

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Preface

Throughout her more than 200 years of existence, one of the major missions of the Budapest University of Technology and Economics is to spearhead modern technological developments. This is especially true for the Faculty of Electrical Engineering and Informatics (VIK), where the only way to pursue excellence is to be the regional leader in research and development in the quickly changing fields of electronics, IT and computer science.

In order to maintain the level of excellence, innovative solutions and expertise are needed where engineering applications are combined with sound scientific results. Therefore, the faculty has its strength both at applied and at basic research. This research potential is connected to the international academic and industrial networks, i.e. VIK is actively participating in various communities, clusters and innovation networks. Because of the high scientific quality of the staff, several departments and research groups are represented in key international and national communities and innovation networks.

The long lasting collaboration with our industrial partners has made it clear that the industry expects methods and results, which make their processes more effective and increase productivity and quality. Being present as an active partner in key research and innovation areas, highly contribute to the competitive edge and continuous development of VIK. These factors have positioned VIK as a significant source of knowledge transfer and a treasured partner in various cooperation activities.

The current paper gives a brief account of the results achieved at the Faculty of Electrical Engineering and Informatics in the year 2015 and, at the same time, tries to encompass the research activities conducted at different departments.

As a result, each individual section introduces a department and summarizes the corresponding results. This organization of the paper is also in accordance with our view, that the strength and excellence of the faculty originates from the innovative research groups working at departmental level. Hence, these teams, departments and their various expertise amount to make VIK a leading organization in ICT.

In this light, we believe that this paper proves to be an informative summary about our scientific and technological contributions made in the year 2015.

László Vajta, Dean of BME VIK
János Levendovszky, Deputy Dean of BME VIK

1 Department of Automation and Applied Informatics

Department of Automation and Applied Informatics (AUT) is one of the largest and dynamically developing departments at BME with diverse scope competences such as control theory, embedded systems, software modelling, applied software development, Internet of Things, power electronics, mechatronics, and many others. The department's main activities are education, research and development. Training versatile electrical and software engineers with solid practical knowledge is our top priority. Our profile also includes developing high quality software and hardware solutions for industry partners. All of our activities are backed by strong research background.

In 2015, the department has organized the 21st European Wireless (EW) Conference. The EW 2015 conference hosted more than 140 participants from 30 different countries. The 2015 edition of EW was aimed at addressing a key theme on "5G and beyond."

The next sections summarize the key research results of the department in year 2015.

1.1 IoT and Smart City

The Internet of Things (IoT) is transforming the surrounding physical objects into an ecosystem of information that enriches our everyday life. The IoT represents the convergence of advances in miniaturization, wireless connectivity, and increased data storage, and is driven by various sensors. Application and service development methods and frameworks are required to support the realization of solutions covering data collection, transmission, data processing, analysis, reporting, and advanced querying. Our *SensorHUB* framework

utilizes the state-of-the-art open source technologies and provides a unified tool chain for IoT related application and service development. *SensorHUB* is both a method and a research accelerator environment to support IoT related application and service development. [1]

In the context of two EIT (European Institute of Innovation & Technology) Climate-KIC [2] projects we utilize the *SensorHUB* framework. These Climate-KIC projects are referred to as URBMOBI and SOLSUN.

The **URBMOBI (Urban Mobile Instruments for Environmental Monitoring)** project integrates a mobile measurement unit that operates on vehicles in urban areas (i.e., local buses and trams), with data postprocessing, inclusion in enhanced environmental models and visualization techniques for climate-related services, environmental monitoring, planning, and research needs. [3]

URBMOBI is a mobile environmental sensor that (i) provides temporally and spatially distributed environmental data, (ii) fulfills the need for monitoring at various places without the costs for a large number of fixed measurement stations, (iii) integrates small and precise sensors in a system that can be operated on buses, trams, or other vehicles, (iv) concentrates on urban heat and thermal comfort, and (v) aims at providing climate services and integration with real-time climate models.

URBMOBI project has been worked out between 2013 and 2015 by the following consortium: RWTH Aachen University (Germany), Netherlands Organization for Applied Scientific Research TNO (Netherlands), ARIA Technologies (France), Budapest University of Technology and Economics (Hungary), and Meteorological and Environmental Earth Observation (Italy).

The **SOLSUN (Sustainable Outdoor Lighting & Sensory Urban Networks)** project is about to demonstrate how intelligent city infrastructure can be created in a cost-effective and sustainable way by reusing existing street lighting as the communications backbone. We apply different technologies and methods to reduce energy consumption at the same time as turning streetlights into nodes on a scalable network that is also expandable for other applications. Sensors capture data on air pollution, noise pollution, and traffic density; gathered information is used to address traffic congestion, a key contributor of greenhouse gas emissions in cities. [4]

SOLSUN project develops an integrated technology platform where several components of the SensorHUB framework and the knowledge of the SensorHUB team are utilized. The project brings together a strong core of public, private, and academic partners with the combined expertise to develop outcomes that can be exploited on a global scale. The project is carried out between 2015 and 2017 by the following partners: Select Innovations Limited (UK), British Telecommunications Plc. (UK), Municipality of the City of Budapest (Hungary), PANNON Pro Innovation Services Ltd. (Hungary), and Budapest University of Technology and Economics (Hungary).

1.2 Quality-assured model-driven requirements engineering and software development

Software development requires adequate methods for requirements engineering, design, development, testing, and maintenance. The more complex the system is, the more sophisticated methods should be applied. Without appropriate development methods, projects may turn into ad-hoc design and development decisions.

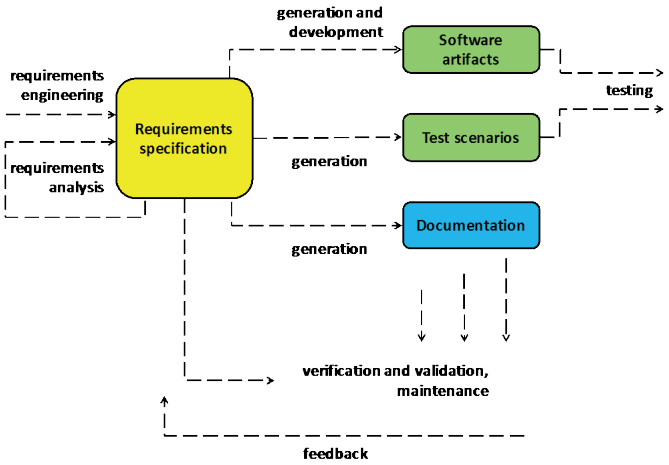

Fig. 1 Quality Assured Model-Driven Requirements Engineering and Software Development

Within the framework of a national project with an industrial partner, we developed a quality-assured model-driven requirements engineering and software development method. It is based on the modeling of the software requirements in a way that these models can be used to automatically generate several artifacts during the engineering process. This method has been continuously developed during the last ten years driven by our software projects and by the experience and lessons learned from these projects. In the last two years, we have developed a supporting tool and reworked the method. The method provides a framework to specify software requirements with four domain-specific languages and automated methods to process the models. The project also collected and shared our best practices on the field of model-driven requirements engineering and software development. [5]

1.3 Mobile platforms, multi-mobile platform development and distributed storage

Mobile devices and mobile applications have a significant effect on the present and on the future of the software industry. The capabilities of mobile phones enable running complex and even network intense solutions on them. In [6] we have provided detailed statistics about our peer-to-peer solution on Android platform. In addition to that, the multimedia hardware on phones like the camera allows implementing special solutions. In [7], we have investigated the possibility of augmented sensing with the camera and we have shown a special method for orientation estimation.

The diversity of mobile platforms necessitates the development of the same mobile application for all major mobile platforms, what requires considerable development effort. Mobile application developers are multiplatform developers, but they still prioritize the platforms, therefore, not all platforms are equally important for them. Appropriate methods, processes and tools are required to support the development in order to achieve better productivity. The main motivation of this research activity is to provide a method, which increases the development productivity and the quality of the applications, and reduces the time to market. The approach provides significant model-driven results on the field of multi-mobile platform development. [8, 9, 10]

Traditionally, distributed storage systems have employed replication to ensure high data availability. However, the high storage cost associated with it has seen a shift towards erasure coded storage, especially for rarely accessed data. This presents a significant challenge for version control systems. Even a small change in the original data can affect a segment of the erasure-coded data that is several orders of magnitude larger. Furthermore, erasure codes must be prepared to adapt to changes in the number of storage nodes or their connectivity.

Our solutions [11] address both issues by creating sparse representations of changes in the erasure-coded data. Our technique can be applied for a wide variety of linear codes. We have also created a set of algorithms to maximize data retrieval performance while ensuring high availability. These algorithms efficiently adapt data distribution to the state of the distributed storage system and take advantage of the flexibility of random linear network codes.

1.4 Biofeedback, adaptive learning and image processing for marble thin section analysis

Research on educational games that adapt to the mental state of the user requires multidisciplinary approach. The expected goal is a flexible framework to monitor game-user interaction and the progress of students while they engage in playing educational games on mobile devices [12]. The player is influenced by rewards, scoring, game difficulty or *minigames* that are suggested by the framework.

Within the AdaptEd project, we use various inexpensive wearable wireless sensors: electroencephalography (EEG), electrocardiography (ECG) and pupillometry. The educational games are loosely coupled to a software framework running on the same device. Every game session and corresponding user information is stored in a backend environment. Using an advanced graphical interface, screenshots, game events, rewards and sensor values are displayed simultaneously and in sync on the same graph. Teachers can connect to one or more players; the supervisor has its own graphical user interface that runs on a different mobile device [13]. The supervisor is able to observe game events (e.g. scores, screenshots, response time) and user activities (e.g. sensor data, mental effort markers) online without any interruption of the interaction.

GrainAutLine [14] is an image processing application designed for the analysis of marble thin section images. Several applications in geology and archeology like provenancing and geomorphologic analysis requires the location and shape of the exact grain boundaries. Due to the lack of proper automation, these are usually identified manually, which is a very time consuming task. GrainAutLine is a tool designed for semi-automatic image analysis: several domain specific tools help the user mark the boundaries. To ensure high quality results under all conditions, the user has options to partially override or modify the results after every step.

1.5 Power engineering – power converter optimization technology

Facing the actual economic situation together with the unavoidable depletion of fossil energy used as fuels in internal combustion engines, developing new types of propulsion systems has become an urgent issue for the car industry. Currently, two approaches dominate research and development in this exciting technological field: (1) biofuels-based internal combustion engines, and (2) electrical propulsion chain integrating systems including hybrid drive train-chain configurations.

For electric vehicles to appear on the roads, a significant improvement in infrastructure, such as chargers (AC, DC) or cooperation of supervising technologies and a dynamic standardization system is required. Current solutions can only satisfy the requirements related to sporadically placed chargers over relatively wide geographical areas. Finding a solution to the arising set of problems is a target of the cooperation of Siemens and the Budapest University of Technology and Economics with the goal to create an optimized technology of drive chain, inverter and battery charger system. Utility grid power quality requirements prescribe sinusoidal active current to be drawn from/or fed-into the AC network, with the harmonic limited to typically 5 % Total Harmonic Distortion (THD) and limited network support requirements. With the increasing number of electrical vehicles, a conclusion can be drawn: new requirements for the regulation of reactive power control and harmonic compensation will arise. The technology should reduce current THD by at least 1-2 % and intelligently handle cooperating e-Vehicle chargers to manage the arising power quality problems. The technology should also take its part in optimization of reactive power management and reducing the time-to market of the different solutions. [15]

1.6 Mechatronics

With regard to mechatronics area, we cover the control of power wind energy conversion systems, ultra high-speed self-excited induction generators, and protein-based computing architectures.

Many trends are becoming apparent in electric distribution driven from both the demand side, where better reliability and efficiency are desired, and from the supply side, where the integration of generation from renewables and peak shaving has to be accommodated. One main trend is the application of wind generators together with other measures to counterbalance their intermittency power production. They can work in parallel with the network or sometime with the microgrid. Our research results are related to the nonlinear properties of wind energy conversion systems applying doubly fed induction generator (DFIG). As a new scientific contribution, a general slip–torque relation is derived with three torque components: one component is derived by the stator voltage, the other component by the *d* component, and the third component by the *q* component of the rotor voltage space vector. [16]

In the past decades, significant efforts have been focused on the development of high and ultra high-speed electrical machines resulting in high performance and economical electrical drives. The same type of electrical machines can be applied not only in motoring mode of operation but they can also be used as induction generators. We have realized the great potentials of applying high-speed technology in the field of Distributed Generation Systems (DGS). [17]

We have concluded that one of our solutions based on the application of space vector theory and applying switched capacitors, offers a promising technology particularly in the field of high-speed energy conversion in systems developed for harvesting renewable energy sources and utilizing waste energies.

Several studies examined the possibility of novel electronic devices that could provide more advantageous alternatives to contemporary microelectronic architectures. Proteins are potentially promising units of molecular electronics-based circuits due to their low cost, excellent self-assembling properties, large variety of characteristics, and that artificial proteins with the desired properties can be developed. We have suggested a novel approach for the realization of protein-based logic architectures potentially suitable for nanometer-scale computing and digital signal processing. [18]

1.7 Summary

BME AUT believes that innovation is the result of teamwork, when scientists and engineers work together, and creativity is the result of drawing inspiration from several sources. The real power is the harmonized team, members from various fields with different background and experience, working together on a specific problem. This motivates us to utilize the knowledge and capabilities of scientists and engineers from various fields of computer sciences (modelling, simulation, software design, development methodologies, data analyses, architecture, and others), i.e. let them work together to inspire each other and support the innovation.

2 Department of Electronics Technology

Electronics technology is one of the most rapidly progressing fields of engineering science. In this multidisciplinary field, new materials and technological procedures appear year by year, immediately becoming an important and indispensable part of the common electronics assemblies. The innovations increasingly demand precise, fast and cheap production technologies. The Department of Electronics Technology (ETT) would like to give a short overview of the latest basic and applied researches in electronics applications and technologies, which point to innovations in the near future.

The researchers of ETT participate in international R&D projects sponsored by the European Union (FP7, H2020, Leonardo) and collaborate with numerous industrial partners (Bosch, Flextronics, Continental, etc.). Our short overview focuses on the following fields:

- application of surface plasmon resonance – generated on both thin films and on nanostructures;
- synthesis of nanostructures, and the application of localized surface plasmons (LSP);
- novel selective electrochemical sample preparation method to remove the tin from a cross-section of a solder joint;
- quantitative analytical method for the characterization of the exposed microstructure of solder joints;
- characterizing the electrochemical migration behavior of the novel micro-alloyed low Ag content solders;
- effect of current load on corrosion induced tin whisker growth from SnAgCu solder alloys;
- investigating thermomechanical properties and formation of intermetallic layers of various lead-free SnAgCu solder alloys;
- numerical and experimental study of the Vapor Phase Soldering (VPS).

2.1 Micro- and nanoscale material characterizations

In the recent years, the focus of the Nanotechnology Laboratory of ETT was the application of surface plasmon resonance (SPR) – generated on both thin films and on nanostructures – for various applications. The most important result in this area (working together with the Biochemical Department at University of Bologna, Italy, and with the Institute of Bioengineering at EPFL, Lausanne, Switzerland) was the confirmation and validation of a method called hybridization chain reaction (HCR) which can be used for the in-situ signal amplification of DNA (deoxyribonucleic acid) based biosensors. Utilizing a custom-built SPRi (surface plasmon resonance imaging) instrument, the group from BME-ETT confirmed a nearly 5x increase in the target binding signal using HCR. This resulted in a detection limit of 100 pM for the target-DNA, which was a specific DNA sequence of Giardia (a known water parasite) [19].

Besides the classical SPR on thin films, the work was also focused on the synthesis of nanostructures, mostly gold nanoparticles, and the application of localized surface plasmons (LSP) excited on them. As part of a cooperation with the University of Debrecen and ITMO University, St. Petersburg, Russia, it was recently confirmed, that the application of gold nanoparticles as additives in acrylate polymer composite systems can positively influence the photo-polymerization process. The same SPRi instrument enabled the real-time monitoring of the polymerization and the influence of the plasmon filed of the gold nanoparticles on the kinetics under various illumination conditions [20]. The current work focuses on the application of localized surface plasmon resonance (LSPR) on gold nanoparticles for biosensor purposes. The optimization of nanoparticle synthesis and sensor-chip fabrication are in the focus.

In the field of ***failure analysis of electronic assemblies,*** it can be concluded that the quality of a solder joint is an important reliability concern. Yet there is no standardized way of characterizing the solder joint according to their metallographic properties.

The mechanical properties of a solder joint are partially determined by the microstructure of the solder alloy. This microstructure is formed during the soldering process and it can highly depend on the technological parameters. A new selective electrochemical sample preparation method was introduced, in which the tin phases can be removed from a cross-section of the solder joint, while the intermetallic phases may remain intact [21]. The interpretation of the spatial information gained by the observation and characterization of the exposed microstructure can be fundamental in the comparison of different solder joints. The optimized selective electrochemical method is now included in the inventory of the Failure Analysis Laboratory of the department. A quantitative analytical method was also developed for the characterization of the exposed microstructure, where the electrochemical impedance spectra (EIS) are measured before and after selective etching process [22]. The complex impedance spectra contain information about microstructure of the solder alloys. Comparison and modelling of two EIS spectra allow obtaining a quantitative parameter describing the surface structure of the etched specimens. The applicability of the combination of the selective etching and EIS to characterize the lead free solder was confirmed with small angle neutron scattering recently.

The possibility of the quantitative analysis of tin-silver based solder alloys is very valuable, as the deeper understanding the correlation of the technological parameters and microstructure is essential for proper optimization of the soldering process. The correlation between the macroscopic properties and the character of the microstructure is important from reliability point of view.

Comparative analyses were also performed in another research concerning various lead-free SAC (Sn96.5Ag3Cu0.5, Sn95.5Ag4Cu0.5) and two types of micro-alloyed SAC (SnAgCu+Bi+Sb) solder alloys from the viewpoint of thermo-mechanical properties and formation of intermetallic layers [23]. A test board was designed containing 0603 size resistors, and the samples were soldered with vapor phase soldering [24] in the experiment. Then, the samples were subjected to Thermal-Shock (TS) lifetime tests with a temperature range of +140 – -40 °C up to 2000 cycles. The intermetallic layer (IML) formation was investigated with Scanning Electron Microscopy (SEM) and Scanning Transmission Electron Microscopy (STEM) (Fig. 1); the growth of the layer was analyzed by measuring the IML thickness on cross-sectional samples after given TS cycles.

Concerning the results, the thickness of the intermetallic layers on the as-reflowed samples increased with the decreasing Ag content. The adsorbing Ag_3Sn IMC grains can explain the observation, while they can obstruct the growing of the IML; if the Ag content in the solder is higher, more Ag_3Sn IMC can adsorb thus, thinner IML can form. Contrary, the Thermal Shock tests showed that the growth rate of intermetallic layers was increasing with the increasing Ag content. This can be explained by the different rate of grain-boundary diffusion of Cu atoms between the scallops of the intermetallic layer, and there could be less grain boundaries in micro-alloyed solders. This assumption was proven by analyzing polarized optical microscopy images. To conclude the research, it was shown that the micro-alloyed solders have the same or better thermo-mechanical properties compared to the traditional SAC alloys along with reduced occurrence of large, plate-like Ag3Sn intermetallic compounds. Therefore, the most prevalent failure mechanism in today's high integrity packages (µBGA – Ball Grid Array), the shrinkage defect can be eliminated.

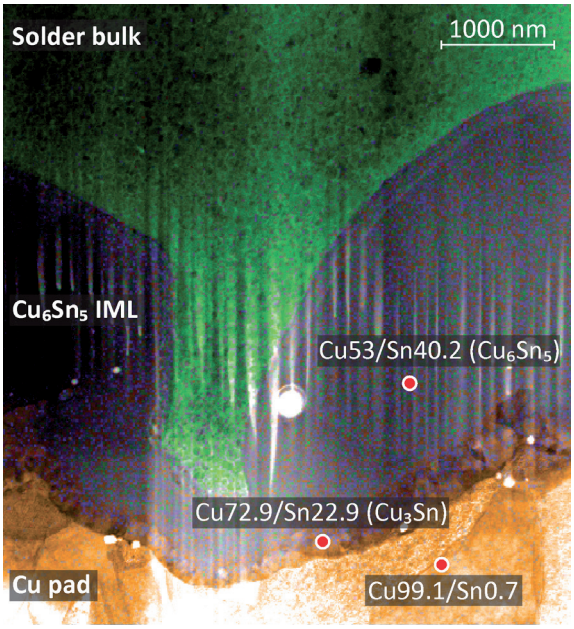

Fig. 2 Structure of the intermetallic layer of sample mSAC2, (the indicated percentages are atomic%).

2.2 Reliability and quality of electronic assemblies

The common characteristics of the electrochemical migration (ECM) phenomenon include the presence of moisture on conductor-dielectric-conductor systems under bias voltage, the electrochemical process and the metallic dendrite growth. This effect causes short-circuits in the electronic circuits, which may lead to failure.

One of the aims focused on the ECM behavior of the micro-alloyed solders with low Ag content (e.g.: Sn98.4Ag0.8Cu0.7 (SAC0807) and 0.1 % of other alloying elements. Dendrites were investigated by Transmission Electron Microscope (TEM). Usual methods used for TEM sample preparation such as Focused Ion Beam (FIB) and ultramicrotomy of dendrites cast in FR4 were attempted, however, due to the very fragile nature of the dendrite structure and poor adhesion between dendrite and FR4 the results were not completely satisfactory. In this investigation, a simple method was adopted in which the dendrite was carefully transferred onto the molybdenum TEM-grid. Since the dendrite thickness was at ~100 nm scale, it was found that it could be directly analyzed by TEM without any post sample preparation procedure. The procedure of sample preparation contains four steps; (1) Removing the dendrite by using scotch-tape; (2) Positioning the dendrite onto the Mo micro-grid; (3) Immersing them into toluene for several hours; (4) Pick up the sample from toluene; then the sample is ready for TEM investigation [25]. In Fig. 2, STEM micrographs of a dendrite can be seen using the above mentioned sample preparation method.

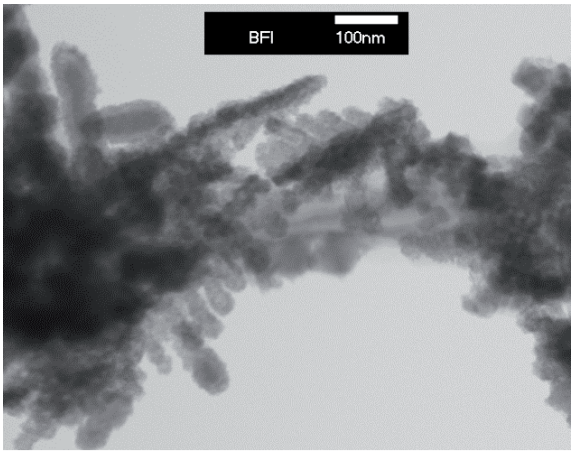

Fig. 3 TEM picture of dendrites formed from SAC0807

According to the results, a micro-alloying element (antimony) has participated in the electrochemical processes. The presence of antimony is an unexpected result, since there are no reports about it in the ECM literature [25].

Tin whiskers (Fig. 3) are surface eruptions of the pure – and in some circumstances alloyed – tin layers [26]. Their usual size is 1-20 µm in diameter and 5-500 µm in length. Tin whisker growth is a serious reliability problem of microelectronic devices since whiskers result in short circuits between the conducting parts of the electronics. Tin whisker formation is caused by the development of mechanical stresses in the tin layer, such as residual stresses of the electroplating; direct mechanical load; volumetric expansions of the tin layer by intermetallic and/or oxide layer growth, or temperature change. Whiskers are extruded from the tin layer by a stress release mechanism.

The effect of current load was investigated on corrosion induced tin whisker growth from three different SnAgCu (SAC) solder alloys [27]. The prepared solder joints were loaded with six different DC current levels between 0–1.5A and they were aged in corrosive environment (85°C/85RH%) for 3000h. It was proven that the corrosion climate can effectively indicate tin whisker growth by the corrosion of the solder joints. The increase of the current load has decreased the spatial corrosion depth, which resulted in lower mechanical stress in the upper region of the solder joints and finally decreased the number of tin whiskers considerably. The decrease of the spatial corrosion depth due to the current load can probably be explained by the following: in the case of biased samples, the applied voltage source is also providing electrons for the reduction processes at Cu cathode. Therefore the oxidation will be slower at the Sn anode and thus the corrosion mechanism produces a relatively thinner oxide layer at the upper region of the solder joints compared to the unbiased cases.

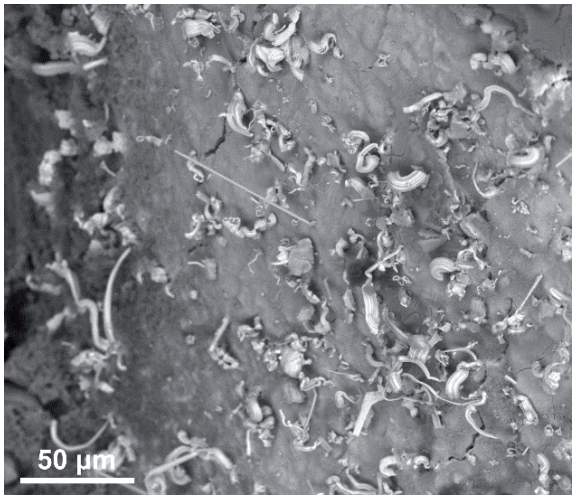

Fig. 4 Scanning electron microscope micrograph from tin whiskers on a SAC solder joint

However, the current load has not shown considerable influence on the whisker lengths. The longest whisker was 192 µm. Therefore, the probability of short circuit failure effect generated by SAC solder whiskers cannot be neglected.

Vapor Phase Soldering (VPS) is an emerging soldering method in electronics manufacturing. During VPS, the prepared assembly (printed circuit board (PCB), printed solder paste and placed components) is inserted to a process chamber, where the hot vapor condenses on the top and bottom surfaces of the PCB. The condensate gives off the latent heat to

melt the solder alloy. The inert film layer keeps out harmful gases (such as oxygen) from the exposed alloy during the soldering process; the continuous film causes homogeneous heating along the surfaces.

In the previous investigations of the department, a multi-physics model was introduced in order to simulate the vapor relations and the temperature of an immersed body. Lately, this work was extended with detailed multi-physics modelling of the film wise layer formation [28]. Also, a novel simplified approach was introduced with an explicit formula [29, 30], where the modelling of the heat transfer was based on film wise condensation theory for horizontal rectangular- and disc-shaped plates. The new method enables much faster calculations with low computing requirements and precise profile prediction in saturated vapor. The method can also point to soldering oven programming, in order to set up optimized profiles to improve soldering quality. The current research focuses on extending and improving the measurement methodology knowledge for VPS. It was found, that for thermocouple measurements during VPS the high temperature solder and Alu-Tape attachments are recommended for optimal repeatability and reduced overall error. A new measurement method is also under development for determining the heat transfer coefficient for different shapes, substrates, and positioning angles of PCBs during VPS.

2.3 Summary

The research fields of ETT reflect the major trends and results in modern engineering science which are chiefly engaged with: (i) usage of gold nanoparticles in photo-polymerization process; (ii) application opportunities of surface plasmon resonance; (iii) novel characterization methods of micro-alloyed solders; (iv) reliability and quality problems of electronic assemblies; (v) developments in vapor phase soldering. These topics may serve the interest of the readers of Periodica Polytechnica Electrical Engineering and Computer Science.

3 Department of Electron Devices

The Department of Electron Devices at the Faculty of Electrical Engineering and Informatics of BME is the only university department in Hungary, where the research and educational portfolio covers the entire spectrum of microelectronics starting from the physics and manufacturing processes of semiconductor devices including micro and nanoelectronic devices; VLSI ICs; MEMS and semiconductor sensors; LEDs and solar cells; through modelling, simulation and design of such devices up to complex VLSI chips; up to complex hardware and system design from system on chip to complete high speed boards, space applications or systems realized with help of cyberphysical design platforms aimed at IoT applications and smart systems integration.

The flagship R&D activity of the department is related to the multi-physical, especially thermal, electro-thermal issues of integrated systems at micro- and nanoscale. In this area, our department is one of the best-known research centers worldwide.

Our current public funded R&D projects include both EU funded and national projects:

- **EuroCPS H2020 ICT IA** (2015-2018): European Network of competencies and platforms for Enabling SME from any sector building Innovative CPS products to sustain demand for European manufacturing;
- **NANOTHERM FP7 IP** (2012-2016): Innovative Nano and Micro Technologies for Advanced Thermo and Mechanical Interfaces;
- **SMARTPOWER FP7 IP** (2012-2016): Smart integration of GaN & SiC high power electronics for industrial and RF applications;
- **OTKA 100794** (2012-2015): Novel electrical and radiometric multi-domain methods and models for the qualification of solar cells
- **OTKA 109232** (2014-2017): Integrated thermal management solutions for System-on-Package devices
- **OTKA 110867** (2014-2017): Nano-electronics based on vanadium-dioxide thin films;

In the subsequent sections we list the actual research results achieved at the Department in 2015.

3.1 Digital system design

Some of the research activities are related to recently launched projects, such as research related to new high level design methodologies; some topics represent direct continuation of research started in prior European project THERMINATOR such is raising the level of abstraction in connection with thermal aware design and simulation techniques and apply these to more complex physical realizations (such as 3D IC structures with integrated micro-channel cooling).

3.2 Optimized RTL design by means of algorithmic formal languages

Nowadays the focus of digital system design seems to be shifted towards System-on-Chips equipped with run-time configurable, application-specific macrocells. Numerous tasks have to be taken over from the instruction-set microprocessors in order to cope with the ever-increasing performance requirements, while the design effort has to be kept low to handle time-to-market pressure and reduce design cost.

In the framework of this research novel solutions for digital system modelling and synthesis are being investigated. The central demand placed upon the target method is to simultaneously ensure the productivity and the possibility of detailed architectural optimizations. These somewhat conflicting requirements are well-known by the existing approaches but they are usually handled in a mutually exclusive manner; HLS (High Level Synthesis) tools are used when the development

time is the primary objective and detailed hand-crafted RTL (Register-Transfer Level) modelling is applied in case of highly timing-sensitive and/or power-critical designs. To find a common ground for the contradictory needs, a novel abstraction called ARTL (Algorithmic RTL) has been introduced in the journal papers [31, 32, 33]. ARTL unites the methods which are identical to traditional RTL from the viewpoint of the structural elements constituting the formal model and slightly increase the abstraction when it comes to expressing the functionality. A mixed behavioural/structural formal language (AMDL, Algorithmic Micro-architecture Description Language) representing ARTL has also been introduced. Using the unique AMDL language constructs the designer may describe the behavior and define the micro-architectural details, by implicitly performing the resource-allocation, scheduling and binding tasks, in the same algorithmic language environment. Moreover, a proposed AMDL-VHDL synthesis method ensures the compatibility with the traditional digital system design flow. Our further results in this field have also been published in a conference paper [46] and a book chapter [63].

3.3 Thermal-aware design of complex digital ICs

Due to the ever-increasing power dissipation densities of today's VLSI and ULSI circuits, temperature-related design considerations have become more and more compelling, especially in case of 3D stacked-die structures where removing the heat from the layers far from the cooling facilities is a great challenge. Traditionally, electro-thermal simulators are used to capture the thermal behavior of integrated circuits, but due to the complexities of current digital ICs, computational requirements of those methods are excessively large. The main objective of this research is to develop new simulation methods, which are capable of co-simulating the thermal/logic behavior, while taking the interactions between the thermal and electrical effects into account. The inhomogeneity in the spatial distribution of logic gates may lead to congested silicon areas, where the eventually forming hot spots may cause thermally induced logic errors. The logi-thermal simulation paradigm is aimed at addressing these issues. So far logi-thermal simulation was realized in standard cell design flows. Our recent research in the field targets raising the abstraction level of the simulated hardware models up to the RTL or even to algorithmic and/or system level. Recently we applied logi-thermal simulation to obtain temperature distribution map of a 3D stacked-die system using a microprocessor's RTL model.

The main goals of this field are to determine (i) how to accurately estimate the geometric and dissipation characteristics of circuits based on such abstract models, (ii) how to make it possible for such different simulation domains (thermal and high level behavioral) to exchange information, and (iii) how to integrate the developed methods into the traditional design flow [34, 47].

3.4 Development of IoT solutions based on European CPS design platforms

As part of the smart anything anywhere (SAE) initiative the European funded EuroCPS project (www.eurocps.org) is to enable companies making new CPS products to get access to leading edge technology platforms from large companies and support from competence partners. The expected outcome of EuroCPS is to boost and sustain the demand for local manufacturing and catch the IoT market by improving the European competitiveness. As one of the competence centers of EuroCPS, the Department of Electron Devices started working with Intel ad ST and Hungarian SMEs to develop new applications for the IoT market. So far, we launched two projects with Hungarian SMEs:

The SmartSSL project

The main goal of the Smart Solid State Lighting (SmartSSL) project is to enable LED luminaires to become parts of smart home, smart building and smart city solutions. Flexible and open communications modules of street lighting luminaires allows supporting advanced functions in future smart city concepts not yet used today. The planned modular and flexible communications subsystem for LED luminaires is foreseen to provide bi-directional flow of data not only about the health of the LED luminaires but will allow transmission of any other environmental information sensed by a luminaire. The foreseen smart LED luminaires will be configurable to the actual environment of the lighting system operators, both in terms of physical channels and protocols.

The SmartLAB project

In routine medical diagnostics, the number of the sample test tubes in the laboratories could even reach the few thousands. The administration overhead of such human or other biological sample test tubes is huge, and attracting more and more interest as the number of samples is growing rapidly, etc. Our Department supports an SME partner to develop an innovative system designed to override the above issues (administration, search and select, tracking of test tubes) by comprising wirelessly identifiable test tubes and intelligent sample holder racks, which are together connected to a cloud based data and quality management system.

3.5 Thermal characterization of physical solutions of future electronics

In modern electronics and solid-state lighting increased heat dissipation means the major bottleneck. Therefore research regarding solution resulting in enhanced cooling of integrated circuit chips / solid-state light sources is essential. These include the development of novel nanoparticle-based thermal interface materials as well as new, embedded micro-scale cooling solutions. Long-term reliability of these new solutions is also of paramount importance. The research conducted by our Department in the framework of two EU FW7 projects

targets e.g. measurement of the thermal performance of new thermal interface materials, assessment of the effect of mechanical stresses e.g. at thermal interfaces and the research and development of new methodologies to study the long-term reliability (from thermal point of view) such novel heat-dissipation solutions.

The OTKA 109232 national project aims at the development of new characterization methods to assess integrated micro-channel based cooling solutions. The activities of this project are strongly related to the research regarding thermal aware system design and our research in micro-fluidics.

3.6 Study of micro-scale cooling structures

As microscale cooling structures are integral parts of modern chip level cooling concepts, understanding the behavior of different assemblies is desirable. Intense research on micro-channel based heat sinks has been conducted to study the heat transfer mechanism and fluid flow characteristics in micro-scale channel structures. This way novel circuit-cooling assembly co-design concepts can be created where the conventional IC design steps are extended with thermal design capabilities resulting in a System-in-Package or System-on-Package design flow. The first step in this process is to create a general formula, which describes the heat transfer mechanism and can be implemented in IC CAD environments as a compact thermal model. In 2015, we presented an analytical study of an integrated micro-channel based cooling structure with the above motivation in mind. A closed analytical formula was given to calculate the partial thermal resistance corresponding to the heat transfer represented by the coolant, which can be used in electro-thermal co-simulation. The analysis based on numerical CFD simulations and thermal transient measurements of a realized micro-channel test structure were also discussed and the results were compared against the analytical ones.

Micro-channel based cooling is very important in the case of the more-than-Moore 3D integration (e.g.: System-in-Packages, stacked dies structure, etc.) where removing the heat from the inner layers or forming homogenous temperature distribution within a selected die are the most up-to-date question nowadays. The determination of the proper length of the channel(s) gives a basis to design the optimal architecture of microscale heat sink structures. The commonly applied microscale cooling structures with radial arrangement and one inlet usually reach the highest achievable heat transfer at low-pressure drop but occupy more surface area than needed at applied flow rates. Our results in this field were published in a journal paper [35] and a few conference papers [50, 51].

3.7 Reliability analysis and life-time estimation of power electronics modules

Related to the SMARTPOWER project of the EU (project-smartpower.com/) we conducted research regarding the reliability and life-time estimation of power electronics modules. The new idea we tried in cooperation with Mentor Graphics MicReD is twofold.

On one hand we tested power electronics modules (such as IGBT modules used e.g. in electric vehicles) such that standard power cycling (up to 1500 A – as allowed by the test equipment used) is combined with thermal transient testing and subsequent non-destructive structural analysis (concentrating on die attach quality) with the help of structure functions. This kind of testing allows continuous in-situ monitoring of device degradation during the power cycling test until ultimate device failure.

On the other hand, we suggest to program power pulse amplitude and duration based on the actual so called mission profile of a given target application. (Mission profile means that the pulse amplitude and length distribution during the power cycling test corresponds to the typical distribution of power pulse lengths and amplitudes in the target application of the device under test. This way a more precise and more realistic product lifetime estimation is possible. Our results related to this activity have been published in two conference papers [52, 53].

Based on our findings, a leading European manufacturer of IGBT modules modified their design to improve the thermal properties of the IGBT modules.

3.8 Study of thermal reliability of new nanoparticle based thermal interface materials

The aim of the NANOTHERM FW7 project of the EU (project-nanotherm.com/) is to develop new high-performance interconnection and integration technologies for heterogeneously integrated high power-density, high-temperature and high reliability applications with methodologies to simulate and characterize them in the multi scale and multi domain. To show the success of the integrated components on system level the developed technologies are applied for building industrial demonstrators in the field of automotive, solid state lighting, avionics and communication applications.

The main task of our Department in this project is to help the industrial partners to optimize the thermal performance of the new interface materials, die attach layers and mold compounds [48, 49]. This multi-scale task involves thermal performance tests – thermal resistance measurement, structure function analysis and thermal imaging – and reliability testing both on bulk material, subsystem and demonstrator level. Our team also elaborated a novel in situ reliability testing method for the characterization of combined semiconductor and TIM aging. In the latter case, the characterization process included a correction to account for the aging of the power LED which was assembled to its substrate with one of the new materials developed in the project [49]. The method was successfully implemented using a complex measurement system, comprising a reliability testing hardware and software system that utilizes a

commercial thermal transient tester (MicReD T3Ster) and optical measurement instrument (MicReD TeraLED) to analyze the stress-induced deviations in the heat flow path during the aging. Unique aging effects were identified such as the combination of burn-in effect in out-of production line new power LEDs and drastic positive change in energy conversion efficiency. The details of the degradation process are being used in forthcoming projects for exploring physics of failure modeling on system level of e.g. solid-state lighting solutions.

3.9 Further results related to thermal characterization

In cooperation with Infineon we investigated how multi-heat source systems can be best described by the so called thermal resistance (impedance) characterization matrices and how elements of such a matrix can be identified by thermal transient measurements [36]. Another topic our team was engaged with was the further development of a measurement card using an array of miniature IR sensing devices which is aimed at IR mapping of boards of live system [37].

3.10 Thermal electric logic circuit (TELC) for nanoelectronics

Until now, the continuous development of electronics has been characterized by Moore's law. The scale down resulted in the nano-sized CMOS integrated circuits, pushing the "red brick walls" towards the lower dimensions. Although the current CMOS integrated circuit development is driven by a lot of innovations, there are still some limits determined by unavoidable physical effects (such as tunneling, stochastic fluctuations in doping, etc…). There are many new ideas for building atomic or molecular scale devices for the information technology. However, there is still a gap between the up-to-date "top-down" CMOS technology and the "bottom-up" devices, i.e. molecular electronics, nanotubes, nanoswitches, single electron transistors. The CMOS compatible thermal-electric logic circuit (TELC) and the new thermal-electric device (phonsistor) may help to fill this gap.

Most of electrical components (transistors, resistors, etc…) are thermally sensitive elements. Thermal coupling between elements of integrated circuits is a well-known parasitic effect, which must be taken into consideration during the design process. Recently we introduced a new principle for logic gate and logic system operation using thermally sensitive electrical switches, such as vanadium-dioxide resistors capable for metal-insulator transition (MIT) and showing thyristor-like characteristics. In the thermal-electrical integrated circuit, both the electrical and thermal signals are treated as logic variables. The thermally sensitive switch integrated with a controllable heating element can be considered as a new electro-thermal device: "phonsistor".

The thermal-electric logic circuit (TELC) is somewhat similar to the brain. Neighbouring gates communicate by thermal diffusion, like neurons may release some chemicals (hormones, for example) which diffuse and affect other cells nearby. Electrical output signal can be transferred for longer distances too, similarly for the case of the neuron's long axon.

Recently we obtained funding for these activities from the Hungarian National Research Fund (OTKA project 110867). The main goals of this research are: practical realisations of different TELC structures and systems, investigation of scaled down (nano-sized) phonsistor related to the hot electron injection by ballistic transport through tunnel junction, combined thermal-electric modelling of the TELC circuits, development of the technology for thermally sensitive materials and devices, investigation on CMOS compatibility of TELC. In 2015, we published our results in two journal papers [38, 39] and in two conference papers [54, 55].

3.11 Multi-domain characterization of power LEDs and their cooling assemblies

In the last decade we have been intensively dealing with thermal investigations of power LEDs and their cooling solutions. In the last few years we have been concentrating on chip level multi-domain modelling of power LEDs and on the implementation options of such models.

The methodology proposed for multi-domain (i.e. electrical, thermal and optical) modelling of LEDs requires measurement of so called isothermal current-voltage-light output (I-V-L) characteristics of LEDs. For that purpose, in cooperation with Mentor Graphics MicReD we suggested refinements of the measurement control scheme of the test setup of T3Ster-TeraLED equipment aimed at characterization of LEDs. With this, dozens of different LED types (both color LEDs and phosphor converted white LEDs) have been measured and their model parameters have also been identified. With this set of data in 2015 we tested different sets of equations (used in built-in diode models of nonlinear circuit simulation programs) aimed at modelling the temperature dependence of the diode characteristics. Our results have been published in an overview paper about Spice-like modelling of power LEDs [40]. A basic description of our LED modelling activities has also been provided in Hungarian in the 2014-2015 yearbook of the Hungarian Lighting Association (VTT) [64].

Besides chip level multi-domain modelling of LEDs we also worked out a systematic method with which compact thermal models of heat sinks can be created directly from thermal transient measurements [56]. In this field, we have worked in cooperation with GE Lighting Hungary as well [65].

3.12 Lab-on-a-Chip micro-fluidic devices

The activity of the department in the field of biomedical devices covers a wide portfolio from model development to device design. A novel reduced order model (ROM) was constructed for the investigation of enzymatic processes

encapsulated in micro droplets. This model provides two orders of magnitude decrement in the design loop time compared to time required when the conventional numerical solvers are used in the design process. A new device platform was also developed for the fast and efficient investigation of enzymatic processes. In a strong cooperation with the Department of Organic Chemistry and Technology of BME, significant studies were carried out in relation with a biomedically relevant enzyme.

3.13 Reduced order modelling of Taylor-flow

A novel reduced order model was developed which enables the heat and mass transfer analysis of micro-channels consisting of continuously moving micro-droplets with enzymatic reactions inside. Due to the low Reynolds number, which is typical in microfluidic applications, the hydrodynamics can be described as Taylor-flow. The reduced order model contains the main features of Taylor-flow such as microcirculation and back flow. The model has been validated by a standard CFD simulation. The results show that the model yields results with around 10% error while the required simulation time has been decreased by two orders of magnitude compared to the CFD simulation. With this novel approach, the temperature profile on the channel wall can be calculated in a few hours compared to conventional numerical techniques which would require weeks.

Our results related to compact (reduced order) modeling of Taylor-flow have been published in two journal papers [41, 42] and in four conference papers [57, 58, 59, 60].

3.14 The "MagneChip" platform

A novel Lab-on-a-Chip (LoC) system was developed which is comprised of micro-sized magnetic reaction cells capable of anchoring biocatalyst-coated magnetic nanoparticles (MNPs) addressable and selectively. In complex microfluidic systems including a plurality of such cells, any order of cascades of differently functionalized MNPs in serial or parallel arrangement is feasible, which allows to design highly flexible and "programmable" execution of multienzyme processes. Thus, the test frequency can be increased by magnitudes while the sample amount needed could be reduced significantly. A robust technique to quantify the entrapped particles used for biocatalysis was developed based on sensitive built-in magnetometer. In repeated cycles of reactions (under various conditions or even with different substrates), the reproducibility of enzyme catalyzed biotransformation in the chip was excellent (>98 %). The original activity of the enzyme layer in the chip remained stable after 14 h involving sequential operations. Benefitting the low reagent consumption and flexibility of the device a new operating mechanism of the phenylalanine ammonia lyase enzyme was explored for the first in the world.

Our results in this field were published in three journal papers [43, 44, 45].

3.15 Manufacturing and characterization of solar cells

In the field of solar cell research, our department is involved in the development of new device technologies and characterization methods, as well as multi-domain modelling of photovoltaic devices.

Ongoing technological developments carried out in the cleanroom of the Department are focused on novel semi-transparent crystalline silicon solar cell structures, where the transparency is provided by through silicon holes. Different transparency values can be reached by altering the size and pattern of the holes during anisotropic etching. The efficiency of the final experimental structure reaches 9.6 % and the devices are suitable for bi-facially active operation [66]. Additional basic research was conducted with dye sensitized solar cells based on anodized titanium dioxide layers, the best experimental cells reaching an efficiency of 2.4 %. The incorporation of perovskite dyes and combination of dye sensitized solar cells with silicon based technologies is planned for the future.

Regarding the metrology of photovoltaic devices thermal transient testing (a well-established non-destructive method for the characterization of electronic device packaging) was adopted for photovoltaic modules [61]. Scanning the surface potential of biased CIGS mini modules was also investigated and found to be a valuable contactless measurement technique that complements the already used techniques like DLiT and electroluminescence imaging.

As a result of our work on modelling PV-devices our research group developed a combined electro-thermal model that is based on the thermal RC ladder of the device and the Lambert-W function based explicit form of the single diode solar cell model [62]. The model predicts the entire current-voltage characteristics of the device, and needs no feedback on the device temperature.

3.16 Summary

As it can be seen from the short descriptions wide range of topics in semiconductor technology and microelectronics is covered by the research activity of the department in many cases with thermal aspects in the focus. Some of the solutions and ideas are among the first in their field such as the "phonsistor" based TELC devices, logi-thermal simulation, mission-profile based life-time prediction of power electronics modules, multi-domain measurement, modelling and simulation of power LEDs and photo-voltaic devices, not to mention different aspects of micro-channel devices used as Lab-on-a-Chip devices or integrated thermal management solutions.

4 Department of Networked Systems and Services

The Department of Networked Systems and Services is focusing on the key areas of networking and networked systems, such as the analysis and design of wired and wireless networks, new network architectures and protocols, mobile communication systems and services, multimedia networking and media distribution, as well as cryptography and network security. Additional strengths that complement the key areas include quantum computing and communications, acoustics and studio technologies, signal processing, and financial information systems.

Our recent research projects in the above listed domains include the following:

- CONCERTO – Content and cOntext aware delivery for iNteraCtive multimEdia healthcaRe applications,
- MEVICO – Mobile Networks Evolution for Individual Communications Experience,
- iParking – Intelligent parking assistant system,
- X-Noise – Aircraft exterior noise reduction,
- Ariadne – Network inventory based high level network design and analysis tool,
- DFL - Device-free localization system based on radio tomographic imaging,
- UAVcom – Unmanned Aerial Vehicle communication subsystem,
- ROSCO – Repository Of Signed COde,
- PLC honeypot – Emulating the behavior of a real PLC and detecting malicious activity in industrial control networks.

Furthermore, the department is dedicated to support and seek environmentally friendly networking solutions. A good example for this is the former EARTH project, which had the objective of reducing energy consumption and improving energy efficiency in mobile telecommunication systems by a factor of two. Another quickly developing research area of the department is quantum communications, where our quantum research group participated in the development of the first Hungarian quantum key distribution device.

In the following, we present, three selected research projects: (i) development of a framework for providing QoS guarantees in cloud environments, (ii) establishment of a large repository of signed objects for detecting digitally signed malware and fake certificates, and (iii) communication aspects of autonomous vehicles. More information on these and other projects and on our research in general can be found on the department's web site at.

4.1 QoS guarantee in cloud environments

The development of computing frameworks such as YARN and Mesos has been motivated by the need of sharing a cluster of commodity servers among different applications [67, 68]. Computing frameworks include appropriate components that run in commodity servers to provide the management and the execution of jobs (submitted by applications) on a specific cluster. These frameworks provide interfaces that hide the complexity of the reservation and the allocation of resources in a specific cluster from applications. Therefore, for a certain degree, computing frameworks simplify the programming of applications for resource reservations from clusters.

In mobile network environments, solutions and products are deployed in the so-called white box scenario, where they run on the same physical infrastructure as applications of the mobile operator, and even more, they share some of the cluster level infrastructure (e.g., shared Hadoop cluster). In such a scenario, a typical Big Data application may consist of multiple jobs that are executed in a distributed manner (up to several thousand machines). Some customers may require a data rate guarantee because their jobs should be finished by a certain deadline. Therefore, the provision of the quality of service regarding a data rate guarantee may play a key factor to attract customers [69, 70].

In recent collaboration works with Nokia [69, 70], we proposed a set of functionality to monitor and isolate I/O demands in production environments. The proposed functionality can be used to minimize contention situations that lead to the I/O degradation offered to applications and clients. We created environments where the competition for resources in hardware level is fully controlled by administrators. In addition, we demonstrated that the proposed solution can be used to control the data I/O bandwidth in two popular computing frameworks [67, 68] as well.

4.2 ROSCO – Repository Of Signed COde

Recent targeted malware attacks, e.g., Stuxnet, Duqu, and Flame, used digitally signed components that appeared to originate from legitimate software makers [71]. In case of Stuxnet and Duqu, the private code signing keys of legitimate companies were suspected to be compromised and used by the attackers. In case of Flame, the attackers generated a fake certificate that appeared to be a valid code signing certificate issued by Microsoft, and used the corresponding private key to sign their malware.

The purpose of code signing is to ensure the authenticity and integrity of software packages, however, ultimately the effectiveness of code signing as a security mechanism also depends on the security of the underlying Public Key Infrastructure (PKI). As the examples above show, attackers have already started to exploit weaknesses in the PKI system supporting code signing, and we expect that this trend will become stronger. Consequently, there is an urgent need to strengthen the PKI which code signing relies on. At the same time, given its size and complexity, making the entire PKI system 100 % secure is illusionary, and one should rather adopt a best effort approach that raises the bar for the attackers even if attacks cannot be completely eliminated.

Motivated by the Stuxnet, Duqu, and Flame cases, the specific problem that we addressed in our work is that standard signature verification procedures used in today's PKI systems do not allow for detecting key compromise and fake certificates. Therefore, the objective of the work was to augment the standard signature verification workflow with checking of reputation information on signers and signed objects.

For this purpose, we built a data collection framework and a data repository for signed software and code signing certificates. We implemented services that use the repository for providing reputation information for signed objects, such as when a given signed object has been first seen and how often it was looked up by users, and we also provide alert services for private key owners that help them detecting when their signing keys were illegitimately used.

Our system, called Repository of Signed Code (ROSCO), does not aim at replacing the entire code signing infrastructure. Rather, it complements existing PKI functions with useful services that can be used by different participants to increase their confidence in the legitimacy of signed code. For end users, the benefits are obvious: our repository serves them when they have to decide about the trustworthiness of a to-be-installed code. For software makers, our repository can be used to detect the malicious use of their signing key. For security companies, our repository could be an invaluable source of information, which they can use to detect malicious campaigns and trends in signing malicious code.

For more information on the project, the interested reader is referred to [72]. The ROSCO system is available for test purposes at https://rosco.crysys.hu/.

4.3 Communication aspects of autonomous vehicles

Nowadays, the field of Intelligent Transport Systems (ITS) has been receiving more and more attention thanks to the rapid evolution of Information and Communication Technologies (ICT). ITS applications and services include traffic management and warning systems, movement- and speed management, driving assistance solutions and co-operative location based services among others. In general, they enhance safety, productivity and efficiency of both terrestrial, aerial and water vehicles. Benefits of ITS can be further enhanced if ITS entities continuously communicate with each other and exchange relevant information using Cooperative ITS (C-ITS) techniques giving scope for V2X (Vehicle to Everything) communication schemes that usually further extend autonomous and self-organizing technologies. Optimization of communication and development of applications for these networks represent a current problem.

In automotive vehicle cooperation schemes, we are focusing on the exploitation of heterogeneous overlapping access networks varying from Wi-Fi, DSRC, CALM, 3G, to 4G/LTE/LTE-A, Satellite, etc., aiming to optimize the exchange of relevant information between vehicles, road side infrastructure and different ITS hosts. We have proposed a Local Dynamic Map (LDM) based predictive decision engine providing prompt and efficient vertical handover (VHO) decisions for V2X ITS applications during different mobility events [73, 74]. In our scheme Cooperative Awareness Messages (CAM) support timely and standard compliant transport of context information providing all the dynamic/static data required for optimal VHO decisions in future vehicular networks. The validation of the proposed scheme was done on an Android-based proof of concept implementation, which is available for test purposes at http://www.mip6d-ng.net/.

In self-organizing autonomous vehicle infrastructures, we are focusing on collective movement of dynamic nodes called "flocking". The existing controlling mechanisms handle the group of any vehicles as a whole, no dynamic and autonomous regrouping or repartition is possible when applying such schemes. Several use cases would require using autonomous regrouping of the flock, where a subset of the flock could leave the group and move to a given destination, to perform various tasks on the spot. It is a challenging task to find the fittest subset of the nodes to perform the given task, taking into consideration the fuel/energy level of the group members, the distance to a target member or spot etc., and this all should happen without any central control, just through distributed node interaction. We have introduced two controlling algorithms, which are capable of choosing the optimal subset without any central supervision and directing them to the given destination, based on node interactions and a token mechanism [75]. In the first case, it is not necessary to provide the connectivity of the leaving subset and the remaining set, however in the second case it is mandatory, this way providing a chain for the multi-hop forwarding of the data from the spot, e.g. sending a data stream from the spot to the ground supervision centre, when real-time surveillance is needed. Both algorithms were implemented and demonstrated in the Proto framework.

The other challenge we are addressing in such self-organizing autonomous vehicle infrastructures is the autonomous task allocation in a flocking system [76]. It is an essential component for the collective movement of mobile nodes in a real life scenario. We have developed a novel algorithm to find the optimal allocation of a number of heterogeneous agents to a number of heterogeneous tasks. The algorithm uses distributed auctions based on local peer-to-peer wireless communication and exploits graph theory with tree-based multicast protocol in order to select the optimal allocation. The solution was evaluated over a number of test scenarios in order to measure and prove its capability of handling complex applications including extended number of tasks and agents.

4.4 Summary

We gave a short overview about the main research activities of the Department of Networked Systems and Services in 2015. Three highlighted research projects focusing on QoS guarantee in cloud environments, authenticity and integrity of software packages and communication aspects of autonomous vehicles were explained in details.

5 Department of Control Engineering and Informatics

Research activities at the Department of Control Engineering and Informatics (IIT) are grouped into five well-defined focus areas. Results achieved in 2015 are presented in the subsequent sections following a similar breakdown. Section 5.1 is devoted to digital systems. Results in the field of parallel processing and software technology are presented in Section 5.2. Section 5.3 describes achievements in visual informatics, including topics related to medical image reconstruction and augmented reality. Finally, Section 5.4 is devoted to robotics, process control and identification. Although subsections provide in-depth information and references, it is convenient to highlight some of the key results at the beginning of each section.

5.1 Digital systems

A front-end high level synthesis tool is under development capable to determine the optimal multiprocessing architectures for given tasks, specified in the C programming language. Our active fish tagging system offers a cheap and reliable way to accurately follow the behavior of a fish population in swallow fresh water environment of limited range.

5.1.1 System level synthesis

Multiprocessing can be considered as the most characteristic shared property of complex digital systems. Due to increasingly complex tasks to be solved for fulfilling often conflicting requirements, the system architecture is strongly determined by the task to be solved. The consequence of this task-dependency is that the component processors of such systems are usually not only general purpose CPUs or cores, but also DSPs, GPUs, FPGA-s and other custom hardware elements as well.

The rapid development in multiprocessing demands new system-level synthesis methods supporting the designer in finding the proper heterogeneous multiprocessing architectures (HMPA). The aim is to develop an experimental HMPA system-level synthesis tool (called DECHLS) relying on the decomposition and high-level synthesis algorithms. DECHLS receives the task to be solved as a C code and after performing the task decomposition assigns the subtasks into component processors considering the requirements and their priority order definable by the designer. The application of the DECHLS has been illustrated and evaluated on practical examples [77, 78, 79].

5.1.2 Active fish tagging an tracking system

Tagging and tracking fish is important in fishpond farms. Fish tracking is used to study the behavior of the animals. An active tagging system has been developed, which consists of active tags placed on several fish, and a number of stationary transceivers or base stations. Since the tags operate on battery power, their transmissions should be short. The base stations also have solar power; therefore, they can transmit for longer periods and can be equipped by a higher power transmitter. The position of an active tag is estimated based on RSSI (Received Signal Strength Indicator) values. The tag communicates only with the nearest base station. Data visualization may be performed on a remote server.

5.2 Parallel processing and software technology

Parallel versions of analysis tools for properties of truss systems were implemented to verify and improve existing conjectures. A user-friendly service description language (SOAL) is designed for distributed applications from heterogeneous software components.

5.2.1 A parameter-based approach to the analysis of quadrilateral grid trusses

Certain mechanical properties of two-dimensional truss structures can be observed using discrete mathematical means. Fast algorithms allow efficient analysis of a single structure of higher complexity. We studied the possibility to process a very large number of structures via a distributed execution of such algorithms, taking advantage of high-performance computing infrastructures.

The identity of the smallest quadrangulation with minimum degree 3 also containing parallel edges is unknown. However, it has already been determined that its order (the number of vertices) is between 11 and 14. We have narrowed this domain by showing that the order is at least twelve.

5.2.2 Distributed service description language

Service-Oriented Architecture (SOA) defines a set of principles for connecting distributed software components. Although SOA is primarily implemented by web services, other technologies (REST, WebSockets, CORBA, etc.) are also suitable for implementation. The main challenge in creating a distributed system of services is the lack of user-friendly description of the overall system and of the individual service interfaces. Microservices is a new emerging concept for creating distributed applications from heterogeneous software components. As microservices also lack a general description language for defining the components of the application a user-friendly distributed service description language has been developed, called SOAL. The language is suitable for defining the architecture of large-scale SOA systems and small-scale microservice applications [92].

5.2.3 Automated test data generation

The availability of appropriate test data is critical in order to develop complex software efficiently. Generally, test data is assembled with time-consuming manual steps, which becomes more and more cumbersome as the system evolves. A new object oriented approach, based on the Java Persistence API has been suggested which may evolve incrementally with the software being developed. In this way the whole development and testing process gets a more natural continuity.

5.2.4 Software quality assessment

We investigated the possibilities to use product-based and process-based software quality approaches in an integrated way. A successful new direction in combining software quality-oriented knowledge and methods was the development of a new methodology based on text analyses and data mining via performing similarity analyses between international quality approaches [93, 94].

5.3 Visual informatics

The results of the Computer Graphics group cover topics including computer-aided geometry design, augmented reality (AR), tomography reconstruction and visualization.

5.3.1 Computer-aided geometric design

In the field of digital shape reconstruction of CAD models based on measured point clouds, new results emerged in detecting and enforcing various engineering constraints (i.e. parallelism, orthogonality, tangency, best-fit coordinate system, symmetry, etc.) [81]. Designing complex shapes requires interpolating free-form curve networks in 3D. We developed various, new multi-sided transfinite surfacing schemes within a loose cooperation with the Boeing Company and KAUST (Saudi Arabia). Global parameterization (flattening) of complex 3D triangular meshes is an ill-posed problem. New parameterization techniques have been developed to align mesh curves and regions with prescribed geometric entities [84]. We also studied an important area of combinatorial geometry. Our focus was directed to investigate hard problems to decompose multiple coverings by shapes in the plane [82, 83].

5.3.2 3D shape recognition for adaptive tangible AR

A particular type of AR systems, called Tangible Augmented Reality (TAR) combines the idea of Tangible User Interfaces (TUIs) with Augmented Reality, creating an environment in which users touch real-world objects, while interacting with virtual ones. This allows for intuitive, natural user interfaces, while removing a conflict between different senses. In most cases, however, TAR systems require the preparation of the physical environment in order to function (markers, or special real-world objects). Our goal is to create a system that is able to process a previously unknown environment and find real-world objects that are fitting placeholders for the virtual objects. In our system, the shape of an object or a scene is represented as a graph of primitive shapes (planes, spheres, etc.) The key algorithm is a learning classification that uses 3D shape data to pair virtual and real objects. In our current research, we use node-by-node graph matching to improve accuracy and to allow for easy alignment of the virtual objects. For this purpose, we proposed a discriminant analysis method that handles between class discrimination and the separation of nodes within a single graph at the same time [80].

5.3.3 3D reconstruction and AR using depth cameras

Current depth cameras are able to add geometry information to color images. To exploit this information, real-time 3D object reconstruction methods are needed, and the resulting 3D scene can be augmented with virtual objects and can be viewed from arbitrary viewpoints. We have developed GPU-based algorithms that fused the information of multiple frames, filtered the noisy depth values based on the information of the color cameras and addressed the occlusion problem [85]. The models obtained in this way can augment virtual scenes or can be rendered with special techniques, e.g. with non-photorealistic rendering [88].

5.3.4 Emission tomography reconstruction

Positron Emission Tomography (PET) aims at the reconstruction of the 3D density of radiotracer materials from the observation of simultaneous gamma-photon detector hits, originating at positron-electron annihilations. The reconstruction process requires the accurate simulation of the complex physical phenomena and an optimization method searching for the maximum-likelihood estimation. Due to the limited allowable radioactive dose, reconstructions are typically of low resolution and noisy. We addressed the problem of dynamic reconstruction, when the time functions of the activity are reconstructed. We have developed a GPU-based enhancement process that can reduce noise while increase the sharpness of the true signal and significantly increase the resolution using information provided by other, e.g. CT or MRI modalities [86].

We have adapted the Algebraic Reconstruction Technique (ART) to the optimal Body-Centered Cubic (BCC) lattice and compared it to its traditional implementation on the Cartesian Cubic (CC) lattice [91]. On the CC lattice, we used a trilinear interpolation kernel, while on the BCC lattice we tested a four-directional box-spline kernel and a trilinear B-spline kernel. The BCC lattice combined with a trilinear B-spline kernel resulted in the most isotropic volume representation.

5.3.5 Shape-based Interpolation

We have shown that a shape-based interpolation of 2D and 3D density distributions can be implemented by a distributional interpolation of the Radon transforms. Recently, we have proven

that a 3D shape-based interpolation based on this approach is completely consistent as the interpolated 2D projections are the 2D projections of a valid 3D density distribution [89].

5.3.6 Comparison of CC, BCC, and FCC lattices in terms of prealiasing

Previously, Cartesian Cubic (CC), Body-Centered Cubic (BCC), and Face-Centered Cubic (FCC) lattices have been compared in terms of prealiasing by sampling and reconstructing the well-known Marschner-Lobb (ML) test signal. We have shown that such a comparison gives an unfair advantage to the FCC sampling due to the anisotropic spectrum of the ML signal and the axis-aligned orientation of the sampling lattices. For the sake of a fair comparison, we proposed to rotate the lattices such that the prealiasing effect is maximized on each lattice [90].

5.4 Control engineering and robotics

New methods were developed to manage singular configurations in robot invers kinematics, to model tumor behavior and control the therapy. A new sensor fusion technique is proposed for under-actuated mechanical systems using unscented Kalman filters.

5.4.1 Developments on the differential solution of the inverse kinematics problem of robot arms

The problem of finding the joint trajectories for the desired end effector motion for robotic arms is called the inverse kinematics problem. Its solution involves a system of nonlinear equations. An applicable method to solve the inverse kinematics problem is based on the linear approximation of robot motion which may become singular. An earlier regularization technique was developed further for the inverse positioning problem of generic robot arms and for elbow manipulators in particular [95]. The numerical integration that has to be done after the solution of the linear system was improved by applying the Crank-Nicolson (CN) method so that the convergence of the linearized solution to the real solution is faster compared to the Euler method [96].

5.4.2 Modelling and control of physiological processes

Our research interests covered a wider range of processes relevant to the behavior and treatment of the human body, including retina function identification [87], breath cycles [100], and glucose absorption [101].

Developments in antiangiogenic tumor therapy were carried out in cooperation with the Physiological Controls Group from the Óbuda University. A new method was proposed to approximate the tumor volume based on caliper measurement [97]. Application of state-feedback on the linearized Hahnfeldt tumor growth model was analyzed, along with the effect of the choice of the operation point used in the linearization. The range of design parameters that result in stable closed-loop was given [98, 99].

5.4.3 State estimation of under-actuated mechanical systems using Kalman filters

Under-actuated mechanical systems (e.g. cranes) exhibit oscillatory behavior. Powerful non-linear feedback techniques require full state information but not all state variables are usually measured, hence some state estimation technique must be applied. The sampling time of the sensors may be different and some sensors may provide measurement information asynchronously. An unscented Kalman filter based sensor fusion method has been developed and successfully tested on a reduced sizes mechanical testbed system [104, 105].

5.5 Summary

The research results of the department belongs to different fields of computer science and electrical engineering. From these, the application of numerical mathematics in medical simulation and imaging seems to be the most promising.

6 Department of Measurement and Information Systems

The Department of Measurement and Information Systems is intent on sustaining the harmony of education, research and professional activities. We concentrate on research stipulating both educational and professional activities in a university. The Department delivers dependable and intelligent services, devices, technologies and tools for smart and trustworthy Cyber-Physical Systems (CPS) to turn embedded systems into smart objects of everyday life by tightly integrating smart computation, communication and signal processing approaches with physical processes of different nature (e.g., electrical, mechanical or biological) executed over Internet-of-Things. Our focus includes foundational research to provide core insights, algorithms and techniques as well as applied research to develop or innovatively exploit existing technologies and deliver business value in multiple application domains:

- Sensing and signal processing [108]: intelligent medical image processing (X-ray image analysis [126]), real-time signal processing (video and radar), biomedical sensing (blood pressure [110], motion-based monitoring), digital signal processing with acoustic applications (active noise control [109], digital sound synthesis), calibration (ADC testing [106, 107]), intelligent sensors [111], modelling complex systems [128];
- Intelligence: machine learning, Big Data analysis (statistical exploratory and confirmatory), decision support systems, optimization and simulation, semantic knowledge representation & query processing [121, 122] data and knowledge fusion (logic/systems/kernel-based);

- Systems & software engineering concepts [118, 119]: model-based design [114, 115, 123] hardware-software co-design, verification & validation [116, 120] testing [124], fault tolerance, deployment automation, runtime monitoring, certification;
- Operating systems and middleware: embedded, real-time and dependable operating systems and middleware technologies, embedded and real-time Linux, system and application software for distributed and/or heterogeneous hardware architectures;
- Computational technologies: distributed computing over the Cloud, microcontrollers and application processors, high-performance computation by reconfigurable FPGAs, DSP processors, computational biomedicine;
- Communication technologies: Ethernet and TCP/IP, real-time networks (AVB, TSN), sensor networks, IoT, automotive & avionics communication protocols & architecture (AUTOSAR, ARINC653), protocols for smart devices (MQTT) & Internet, precision clock synchronization;
- Infrastructure technologies [117]: Carrier-grade Cloud, Educational Cloud (Apache VCL), virtualization, heterogeneous embedded computing (CPU, GPU, FPGA);
- Tools for engineering CPS [112]: domain-specific modeling frameworks, model and code generation, verifiers, simulators, tool qualification [113], open source software projects;
- Application domains: ambient-assisted living [127], bioinformatics [125] & biomedical, business intelligence and optimization, critical embedded systems (automotive, avionics, railway), Industrial Internet of Things, IT systems infrastructure, telecommunications (infrastructure & software technology);

6.1 Main research fields

The Department developed an end-to-end demonstrator for smart & trustworthy Cyber-Physical Systems, which synergistically integrates recent advances from knowledge-based engineering, model-driven planning and exploration, and reconfigurable intelligent services with Quality of Service guarantees. The whole system is deployed over a cloud infrastructure with the additional benefit to interact with the physical world to gather sensor information and to access actuators. The framework provides dynamic access to services for many users, computation capability, dynamic resource allocation and reallocation at run-time, support for application development by means of a knowledge base. High level of virtualization provides interoperability across the diverse network of embedded nodes. The demonstrator is a smart office environment equipped with many sensors, actuators, embedded computers and servers, where different users with different roles (owner of the infrastructure, company renting the office, employees) may develop their own applications utilizing the same cyber-physical framework.

Acknowledging the scientific results of our staff the Department hosted a prominent international conference in 2015, the 3rd International IBM Cloud Academy Conference [129]. Among the 300 participants were outstanding experts as well as young researchers of great promise. With the First European Biomedical Engineering Conference for Young Investigators [130] we initiated a biannual conference series.

The Department has three research groups with partly overlapping R&D activities.

The Embedded Systems Group maintains the traditional research activities of the Department in signal processing: acoustic research [109], power spectrum estimation in the presence of data loss [108], ADC testing [106, 107], compensation of linear and non-linear distortion of sensors and measurement systems [111], non-invasive blood pressure measurement with increased reliability [110]. Recently the group has acquired competencies in the field of observer based surveillance systems, industrial and automotive applications of real-time embedded networking (CAN, CAN FD, FlexRay, Ethernet, IEEE 1588 precision clock synchronization, AVB, and Time Sensitive Networks), testing and verification of embedded systems, wired and wireless sensor networks, large-scale sensor integration. Two R&D projects should be highlighted in 2015: (i) Reconfigurable ROS-based Resilient Reasoning Robotic Cooperating Systems (R5-COP) 2014–2017, (ii) Investigation of optimal parameter estimation methods, OTKA, 2015–2018.

The group has intensive cooperation with many electrical and electronic R&D companies like Robert Bosch Ltd., Intel, Ericsson, National Instruments, OMICRON Lab, Silicon Laboratories, Texas Instruments, TTTech Computertechnik AG, Zodiac Data Systems GmbH, ThyssenKrupp Presta Hungary Ltd.

The research activity of the Fault-tolerant Systems Group extends over the following main fields. Dependable systems [117], including design, implementation, analysis, and management of computer systems characterized by guaranteed quality of service, reliability, high availability, and safety [120] as well as certification processes. Resilience of cloud-based cyber-physical systems [113]: risk assessment [112], cloudification, analytics of resource transients, empirical assessment; cost prediction. Model based software and systems engineering [114, 115, 121, 122]: techniques and tools for requirements engineering, design, analysis, optimization, deployment, testing [116], maintenance, domain-specific modeling languages, model transformations [123] and code generation). Formal methods [118, 119, 124]: application of formal methods for the design, synthesis, analysis, and verification of functional and extra-functional (dependability, performance, safety) properties of critical services and systems. The successful R&D activity of the group is hallmarked by involvement in the following projects in 2015:

- Reconfigurable ROS-based Resilient Reasoning Robotic Cooperating Systems (R5-COP) 2014-2017
- Scalable Modelling and Model Management on the Cloud (MONDO) 2014-2016
- CErtification of CRItical Systems (CECRIS) 2013-2016
- Guaranteed Component Assembly with Round Trip Analysis for Energy Efficient High-integrity Multi-core systems (CONCERTO) 2013-2016
- Host of the MTA-BME Lendület 2015 Research Group on Cyber-Physical Systems

Active and recent industrial collaboration of the group includes Ericsson, Robert Bosch Ltd., IBM Hungary, TTTech Computertechnik AG, ThyssenKrupp Presta Hungary Ltd., Budapest Bank, Morgan Stanley, Nokia.

The Intelligent Systems Group is competent and dedicated to research in ambient intelligent systems [127], heterogeneous information processing, data analysis, medical image analysis [126], modeling complex systems [128], bioinformatics, biomedical informatics [125].

In 2015, the group was involved in the following projects:

- Development of low-dose radiological chest imaging system based on the principle of digital tomosynthesis extended with and computer aided diagnostic capability, 2013-2015
- M3W (Measuring and Maintaining Mental Wellness) project, AAL Joint Programme 2011-2015
- Decision Support and Intelligent Automation of Next-Generation Sequencing Workflows, OTKA, 2015-2018
- R5-COP Reconfigurable ROS-based Resilient Reasoning Robotic Cooperating Systems, ARTEMIS Joint Undertaking project, 2015-2017

Co-operating partners helped in the field of medical image processing: Innomed Medical Co, Semmelweis University Pulmonological Department; in the field of genomic investigations: Csertex Ltd., Semmelweis University; in the field of smart homes: eNET Ltd.

6.2 Summary

The Department has strong research groups pursuing research and development in various fields of engineering and information systems. The main common activity of BME MIT has been Cyber-Physical Systems (CPS); this is the common ground for the three research groups.

7 Department of Computer Science and Information Theory

The members of our department perform research in several areas of mathematics and computer science, including combinatorics, theory of graphs, hypergraphs and matroids, algorithms and data structures, computational complexity, stochastic processes, information theory, data science etc. Special emphasis is given to the applications of these tools in various areas of engineering as well, for example in the design of very large-scale integrated circuits, in wavelength assignment, in network reliability and in virtual machine allocation.

In the present survey, we concentrate on two selected topics only, a more theoretical one on the borderline of combinatorics and number theory, and a more practical one on virtual machine allocation.

7.1 Optimization of virtual machine allocation in cloud computing

7.1.1 Technology background

Most of the world's ever growing demand for computational capacity is served by large data centers (DCs). A DC contains a number of physical machines (PMs), also called servers or hosts. The number of PMs of a DC can range from dozens to hundreds of thousands.

Traditionally, a major challenge for DC operators was the fluctuation of the hosted workload. PMs had to be sized so that they can serve the peak load of the accommodated applications. This is a problem because for many applications, the typical resource requirement is much lower than the peak [138]. Consequently, PMs had very low utilization most of the time. Therefore, an unnecessarily high number of PMs had to be purchased and operated, leading to high costs and considerable superfluous energy consumption.

In order to overcome these issues, today's DCs typically use virtualization technology. With the help of virtualization, multiple virtual machines (VMs) can be instantiated on a single PM. Applications are accommodated by the VMs, not directly by the PMs. This way, applications can share the PM's resources in a safe and secure, logically isolated manner: for instance, a fault in one application may crash its VM, but this does not impact other VMs on the same PM. Moreover, the load of one VM has (in most cases) negligible impact on the performance of the co-located VMs [158].

Using virtualization, the applications can be consolidated on a smaller number of PMs. Unused PMs can be switched to a low-power mode, thus saving energy. Therefore, virtualized DCs are an important enabler of cloud computing.

Moreover, VMs can be migrated between PMs. In particular, live migration allows moving a VM from one PM to another one with practically no noticeable service downtime. This way, the DC operator can react to changes in the workload: in times of low demand, the VMs can be consolidated to relatively few PMs; when the load increases, further PMs can be powered on and VMs can be migrated from overloaded PMs to others with lower utilization. DC operators can thus dynamically balance between the resources requirements of the VMs and physical resource consumption. This leads to an optimization problem that we call the VM allocation problem. As can be seen from

the above, VM allocation is an optimization problem of crucial importance with far-reaching impact on operational costs, carbon emission, and the performance of the hosted applications.

7.1.2 Problem formalization

Basically, cloud providers must allocate VMs to PMs in such a way that application performance requirements are met, PMs are well utilized but not overloaded, and overall power consumption is minimized. However, several subtle details make the problem more complicated:

- The number of VMs changes over time.
- PMs have given capacity and VMs have given current load in multiple resource dimensions, like CPU, memory, and disk.
- The resource requirements of a VM vary over time.
- Resource usage incurs costs or consumes power, the amount of which depends on the type, state, and utilization of the resources.
- Migration takes time and creates additional load for the network as well as the affected PMs.
- If performance requirements are not met, this may result in a penalty.
- VMs may have different priorities.
- PMs may be different in terms of capacity and power consumption characteristics.
- If the provider's own resources are not sufficient, further VMs may be leased from external cloud providers.

For these reasons, VM allocation is a very complex optimization problem, for which multiple problem formulations and solution algorithms have been proposed in the literature in recent years.

We started our research in this field by surveying existing work and categorizing the previously published papers according to the variants of the problem that they addressed [147].

Beside the diversity of the considered problem models, there is also a more fundamental issue that makes it very difficult to compare previous works: in many cases, the problem is not even defined accurately (let alone formally) and must be figured out from the description of the proposed algorithms or their evaluation. Therefore, the next step in our research was to come up with a precise, formal problem model, or rather a set of problem models corresponding to the different versions of the problem [149]. It is also clear based on the formal problem model that each sufficiently general version of the problem is NP-hard.

Building on and extending this work, we then introduced a taxonomy and notational system for categorizing the different versions of the problem [151]. The notational system is defined on the basis of the well-known alpha | beta | gamma notation used for scheduling problems, but is more sophisticated so as to accommodate the many aspects that influence VM allocation.

7.1.3 Algorithmic approaches

Most algorithms that had been proposed previously for the VM allocation problem are simple heuristics, without any performance guarantees. One of our aims was to investigate to what extent approximation algorithms are possible for VM allocation. In [148], we gave formal proofs that some of the previously proposed heuristics are actually approximation algorithms for some important sub problems, like the optimal selection of VMs to migrate from an overloaded host.

Several researchers have noted the similarity between the VM allocation problem and the much-studied bin packing problem, and proposed to adopt well-known simple packing heuristics like First-Fit or Best-Fit – that are known to be approximation algorithms for bin packing – also for VM allocation. In [152], we identified several aspects that make VM allocation algorithmically harder than bin packing and assessed their impact on approximability. It turns out that some of these aspects indeed make it harder to approximate VM allocation than bin packing. In particular, if there are multiple PM types, each with different power efficiency, and a limited number of PMs per PM type, then the resulting version of the VM allocation problem admits no polynomial-time constant-factor approximation algorithm, unless $P=NP$.

Another algorithmic area that was previously mostly unexplored in the context of VM allocation is the application of problem-specific exact algorithms. As an example of this family of approaches, we devised an algorithm based on branch-and-bound [133]. In contrast to the heuristics suggested previously, this algorithm could compute the optimum, if sufficient time is available. More importantly, it is an anytime-algorithm: it can be interrupted at any time, returning the best result it has found until that point. According to our empirical assessment, the algorithm finds very good results quickly, so that it is competitive with heuristics in terms of practical performance. Moreover, in contrast to heuristics, it has the unique feature that it also provides a lower bound for the cost of the optimal allocation, and thus an estimate of how far its result can be from the optimum. In terms of scalability, the algorithm compares favorably to general-purpose integer programming solvers, being able to handle problems with thousands of machines in reasonable time.

In the following, we turned our attention to the investigation of the algorithmic implications of some less mainstream problem variants.

In order to deploy critical applications in a compute cloud, extra constraints are needed to ensure a sufficient level of performance isolation. In [141] we formalized the deployment optimization problem to include both provider and tenant objectives: consolidation opportunities together with guarantees for the performance of critical applications. The resulting problem is solved using integer linear programming. The results show that it is indeed feasible to optimize operation costs while at the

same time giving the necessary assurance for the deployment of critical applications with soft real-time requirements.

In [131], we addressed the problem of selecting data centers for a large-scale task, requiring thousands of virtual machines, in a distributed cloud consisting of dozens of DCs, with the objective of minimizing inter-DC communication. We proved that the problem is strongly NP-hard and devised a heuristic for it based on the A* algorithm. Extensive simulation results show the superior performance of our algorithm over simpler heuristics commonly proposed for contemporary cloud systems.

7.1.4 Current and future work

Our ongoing activities further extend the research results presented so far with new aspects:

- Handling multicore processors: taking into account the effect of the different scheduling issues that arise when multiple VM cores (vCPUs) must be mapped to the cores of a PM (pCPUs).
- Handling intra-DC communication costs: adapting our A*-based algorithm for inter-DC communication minimization to the problem of selecting PMs within a DC with the aim of minimizing data transfer costs within a single DC.
- Disciplined experimental comparison: elaborating a methodology and a test environment with which the effectiveness of different VM allocation algorithms can be compared empirically in an objective way.

Looking at the skyrocketing energy consumption of DCs, optimizing VM allocation will remain a challenging problem for the years to come. Moreover, technology innovation and the expanding scope of applications that are to be "cloudified" keep introducing new aspects of the problem. On the other hand, combinatorial algorithms and operations research methods offer a wealth of tools that can be applied to solve these problems effectively.

7.2 Further combinatorial results

Csikvári, Gyarmati and Sárközy [134] asked whether there exist Ramsey type theorems for the equations $a+b=cd$ and $ab+1=cd$ in $Z(m)$ for large enough m. In [153] we proved that for any r-coloring of $Z(m)$ the more general equation $a1+...+an=cd$ has a nontrivial monochromatic solution, that is, a solution, where the color of the variables a_1, ..., a_n, c,d is the same.

Pomerance and Schinzel [157] proved that any 2-coloring of the squarefree positive integers the equation $ab=c$ has a monochromatic solution. In [156] we solved the problem for arbitrary r and extended this result by proving that the more general equation $a_1a_2...a_k=b_1b_2...b_l$ has a nontrivial monochromatic solution for every r-coloring of the square free numbers. The special case when $k=l$ is even more interesting. If the equation $a_1a_2...a_k=b_1b_2...b_k$ is not solvable in a set, then we say that it is a multiplicative k-Sidon set. Let $G_k(n)$ denote the maximal size a multiplicative k-Sidon subset of $\{1, 2, ..., n\}$. Erdős [135], [136] determined very precisely $G_2(n)$. In [7] $G_k(n)$ is determined asymptotically precisely for every k, moreover both lower and upper bounds are given for the "error term". For instance, for $k=3$ we show that $\pi(n)+\pi(n/2)+cn^{2/3}(\log n)^{4/3}\leq G_3(n)\leq\pi(n)+\pi(n/2)+cn^{2/3}(\log n)/(\log\log n)$, and for $k=4$ $\pi(n)+n^{3/5}/(\log n)^{6/5}\leq G_4(n)\leq\pi(n)+cn^{2/3}$ (where $\pi(x)$ denotes the number of primes up to x). These results strengthen some results of Erdős, Sárközy, T. Sós [137] and Győri [139] concerning a strongly related problem from combinatorial number theory: How many elements of the set $\{1, 2, ..., n\}$ can be chosen in such a way that none of the $2k$-factor products from this set is a perfect square?

In [155] the number of rooted trees of given depth is investigated. Namely, we show that the logarithm of the number of non-isomorphic rooted trees of depth $k>3$ is asymptotically $(\pi^2/6)\cdot n/\log\log...\log(n)$, where log is iterated $k-2$ times in the denominator.

7.3 Summary

Current research in two areas have been presented in order to give an impression on the multifaceted research activities performed at our department. We were glad to learn that Dr. Zoltán Mann, the principal author of most of the results surveyed in Section 7.1 has been invited to deliver one of the principal talks at the Ninth Japanese-Hungarian Joint Symposium on Discrete Mathematics and its Applications in Fukuoka, Japan in the summer of 2015 and Dr. Péter Pál Pach, the author of the results in Section 7.2 has recently been awarded the prestigious Géza Grünwald Prize of the János Bolyai Mathematical Society in December 2015.

Most of the research activities reported in this chapter are supported by the OTKA grant 108947.

8 Department of Broadband Infocommunications and Electromagnetic Theory

The researchers of the Department of Broadband Infocommunications and Electromagnetic Theory have expertise in telecommunication technologies operating from radio to optical frequencies and in the design and optimization of electromagnetic devices. Antenna design and characterization, optical devices, ferrite based microwave devices, nanofabrication experience related to metamaterial and photonic crystals are just a few of expertise areas what we possess. In-house and commercial codes running on workstations are available, which presents a good starting point for several research and industry sponsored project. As a unique infrastructure, anechoic chamber and antenna measurement facilities are available in the range of radio and microwave frequencies. In the following the main projects and research activities of the Department are summarized. Our Department is organized based on the Matrix Scheme. Several cooperating laboratories are responsible for

specific areas of expertise, however the projects are run on the Take Who Can Serve basis.

The following chapter summarizes the main activity of the department in the year 2015.

8.1 Space technology laboratory

The Space Research Group (SRG) was officially established in 1970 and was supported by the government. In the seventies, we had a multilevel cooperation with INTERCOSMOS. We participated in different missions by developing onboard power supplies, data collection systems and communication equipment. The most well-known mission we participated in was the VEGA, which was our first interplanetary mission. The target of the mission was the Halley comet. We developed the data collection system and all the power supplies of the Hungarian on board units.

From its establishment, the Group participated in the programs of AMSAT. Our BCR operated more than 26 years on board AO-10. In the last program in 1995, the integration was performed in Orlando (AO-40). During the last two decades, we participated in other ESA and NASA programs as well.

One of the successful projects is the ESA Rosetta space probe, which was launched 11 years ago. The aim of the mission is the in situ examination of the comet. We prepared the Power Subsystem (PSS) of the Philae Lander.

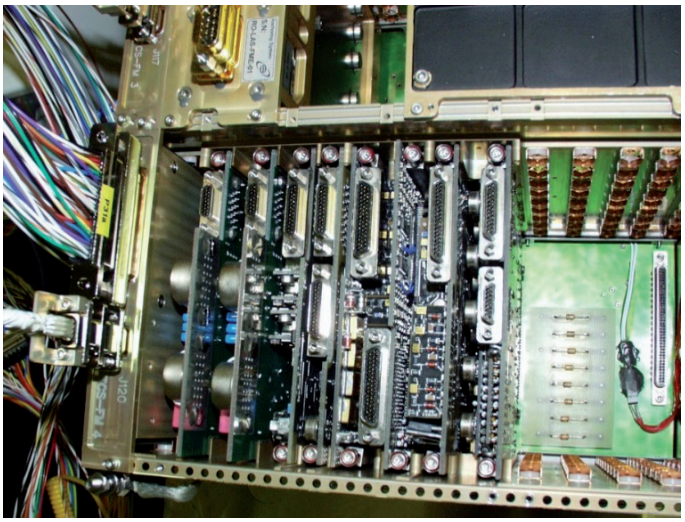

Fig. 5 Common-E Box with 8 PCB card of Philae Lander

8.2 Electromagnetic simulation and design laboratory

The solution of electromagnetic optimization or inverse problems usually requires the solution of many direct problems. Consequently, the numerical burden of the direct problem solutions can even be multiplied in such scenarios. This has been inspiring the use of *surrogate models* that replace the complex direct simulation: they provide approximate results at a much lower computational cost.

Our related research is organized around the grant of the Hungarian Scientific Research Fund (OTKA, no. K-105996: "*Surrogate modeling for the solution of electromagnetic inverse problems*") during the period 2012-2015. In this framework, both electromagnetic simulation tools with special attention to the requirements of surrogate modelling are developed and surrogate modelling algorithms are studied as well.

A full-wave model applying a certain potential formulation is developed. This ensures numerical stability at both the high and the low frequency limits as well [159]. Another full-wave model is developed for the simulation of Frequency Selective Surfaces (FSS) using an impedance-type boundary condition that is applicable in a wide frequency range. Both approaches are ready for coupling with surrogate model assisted optimization methods.

The latest developments of surrogate modelling algorithms are related to optimal database generation methods. Such databases are used to store pre-calculated direct problem solutions (i.e., training data). The choice of the direct problems to be stored rises a complex optimization problem. A sampling strategy based on adaptive mesh generation is reported in [160]. A database generation technique using the sparse grid approach is introduced in [161]. These results are partially transformed to industrial applications of Nondestructive Testing (NdT) in the frame of the project "*Development of Inversion Procedures based on the Exploitation of Database of Simulated NdT Signals*" with the French *Commisariat á l'énergie atomique et aux énergies alternatives (CEA)*, during 2015-2016.

A recently started activity at the Laboratory is the electromagnetic simulation of magnetically coupled resonant WPT configurations. In 2015, the department joined the COST ActionIC1301 "*Wireless Power Transmission for Sustainable Electronics (WiPE)*". The latest results are related to the simulation of coupled resonant coils made of thin wires. Integral formulations have been developed for homogeneous dielectrics [162] and for heterogeneous media [163]. The integral formulation is coupled with the Finite Element Method as discussed in [164]. All approaches result in computationally efficient simulation tools.

8.3 Microwave remote sensing laboratory

The Department joined the international project "Multichannel Passive ISAR Imaging for Military Applications (MAPIS)" that lasts from 2014 to 2017, with the participation of 9 institutes from 5 countries. The project is coordinated by the European Defence Agency. The scope of the project includes both research and development (R&D) related to passive radars. Just to name a few, antenna array characterization, adaptive beamforming, space-time adaptive processing, coverage measurement and simulation of the emitters (e.g., video broadcasting) is concerned, along with target tracking and ISAR imaging algorithms that are especially in the main focus.

The department takes part in all of these tasks, in cooperation with the international partners.

Our activities are gathered around our experimental hardware recently developed: digital adaptive beamforming is studied via a 4-channel DVB-T band passive radar and ISAR imaging algorithms are dealt with in the context of a wideband active imaging radar. Special attention is paid to the challenging detection problems of small-sized Unmanned Aerial Vehicles (UAVs). This up-to-date task is addressed by means of both electromagnetic simulation and anechoic chamber measurements at the department. To sum up, a wide range of activities related to passive radars are in progress at the department, where the cooperation of colleagues with different competences and facilities (electromagnetic modelling, signal processing, hardware development and measurement infrastructure) is the key to the success in this field [165, 166].

In cooperation with Bonn Hungary Electronics Ltd. and Hungarocontrol Zrt, in-situ radar antenna measurement system had been developed and tested at Liszt Ferenc International Airport, in Kőrishegy and Püspökladány (air traffic control radar stations) [167].

After Masat-1, on educational way, the engineering model of Smog-1 satellite had been developed including electrical power system, on-board computer, communication and spectrum monitoring system, automated and remote controlled satellite control ground station [168].

8.4 Laboratory of antennas, EMC and wave propagation

The main profile of the laboratory is the simulation, design, fabrication and measurement of passive and active microwave devices, electromagnetic compatibility testing, indoor and outdoor wave propagation simulations and measurements. In a unique way at the BME, the laboratory has a professional anechoic chamber, where the electromagnetic measurements can be performed without any outer interference.

In the field of material parameter measurement a novel Fano-resonance based technique is researched. We have evaluated experimentally and modelled theoretically the sensitivity of Fano-resonance in periodically arranged split ring resonator and complementary inverse split ring resonator metasurfaces. The measured transmission and reflection data shows that the line shape is asymmetric and the bandwidth is narrower than in case of the dipole mode resonance. With the metasurfaces supporting the Fano-type resonance more precise sensors can be developed, for example our setup makes it possible to detect with microwave measurements the presence of thin polystyrene foils and to extract the material parameters more precisely than utilizing dipoles with Lorentz-shape.

We have investigated the possibility of combination of linear and circular polarized antennas in case of indoor positioning techniques based on signal strength measurement [169]. The proposed technique decreases the standard deviation of the received power and enhances the effective range hence the average positioning error is significantly reduced. The collision avoidance systems, in case of UAV's demand an exact knowledge of the position of an object, however when the other vehicle is close, the performance of the conventional DOA (Direction of Arrival) algorithms are decreased. A publication was written from comparison of the conventional beamforming algorithms for extended radar targets [170].

8.5 Optical and microwave telecommunication laboratory

The research field of this laboratory is specialized in the physical level development and investigation of microwave-photonic components and subsystems, focusing on telecommunication applications. The lab has expertise on wireless and optical communication systems, radio over fiber technology, wireless modulation formats, microwave and optical circuit and system design, construction, and test.

The present activity of the laboratory is relating also for optical and microwave fields. The department participated the COST Action IC1101 "Optical Wireless Communications", where our researchers investigated visible light communication (VLC) channel [171]. System demonstrators for VLC applications are built with industrial cooperation. Optical access networks related work is organized around Hungarian Scientific Research Fund (OTKA PD 109288 Investigation of in-line and reflective semiconductor optical amplifiers for broadband optical access). It includes simulation and measurement of semiconductor optical amplifier based colorless optical unit for wavelength division multiplexed optical access networks [172] and theoretical and experimental investigation of proposed dispersion compensation method in millimeter wave radio over multimode fiber systems [173].

The lab has long-term cooperation with Ericsson Hungary in fields of radio over fiber and microwave circuits. A novel method for linearity improvement of microwave amplifiers is proposed and investigated. We have been involved in international Eureka project, called Metafer. The main goal of the project is development of novel metamaterial-based microwave isolators [174].

8.6 Laboratory of multiscale electromagnetic systems

The activities of the laboratory are focused on the theory and design of metamaterials possessing novel electromagnetic properties. We utilize the metamaterials in antennas, for sub-diffraction imaging or for electromagnetic cloaking, etc. Beside that the laboratory is involved in LTE and 5G telecommunication research [175].

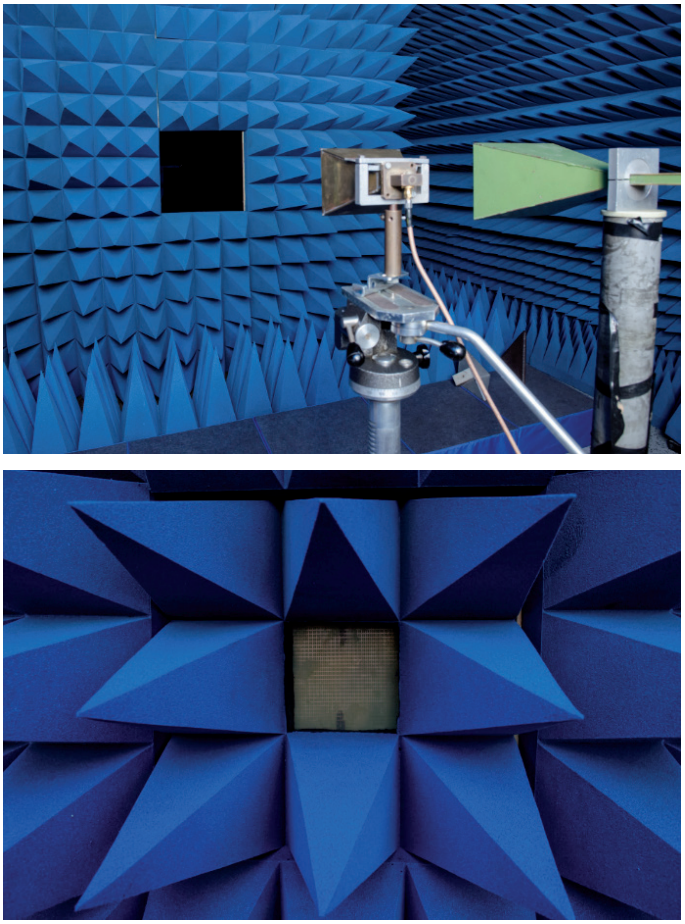

Fig. 6 Transmission-reflection measurement setup of Split Ring Resonator in anechoic chamber

Metamaterials are expected to commercialize in the near future, and metamaterial antennas for telecommunication applications are expected to dominate the market. We have been involved in the project Development of novel metamaterial based antennas for telecommunication lead by Hitelap International Zrt and supported by the Új Széchenyi Terv. The project activities focused on the development of metamaterial antennas, which can be fabricated with conventional PCB technology and present improved parameters. We have designed Split Ring Resonator (SRR) type metamaterial lenses to enhance the gain of patch antennas.

Computationally efficient Magnetic Hysteresis Models have been deduced [176]. The closed form expressions are incorporated in moving and a rate dependent hysteresis model, which can simulate the frequency dependence of the magnetization process. The model parameters are identified from concentric hysteresis loops. It is presented how to proceed when the shape of the analytical Preisach function, which leads to the closed form expressions which does not matches the ferromagnetic material and it is shown that the moving model can be applied to increase the accuracy of the fitting in such circumstances [177].

We have proposed a procedure to efficiently calculate the image of an extended object placed behind a metamaterial slab as it would be seen by an observer, which can greatly differ from the image formed by the intensity maxima [178]. Aberration-free flat lenses can be created by introducing phase discontinuities with hyperboloidal distribution on a metasurface. These lenses are able to focus light without aberration under axial illumination but suffer from serious aberration in case of oblique incidence. We have introduced a simple design including an aperture stop and a flat lens with a modified phase distribution that has negligible aberration for incident angles in the range of -40° to 40° [179].

8.7 RF laboratory for space research

The research field of this laboratory during the past decades was radio frequency developments for different projects of the department's Space Research group. The present activity of the laboratory is relating also for RF circuits, antennas, simulations and CAD design. In years 2012-14, the laboratory participated in the TAMOP-FIRST project and performed research of cognitive wireless infocommunications technologies [180]. Actually, the main activity is the participation in Ka and Q band propagation experiments in frame of ESA (European Space Agency) cooperation. A two-band satellite beacon receiver station was developed and built, which records the received power data along with several meteorological parameters [181].

Besides of the propagation research activity, the laboratory also takes part in the development of a satellite power system, where the main task is CAD design for its electronics.

A newly started project is a satellite communications experiment, where the goal is to design a high precision receiver to qualify the Q/V-band DVB-S2 radio channel. The project is founded by ESA. Within this work, we cooperate with the DOCS laboratory of the department and with an international partner from Austria (Joanneum Research).

8.8 Digital and optical communication system laboratory

In the subject of wave propagation, the Digital and Optical Communication System (DOCS) laboratory made experimental and theoretical studies in the next radio wave propagation projects: FP Network of Excellence projects Satnex I and II. Special satellite propagation, including problems of fixed and land mobile links were investigated in COST Action 255 (up to V band), FP IP projects Embrace and Broadwan, COST Actions 235, 280, IC0802, IC1004 and IC 1101. The laboratory had multilateral projects Milliprop and Gigabit, coordinated by Telenor, mainly fixed microwave and millimeter wave, FSO terrestrial [182] and satellite propagation. In the topic of dynamic spectrum allocation in the FP IP project QOSMOS and EU CELTIC project MARCH both networking and physical layer problems of cognitive radio systems were studied including white space detection, optimal spectrum allocation, new concepts in joint use of spectrum for primary and secondary users, novel multicarrier modulation schemes (i.e. FBMC,

OFDM) and MIMO systems [183]. In the above topics several publications did appear, journal and conference papers and also books resp. book chapters. Recently, different aspects lower layer of 5G and beyond networks [184] are in focus of research activities at DOCS laboratory.

8.9 Summary

In 2015, we took important steps towards the achievement of our plans to start important research projects in theoretical and in practical engineering areas.

Extending the traditional research areas of the department, we also focus on wireless power transmission, metamaterials and passive radars. We hope that these new areas will be attractive for our partners and for our students.

9 Department of Telecommunications and Media Informatics

The Department of Telecommunication and Media Informatics has been performing activities in data science, content technologies, Internet and cloud communications, engineering management, cognitive info-communications, speech technology and smart interactions, in some cases not only in engineering but also in a multidisciplinary manner. In the following chapter, we commend these valuable activities to the honorable attention of readers.

9.1 Data science and content technologies

In data science, our most recent research subjects are the time series, especially the energy forecasting methods and Big Data. Furthermore, in the area of content technologies we have dealt with image browsing, multimedia mining, (e.g. image-based plant identification) and multimedia retrieval.

We have participated in an exclusive Energy Forecasting Challenge hosted by one of Great Britain's main electricity and gas providers. The task was to forecast electric load of an unspecified area in the country. The competition consisted of 3 rounds of challenge each covering 6 months' worth of data, thus offering the potential to incrementally refine the utilized models. Our team using the experience from previous global energy forecasting competitions won the first round and finished second in the overall ranking. The participants included students and professionals from all over the world [189].

We worked on two projects to solve the problems at Hadoop-based Big Data technologies and cluster maintenance. During the first one, we worked out a test cluster in an ETL framework, named Morphlines. The other project was a cluster maintenance one, where we imitated a business environment, and executed SQL like Hive, and Impala queries.

In the research of content technologies, we have implemented an image browsing system and we have solved semantic multimedia search task in a Future Internet research project [185]. In this project we have worked out a method for clustering the search results; the aim of our work was the improvement of classification methods. We have used sophisticated classification method in another task for the solution of image-based plant identification international challenge. The challenge was focused on tree, herbs and ferns species identification based on different types of images, and the aim was to predict species for each observation of a plant of the test dataset. For this challenge, we have successfully elaborated a viewpoints combined classification method using the weighted average of reliability values of classifier at each viewpoint [186].

In multimedia retrieval research area, we have implemented an image ranking solution, where the system orders the unknown images from relevance and diversity viewpoints. The possibilities of using visual and textual information are investigated to improve the ranking of photos about famous places, and we have performed improved textual, visual features, and combination of them. The comparison with a known image search Web system has shown that our solution exceeds the Flickr results by using search result clustering and reordering.

9.2 Internet and cloud communications

In the last three years, the Telecommunication Signal Processing Laboratory (TSPLab) has been involved in the design of a 100 Gbit/s Ethernet platform that has FPGA-based, lossless packet processing capabilities with highly accurate time-stamping features. By now, it is a live, commercialized equipment [199] by Aitia International Inc.

This year we have also been involved in a large project with Nokia Networks Inc., where we have profiled ten mobile applications. After domain- and heuristics-based detection, we created Key Performance Indicators and QoE controls for them, which allows the Self-organizing Network (SON) controllers to provide the required network resources.

The main objective of the European project ECSEL MANTIS is to develop a Proactive Maintenance Service Platform Architecture, enabling collaborative maintenance ecosystems. The concept is based on the Cyber Physical System approach. We are involved in the definition, design, and development of the central platform - where our experience with fault management and root cause analysis pays off. Another European project with the similar setup is Artemis ARROWHEAD. Its central framework [199] - majorly defined by us - provides fundamental functionality to support the development and deployment of interoperable automation systems, as they become part of the Internet of Things.

The High Speed Networks Laboratory (HSNLab) main research areas are: intelligent communication algorithms and protocols for packet switched technologies, network design and routing, performance and teletraffic modeling of broadband multimedia networks, performance monitoring of packet systems, adaptive self-managing networks and protocols, performance of QoS architectures and protocols, mobile

communications, mobile (ad-hoc) networking research, protocol technology and testing, multimedia services and security. Analytics, cloud storage, communications and computing are also in our focus. Interdisciplinary research such as physics of optical communications and network science is also the feature of our activities [200, 201, 202, 207].

The Internet became a critical infrastructure for our society. The primary goal of the MTA-BME Future Internet Research Group (as part of HSNLab) at our department is to seek for high impact short and long term solutions in access and backbone networks reaching the next level of reliability, where the Internet will become an always operating and fast communication system for the society. This concept slightly conflicts with the current industry trends, where high reliability and bandwidth are associated with premium services [203, 204].

Network Service Providers today are limited in maximizing usage efficiency of their resources and limited in revenue generation capability from rigid service offerings, which often take up to 90 days to provision. The H2020 5G-PPP 5GEx project is working towards a flexible and automated 5G network architecture for provisioning multi-operator and multi-technology infrastructure services over network and cloud resources. The project is creating an agile exchange mechanism for contracting, invoking and settling for the wholesale consumption of resources and virtual network services, which can be provisioned in less than 90 minutes and rapidly invoked (www.5gex.edu) [206].

In the past, fixed and mobile networks have been optimized and evolved independently. The EU FP7 COMBO project will allow the convergence of fixed and mobile networks themselves, combining both an optimal and seamless quality of experience for the end user together with an optimized network infrastructure ensuring increased performance, reduced cost and reduced energy consumption. To achieve this target, in COMBO (www.ict-combo.eu/) we will participate to propose and investigate new integrated approaches for Fixed/Mobile Converged (FMC) broadband access /aggregation networks for different scenarios (dense urban, urban, rural) (www.ict-combo.edu).

Today, rigid network control limits the flexibility of service creation. Although cloud computing and networking have been two very active fields of research, there is currently little integration between the vast networking assets and data centers of telecom providers. The idea behind the EU FP7 UNIFY project is to pursue full network and service virtualization to enable rich and flexible services and operational efficiency. In the project we take part in investigating, developing and evaluating means to orchestrate, verify and observe end-to-end service delivery from home and enterprise networks through aggregation and core networks to data centers (www.fp7-unify.eu/) [205].

While in recent years, much has been done all over the world to raise awareness of the challenges caused by the aging population and the sharply increasing number of elderly people. The evolution of information technology and telecommunications opens new possibilities for dealing with this situation. The objective of our TeleCalmPlus project was to deliver the solution for effective configuration, control and management of newly developed healthcare system.

The High Speed Networks Laboratory is a strategic partner of Ericsson. Within this cooperation the following projects have been performed.

The Indoor Location Analytics project is creating a completely big data driven human mobility model for hybrid indoor/outdoor environments.

The goal of the Smart Active project is to develop a system prototype to demonstrate efficient sensory (IoT) data gathering, analysis and visualization in smart spaces. Sensor data include all kinds of data gathered from the physical environment, as well as physiological and health information of humans involved. The implemented back-end consists of a cloud-based analytics engine, primarily aiming at sport analytics tasks in recreational use cases.

Within the Time Sensitive Networking project, the impact of the selected IEEE 802.1Q Time-sensitive networking (TSN) mechanisms was investigated on packetized radio control traffic in a switched Ethernet fronthaul network that also carries low priority (background) traffic.

In the OptiCloud project, an automated measurement tool is to be built to assess resource consumption of applications running in virtualized environments. The benefit of this tool is that it supports the performance estimation of network functions, allowing the assessment of resource usage profile through measurements and the prediction the SLA violation from traffic characteristics.

Our SmartCityCrowd project aims at challenges in the topic of crowdsourcing and crowdsensing. Motivation, incentives, analysis, resource demands, cheats, wrong data—the project promises to cure these problems.

9.3 Speech communication and smart interactions

The Speech Technology and Smart Interactions Lab (SpeechLab) has been part of a consortium that won an EU AAL project in 2015.

As part of the SCOPES (Scientific co-operation between Eastern Europe and Switzerland) SP2 project our team has also actively worked on optimizing Hidden Markov Model (HMM) based speech synthesis and corpus-based solutions. Both speaking styles [193] and speech coding techniques [190], [191] have been under investigation.

Deep Neural Networks (DNN) based text-to-speech solutions are also under investigation, which is supported by an equipment grant from NVIDIA.

The largest scale application of the Lab is the polyglot domain-optimized text-to-speech system for the Hungarian

Railways [197] that has been in operation at more than 60 railway stations and stops.

The Speech Recognition and Audio Mining Laboratory (ASRLab) puts its focus on broadcast news [196] and spontaneous speech recognition of CEE languages as well. Moreover, in cooperation with SpeechLab it has broadened its portfolio with audio fingerprint detection for monitoring television and radio broadcasts. Our basic research aim is robust, very large vocabulary continuous speech recognition in real time - in other words generalized speech-to-text. The sub-fields supporting this aim are as follows:

Acoustic modeling: deep neural networks for modeling speech sounds and pronunciations, semi-supervised techniques for cost effective acoustic model training, language independent technologies (grapheme-based acoustic modeling)

Language modeling: morph based and very large vocabulary word based methods for morphologically rich languages (e.g. Uralic, Turk or Slavic languages). Generative and discriminative language models.

Feature extraction and signal processing: non-linear and deep learning methods for acoustic feature extraction. Speech-music separation, speech endpoint detection, channel compensations, audio fingerprint generations.

Recent applications include call-center speech transcription and analytics, voice routing, real-time closed captions for TV broadcasts, content based indexing of large multimedia archives and dictation systems.

The application of LVCSR (Large Vocabulary Continuous Speech Recognition) technology was investigated for real-time, resource-limited broadcast close captioning. The work focuses on transcribing live broadcast conversation speech to make such programs accessible to deaf viewers. This solution is under tests at the Hungarian Media Support and Asset Management Fund (MTVA). The technology has also been applied at major Hungarian banks and insurance companies in their call center analytics.

The Laboratory of Speech Acoustics (LSA) has performed research on different automated medical decision support systems, which are based on speech processing. These activities are as follows:

- Laringeal abnormality detector research: the aim is that this system could warn us of the presence of vocal problems (for example cancerous mutations in an early state [192].
- The early state Parkinson detection research is also a related topic [195].
- Depression detector research: this system will be one of the potential biomarkers for the severity of depression will also serve as an indicator for the response to treatment.

A related topic is the examination of the sensitivity of acoustic-phonetic parameters of speech to hypoxia and to Seasonal Affective Disorder and the definition of a metric that alert crews at early stage of cognitive dysfunction (Automatic detection) using Concordia Antarctic Station as Human Exploration Analogue. This research is financed by the European Space Agency, ESA.

The other main research direction is a Computer-Assisted Prosody Pronunciation Teaching System, what will teach supra-segmental parameters as intonation, stress and speech rhythm. Prosody modeling is one of the most up to date topics in the speech community, and our prosody modeling research is performed in strong cooperation between the SpeechLab and LSA [194].

9.4 Engineering management and cognitive info-communications

The increasing role of the collaboration in the engineering management based on cognitive infocommunications is an important trend. The Future Internet vision is realized, the human life is more and more pervaded by the integrated and smart usage of ICT devices [185]. This trend is reflected in the annual activity of the Engineering Management Laboratory (EMLab) and the CogInfoCom Laboratory. A book entitled Cognitive Infocommunications (CogInfoCom) was published [187], and the 6th IEEE International Conference on Cognitive Infocommunications [188] was organized in 2015 involving 120 scientific papers from 21 countries. The Second Hungarian Future Internet Conference (MJIK 2015) focused on Smart City issues was held at November 11, in Budapest. The program of MJIK 2015 comprised presentations from foreign and domestic speakers including scientists from our department.

9.5 Summary

The scientific and research activities of TMIT in 2015, since many years as well, have been substantial, valuable and highly influential in both domestic and international professional circles. Inevitably, this review cannot be intended to be exhaustive, for more details and deeper insight, we ask the kind readers to visit our home page: www.tmit.bme.hu.

10 Department of Electric Power Engineering

Department of Electric Power Engineering consists of three groups, namely the Group of Electric Machines and Drives, Group of Electric Power Systems and Environment, Group of High Voltage Engineering and Equipments. The names of the groups indicate the traditional fields on which the Department is still very active. However, our activity has been expanded towards new fields as it can be seen from the following overview.

In 2015, successful international conference was organized by the Department (after the International Conference on Electrostatics in 2013 and Live Line Maintenance, ICOLIM 2014). This time DEMSEE 2015, the Conference

on Deregulated Energy Market in South Eastern Europe was hosted by the Department; the chairman of the conference was Dr. Dávid Raisz.

In 2015, prof. em. György Varjú received Dennis Gábor Prize, which is one of the prizes of high prestige. With that, innovative scientific and industrial results are acknowledged by leading scientists and industrial leaders as well as scientific organizations. Prof. Varjú is the third one who could receive the prize from our department after Prof. Berta and Prof. em. Dán.

Members of the department take part in several national and international technical and scientific committees, working groups (like IEC and CIGRE). Their activity is acknowledged by different prizes, e.g. the prizes from the Hungarian Electrotechnical Association, see www.mee.hu/cikk/4003.

10.1 Development of integrated railway energy system (VINTER)

Our Department has investigated the energy saving potential of the following railway technologies during the project: switch point heating, railway lighting system, pre-heating technology, energy trading system. During the research of the above fields, energy saving potential of each issue was determined; solutions and algorithms were worked out for the utilization of these potentials.

Prolan Co. has developed the necessary software components related to two-seeded field (switch point heating, railway lighting system) on the basis of our research study.

10.2 Investigation of effect of inverters related to accuracy of electronic power meters

The purpose of work was to investigate the effect of PWM inverters in the frequency range of 2–150 kHz related to electronic power meters (both Smart and non-Smart) used in ELMŰ-ÉMÁSZ supply area. Immunity or emission limits in the relevant electromagnetic compatibility (EMC) standards in the above mentioned frequency range have not defined until then. Nevertheless, the experience of international Smart meter pilot projects shows that the inverters have a significant effect on accuracy (15-100 %) of electronic power meters, because the meters have no compulsory immunity test in the range of 2–150 kHz frequency because of the lack of requirements.

During the work, EMC between PWM inverters and electronic power meters were investigated by laboratory measurements. The result of measurements serves the preparation and solution for the predicted problems on the network for the Utility.

10.3 Electricity market modeling

Simulation and Development of an Experimental Market Design based on Co-Optimization of Energy and Ancillary Service Markets was done in consortium with MAVIR, the Hungarian TSO.

The goal of the market oriented R+D+I Project was the realization of the day-ahead power exchange and power reserve market integration model, with which the resource allocation of both markets can be optimized. A market clearing algorithm has been developed which enables the concurrent optimization of network transfer capacity, electricity generation and control reserve allocations, which leads to a cost efficient improvement in security of electricity supply. Moreover, the implemented algorithm is designed to cover long-term simulation, market monitoring and other analysis tasks as well.

The development resulted in three market oriented software products: a power market clearing tool, a market surveillance tool and a training simulator for traders.

The project not only delivered a novel co-optimized day-ahead power market design, but the three software tools can effectively support the inclusion of the new market structure into the Internal Energy Market framework still under final codification. [208]

10.4 Fault location method and system

As a result of a joint R+D project with E.ON Hungária Zrt. and BME, a new innovative fault localization system was deployed at Polgár substation. This device (called FZHM) has not yet reached commercial level, but results achieved so far are very promising. The primary goal of the current research project is to further develop the device so that it becomes more accurate and more reliable, and also to define the optimal way of integrating FZHM into the network operation system and practice. The focus points of the project are:

- Detailed analysis of fault location system (FZHM) performance in the time from 09.2011 to 04.2014.
- System integration into control center operations (GIS and SCADA).
- Improvement of the measurement and evaluation algorithm for a better feeder selection and localization within the faulted feeder.
- Incorporation of additional data (coming from fault indicators and remotely controlled pole-mounted switches)
- System redesign from a prototype to an industrial platform.

Though development is still in progress, the proposed FZHM system seems to be

- a fast and accurate fault localization method (with 1.5 sec localization speed and <400 m accuracy),
- suitable for outage prevention by detecting short-duration faults (that stem e.g. from vegetation)
- a very promising tool for SAIDI reduction.

10.5 eAutoTech: Power converter optimization technology for eVehicles (in consortium with Siemens)

The project consisted of three sub-modules. DEPE was responsible for Module 1: Developing digital and real-scale test environment for studying the influence of e-mobility infrastructure to the voltage quality and control methods on a distribution grid. The goal of Module 2 and 3 was to deploy the linearized and verified PWM unit control algorithms in an actual power converter and they have been elaborated by the Department of Automation and Applied Informatics (AUT). Module 1 included computer simulations and control strategy optimization by means of DIgSILENT Power Factory and ATPDraw/EMTP-ATP software packages. By analyzing the simulation results, the fundamental power loss minimization strategy was found to be the best method that can be realized by using distribution transformers with OLTC capability or enabling reactive power injection capability of grid connected PV converters and e-chargers.

10.6 Simulation of a re-designed renewable support scheme

The Hungarian support schemes of renewable generation has often been changed in the last years. Since the 2010s, it is managed in the system of obligatory off-take applying feed-in tariffs.

Green energy supplied by the renewables is bought on supported tariff by the transmission system operator. The total amount taken energy has a daily seasonality due to the volatile generation of renewables. Its so-called base part has been taken over by the trader in the ratio of power consumption, while the remaining, volatile and hard-to-forecast part is sold on the Hungarian PX. The fee paid by the traders is determined by the TSO to cover the production cost of renewables and the other costs regarding the operation of the feed-in tariff system.

The project studied the effect of selling the whole energy on the PX without allocating the base part onto the traders. Based on the simulation, the number of hours in decoupling is expected to decrease by 50 %.

The codification of this model is started and is expected to come into effect in 2016.

10.7 Beyond state-of-the-art technologies for re-powering AC corridors and multi-terminal HVDC systems (BEST PATHS)

"Best Paths" project is one of the latest, but highest EU FP 7 projects. It consist of different parts (http://www.bestpaths-project.eu)

The challenge of integrating large volumes of renewable energies into the grid hinges on their intermittent nature and uneven geographical distribution. Major development of the European grid infrastructure is thus considered critical to maintaining reliable power supplies and bringing renewable-generated electricity from generation sites to far away consumption sites.

Our department is involved into the following field: "DEMO 4: Innovative Repowering of AC Corridors." Staff members of the Department are deeply involved in two sub-projects, namely the Dynamic Line Rating (DLR) [213, 214] and the Live Line Maintenance (LLM).

10.8 Equipment diagnostics and procurement

Nowadays the number of producers of network equipment and the assortment of products in electrical network even more increasingly widens. Furthermore, the producers provide equipment based on new materials, new manufacturing technologies, new constructions (e.g. new artificial resin insulators, composite insulators, poles with new impregnation etc.). Neither Technology organization, nor Procurement organization have sufficient knowledge about the long-term behavior of such new products. From the Operational organization there are signs that some new products have behaved not so reliable than traditional ones. [219, 220] Furthermore due to new technologies and materials the lifetime of such products are very questionable compared to e.g. traditional insulators or/and products of well-known producers. The aim of our investigation and project is to define the key network items which pose the most reliability-related questions, to establish such laboratory testing/diagnostics method which checks whether the new equipments meet the DSO requirements (e.g. 40 years lifetime), to prepare a study based on key item definition and test method which will be the basis of a procedure for Procurement Organization and Producers (namely propose a method which inhibit the application of not appropriate network items/equipments)

10.9 Cable diagnostics and lifetime management

Operating cables includes the common application of very distinct kind of information. Research into cable diagnostics has mostly concentrated on technical details, while it remained in the background that it should be considered as a part of asset management. This implies that diagnostic methods themselves have to be investigated in terms of their applicability for decision making. The importance of other factors (e.g. risk of external damage) has to be considered as well, upon making any decision about interventions.

Thus, diagnostic methods for cables are investigated concerning the kind of information they provide for ranking the condition of the cable sections. It allows comparing the technical condition of the cables.

The enumeration of risk factors of external damages to cables and other factors affecting operation can provide information about the profitability of other-than-technical interventions.

Based on them, an expert system can be developed for decision support between interventions. The standardized

evaluation allows comparison and ranking, thus optimal utilization of resources, where the expenses are assigned to the most problematic cable sections.

The collected information allows on the long run the best utilization of the lifetime of the cables, preventing their replacement based just on their age.

10.10 Development of condition monitoring techniques and ageing management of nuclear power cables

Properties of cables - especially their change during ageing - are very important from the point of the operation of critical infrastructures such as nuclear power plants. For the perfect monitoring of cable condition it is vital to build up an expert system, containing a knowledge base constructed based on diagnostic measurements and procedures, criteria providing aid for the operators. (Similar to the one mentioned in the previous chapter but specialized for the critical application.) Our department took part a worldwide project hosted by IAAE.

10.11 Development of education of Live Line Maintenance

Live Line Maintenance (LLM) plays more and more important role in the world because of the increased need for continuous power supply. For the safe and effective application it is not enough to investigate protective clothes, equipment, tools but it is also important to train the workers. For that purpose a medium voltage and a high voltage training line was constructed in the High Voltage Laboratory in cooperation with MVM OVIT and E.ON, ELMU-ÉMÁSZ, MAVIR. [212, 215, 216, 217, 218]

10.12 Summary

The previous overview was just a short cross-section of the research activity of our department focused on the projects that were active or closed in 2015. There are many other fields where scientific results have been reached earlier (e.g. [209, 210, 211, 222, 223, 224, 225]) and further achievements are expected in 2016. However this overview was good to give an impression about the research work of the department.

References

[1] Lengyel, L., Ekler, P., Ujj, T., Balogh, T., Charaf, T. "SensorHUB – An IoT Driver Framework for Supporting Sensor Networks and Data Analysis." *International Journal of Distributed Sensor Networks.* Vol. 2015. 2015. DOI: 10.1155/2015/454379

[2] EIT Climate-KIC, Knowledge & Innovation Community. [Online]. Available from: http://www.climate-kic.org [Accesed: 17th February 2016]

[3] URBMOBI. [Online]. Available from: http://www.climate-kic-centre-hessen.org/mobile-instruments-for-environmental-monitoring-164.html [Accesed: 17th February 2016]

[4] SOLSUN. [Online]. Available from: http://www.solsun.co.uk/index.php/SOLSUN [Accesed: 17th February 2016]

[5] Lengyel, L., Meszaros, T., Asztalos, M., Boros, P., Mate, A., Madacs, G., Hudak, P., Kovacs, K., Tresch, A., Charaf, H. "Quality Assured Model-Driven Requirements Engineering and Software Development." *The Computer Journal.* 58(11). pp. 3171-3186. 2015. DOI: 10.1093/comjnl/bxv051

[6] Ekler, P., Csorba, K. "The Usage and Behavior Patterns of Mobile BitTorrent Clients." *Journal of Advanced Computational Intelligence and Intelligent Informatics.* 18 (3). pp. 320-323. 2014.

[7] Kundra, L., Ekler, P., Charaf, H. "Orientation estimation in modern wearables with visual feature tracking." *Journal of Multimodal User Interfaces.* 9(4). pp. 1-10. 2015. DOI: 10.1007/s12193-015-0180-9

[8] Charaf, H., Ekler, P., Mészáros, T., Kelényi, I., Kővári, B., Albert, I., Forstner, B., Lengyel, L. "Mobile Platforms and Multi-Mobile Platform Development." *Acta Cybernetica-Szeged*. 21(4). pp. 529-552. 2014.

[9] Lengyel, L., Charaf, H. "Test-driven verification/validation of model transformations." *Frontiers of Information Technology & Electronic Engineering.* 16(2). pp. 85-97. 2015. DOI: 10.1631/fitee.1400111

[10] Lengyel, L., Charaf, H. "Open Issues in Model Transformations for Multimodal Applications." *Journal of Multimodal User Interfaces.* 9(4). pp. 377-385. 2015. DOI: 10.1007/s12193-015-0192-5

[11] Sipos, M., Heide, J., Lucani, D. E., Pedersen, M. V., Fitzek, F. H. P., Charaf, H. "Adaptive Network Coded Clouds: High Speed Downloads and Cost-Effective Version Control." *IEEE Transactions on cloud computing.* 99(10). pp.1-1. 2015. DOI: 10.1109/tcc.2015.2481433

[12] Szegletes, L., Forstner, B. "Applications of modern HCIs in adaptive mobile learning." *Journal of Advanced Computational Intelligence and Intelligent Informatics.* 18(3). pp. 311-314. 2014.

[13] Bodolai, D., Gazdi, L., Forstner, B., Szegletes, L. "Supervising Biofeedback-based Serious Games." In: *Proceedings of 6th IEEE International Conference on Cognitive Infocommunications.* pp. 273-278. 2015.

[14] Csorba, K., Barancsuk, L., Székely, B., Zöldföldi, J. "GrainAutLine - A Supervised Grain Boundary Extraction Tool Supported by Image Processing and Pattern Recognition." In: *Proceedings of ASMOSIA XI. Association for the Study of Marble & Other Stones In Antiquity, XI. International Conference*, Split, Croatia. pp. 95-96, 2015. DOI: 10.13140/RG.2.1.4177.1683

[15] Futo, A., Varjasi, I. "Simple Model Based Dead Time Compensation Using Fast Current Measurement." *AASRI Procedia.* 9. pp. 146-151. 2014. DOI: 10.1016/j.aasri.2014.09.023

[16] Stumpf, P., Nagy, I., Vajk, I. "Control of Power Flow Between the Wind Generator and Network." *IEEE Transactions on Industry Applications.* 51(6). pp. 4699-4708. 2015. DOI: 10.1109/TIA.2015.2445821

[17] Jardan, R. K., Stumpf, P., Varga, Z., Nagy, I. "Novel Solutions for High-Speed Self-Excited Induction Generators." *IEEE Transactions on Industrial Electronics.* 99. pp. 1-1. 2015. DOI: 10.1109/TIE.2015.2506149

[18] Rakos, B. "Modeling of dipole-dipole-coupled, electric field-driven, protein-based computing architectures." *International Journal of Circuit Theory and Applications.* 43(1). pp. 60-72. 2015. DOI: 10.1002/cta.1924

[19] Spiga, F. M., Bonyár, A., Ring, B., Onofri, M., Vinelli, A., Sántha, H., Guiducci, C., Zuccheri, G. "Hybridization Chain Reaction performed on a metal surface as a means of signal amplification in SPR and electrochemical biosensors." *Biosensors & Bioelectronics.* 54. pp. 102-108. 2014. DOI: 10.1016/j.bios.2013.10.036

[20] Burunkova, J., Kokenyesi, S., Csarnovics, I., Bonyár, A., Veres, M., Csik, A. "Influence of gold nanoparticles on the photo-polymerization processes and structure in acrylate nanocomposites." *European Polymer Journal.* 64. pp. 189-195. 2015. DOI: 10.1016/j.eurpolymj.2015.01.011

[21] Hurtony, T., Bonyár, A., Gordon, P., Harsányi, G. "Investigation of intermetallic compounds (IMCs) in electrochemically stripped solder joints with SEM." *Microelectronics Reliability.* 52(6). pp. 1138-1142. 2012. DOI: 10.1016/j.microrel.2011.12.035

[22] Hurtony, T., Bonyár, A., Gordon, P. "Microstructure comparison of soldered joints using electrochemical selective etching." *Material Science Forum.* 729. pp. 367-372. 2013. DOI: 10.4028/www.scientific.net/msf.729.367

[23] Krammer, O., Garami, T., Horváth, B., Hurtony, T., Medgyes, B., Jakab, L. "Investigating the thermomechanical properties and intermetallic layer formation of Bi micro-alloyed low-Ag content solders." *Journal of Alloys and Compounds.* 634. pp. 156-162. 2015. DOI: 10.1016/j.jallcom.2015.02.092

[24] Garami, T., Krammer, O. "Quantitative analyses of Ag3Sn intermetallic compound formation in SnAgCu solder alloys." *Journal of Materials Science: Materials in Electronics.* 26(11). pp. 8540-8547. 2015. DOI: 10.1007/s10854-015-3526-x

[25] Medgyes, B., Horváth, B., Illés, B., Shinohara, T., Tahara, A., Harsányi, G., Krammer, O. "Microstructure and elemental composition of electrochemically formed dendrites on lead-free micro-alloyed low Ag solder alloys used in electronics." *Corrosion Science.* 92. pp. 43-47. 2015. DOI: 10.1016/j.corsci.2014.11.004

[26] Illés, B., Horváth, B. "Tin Whisker Growth from Micro-alloyed SAC Solders in Corrosive Climate." *Journal of Alloys and Compounds.* 616. pp. 116–121. 2014. DOI: 10.1016/j.jallcom.2014.07.103

[27] Illés, B., Hurtony, T., Medgyes, B. "Effect of current load on corrosion induced tin whisker growth from SnAgCu solder alloys." *Corrosion Science.* 99. pp. 313-319. 2015. DOI: 10.1016/j.corsci.2015.07.026

[28] Illés, B., Géczy, A. "Numerical Simulation of Condensate Layer Formation During Vapour Phase Soldering." *Applied Thermal Engineering.* 70(1). pp. 421-429. 2014. DOI: 10.1016/j.applthermaleng.2014.05.032

[29] Géczy, A., Illés, B., Péter, Zs., Illyefalvi-Vitéz, Zs. "Simplified Heat Transfer Modeling for Vapour Phase Soldering Based on Filmwise Condensation for Different Horizontal Printed Circuit Board." *Heat and Mass Transfer*. 51(3). pp. 335-342. 2015. DOI: 10.1007/s00231-014-1386-1

[30] Géczy, A., Illés, B., Darnai, T. "Investigating Condensation Heat Transfer during Vapour Phase Soldering on Round-Shaped PCB Plates." *International Journal of Heat and Mass Transfer.* 86. pp. 639-647. 2015. DOI: 10.1016/j.ijheatmasstransfer.2015.02.068

[31] Horváth, P., Hosszú, G. "ARTL-based Hardware Synthesis to Non-Heterogeneous Standard Cell ASIC Technologies." *Journal Of Low Power Electronics.* 11(3). pp. 278-289. 2015. DOI: 10.1166/jolpe.2015.1402

[32] Horváth, P., Hosszú, G., Kovács, F. "A proposed synthesis method for Application-Specific Instruction Set Processors." *Microelectronics Journal.* 46(3). pp. 237-247. 2015. DOI: 10.1016/j.mejo.2015.01.001

[33] Horváth, P., Hosszú, G., Kovács, F. "Semi-Automatic RTL Methods for System-on-Chip IP Delivery in the Cyber-Physical System Era." *Periodica Polytechnica Electrical Engineering and Computer Sciences.* – in press. 2016.

[34] Nagy, G., Horváth, P., Pohl, L., Poppe, A. "Advancing the thermal stability of 3D ICs using logi-thermal simulation." *Microelectronics Journal.* 46(12A). pp. 1114-1120. 2015. DOI: 10.1016/j.mejo.2015.06.025

[35] Takács, G., Szabó, P. G., Bognár, Gy. "Thermal management in System-on-Package structures by applying microscale heat sink. Part I: Consideration of the appropriate channel length of microscale heat sink(s)." *Microelectronics Journal.* 46(12A). pp. 1202-1207. 2015. DOI: 10.1016/j.mejo.2015.10.014

[36] Schweitzer, D., Ender, F., Hantos, G., Szabó, P. G. "Thermal transient characterization of semiconductor devices with multiple heat sources – Fundamentals for a new thermal standard." *Microelectronics Journal.* 46(2). pp. 174-182. 2015. DOI: 10.1016/j.mejo.2014.11.001

[37] Bognár, Gy., Szabó, P. G., Takács, G. "Generalization of the thermal model of infrared radiation sensors." *Microelectronics Journal.* 46(6). pp. 543-550. 2015. DOI: 10.1016/j.mejo.2015.03.024

[38] Mizsei, J., Bein, M. C., Lappalainen, J., Juhász, L. "Thermal-electronic logic circuits: Scaling down." *Microelectronics Journal.* 46(12A). pp. 1175-1178. 2015. DOI: 10.1016/j.mejo.2015.10.003

[39] Mizsei, J., Bein, M. C., Lappalainen, J., Juhász, L., Plesz, B. "The Phonsistor – A Novel VO2 Based Nanoscale Thermal-electronic Device and Its Application in Thermal-electronic Logic Circuits (TELC)." *Materials Today: Proceedings.* 2(8). pp. 4272-4279. 2015. DOI: 10.1016/j.matpr.2015.09.013

[40] Poppe, A. "Multi-domain compact modeling of LEDs: an overview of models and experimental data." *Microelectronics Journal.* 46(12A). pp. 1138-1151. 2015. DOI: 10.1016/j.mejo.2015.09.013

[41] Németh, M., Ender, F., Poppe, A. "Heat and mass transfer reduced order modeling approach of droplet microreactor based Lab-on-a-Chip devices." *Microelectronics Journal.* 46(12A). pp. 1152-1161. 2015. DOI: 10.1016/j.mejo.2015.09.008

[42] Németh, M., Poppe, A. "Two-phase Taylor-flow reduced order thermal modeling." *Microsystem Technologies.* pp. 1-14. 2015. DOI: 10.1007/s00542-015-2796-9

[43] Weiser, D., Bencze, L. Cs., Bánóczi, G., Ender, F., Kiss, R., Kókai, E., Szilágyi, A., Vértessy, B. G., Farkas, Ö., Paizs, Cs., Poppe, L. "Phenylalanine ammonia-lyase catalyzed deamination of an acyclic amino acid - Enzyme mechanistic studies aided by a novel microreactor filled with magnetic nanoparticles." *ChemBioChem*. 16(16). pp. 2283-2288. 2015. DOI: 10.1002/cbic.201500444

[44] Ender, F., Weiser, D., Vitéz, A., Sallai, G., Németh, M., Poppe, L. "In-situ measurement of magnetic nanoparticle quantity in a microfluidic device." *Microsystem Technologies.* pp. 1-12. 2015. DOI: 10.1007/s00542-015-2749-3

[45] Ender, F., Weiser, D., Nagy, B., Bencze, Cs. L., Paizs, Cs., Pálovics, P., Poppe, L. "Microfluidic multiple cell chip reactor filled with enzyme-coated magnetic nanoparticles: An efficient and flexible novel tool for enzyme catalyzed biotransformation." *Journal of Flow Chemistry.* 2015. DOI: 10.1556/1846.2015.00036

[46] Horváth, P., Hosszú, G., Kovács, F. "A Proposed RTL Design Technique for Highly Optimized On-Chip Data Processors of MEMS Sensors." In: *Proceedings of the Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP'15)*, Montpellier, France, 27-30 April 2015, pp. 136-139. DOI: 10.1109/DTIP.2015.7160989

[47] Jani, L., Poppe, A. "Extension of SystemC with Logi-Thermal Simulation Capabilities." In: *Proceedings of the 21st International Workshop on THERMal INvestigation of ICs and Systems (THERMINIC'15)*, Paris, France, 30 September – 2 October 2015. pp. 1-4. DOI: 10.1109/therminic.2015.7389604

[48] Cardoso, A., Pires, M., Pinto, R., Hantos, G. "Thermally enhanced FOWLP-development of a Power-eWLB demonstrator." In: *Proceedings of the 65th Electronic Components and Technology Conference (ECTC)*, San Diego, USA, 26-29 May 2015. pp. 1682-1688. DOI: 10.1109/ECTC.2015.7159823

[49] Hantos, G., Hegedüs, J., Rencz, M., Poppe, A. "Aging Tendencies of Power LEDs Under Different Stress Conditions During Thermal Reliability Testing." In: *Proceedings of the 21st International Workshop on THERMal INvestigation of ICs and Systems (THERMINIC'15)*, Paris, France, 30 September – 2 October 2015. pp. 1-4. DOI: 10.1109/THERMINIC.2015.7389624

[50] Takács, G., Szabó, P. G., Bognár, Gy. “Modelling of the flow rate dependent partial thermal resistance of integrated microscale cooling structures.” In: *Proceedings of the Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP’15),* Montpellier, France, 27-30 April 2015. pp. 252-255. DOI: 10.1109/DTIP.2015.7161012

[51] Takács, G., Szabó, P. G., Bognár, Gy. "Enhanced Thermal Characterization Method of Microscale Heatsink Structures." In: *Proceedings of the 21st International Workshop on THERMal INvestigation of ICs and Systems (THERMINIC’15)*, Paris, France, 30 September – 2 October 2015. pp. 1-4. DOI: 10.1109/THERMINIC.2015.7389617

[52] Szél, A., Sárkány, Z., Bein, M. C., Bornoff, R., Vass-Varnai, A., Rencz, M. "Mission profile driven component design for adjusting product lifetime on system level." In: *Proceedings of the International Electronics Packaging and iMAPS All Asia Conference (ICEP-IACC)*, Kyoto, Japan, 14-17 April 2015. pp. 385-389. DOI: 10.1109/ICEP-IAAC.2015.7111041

[53] Szél, A., Sárkány, Z., Bein, M. C., Bornoff, R., Vass-Varnai, A., Rencz, M. "Lifetime estimation of power electronics modules considering the target application." In: *Proceedings of the 31st IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM’15)*, San Jose, USA, 15-19 March 2015. pp. 332-335. DOI: 10.1109/SEMI-THERM.2015.7100183

[54] Mizsei, J., Bein, M. C., Lappalainen, J., Juhász, L. "Thermal-Electronic Circuits: Basics, Simulations, Experiments." In: *Proceedings of the 21st International Workshop on THERMal INvestigation of ICs and Systems (THERMINIC’15)*, Paris, France, 30 September – 2 October 2015. pp. 1-6. DOI: 10.1109/THERMINIC.2015.7389599

[55] Mizsei, J., Bein, M. C., Juhász, L., Jelinek, É. "Thermal-electronic devices and thermal-electronic logic circuits (TELC)." In: *Proceedings of the 38th International Spring Seminar on Electronics Technology (ISSE),* Eger, Hungary, 6-10 May 2015. pp. 61-65. DOI: 10.1109/ISSE.2015.7247963

[56] Poppe, A., Hantos, G., Hegedüs, J. "Application of the Transient Dual Interface Method in Test Based Modeling of Heat-sinks Aimed at Socketable LED Modules." In: *Proceedings of the 31st IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM’15)*, San Jose, USA, 15-19 March 2015. pp. 261-266. DOI: 10.1109/SEMI-THERM.2015.7100170

[57] Németh, M., Poppe, A. "Two-phase Taylor-flow reduced order thermal modeling." In: *Proceedings of the Symposium on Design, Test, Integration and Packaging of MEMS/MOEMS (DTIP’15)*, Montpellier, France, 27-30 April 2015. pp. 314-319. DOI: 10.1109/DTIP.2015.7161025

[58] Németh, M., Poppe, A. "Reduced Order Modeling of Thermal Effects in Droplet Microreactors." In: *Proceedings of the 21st International Workshop on THERMal INvestigation of ICs and Systems (THERMINIC’15)*, Paris, France, 30 September – 2 October 2015. pp. 1-6. DOI: 10.1109/THERMINIC.2015.7389639

[59] Németh, M., Poppe, A. "Reduced Order Thermal Modeling of Gas-Liquid Droplet-Flow." In: *Proceedings of the First European Biomedical Engineering Conference for Young Investigators: ENCY 2015.* Budapest, Hungary, 28-30 May 2015. pp. 106-109. DOI: 10.1007/978-981-287-573-0_26

[60] Németh, M., Ender, F., Poppe, A. "Modeling of Circular Mass Transport of Nutrients in Capillary Vessels Using Microfluidics Approach." In: *Proceedings of the First European Biomedical Engineering Conference for Young Investigators: ENCY 2015.* Budapest, Hungary, 28-30 May 2015. pp. 102-105. DOI: 10.1007/978-981-287-573-0_25

[61] Plesz, B., Szabó, P. G., Dudola, D., Hantos, G., Ress, S. "Possibilities and Challenges of Thermal Transient Testing as a Characterization Method for Photovoltaic Devices." In: *Proceedings of the 31st European PV Solar Energy Conference and Exhibition: EU PVSEC 2015*, Hamburg, Germany, 14-18 September 2015. pp. 2023-2026. DOI: 10.4229/EUPVSEC20152015-5AV.6.31

[62] Plesz, B., Kohári, Zs., Szabó, P. G., Timár, A., Bognár, Gy. "Novel Semi-Empirical Combined Electro-Thermal Model for Solar Modules." In: *Proceedings of the 31st European PV Solar Energy Conference and Exhibition: EU PVSEC 2015*, Hamburg, Germany, 14-18 September 2015. pp. 2014-2018. DOI: 10.4229/EUPVSEC20152015-5AV.6.26

[63] Horváth, P., Hosszú, G., Kovács, F. "A proposed novel description language in the digital system modeling." In: *Encyclopedia of Information Science and Technology.* (Khosrow-Pour, M. (ed.)) Third Edition, Hershey, New York. 2015. pp. 6966-6980. DOI: 10.4018/978-1-4666-5888-2.ch686

[64] Poppe, A., Szalai, A., Hegedüs, J. "LED-ek multi-domain szimulációs modelljei és azok gyakorlati vonatkozásai." (Multi-domain simulation models of LEDs and their practical aspects.) In: *Világítástechnikai Évkönyv 2014-2015*, Budapest, MEE Világítástechnikai Társaság (Hungarian Lighting Association), 2015. pp. 112-121. (in Hungarian)

[65] Poppe, A., Kollár, E., Tóth, Z., Simonovics, J. "Foglalatba illeszthető LED modulok hűtő szerelvényeinek termikus vizsgálata." (Thermal investigation of cooling assemblies of socketable LED modules.) In: *Világítástechnikai Évkönyv 2014-2015*, Budapest, MEE Világítástechnikai Társaság (Hungarian Lighting Association), 2015. pp. 98-103. (in Hungarian)

[66] Bándy, E. "Félig átlátszó egykristályos szilícium alapú napelem cella technológiája és vizsgálata." (Manufacturing process and investigation of semi-transparent solar cells.) PhD dissertation (electrical engineering), Budapest University of Technology and Economics, Faculty of Electrical Engineering and Informatics. 2015. 109 p. (in Hungarian)

[67] Vavilapalli, V. K., Murthy, A. C., Douglas, C., Agarwal, S., Konar, M., Evans, R., Graves, T., Lowe, J., Shah, H., Seth, S., Saha, B., Curino, C., O’Malley, O., Radia, S., Reed, B., Baldeschwieler, E. "Apache Hadoop YARN: Yet Another Resource Negotiator." In: *Proceedings of the 4th Annual Symposium on Cloud Computing*, ACM, New York, NY, USA. 2013. pp. 5:1-5:16. DOI: 10.1145/2523616.2523633

[68] Hindman, B., Konwinski, A., Zaharia, M., Ghodsi, A., Joseph, A. D., Katz, R., Shenker, S., Stoica, I. "Mesos: A platform for fine-grained resource sharing in the data center." In: *Proceedings of the 8th USENIX Conference on Networked Systems Design and Implementation, ser. NSDI’11.* USENIX Association, Berkeley, CA, USA. 2011. pp. 295-308. URL: http://mesos.berkeley.edu/mesos_tech_report.pdf

[69] Do, T. V., Vu, B. T., Do, N. H., Farkas, L., Rotter, C., Tarjanyi, T. "Building Block Components to Control a Data Rate in the Apache Hadoop Compute Platform." In: 18th International Conference on Intelligence in Next Generation Networks (ICIN), Paris, France, 2015. pp. 23-29. DOI: 10.1109/icin.2015.7073802

[70] Tran, X. T., Do, T. V., Do, N. H., Farkas, L., Rotter, Cs. "Provision of Disk I/O Guarantee for MapReduce Applications." In: T*he 2nd IEEE International Workshop on Data, Text, Web, and Social Network Mining,* Helsinki, Finland, 20-22 Augustus 2015. pp. 161-166. DOI: 10.1109/Trustcom.2015.576

[71] Bencsáth, B., Pék, G., Buttyán, L., Félegyházi, M. "The Cousins of Stuxnet: Duqu, Flame, and Gauss." *Future Internet.* 4(4). pp. 971-1003. 2012. DOI: 10.3390/fi4040971

[72] Papp, D., Kócsó, B., Holczer, T., Buttyán, L., Bencsáth, B. "ROSCO: Repository Of Signed Code." In: Virus Bulletin Conference, Prague, Czech Republic, September 2015. URL: http://www.hit.bme.hu/~buttyan/publications.html

[73] Varga, N., Bokor, L., Fischer, H.-J. "LDM-based dynamic network discovery and selection for IPv6 mobility management optimization in C-ITS environments." In: *Proceedings of the 4th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS)*, Budapest, Hungary, 2015. pp. 483-490. DOI: 10.1109/mtits.2015.7223298

[74] Bokor, L., Jeney, G., Kovács, J. "A Study on the Performance of an Advanced Framework for Prediction-based NEMO Handovers in Multihomed Scenarios." *Infocommunications Journal*, 6(3). pp. 16-27. 2014. URL: http://www.infocommunications.hu/documents/169298/831299/InfocomJ_2014_3_4_Bokor.pdf

[75] Kokuti, A., Simon, V., Wiandt, B. "A Novel Spatial Property Aware Multihop Communication Solution for Autonomous Mobile Networks." In: Seventh IEEE International Conference on Self-Adaptive and Self-Organizing Systems, AWARE Workshop. Philadelphia, USA, 9-13 September 2013. pp 107-112. DOI: 10.1109/SASOW.2013.26

[76] Wiandt, B., Kokuti, A., Simon, V. "Application of Collective Movement in Real Life Scenarios: Overview of Current Flocking Solutions." *Scalable Computing: Practice and Experience.* 16(3) pp. 233-247. 2015. DOI: 10.12694/scpe.v16i3.1099

[77] Arató, P., Drexler, D. A. "Comparison of two loop-free decomposition methods." In: *Proceedings of the 10th IEEE International Symposium on Applied Computational Intelligence and Informatics (SACI 2015)*, Timisoara, România, 2015. pp. 477-481. DOI: 10.1109/saci.2015.7208251

[78] Drexler D. A., Arató P. "A modified inertial method for loop-free decomposition of acyclic directed graphs." In: *Proceedings of the 5th International Conference on Recent Achievements in Mechatronics, Automation, Computer Sciences and Robotics*. pp. 63-74. 2015. DOI: 10.1515/macro-2015-0006

[79] Arató, P. "System Level Synthesis of Heterogeneous Multiprocessing Architectures." In: *Proceedings of the Workshop on Information Technology and Bionics. Symposium in Memory of Tamás Roska*, Budapest, Hungary, 23-24 June, 2015.

[80] Szemenyei, M., Vajda, F. "Dimension Reduction for Structured Composite Classes in Multi-Object Environments." In: 15th International Conference on Artificial Intelligence, Knowledge Engineering and Data Bases, 2016.

[81] Kovács, I., Várady, T., Salvi, P. "Applying geometric constraints for perfecting CAD models in reverse engineering." *Graphical Models*. 82. pp. 44-57. 2015. DOI: 10.1016/j.gmod.2015.06.002

[82] Kovács, I., Tóth, G. "Multiple coverings with closed polygons." *Electronic Journal of Combinatorics.* 22(1). Paper P1.18. 2015. URL: http://www.combinatorics.org/ojs/index.php/eljc/article/viewFile/v22i1p18/pdf

[83] Kovács, I. "Indecomposable Coverings with Homothetic Polygons." *Discrete and Computational Geometry.* 53(4). pp. 817-824. 2015. DOI: 10.1007/s00454-015-9687-9

[84] Vaitkus, M., Várady, T. "A General Framework for Constrained Mesh Parameterization." In: *SCCG'15, Proceedings of 31st Spring Conference on Computer Graphics*, ACM, New York, NY, USA. pp. 15-21. 2015. DOI: 10.1145/2788539.2788541

[85] Szirmay-Kalos, L. "Filtering and Gradient Estimation for Distance Fields by Quadratic Regression." *Periodica Polytechnica Electrical Engineering and Computer Science.* 59(4). pp. 175-180. 2015. DOI: 10.3311/PPee.8529

[86] Szirmay-Kalos, L., Magdics, M., Tóth, B. "Volume Enhancement with Externally Controlled Anisotropic Diffusion." *Visual Computer.* pp.1-12. 2016. DOI: 10.1007/s00371-015-1203-y

[87] Szécsi, L. "GPU Pattern Generation for Retina Stimulation Experiments." In: *KEPAF 2015.* pp. 388-393. 2015.

[88] Szécsi, L., Szirányi, M. "Tonal Art Maps with Image Space Strokes." In: *WAIT 2015*. pp. 155-159. 2015.

[89] Tóth, M. J., Csébfalvi, B. "Distribution Interpolation of the Radon Transforms for Shape Transformation of Gray-Scale Images and Volumes." In: *Computer Vision, Imaging and Computer Graphics - Theory and Applications*. (Battiato, S. et al. (ed.)), Springer International Publishing, pp. 15-28. 2015. DOI: 10.1007/978-3-319-25117-2_2

[90] Vad, V., Csébfalvi, B., Rautek, P., Gröller, E. "Reproducibility, Verification, and Validation of Experiments on the Marschner-Lobb Test Signal." In: *EuroVis Workshop on Reproducibility, Verification, and Validation in Visualization.* 2015.

[91] Rácz, G., Csébfalvi, B. "Tomographic Reconstruction on the Body-Centered Cubic Lattice." In: *Proceedings of the 31st Spring Conference on Computer Graphics.* pp. 23-29. 2015. DOI: 10.1145/2788539.2788542

[92] Simon, B., Goldschmidt, B. "SOAL: A Distributed Service Description Language." In: *WAIT 2015*. pp. 29-34. 2015.

[93] Karaffy, Z., Balla, K. "Applying Text Analyses and Data Mining to Support Process Oriented Multimodel Approaches." In: *Systems, Software and Services Process Improvement, CCIS 543,* (O'Connor, R. V. et al. (ed.)), Springer International Publishing, pp. 180-189. 2015. DOI: 10.1007/978-3-319-24647-5_15

[94] Karaffy, Z. "Applying text analyses and data mining in the field of SW quality assurance." In: Context Text mining conference, Budapest, Hungary. 2015.

[95] Drexler, D. A. "Regularization of the differential inverse positioning problem of an elbow manipulator." In: *Proceedings of the IEEE 13th International Symposium on Intelligent Systems and Informatics.* pp. 289-294, 17-19 Sept. 2015. DOI: 10.1109/sisy.2015.7325397

[96] Drexler, D. A. "Solution of the closed-loop inverse kinematics algorithm using the Crank-Nicolson method." In: *Proceedings of the IEEE 14th International Symposium on Applied Machine Intelligence and Informatics.* 2016.

[97] Sápi, J., Ferenci, T., Drexler, D. A., Kovács, L. "Tumor model identification and statistical analysis." In: *Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics.* pp. 2481-2486, 9-12 Oct. 2015. DOI: 10.1109/smc.2015.434

[98] Sápi, J., Kovács, L., Drexler, D. A., Kocsis, P., Gajári, D., Sápi, Z. "Tumor Volume Estimation and Quasi- Continuous Administration for Most Effective Bevacizumab Therapy." *Plos One.* 10(11). 2015. DOI: 10.1371/journal.pone.0142190

[99] Sápi, J., Drexler, D. A., Harmati, I., Sápi, Z., Kovács, L. "Qualitative analysis of tumor growth model under antiangiogenic therapy – choosing the effective operating point and design parameters for controller design." *Optimal Control Applications and Methods.* 2015. DOI: 10.1002/oca.2196

[100] Major, V., Corbett, S., Redmond, D., Beatson, A., Glassenbury, D., Chiew, Y. S., Pretty, C., Desaive, T., Szlávecz, Á., Benyó, B., Shaw, G. M., Chase, J. G. "Respiratory mechanics assessment for reverse-triggered breathing cycles using pressure reconstruction." *Biomedical Signal Processing and Control.* 23(1). pp. 1-9. 2016. DOI: 10.1016/j.bspc.2015.07.007

[101] Dickson, J., Signal, M., Harris, D., Marics, G., Weston, P., Harding, J., Tóth-Heyn, P., Homlok, J., Benyó, B., Chase, J. G. "Modelling Intestinal Glucose Absorption Using Continuous Glucose Monitor Data." *IFAC-PapersOnLine.* 48(20). pp. 118-123. 2015. DOI: 10.1016/j.ifacol.2015.10.125

[102] Hesz, G., Szlávecz, Á., Kovács, K., Benyó, B. "Investigation of 3D SPECT Reconstruction with Multi-energy Photon Emitters." *IFAC-PapersOnLine.* 48(20). pp. 30-35. DOI: 10.1016/j.ifacol.2015.10.110

[103] Szilágyi, L., Lefkovits, L., Iantovics, B. L., Iclanzan, D., Benyó, B. "Automatic Brain Tumor Segmentation in Multispectral MRI Volumetric Records." In: *Neural Information Processing,* Lecture Notes in Computer Science, Vol. 9492, Springer International Publishing, pp. 174-181. 2015. DOI: 10.1007/978-3-319-26561-2_21

[104] Patartics, B., Kiss, B. "Application of laser slot sensors for the state estimation of overhead crane." In: 20th International Conference on Process Control, Strbske Pleso, Slovakia, 9-12 June 2015, pp. 387-392. DOI: 10.1109/pc.2015.7169994

[105] Kiss, B., Patartics, B. "Control of underactuated mechanical systems: the overhead crane example." In: International Symposium on Stability, Vibrations and Control Systems. 2015.

[106] Pálfi, V., Virosztek, T., Kollár, I. "Full information ADC test procedures using sinusoidal excitation, implemented in MATLAB and LabVIEW." *ACTA IMEKO.* 4(3). pp. 4-13. 2015.

[107] Carbone, P., Schoukens, J., Kollár, I., Moschitta, A. "Accurate Sine-Wave Amplitude Measurements Using Nonlinearly Quantized Data." *IEEE Transactions on Instrumentation and Measurement.* 64(12). pp. 3201-3208. 2015. DOI: 10.1109/tim.2015.2463331

[108] Sujbert, L., Orosz, Gy. "FFT-based Spectrum Analysis in the Case of Data Loss." In: *Proceedings of IEEE International Instrumentation and Measurement Technology Conference*, Pisa, Italy, 11-14 May 2015. pp. 800-805. DOI: 10.1109/i2mtc.2015.7151371

[109] Szarvas, A., Sujbert, L. "Efficiency Testing of Active Noise Control by Acoustic Field Modeling." *Periodica Polytechnica Electrical Engineering and Computer Science.* 59(4). pp. 147-159. 2015. DOI: 10.3311/PPee.8453

[110] Jobbágy, Á., Nagy, P. "Pulse Wave Velocity as a Function of Cuff Pressure - Extra Information About the Cardiovascular System." In: *World Congress on Medical Physics and Biomedical Engineering,* June 7-12, 2015, Toronto, Canada, IFMBE Proceedings, Vol. 51. Springer International Publishing. 2015. pp. 1279-1282. DOI: 10.1007/978-3-319-19387-8_310

[111] Dülk, I., Kovácsházy, T. "Parameter Estimation in Linear Electromagnetic Devices." *IEEE Transactions on Industrial Electronics*. 62(6). pp. 3619-3628. 2015. DOI: 10.1109/tie.2014.2374573

[112] Bozóki, Sz., Koronka, G., Pataricza, A. "Risk Assessment Based Cloudification." In: *Software Engineering for Resilient Systems*, Lecture Notes in Computer Science, Vol. 9274. Springer International Publishing, pp. 71-81. 2015. DOI: 10.1007/978-3-319-23129-7_6

[113] Gönczy, L., Majzik, I., Bozóki, S., Pataricza, A. "MDD-Based Design, Configuration and Monitoring of Resilient CPS." In: *Trustworthy Cyber-Physical Systems Engineering*. (Romanovsky, A., Ishikawa, F. (eds)), Chapman and Hall/CRC. 2016.

[114] Hajdu, Á., Vörös, A., Bartha, T. "New Search Strategies for the Petri Net CEGAR Approach." In: *Application and Theory of Petri Nets and Concurrency*, Lecture Notes in Computer Science, Vol. 9115. Springer International Publishing, pp. 309-328. 2015. DOI: 10.1007/978-3-319-19488-2_16

[115] Hegedűs, Á., Horváth, Á., Varró, D. "A model-driven framework for guided design space exploration." *Automated Software Engineering.* 22(3). pp. 399-436. 2015. DOI: 10.1007/s10515-014-0163-1

[116] Honfi, D., Vörös, A., Micskei, Z. "SEViz: A Tool for Visualizing Symbolic Execution." In: *2015 IEEE 8th International Conference on Software Testing, Verification and Validation (ICST)*, Graz, Austria, 13-17 April 2015, pp. 1-8. DOI: 10.1109/icst.2015.7102631

[117] Kocsis, I., Salánki, Á., Pataricza, A. "Measurement-based identification of infrastructures for TCPS." In: *Trustworthy Cyber-Physical Systems Engineering*. (Romanovsky, A., Ishikawa, F. (eds.)). Chapman and Hall/CRC. 2016.

[118] Molnár, V., Darvas, D., Vörös, A., Bartha, T. "Saturation-Based Incremental LTL Model Checking with Inductive Proofs." In: *Tools and Algorithms for the Construction and Analysis of Systems,* Lecture Notes in Computer Science, Vol. 9035, Springer Berlin Heidelberg, pp. 643-657. 2015. DOI: 10.1007/978-3-662-46681-0_58

[119] Molnár, V., Vörös, A., Darvas, D., Bartha, T., Majzik, I. "Component-wise Incremental LTL Model Checking." *Formal Aspects of Computing.* pp. 1-35. 2016. DOI: 10.1007/s00165-015-0347-x

[120] Tóth, T., Vörös, A., Majzik, I. "A Decomposition Method for the Verification of a Real-Time Safety-Critical Protocol." In: *Software Engineering for Resilient Systems*, Lecture Notes in Computer Science, Vol. 9274, Springer International Publishing, pp. 31-45. 2015. DOI: 10.1007/978-3-319-23129-7_3

[121] Ujhelyi, Z., Bergmann, G., Hegedüs, Á., Horváth, Á., Izsó, B., Ráth, I., Szatmári, Z., Varró, D. "EMF-IncQuery: An integrated development environment for live model queries." *Science Computer Programming.* 98(1). pp. 80-99. 2015. DOI: 10.1016/j.scico.2014.01.004

[122] Ujhelyi, Z., Szoke, G., Horváth, Á., Csiszár, N. I., Vidács, L., Varró, D., Ferenc, R. "Performance comparison of query-based techniques for anti-pattern detection." *Information & Software Technology.* 65. pp. 147-165. 2015. DOI: 10.1016/j.infsof.2015.01.003

[123] Bergmann, G., Dávid, I., Hegedüs, Á., Horváth, Á., Ráth, I., Ujhelyi, Z., Varró, D. "Viatra 3: A Reactive Model Transformation Platform." In: *Theory and Practice of Model Transformations*, Lecture Notes in Computer Science, Vol. 9152, Springer International Publishing, pp. 101-110, 2015. DOI: 10.1007/978-3-319-21155-8_8

[124] Cseppento, L., Micskei, Z. "Evaluating Symbolic Execution-Based Test Tools." In: *2015 IEEE 8th International Conference on Software Testing, Verification and Validation (ICST)*, Graz, Austria, 13-17 April 2015, pp. 1-10. DOI: 10.1109/icst.2015.7102587

[125] Gézsi, A., Lautner-Csorba, O., Erdélyi, D. J., Hullám, G., Antal, P., Semsei, A. F., Kutszegi, N., Hegyi, M., Csordás, K., Kovács, G., Szalai, C. "In interaction with gender a common CYP3A4 polymorphism may influence the survival rate of chemotherapy for childhood acute lymphoblastic leukemia." *Pharmacogenomics Journal.* 15(3). pp. 241-247. 2015. DOI: 10.1038/tpj.2014.60

[126] Horváth, Á., Wolf, P., Nagy, J., Kelemen, A., Horváth, G., Hadházi, D., Horvath, Á., Czétényi, B., Süttő, Z., Szondy, K. "Overview of a Digital Tomosynthesis Development: New Approaches for Low-Dose Chest Imaging." *Radiation Protection Dosimetry*. 2015. DOI: 10.1093/rpd/ncv469

[127] Györke, P., Pataki, B. "Energy Harvesting Wireless Sensors for Smart Home Applications." In: *2015 IEEE International Instrumentation and Measurement Technology Conference (I2MTC) Proceedings*, Pisa, Italy, 11-14 May 2015, pp. 1757-1762, DOI: 10.1109/i2mtc.2015.7151546

[128] Dobrowiecki, T. P., Schoukens, J. "Reducing the measurement time of the Best Linear Approximation of a Nonlinear System using improved averaging methods." In: *2015 IEEE International Instrumentation and Measurement Technology Conference (I2MTC) Proceedings*, Pisa, Italy, 11-14 May 2015, pp. 623-628. DOI: 10.1109/i2mtc.2015.7151340

[129] 3rd International IBM Cloud Academy Conference ICACON 2015. [Online]. Available from: http://www.ibm.com/solutions/education/cloud-academy/us/en/cloud_academy_conference_2015_4.html

[130] ENCY15 First European Biomedical Engineering Conference for Young Investigators. [Online]. Available from: http://ency15.mit.bme.hu/

[131] Ahvar, E., Ahvar, S., Crespi, N., Garcia-Alfaro, J. Mann, Z. Á. "NACER: a Network-Aware Cost-Efficient Resource allocation method for processing-intensive tasks in distributed clouds." In: 2015 IEEE 14th International Symposium on Network Computing and Applications, Cambridge, MA, USA, 28-30 September 2015, pp. 90-97. DOI: 10.1109/nca.2015.37

[132] Bartók, D., Mann, Z. Á. "Accelerating SAT solving with best-first-search." In: *Proceedings of the 15th IEEE International Symposium on Computational Intelligence and Informatics.* pp. 43-48. 2014. DOI: 10.1109/CINTI.2014.7028722

[133] Bartók, D., Mann, Z. Á. "A branch-and-bound approach to virtual machine placement." In: HPI Cloud Symposium "Operating the Cloud", 2015.

[134] Csikvári, P., Gyarmati, K., Sárközy, A. "Density and Ramsey type results on algebraic equations with restricted solution sets." *Combinatorica.* 32(4). pp. 425-449. 2012. DOI: 10.1007/s00493-012-2697-9

[135] Erdős, P. "On sequences of integers no one of which divides the product of two others and some related problems." *Tomsk. Gos. Univ. Ucen. Zap.* 2. pp. 74-82. 1938.

[136] Erdős, P. "On some applications of graph theory to number theoretic problems." Publ. Ramanujan Inst. 1. pp. 131-136. 1969.

[137] Erdős, P., Sárközy, A., Sós, V. T. "On the product representations of powers, I." *European Journal of Combinatorics.* 16. pp. 567-588. 1995. DOI: 10.1016/0195-6698(95)90039-x

[138] Gmach, D., Rolia, J., Cherkasova, L., Kemper, A. "Resource pool management: Reactive versus proactive or let's be friends." *Computer Networks.* 53(17). pp. 2905-2922. 2009. DOI: 10.1016/j.comnet.2009.08.011

[139] Győri, E. "C_6-free bipartite graphs and product representation of squares." *Discrete Mathematics*. 165-166. pp. 371-375. 1997. DOI: 10.1016/s0012-365x(96)00184-7

[140] Jani, L., Mann, Z. Á. "Cache optimization for CPU-GPU heterogeneous processors." *American Journal of Algorithms and Computing.* 2(1). pp. 18-31. 2015.

[141] Kocsis, I., Mann, Z. Á., Zilahi, D. "Optimal deployment for critical applications in Infrastructure as a Service." In: 3rd International IBM Cloud Academy Conference (ICACON 2015). 2015.

[142] Mann, Z. Á., Szajkó, A. "Average-case complexity of backtrack search for coloring sparse random graphs." *Journal of Computer and System Sciences.* 79(8). pp. 1287-1301. 2013. DOI: 10.1016/j.jcss.2013.06.003

[143] Mann, Z. Á., Papp, P. A. "Predicting algorithmic complexity through structure analysis and compression." *Applied Soft Computing.* 13(8). pp. 3582-3596. 2013. DOI: 10.1016/j.asoc.2013.04.018

[144] Mann, Z. Á. "Typical-case complexity and the SAT competitions." *Proceedings of the 5th Pragmatics of SAT Workshop (POS-14), EasyChair Proceedings in Computing.* 27. pp. 72-87. 2014.

[145] Mann, Z. Á., Papp, P. A. "Formula partitioning revisited." In: Proceedings of the 5th Pragmatics of SAT Workshop (POS-14), EasyChair Proceedings in Computing, Vol. 27, pp. 41-56, 2014.

[146] Mann, Z. Á., Szép, T. "Accelerating backtrack search with a best-first-search strategy." *International Journal of Applied Mathematics and Computer Science*. 24(4), pp. 901-916. 2014. DOI: 10.2478/amcs-2014-0066

[147] Mann, Z. Á. "Allocation of virtual machines in cloud data centers - a survey of problem models and optimization algorithms." *ACM Computing Surveys*. 48(1), 2015. DOI: 10.1145/2797211

[148] Mann, Z. Á. "Rigorous results on the effectiveness of some heuristics for the consolidation of virtual machines in a cloud data center." F*uture Generation Computer Systems*. 51, pp. 1-6. 2015. DOI: 10.1016/j.future.2015.04.004

[149] Mann, Z. Á. "Modeling the virtual machine allocation problem." In: Proceedings of the International Conference on Mathematical Methods, Mathematical Models and Simulation in Science and Engineering, pp. 102-106, 2015.

[150] Mann, Z. Á. "Approximability of virtual machine allocation: much harder than bin packing." Proceedings of the 9th Hungarian-Japanese Symposium on Discrete Mathematics and Its Applications, pp. 21-30, 2015.

[151] Mann, Z. Á. "A taxonomy for the virtual machine allocation problem." *International Journal of Mathematical Models and Methods in Applied Sciences*. 9, pp. 269-276. 2015.

[152] Pach, P. P. "Generalized multiplicative Sidon sets." *Journal of Number Theory*. 157, pp. 507-529. 2015. DOI: 10.1016/j.jnt.2015.05.018

[153] Pach, P. P. "Ramsey type results on the solvability of certain equations in Z_m." *Integers*. 13, 2013.

[154] Pach, P. P., Pinsker, M., Pongrácz, A., Szabó, Cs. "A new operation on partially ordered sets." *Journal of Combinatorial Theory Series A Structure Design and Applications*. 120(7), pp. 1450-1462. 2013. DOI: 10.1016/j.jcta.2013.04.003

[155] Pach, P. P., Pluhár, G., Pongrácz, A., Szabó, Cs. "The number of rooted trees of given depth." *The Electronic Journal of Combinatorics*. 20(2), P38, 2013.

[156] Pach, P. P. "The Ramsey-type version of a problem of Pomerance and Schinzel." *Acta Arithmetica.* 156 (1), pp. 1-5. 2012. DOI: 10.4064/aa156-1-1

[157] Pomerance, C., Schinzel, A. "Multiplicative properties of sets of residues." *Moscow Journal of Combinatorics and Number Theory*. 1(1), pp. 52-66. 2011.

[158] Verma, A., Ahuja, P., Neogi, A. "pMapper: power and migration cost aware application placement in virtualized systems." In: *Middleware 2008*, Lecture Notes in Computer Science, Vol. 5346, Springer Berlin Heidelberg, pp. 243-264, 2008. DOI: 10.1007/978-3-540-89856-6_13

[159] Badics, Z., Pávó, J. "Full wave potential formulation with low-frequency stability including Ohmic losses." *IEEE Transactions on Magnetics*. 51 (3), pp. 1-4, 2015. DOI: 10.1109/TMAG.2014.2362114

[160] Gyimóthy, S. "Optimal sampling for fast eddy current testing inversion by utilising sensitivity data." *IET Science Measurement and Technology*. 9(3), pp. 235-240. 2015. DOI: 10.1049/iet-smt.2013.016

[161] Bilicz, S. "Sparse grid surrogate models for electromagnetic problems with many parameters." *IEEE Transactions on Magnetics.* 52(3), pp. 1-4. 2016. DOI: 10.1109/TMAG.2015.2477241

[162] Bilicz, S. "High-frequency modelling of coils by integral formulations." COMPEL: The International Journal for Computation and Mathematics in Electrical and Electronic Engineering. 34(5), pp. 1447-1459. 2015. DOI: 10.1108/COMPEL-02-2015-0042

[163] Bilicz, S., Gyimothy, S., Pavo, J., Toth, L., Badics, Z., Balint, B. "Modeling of resonant wireless power transfer with integral formulations in heterogeneous media." *IEEE Transactions on Magnetics*. 52(3), 2016. DOI: 10.1109/TMAG.2015.2496728

[164] Badics, Z., Bilicz, S., Gyimothy, S., Pavo, J. "Finite Element-Integral Equation Full-Wave Multi-Solver for Efficient Modeling of Resonant Wireless Power Transfer." *IEEE Transactions on Magnetics.* 52(3), 2016. DOI: 10.1109/TMAG.2015.2479402

[165] Pető, T. "Multichannel Passive Radar Receiver Platform." In: International Interdisciplinary PhD Workshop, Miedzyzdroje, Poland, 2015.

[166] Rösner, V., Pető, T., Seller, R. "Koch Fractal Antenna Application in Monopulse Antenna Array." In: Radioelektronika, 2015 25th International Conference, Pardubice, Czech Republic, 21-22 April 2015, pp. 240-243. DOI: 10.1109/RADIOELEK.2015.7129021

[167] Szullo, A., Orban, J., Miko, G. "Development of a multichannel vector network analyzer for 'In Situ' measurement of radar antennas." In: *14th Conference on Microwave Techniques, COMITE 2015*, Pardubice, 22-23 April 2015, pp. 1-4. DOI: 10.1109/COMITE.2015.7120317

[168] Dudás, L., Szűcs, L., Gschwindt, A. "The Spectrum Monitoring System of Smog-1 Satellite." In: 14th Conference on Microwave Techniques, COMITE 2015, Pardubice, Czech Republic, 2015.

[169] Szalay, Z., Nagy, L. "Utilization of linearly and circularly polarized antennas for indoor positioning." In: 17th International Conference on Transparent Optical Networks (ICTON), Budapest, 5-9 July 2015, pp. 1-4. DOI: 10.1109/ICTON.2015.7193446

[170] Szalay, Z., Nagy, L. "Target modeling, antenna array design and conventional beamforming algorithms for radar target DOA estimation." In: 17th International Conference on Transparent Optical Networks (ICTON), Budapest, 5-9 July 2015, pp. 1-4. DOI: 10.1109/ICTON.2015.7193501

[171] Fekete, G., Mészáros, G., Udvary, E., Fehér, G., Berceli, T. "Visible light communication channel disturbances and examination of the modulation formats." *International Journal of Microwave and Wireless Technology*. 2015. DOI: 10.1017/S1759078715001269

[172] Udvary, E. "Investigation of Semiconductor Optical Amplifier Direct Modulation Bandwidth." *Infocommunications Journal*. 7(1), pp. 22-27, 2015.

[173] Cseh, T., Berceli, T. "Dispersion compensation in millimeter wave radio over multimode fiber systems." *Microwave and Optical Technology Letters*. 57(1), pp. 204-207, 2015. DOI: 10.1002/mop.28819

[174] Toth, G., Zolomy, A., Feher, G., Berceli, T. "Effect of parasitics in tunable X-band metamaterial isolators." In: *17th International Conference on Transparent Optical Networks (ICTON)*, 5-9 July 2015, pp. 1-4. DOI: 10.1109/ICTON.2015.7193416

[175] Szalay, Z., Farkasvölgyi, A., Szabó, Z., Yamada, S. "Hetnet Measurement and Reporting Enhancement." United States of America Patent US 2015/0004979 A1, 2015.

[176] Szabó, Z., Füzi, J. "Preisach Type Hysteresis Models with Everett Function in Closed Form." In: Proceedings of the COMPUMAG 20th Conference on the Computation of Electromagnetic Fields, Montreal, Canada, 2015.

[177] Szabó, Z., Füzi, J. "Implementation and Identification of Preisach Type Hysteresis Models with Everett Function in Closed Form." *Journal of Magnetism and Magnetic Materials*. 406, pp. 251-258. 2016. DOI: 10.1016/j.jmmm.2016.01.027

[178] Kalvach, A., Szabó, Z. "Calculation of Imaging Properties of Metamaterials." In: Proceedings of the COMPUMAG 20th Conference on the Computation of Electromagnetic Fields, Montreal, Canada, 2015.

[179] Kalvach, A., Szabó, Z. "Aberration-free flat lens design for a wide range of incident angles." *Journal of the Optical Society of America B*. 33(2), pp. A66-A71. 2016. DOI: 10.1364/JOSAB.33.000A66

[180] Csurgai-Horvath, L., Rieger, I., Kertesz, J. "Mobile access of the DVB-T channel and the opportunity for cognitive spectrum utilization." In: *1*7th International Conference on Transparent Optical Networks (ICTON), 2015, 5-9 July 2015, pp. 1-4. DOI: 10.1109/ICTON.2015.7193414

[181] Csurgai-Horvath, L., Rieger, I., Kertesz, J. "The Aldo Paraboni Scientific Experiment: Ka/Q Band Receiver Station in Hungary." In: The 9th European Conference on Antennas and Propagation (EuCAP), Lisbon, Portugal, 2015.

[182] Frigyes, I., Csurgai-Horvath, L., Horvath, P. "FSO-MIMO Behavior in Variable Atmospheric Turbulence - an Asymptotic Approach." In: 3rd IEEE Workshop on Optical Wireless Communications (OWC'12), Anaheim, USA, 2012.

[183] Horvath, B., Horvath, P. "Establishing Lower Bounds on the Peak-to-Average-Power Ratio in Filter Bank Multicarrier Systems." In: European Wireless 2015, Proceedings of 21th European Wireless Conference, 20-22 May 2015, pp. 1-6. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7147685&isnumber=7147659

[184] Kantor, P., Csurgai-Horvath, L., Drozdy, A., Bito, J. "Precipitation modelling for performance evaluation of ad-hoc microwave 5G mesh networks." In: 9th European Conference on Antennas and Propagation (EuCAP), 2015, Lisbon, Portugal, 13-17 April 2015.

[185] FIRST (Future Internet Research, Servives and Technologies) project, TÁMOP-4.2.2.C-11/1/KONV-2012-0001, Semantic multimedia search algorithms task, from 2012 to 2015.

[186] Szűcs, G., Papp, D., Lovas, D. "Viewpoints Combined Classification Method in Image-based Plant Identification Task." In: Working Notes for CLEF 2014 Conference. Vol. 1180, Sheffield, UK, Sept. 15-18 2014, pp. 763-770.

[187] Baranyi, P., Csapó, Á. B., Sallai, Gy. "Cognitive Infocommunications (CogInfoCom)." Berlin, Springer, 2015. DOI: 10.1007/978-3-319-19608-4

[188] CogInfoCom 2015 – 6th IEEE International Conference on Cognitive Infocommunications, October 19-21, 2015, Győr, Hungary.

[189] Barta, G., Borbely, Gy., Henk, T., Nagy, G., Kazi, S. "GEFCOM 2014 - Probabilistic Electricity Price Forecasting." In: Proceedings of the 7th KES International Conference on Intelligent Decision Technologies (KES-IDT 2015), Vol. 39, 2015, pp. 67-76.

[190] Csapó, T. G., Németh, G. "Automatic transformation of irregular to regular voice by residual analysis and synthesis." In: Interspeech 2015, Dresden, Germany, ISCA, pp. 613-617.

[191] Csapó, T. G., Németh, G., Cernak, M. "Residual-based Excitation with Continuous F0 Modeling in HMM-based Speech Synthesis." In: *Statistical Language and Speech Processing*, Lecture Notes in Computer Science, Vol. 9449., Springer International Publishing, pp. 27-38. 2015. DOI: 10.1007/978-3-319-25789-1_4

[192] Kazinczi, F., Mészáros, K., Vicsi, K. "Automatic Detection of Voice Disorders." In: *Statistical Language and Speech Processing*, Lecture Notes in Computer Science, Vol. 9449., Springer International Publishing, pp. 143-152. 2015. DOI: 10.1007/978-3-319-25789-1_14

[193] Nagy, P., Zainkó, Cs., Németh, G. "Synthesis of Speaking Styles with Corpus- and HMM-Based Approaches." In: *6th IEEE International Conference on Cognitive Infocommunications (CogInfoCom), 2015*. Győr, Hungary, 2015, pp. 195-200. DOI: 10.1109/CogInfoCom.2015.7390589

[194] Szaszák, Gy., Beke, A., Olaszy, G., Tóth, B. P. "Using automatic stress extraction from audio for improved prosody modeling in speech synthesis." In: Interspeech 2015. Dresden, Germany, ISCA, pp. 2227-2231.

[195] Sztahó, D., Kiss, G., Vicsi, K. "Estimating the Severity of Parkinson's Disease from Speech Using Linear Regression and Database Partitioning." In: Interspeech 2015, Dresden, Germany, ISCA, pp. 498-502.

[196] Varga, Á., Tarján, B., Tobler, Z., Szaszák, G., Fegyó, T., Bordás, C., Mihajlik, P. "Automatic Close Captioning for Live Hungarian Television Broadcast Speech: A Fast and Resource-Efficient Approach." In: *Speech and Computer*, Lecture Notes in Computer Science, Vol. 9319., Springer International Publishing, pp. 105-112. 2015. DOI: 10.1007/978-3-319-23132-7_13

[197] Zainkó, Cs., Bartalis, M., Németh, G., Olaszy, G. "A Polyglot Domain Optimised Text-To-Speech System for Railway Station Announcements." In: Interspeech 2015 - Proceedings of the 16th Annual Conference of the International Speech Communication Association, Dresden, Germany, 06-10 September 2015, ISCA, pp. 1236-1240.

[198] Orosz, P., Tothfalusi, T., Varga, P. "C-GEP: Adaptive Network Management with Reconfigurable Hardware." In: IFIP/IEEE International Symposium on Integrated Network Management (IM), 2015, Ottawa, ON, Canada, 2015, pp. 954-959. DOI: 10.1109/INM.2015.7140417

[199] Varga, P., Hegedus, Cs. "Service Interaction through Gateways for InterCloud Collaboration within the Arrowhead Framework." 5th IEEE WirelessVitae, Hyderabad, India, 2015.

[200] Gulyás, A., Bíró, J., Kőrösi, A., Rétvári, G., Krioukov, D. "Navigable networks as Nash equilibria of navigation games." *Nature Communications*. 6(7651), 2015. DOI: 10.1038/ncomms8651

[201] Megyesi, P., Szabó, G., Molnár, S. "User behavior based traffic emulator: A framework for generating test data for DPI tools." *Computer Networks*. 92(1), pp. 41-54, 2015. DOI: 10.1016/j.comnet.2015.09.026

[202] Öllös, G., Rolland, V. "Adaptive Multiresolution Sampling in Event-driven Wireless Sensor Networks." *Telecommunication Systems*. 61(2), pp. 337-347, 2016. DOI: 10.1007/s11235-015-0005-x

[203] Rétvári, G., Tapolcai, J., Kőrösi, A., Majdán, A., Heszberger, Z. "Compressing IP Forwarding Tables: Towards Entropy Bounds and Beyond." *IEEE/ACM Transactions on Networking*. 24(1), pp. 149-162, 2016. DOI: 10.1109/TNET.2014.2357051

[204] Tapolcai, J., Bíró, J., Babarczi, P., Gulyás, A., Heszberger, Z., Trossen, D. "Optimal False-Positive-Free Bloom Filter Design for Scalable Multicast Forwarding." *IEEE/ACM Transactions on Networking*. 23(6), pp. 1832-1845, 2015. DOI: 10.1109/TNET.2014.2342155

[205] Sonkoly, B., Czentye, J., Szabó, R., Jocha, D., Elek, J., Sahhaf, S., Tavernier, W., Risso, F. "Multi-Domain Service Orchestration Over Networks and Clouds: A Unified Approach." In: SIGCOMM '15 August 17-21, 2015, London, United Kingdom.

[206] Szabó, D., Németh, F., Sonkoly, B., Gulyás, A., Fitzek, F. H. P. "Towards the 5G Revolution: A Software Defined Network Architecture Exploiting Network Coding as a Service." In: SIGCOMM '15 August 17-21, 2015, London, United Kingdom. DOI: 10.1145/2785956.2790025

[207] Szabo, A., Varallyai, K. "Numerical Study of the Saturable Absorber Parameter Selection in an Erbium Fiber Ring Oscillator." *IEEE Photonics Technology Letters*. 24(2), pp. 122-124, 2012. DOI: 10.1109/LPT.2011.2173796

[208] Polgári, B., Sőrés, P., Divényi, D., Sleisz, Á., Raisz, D. "New Offer Structure for a Co-optimized Day-ahead Electricity Market." In: 12th International Conference on the European Energy Market (EEM), 2015. Lisbon, Portugal, 2015, pp. 1-5. DOI: 10.1109/EEM.2015.7216668

[209] Ladányi, J., Smohai, B. "The inductive coupling between leads while measuring resistance to earth of transmission line towers." *Electrotehnica Electronica Automatica.* 3, pp. 60-67, 2015.

[210] Csatár, J., Dán, A. "LV Grid Modeling Including Consumption and Distributed PV Generation with Focus on Voltage Profile." *Periodica Polytechnica Electrical Engineering and Computer Science*. 59(3), pp. 110-117, 2015. DOI: 10.3311/PPee.8574

[211] Raisz, I., Raisz, D. "Hazai szénbázisok bevonása az energiatermelésbe megújuló források felhasználásával." *Energiagazdálkodás*. 55(5-6), 2015. (in Hungarian)

[212] Halász, B. G., Göcsei, G., Németh, B., Cselkó, R., Bokor, T. "Arc protection during live-line maintenance on high voltage systems." In: 5th International Youth Conference on Energy (IYCE), 2015, Pisa, Italy, 27-30 May 2015, pp. 1-6. DOI: 10.1109/IYCE.2015.7180762

[213] Balangó, D., Németh, B., Göcsei, G. "Predicting conductor sag of power lines in a new model of dynamic line rating." In: Electrical Insulation Conference (EIC), 2015 IEEE, Seattle, WA, USA, 07-10 June 2015, pp. 41-44. DOI: 10.1109/ICACACT.2014.7223496

[214] Balangó, D., Pácsonyi, I., Németh, B. "Overview of a new dynamic line rating system, from modelling to measurement." In: 5th International Youth Conference on Energy (IYCE), 2015, Pisa, Italy, 27-30 May 2015, pp. 1-6. DOI: 10.1109/IYCE.2015.7180801

[215] Göcsei, G., Kiss, I., Németh, B. "Effects of magnetic fields during high voltage live-line maintenance." *Journal of Physics: Conference Series*. 646 (1), Paper 012026, 2015. DOI: 10.1088/1742-6596/646/1/012026

[216] Göcsei, G., Németh, B. "New challenges in live-line maintenance." In: Electrical Insulation Conference (EIC), 2015 IEEE, Seattle, WA, USA, 07-10 June 2015, pp. 185-188. DOI: 10.1109/ICACACT.2014.7223498

[217] Göcsei, G., Németh, B., Berta, I. "Electric fields and arc protection during live-line maintenance." In: XIX. International Symposium on High Voltage Engineering 2015. Plzen, Czeh Republic, 23 August 2015, Paper 631.

[218] Göcsei, G., Berta, I., Németh, B. "Safety considerations regarding to the shielding of electric fields during high voltage live-line maintenance." *Acta Technica Jaurinensis*. 8(2), pp. 153-164, 2015. DOI: 10.14513/actatechjaur.v8.n2.368

[219] Göcsei, G., Németh, B. "New Method for Inspection & Detection of Composite Insulator Designs Susceptible to Brittle Fracture." In: INMR World Congress 2015. Munich, Germany, 18 October 2015, Paper MC9.8.

[220] Cselkó, R., Németh, B., Göcsei, G., Mucsi, D., Kiss, I. "Critical Review of the Dielectric Testing of Some Live Line Tools." In: Electrical Insulation Conference (EIC), 2015 IEEE, Seattle, WA, USA, 07-10 June 2015, pp. 176-180. DOI: 10.1109/ICACACT.2014.7223497

[221] Farkas, B., Veszprémi, K. "Regenerative Cascaded Cell Inverter with Active Filter." *Periodica Polytechnica Electrical Engineering and Computer Science*. 59 (2), pp. 36-42, 2015. DOI: 10.3311/PPee.8165

[222] Farkas B., Veszprémi K. "Párhuzamosan kapcsolt inverterek." *Elektrotechnika*. 108(6), pp. 15-19, 2015. (in Hungarian)

[223] Veszprémi, K., Wallner, M., Patonay, G. "Frekvenciaváltók közvetlen szabályozása." *Elektrotechnika*. 108(3), pp. 5-8, 2015.

[224] Vajsz T., Számel L. "Robust speed-control for permanent magnet synchronous motor servo drives." In: Kiss, B., Szirmay-Kalos, L. Proceedings of the Workshop on the Advances of Information Technology: WAIT 2015. Budapest, Hungary, 2015.05.19 (BME VIK) Budapest: BME Department of Control and Informatics, 2015. pp. 78-82.

[225] Vajsz, T., Számel, L. "An investigation of robust speed-controllers for permanent magnet synchronous motor servo drives." In: Vajk, I., Dunaev, D.: Proceedings of the Automation and Applied Computer Science Workshop 2015: AACS'15. 262 p., Budapest, Hungary, 2015.06.26 Budapest: Budapest University of Technology and Economics, 2015. Paper Vajsz_Szamel. 12 p. (ISBN:978-963-313-187-9)