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Foreword

The detailed overview of the activities (research, organising research, education, and development of teaching materials) performed within the framework of the TÁMOP project with the title Future Internet Research, Services and Technology (FIRST) cannot be the objective of this publication. Instead of us, let the articles and papers, the submitted patents, the teaching materials speak and all those documents which we produced during the project. Our closing publication is a summary of our work which provides help in overviewing the results we achieved. Besides the Faculty of Informatics of the University of Debrecen, the Inter-University Centre for Telecommunications and Informatics, the Institute of Nuclear Research of the Hungarian Academy of Sciences and the National Information Infrastructure Development Institute belong to the consortium.
When the tender was submitted, we articulated our general objectives in the following way:

> *"In close cooperation with our partners in the Future Internet research our aim is to promote the extension of the Internet. We wish to contribute to surmounting the existing technological barriers and to extending the potentials of the application of the Internet. Based on this idea we aim to develop the informatics training in the tertiary education and we wish to establish a coordinating research centre which will promote national and international cooperation."*

We performed our research activities in the form of thematic subprojects. The justification of this idea is well reflected by the reports of the subprojects as well, since research communities, workshops came into being which did their work in a well-defined field. With the establishment of the Future Internet Research Coordination Center – FIRCC – we undertook a national coordinating role. The foundation of the Future Internet Research Platform ensures the long-term harmonization of research and development in the given field nationwide. FIRCC has made remarkable progress in building relationships between international organizations which deal with Future Internet research. The expansion of our network is an important result of both of our research activities and of our research organizing activities. Relying on this, we have initiated new projects and we have established the basis for further Future Internet researches.

János Sztrik
Head of Research

Subproject 1:

Theoretical Foundation of Future Internet

Subproject Leader: Attila Pethő

The work of this subproject is very diversified. Research groups of three consortium members – UD, MTA Atomki and ETIK - participats here. Moreover from the side of UD, collegues from three departments: Computer Science, Applied Mathematics and Probability Theory from the Faculty of Informatics as well as Theoretical Physics from the Faculty of Science are represented. Despite this heterogenety our research group does good job.
Through this project our international relations became more intensive. We participated directly in the organisation of four international conferences; our collegues gave talks yearly at least two international scientificc conferences; and several scientists from e.g. Germany, Austria, Italy, Japan, Taivan and Romania visited Debrecen for shorter or longer time.
The effective usage of the sources of the project proves that two members, Gábor Halász and György Vaszil became doctor of the HAS, Andrea Huszti started her habilitation, finally András Csehi, Veronika Halász, László Hegedűs és István Hornyák started the process to get PhD.
The scientific work of our subproject is grouped around three topics. The members belong formally to these groups, but there were several investigations between the groups. We present the most important scientific achivements by these groups.

1.1 Data seccurity and cryptography

Leader: Attila Pethő

We gave a detailed security analysis of a key exchange protocol introdused by H. Yosh in 2012, which is based on the hardness of computing solutions of diophantine equations. We proved that this protocol is not secure over finite fields. However for classical diophantine equations the parameters can be chosen such that the protocol is secure. We presented such choices of the parameters, which decreased the size of the public key drastically, but does not affect the seecurity.

Our new protocol seems to be resistant against quantum algorithms.
We investigated security aspects of mixnets, which are based on bilinear pairing. Based on it a new mixnet was developed, which is capable to send messages of arbitrary length and guaranties the answer of the anonim sender [2]. We worked out the theoretical bases of a pseudorandom number generator, which produces numbers with Gaussian distribution. This has applications in lattice based encryption, which playes an role important in quantum resistant cryptography. Tamás Herendi dealt with pseudorandom number generators over the residue class rings modulo 2^s. Together with his PhD student Sándor Roland Major prepared its FPGA implementation and submitted a patent [3]. We developed a new encryption method for the Dömösi cryptosystem, which is based on the so called Gluskov multiplication of automata.
The main focus of the research group in MTA Atomki (Dr. Károly Pál és Dr. Tamás Vértesi) is to exploit quantum non-local effects in so-called device-independent quantum information protocols. That is, our aim is to devise novel quantum information applications, where the users do not have to rely on the inner working of their devices. Below are listed our main results in this research field:
We characterized quantum nonlocality under local dimension constraints via a complete hierarchy of semidefinite programming relaxations (SDP). Our method enables to witness dimension of multipartite quantum system in a device-independent manner (that is, the devices are treated as boxes regardless of their actual inner working).
Using a photonic setup, we devise and experimentally certify entangled measurements using only input-output measurement statistics. These type of measurements play a central role in many quantum information tasks such as quantum teleportation.
We developed the so-called SWAP method, which allows us to estimate physical properties of quantum information protocols from observed statistics only. To this end, we generate a formula for the SWAP operator using the algebraic relations between the elements of the model and then implement it to copy the black box system to a quantum device whose physics we trust. We find that the SWAP tool provides results orders of magnitude better than previously-known techniques.
We developed methods based on linear programming to derive Bell inequalities having some specific properties. This way we have created three-party two-setting two-outcome Bell inequalities maximally violated by the W state, and

only by the W state. These inequalities, in the framework of the SWAP method, made it possible to work out a robust procedure for self-testing of the W state in a device-independent manner. We have demonstrated on several examples that the procedure is appropriate for self-testing of other states as well, whenever Bell inequalities maximally violated by those states are available.

We have also used linear programming to construct Bell inequalities whose violation may be observed using detectors of lower efficiency. As photon detectors are still quite inefficient, such inequalities may be useful for closing the so-called detection loophole, and also in practical applications of quantum information technology. We have developed methods based on linear programming to derive Bell inequalities having some specific properties. We have derived several three- and more-party inequalities with low critical detector efficiencies, requiring different quantum states. We could generalize some of those numerically constructed inequalities for any number of parties and any number of measurement settings. This enabled us to give an upper bound for the minimum of the critical detector efficiency as a function of these variables. We have constructed another family of inequalities whose optimum state is the multipartite GHZ state, independent of the detector efficiency. Although the critical efficiencies for this family are somewhat less impressive, probably this family is more important from a practical point of view: the state is easier to prepare, the measurement settings are well separated and the noise tolerance is much better.

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1.2 Theoretical foundation of large networks

Leader: Tamás Mihálydeák

This research group worked on four different topics, therefore we present the results of them separately. In the group dealing with rough sets and their applications in computer science was leaded by Tamás Mihálydeák and contained the following researchers: Dr. László Aszalós, Dr. Zoltán Csajbók, Dr. György Vaszil and Tamás Kádek, Participant from foreign countries: Davide Ciucci, Milan.

Rough sets and the different possibilities of their applications were in the center of the investigation of the group. The importance of investigation is the following: decisions concerning a property of an individual object made on the basis of a given amount of information (i.e. in the case of an information system/database) have direct influence for objects which are indiscernible from the given one. From the theoretical and practical point of view the situation becomes more complicated if our database is not total. The further importance of their investigation is in the fact that we have total databases (which do not involve NULL fields) very rarely.

Their results are the followings:

The generalization of theory of rough sets worked out by Pawlak: After precise definition of general approximation spaces they showed the properties of general (generalized) approximation spaces. They investigated how the general properties of lower and upper approximation functions change the behavior of approximation spaces. After analyzing the possibilities of fuzzyfication of approximation spaces the found some approximation pairs which can fuzzyficate the spaces. They achieved some general results concerning the connections os exactness, definability and roughness. They applied general approximation spaces to represent medical data correctly.

Logical investigations relying on general approximation spaces: Set theory is the semantic basis of classical logical systems. In the most general form the main question was the following: What happens with the logical laws if the logical semantics relies on the different systems of rough sets (instead of the classical notion of sets)? If we have a database/information system as background knowledge, then which inferences remain logically valid? The first step was the investigation concerning the possibility of a first-order logical system relying on the general theory of rough sets. In order to get a positive answer partiality had to be permitted necessarily. So we had to give up the principle of tertium non datur (the principle of excluded middle). The new logical systems are three

valued or partial three valued. The investigation of behavior of these system is a huge task (and there was no enough time to finish it). After showing the most fundamental properties (as modus ponens and modus tollens) the behavior of quantifications (existential and universal) were in the focus. The most important inferences containing quantified propositions (the first figure of Aristotle's syllogism) were investigated in order to get sufficient conditions of their validity. They analyzed partial fuzzy logical systems relying on different membership (optimistic, pessimistic and average). There is a big problem of applications of fuzzy logical systems: we have to suppose that fuzzy functions which characterize fuzzy sets are given in advance. In the case of finite universe the problem can be solved by using general approximation spaces. Generated partial fuzzy functions open a way before logical semantics which relies fuzzy functions on not only in abstract sense but taking into consideration given information/background knowledge.

László Aszalós pointed out a very important computer science application: sets appearing as the results of correlation clustering are useful as the base sets of general approximation spaces. The importance of his investigation is that we can approximate not only sets but objects by base sets.

The research of György Vaszil concentrated on the so called chemical paradigm of computation, and on certain abstract computational models based on the chemical paradigm: membrane systems, or P systems. The computational models based on these principles are interesting because they might provide a theoretical basis for the new interaction model necessary to describe the novel types of network architectures for Future Internet applications. As a typical research direction, with Péter Battyányi, they studied the possibilities of describing membrane systems with tools, such as the so called "higher order chemical language". They showed how to use the Gamma formalism of J. P. Banatre to specify certain types of membrane system computations.

Concerning P systems, his research was carried out in broad national and international cooperation. With Erzsébet Csuhaj-Varjú (Eötvös Loránd University, Budapest) they studied several types of P automata and their cooperating, distributed variants. Some of the typical results of this research can be found in the article [5]. In this work they examined the relationship of P automata and certain types of counter machines using restricted workspace (restricted counter machine acceptors, RCMA).

The research of Benedek Nagy focusing on unconventional automata included the exploration of the relationship of these models with other types of unconventional computational devices. An interesting results in this respect can be found in [6], where they showed that finite automata and pushdown automata using translucent letters, a model introduced with Friedrich Otto (University of Kassel, Germany), can be efficiently used for the description of rational and context-free trace languages, which are languages used for the specification of the behavior of parallel computations, computational processes.

A number of practical applications have been found for correlation clustering since its introduction in 2004. As shown in our experiments, typically there in not only one unique solution for a problem, therefore it is worth to combine these solutions. This idea led to rough clustering, where the lower and upper approximation sets of the objects are given based on several solutions of the correlation problem. By using this method, we constructed the rough classification. These algorithms are universal, but we also used them for specific tasks. The clustering of the natural numbers, based on relative prime property brought a surprising result, and carefully examining this problem a few more general result were obtained. We applied our methods to solve correlation clustering problems for data from real life. As the correlation clustering is an NP-hard problem, at practical tasks only the approximation gives a near-optimal solution. Previously we implemented several methods for dense graphs, and they can be used for sparse graphs, too; however it is an ineffective solution. Therefore, we implemented a variant of the YSMF data structure that speeds up the calculation for the sparse graphs, and based on the experiments on this implementation, conjectures were formulated for large sparse graphs. We continued the development, and using these methods we are able to generate the near optimal solution for sparse graphs with 3000 nodes, while previously our limit was dense graphs with 500 nodes.

The group of ETIK, leaded by Károly Simon achieved the following results: Two random graph models are considered which belong to the class of Apollonian networks, one is called High dimensional random apollonian network (RAN), the other is Evolutionary apollonian network (EAN). These random graphs evolve in discrete time, and they share properties with real-life networks. In our work we showed that the asymptotic degree distribution of d-dimensional RAN can be similarly determined as that of the 2 dimensional one, and we also determined this distribution in case of a modified version of EAN. This latter result made precise one idea of Zhang and his co-authors, and we showed that the corresponding RAN and EAN graphs have the same asymptotic degree distribution. We investigated an Internet network model in the absence of congestion control.

We consider the queue length processes of data-flows on directed graphs. The evolution of queue lengths is supposed to be Markovian with state-dependent transition rates. The ergodicity of the process and the efficiency of the network are studied. We prove the achievable efficiency limit in a stable network without any congestion control for very general conditions, given some constraints on the input rates of incoming flows. Moreover, we show that even for cyclic networks, which usually cause severe instability in networks, an upper bound for the loss of efficiency can be given independently of the size of the network under tail dropping buffer management policy. Our results demonstrate that with a proper setting of access rates of incoming flows the congestion collapse of the Internet can be avoided even without congestion control.

Károly Simon Júlia Komjáthy, Péter Móra and Sándor Molnár compared the large deviation spectra of the TCP Cubic to the same spectra of TCP Reno. Their calculations verify and quantify the bursty behavior of the traffic. This bursty behavior is one of the reasons for long queues in TCP traffic. We pointed out that the bursty behavior is much more common in the case of Reno TCP. The research paper containing their results is under preparation.

Albert László Barabási introduced a model that explains the bursty nature of many human driven actions. In this model one person executes various tasks based on the priority of these tasks. In our research on the one hand, we have improved Vazquez's earlier analytic results on this field. On the other hand, we have generalized the decision rule used in the original Barabási paper and we investigated the existence of stationary state in this generalized model. Further we investigated the time spent on the list by a task.

Marianna Bolla investigated the spectral characterization of generalized random graphs, corresponding to the multiclass extensions of the classical Erdős-Rényi model. She proved that the normalized spectrum and spectral subspaces of the random graph sequences obeying this model converge in the sense of the notions of László Lovász and his coauthors. Her investigations were extended to the biclustering of the rows and columns of contingency tables such that the clusters show homogeneous behavior with respect to each other (for example, characteristic groups of genes or conditions in microarrays). We proved relations between the multiway cut, characterizing this property, and the SVD of the normalized table, see the following paper.

István Kolossváry and Júlia Komjáthy investigated the length of the shortest path between two randomly chosen vertices in an inhomogeneous random graph model. The model, introduced by Bollobás, Janson and Riordan, can be

considered as a generalization of the well-known Erdős-Rényi random graph. Each node is assigned a type from some set and edges are drawn independently of each other, where the probability of connecting two vertices depends on the types of the nodes. The Erdős-Rényi graph is retrieved when every vertex has the same type. Each edge independently of each other is given an exponentially distributed random edge weight.

The main result is that this model also satisfies the small world property. Furthermore, after proper normalization the number of edges on this path satisfies a Central Limit Theorem and the weight of the path also converges to a random variable. This variable can be derived from a branching process, which arises naturally when exploring the neighborhood a vertex.

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1.3 Molecular switches

Leader: Ágnes Vibók

Participants of this group: Ágnes Vibók, professor; Gábor Halász, associate professor; András Csehi, assistant Sándor Borbély assistant professor, Babes Bolyai University; Aurelie Perveaux, Ph.D student, University of Montpellier II. Montpellier, Franciaország (1 week from January 6).

In our work related to molecular switches, our primary aim was to systematically investigate the switching properties of quinoline compounds. The effect of several functional groups on the potential energy surfaces, excitation energies, oscillator strengths and dipole moments have been studied. Our efforts were successful, since plenty of switching characteristics have been explored for the above-mentioned quinoline systems:

All the studied molecules possess two stable, well separated minima on the ground state potential energy surface. These stable isomers, constituting the terminal points of the considered microscopic reaction paths, exhibit well distinguishable vertical excitation spectra. Transition dipole moments between the ground and first excited states turned out to be reasonably large in the majority of the compounds, while in some cases only indirect excitation was possible.

According to the potential energy profiles of the ground and first excited states (along the mentioned reaction paths) it was found that the ground state energy curves of carbxyboryl and carboxycyanide substituted systems (at the crane position) are significantly lifted around the perpendicular twist.

We could show that amide groups attached to the frame part have minor effect on the switching properties, they cause only a slight shift in the energies (< 0.1 eV). We were able to optimize conical intersections (a crucial characteristic for switch systems) in all of the molecules near the 90 degree twists.

Based on the potential energy profiles, we demonstrated that four of the carboxamide, carbxyboryl and carboxycyanide systems are switchable in one direction, and the rest in both directions through the point of CIs. The methyl and amino compounds were shown to possess all the required switching features, thus they are promising candidates for information-storage systems. Our results are based on reliable high-level electronic structure models (MP2, CC2, CASSCF).

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Subproject 2:

Modelling and Analysis of Future Internet Networks

Subproject Leader: János Sztrik

Research topics of the subproject cover a wide spectrum of mathematical modelling and traffic analysis. As a common goal we searched answers for the challenges derived from the architecture of today's Internet to contribute to its evolution towards the Internet of the future.

First topic focuses on the modelling of infocommunication networks. We successfully applied finite source queuing models for various issues related to mobile and sensor networks. Besides this work we modelled information spreading in declining social networks.

Research group of the second topic, recognizing the importance of the objective evaluation of the quality of real-time media services, investigated the correlation of the objective and subjective quality. Based on the results, they elaborated novel objective methods for the automated assessment of perceptive quality (QoE).

Researchers of the third topic investigated queuing models and developed a model for the examination of scheduling tasks in computational clusters, among other results. The group carried out research in the field of secondary spectrum renting and proposed a scheme for the cooperation in the renting process.

Fourth research team worked on Discriminatory Processor Sharing models and information dissemination in multicast communications. In this project they investigated DPS models which incorporate access rate limitations in a bandwidth economical manner and revised the idea of in-packet Bloom filters and source routing. Furthermore, the group explored effective techniques for influencing the navigability of real world networks.

Relating to the work of the subproject we organized a national and an international workshop and regularly gave seminars in which our researchers had the opportunity to locally represent and discuss the results. Achievements and results are presented in high quality international journals and conferences. We involved seven (PhD and master) students to the research, who actively contributed to the work and the results of our research groups. Based on our experiences we found that the project membership influenced our students to enhance their studies to master and PhD levels. We set up productive and maintainable co-operations with our academic and industrial partners.

Recently, our colleagues successfully applied for personal scientific grants: one Szentágothai János Experienced Researcher Grant, two Magyary Zoltán Postdoctoral Grants and one Cross-Border Doctoral Grant. Two of our colleagues got the doctoral candidate status. For four researchers, the project membership contributed to the preparation of their habilitations.

2.1. Modeling and Performance Evaluation of Networks

Leader: János Sztrik

Now we present briefly the results achieved during the project:

We proposed a new finite-source retrial queueing model to consider spectrum renting in mobile cellular networks [1]. The retrial queue incorporates necessary ingredients such as a variable number servers which are switched on and off in groups, a finite number of subscribers, their impatience, and a queue for the outbound service. We presented a novel way to take into account the renting fee, which can be used to fine-tune the operation of the spectrum renting procedure. Numerical results showed that, at high loads, it had been still desirable to initiate a spectrum renting request, even if no discount was offered by the frequency bands' owners.

We've studied the radio frequency (RF) transmission in wireless sensor networks. A new finite source retrial queueing model was introduced in order to calculate the most important system performance characteristics (e.g. mean waiting time, mean number of requests waiting for transmission). The sensors formed the "sources" and the RF unit represented the "service station" of the queueing model. The sensors were classified according to their working purposes: The first class was the "Emergency" class, which was responsible to notify special emergency situations (e.g. fire alarms). The second class was the "Standard" class, which performed the measurement of standard environmental data (e.g. humidity, temperature). The RF unit might enter into energy saving (or "sleeping") working mode in order to spare energy and have longer battery life. The RF communication was stopped in the sleeping mode. Concerning the "wake up" mechanism from the energy saving mode we differentiated two cases and created two models to compare their steady-state system performance measures: In the first model the RF transmission possibility was available

randomly for the sensor nodes (Non Controlled case). In the second model the RF transmission requests coming from the emergency class were able to access the wireless channel immediately (Controlled case) (see [2], [4]).
The performance of radio frequency licensing could be increased by the idea of the cognitive radio. Licensed users (Primary Users - PUs) and normal users (Secondary Users - SUs) were considered. The main idea was, that the SUs were able to access to the available non-licensed radio frequencies. Queueing theory could be successfully applied to analyze this problem. A finite source queueing model was introduced with two (non-independent) frequency bands. A service unit with a priority queue and a service unit with an orbit were assigned to the PUs and SUs, respectively. The users were classified into two classes: the PUs had got a licensed frequency. The SUs had got a frequency band too, but it suffered from the overloading. We performed numerical calculations to investigate the behavior the cognitive radio.
We introduced a finite source retrial queueing model to investigate the performance measures of a cognitive infocommunication system subject to random network communication breakdowns. The sources of the queueing model represented the communication entities, which were divided into two classes: The first class was the class of "Intelligent sources", where the source entity was able to get information about the state of the network environment, and so they were able to retry the started request in the case of special communication problems. The second class was the "Normal sources" (e.g. sensors), where the source entity started the network communication, but was not able to sense the state of the network environment, so it was unable to retry the transmission in the case of special problems or errors. A novel Markovian model was constructed focusing on the question how the breakdowns of the communication network influence the system's performance assuming that the service can be in 3 different states, fully operational, limited operation, broken offering different communication capabilities to the "Sources". The main interest of the present paper was to investigate the main steady-state performance measures of the system [3].
The structure of online social networks and the information spreading on these networks have been studied. Our work can be divided into two phases. We developed different algorithms to generate scale-free networks with tunable topological properties such as degree-distribution, average degree, clustering, average shortest path length, etc. We used them to create a model of online social networks in their declining phase or the effect of cliques to the structure of social networks. On the networks produced in the previous phase have been subjected to analysis of information spreading by cellular automata simulations. We have studied the effect of different kind of declining scenarios to the speed of information spreading. We developed a spreading model, which takes into account the possible inactivity of agents and then we improved it to handle the heterogeneous inactivity of agents [5].

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2.2. Online analysis of QoS/QoE in high speed networks

Leader: Péter Orosz

Primary focus of our research group is the evaluation of media service quality in IP networks. Lack of QoS/QoE correlation in some cases renders the objective evaluation of a service difficult. There is no any broadly accepted, universal QoE assessment method based on objective metrics, which provides a good approximation of the perceptive quality. Monitoring service quality from endpoint to endpoint is not an easily automated task, even from the research aspect it is a

serious challenge to establish an objective method replacing the analysis based on subjective quality perception.

In this project we elaborated new QoE assessment methods for evaluating service quality of VoIP, IPTV and mobile voice. In order to determine the directions, we performed laboratory evaluation of some critical media traffic types. We investigated the effect of network perturbation (packet delay, jitter, loss and reordering) on services that integrates new generation media codecs, i.e., Opus and H.264. We analyzed the sensibility of the services to packet delivery parameters in the network (latency, jitter, loss, reordering): How does the measured packet-level QoS correlate to the perceived quality? Besides the laboratory QoS evaluations we performed subjective QoE assessments inviting volunteers to evaluate voice and video test clips.

During this work we analyzed the correlation of three measurement dataset: objective (packet-level) QoS metrics, objective QoE (PSNR, VQM, SSIM) video quality metrics and subjective user evaluations (MOS). We showed that the temporal position of the visual artifact has a direct effect on the perceptive quality. Video clips including artifact at the beginning or at the end consequently got a lower MOS score from the evaluators. Perception is also affected by previous contents and experiences of the volunteers. We showed that none of the QoS metrics correlates well to the perceived quality. However the linear combination of the metrics, with appropriately tuned coefficients, provides a good approximation of the subjective quality.

By investigating voice quality, we found that some of the network metrics show correlation to the perceptual quality of the VoIP service. Using this result, we elaborated a new method for approximating the perceptive quality of RTP-based voice transmission without involving any reference data [3]. This method gives an alternative to the subjective quality assessment solutions. Our staring point was the requirement for an automated method based on objective evaluation that provides an output with good correlation to the result of perceptive, human feedback-based quality assessment. In this method, perceptive voice quality is approximated with a multi-variable polynomial based on the packet-level QoS metrics. This method, besides working without reference data, supports real-time processing. Belonging to this work, we have developed a hardware accelerated, on-the-fly QoS monitoring system that has been prototyped on NetFPGA networking platform. The basis of the second quality-analysis method is a multi-threaded timestamping mechanism that enables the measurement of network and system perturbation in several layers [2].

Using the subjective evaluation-based assessment approach we came up with a solution tailored to mobile environments based on the demands of the operators in which the subscriber evaluates the quality of the voice service at the end of the call. This assessment, depending on the operator's needs and aims, can be a MOS-type grade, but more complex options are also available e.g., "very good"-"satisfactory"-"distorted voice"-"interrupted"-"one side muted "-"echo" etc. The developed method was implemented on Android mobile operating system by our industrial partner in collaboration with experts from a mobile operator.

We showed that our voice QoE approximation method could not be adopted to video flows due to the structural differences. Accordingly, we extensively analyzed H.264 encoded flows to provide underlying results for a video QoE assessment algorithm. There is no trivial way reaching this goal, since the type and the extent of the video artifact depend on the type of the lost or corrupted video frame (I-frame, P-frame, or B-frame). Therefore, the frame type should be identified and the error should be weighted according to the type, size and position of the frame within the GOP. Approximated QoE could be calculated for each GOP of a video-flow processed in the presented way.

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2.3. New traffic characterizing and anylysis methods for Future Internet

Leader: Miklós Telek

Our working group achieved significant results in a number of fields during the past two years. These results were presented in leading papers and conferences of their respective fields.

We carried out research regarding the characterization of M/M/c retrial queues [1], in which requests move to a separate file if they fail to get service before a given random time. From this file requests can retry, however their total retrial intensity is bounded. Along the exact analytical expressions we also used simplified equations that provide fast solution methods for various performance parameters that can be used effectively in practice. We investigated the behavior of M/M/1 queues with negative requests and vacation, in which positive requests enter an infinite size orbit if they fail to get service due to vacation or occupancy of the server. We developed an efficient methodology for the model and examined several specific systems.

We analyzed queues with two priority classes, feedback control, and finite puffer. This system can be used to model the Differentiated Services Architecture in IP networks. Aside from the formula for steady state probabilities we also constructed methods for the calculation of other performance parameters. We developed a computationally efficient method for two-server heterogeneous retrial queues that use analytical formulas instead of the iterative approach of formerly known numerical methods. We demonstrated through numerical examination that the new procedure has significantly better performance than previous algorithms.

Another major topic of our research was the investigation of Markov chain based models, with particular emphasis on Markovian representation of non-Markovian classes and canonical forms of Markovian structures. We developed a heuristic method that transforms rational arrival processes to Markovian representations with high reliability [2]. The new method outperforms earlier algorithms using flexible transformation steps that may include changing the size of the representation if necessary. We derived canonical forms for discrete time order 3 phase-type distributions and order 2 discrete time Markov arrival processes [3]. Using these forms we proved the long-standing conjectures regarding the equivalence of these classes to their non-Markovian counterparts. Exploiting the parametrization of the canonical representations we developed effective exact parameter fitting methods. Furthermore we demonstrated that also in case of non-exact fitting methods the usage of canonical forms is often beneficial.

We established and extended an algorithm package that can be effectively used in the research of Markov chain based models. In this package we implemented already existing methods but also developed new methods for efficient analysis of these structures. We developed a model for the examination of scheduling tasks in computational clusters [4]. This model was also analyzed it thoroughly with regards to performance and energy consumption.

Finally we carried out research in the field of secondary spectrum renting [5] and proposed a scheme for the cooperation in the renting process and investigated its characteristics in detail.

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2.4. New Scalable Resource Allocation and Traffic Management Methods

Leader: József Bíró

Current trends in cloud computing suggest that both large, public clouds and small, private clouds will proliferate in the near future. Operational requirements, such as high bandwidth, dependability and smooth manageability, are

similar for both types of clouds and their underlying data center architecture. Such requirements can be satisfied with utilizing fully distributed, low-overhead mechanisms at the algorithm level, and an efficient layer 2 implementation at the practical level. On the other hand, owners of evolving private data centers are in dire need of an incrementally upgradeable architecture which supports a small roll-out and continuous expansion in small quanta. In order to satisfy both requirements, we proposed Poincaré, a data center architecture inspired by hyperbolic tessellations, which utilizes low-overhead, greedy routing. On one hand, Poincaré scales to support large data centers with low diameter, high bisection bandwidth, inherent multipath and multicast capabilities, and efficient error recovery. On the other hand, Poincaré supports incremental plug & play upgradability with regard to both servers and switches. We evaluated Poincaré using analysis, extensive simulations and a prototype implementation [1].

The increasing popularity of both small and large private clouds and expanding public clouds poses new requirements to data center (DC) architectures. First, DC architectures should be incrementally scalable allowing the creation of DCs of arbitrary size with consistent performance characteristics. Second, initial DC deployments should be incrementally expandable supporting small-scale upgrades without decreasing operation efficiency. A DC architecture possessing both properties satisfies the requirement of free-scaling. Recent work in DC design focuses on traditional performance and scalability characteristics, therefore resulting in symmetric topologies whose upgradability is coarse-grained at best. In our earlier work we proposed Scafida, an asymmetric, scale-free network inspired DC topology which scales incrementally and has favorable structural characteristics. In this project, we built on Scafida and proposed a full-fledged DC architecture achieving free-scaling called FScafida. Our main contribution is threefold. First, we proposed an organic expansion algorithm for FScafida; this combined with Scafida's flexible original design results in a freely scalable architecture. Second, we introduced the Effective Source Routing mechanism that provides near-shortest paths, multi-path and multicast capability, and low signaling overhead by exploiting the benefits of the FScafida topology. Third, we showed based on extensive simulations and a prototype implementation that FScafida is capable of handling the traffic patterns characteristic of both enterprise and cloud data centers, tolerates network equipment failures to a high degree, and allows for high bisection bandwidth [2].

Discriminatory Processor Sharing models play important role in analyzing bandwidth allocation schemes in packet based communication systems. Users

in such systems usually have access rate limitations which also influence their bandwidth shares. In this project we investigated DPS models which incorporate these access rate limitations in a bandwidth economical manner. The interlock between access rate limited Discriminatory Processor Sharing (DPS) models and some constrained optimization problems is also disclosed. We showed, that incorporating the access rate limit into the DPS model is equivalent to extending the underlying constrained optimization by constraints on the access rates. It also means that the available bandwidth share calculation methods for the access rate limited DPS are also non-conventional solution methods for the extended constrained optimization problem. We also foreshadowed that these results might be important steps towards obtaining efficient pricing and resource allocation mechanism when users are selfish and subject to gaming behavior when competing for communication resources [3].

Large-scale information dissemination in multicast communications has been increasingly attracting attention, be it through uptake in new services or through recent research efforts. In these, the core issues are supporting increased forwarding speed, avoiding state in the forwarding elements, and scaling in terms of the multicast tree size. In this project we addressed all these challenges—which are crucial for any scalable multicast scheme to be successful—by revisiting the idea of in-packet Bloom filters and source routing. As opposed to the traditional in-packet Bloom filter concept, we build our Bloom filter by enclosing limited information about the structure of the tree. Analytical investigation is conducted and approximation formulas are provided for optimal-length Bloom filters, in which we got rid of typical Bloom filter illnesses such as false-positive forwarding. These filters can be used in several multicast implementations, which are demonstrated through a prototype. Thorough simulations are conducted to demonstrate the scalability of the proposed Bloom filters compared to its counterparts [4].

Navigability (or information routing) is known to be a key feature without which the network is simply a maze and practically useless for any information transmitting or transport purposes. Improving navigability can make the network perform better and by disturbing it we can disfunction a network without structural disintegration which is a much cheaper and less drastic intervention. In the project we explored effective techniques for influencing the navigability of real world networks. We invoked game theory to explore minimal structures (regarding the number of edges) with maximal navigability and prove their presence in real world complex networks (AS-level Internet, E. coli metabolic

network, English word network and the US airport network). Our findings suggests that incentive for navigability in itself may be sufficient to explain the properties of complex networks to a certain degree. These idealistic structures also help us to develop efficient algorithms which can dramatically improve or paralyze the navigation in a network by altering only a few percent of the edges. Our algorithms can be used e.g. to cure networks if their navigability suddenly deteriorates, possibly signifying an onset of a disease, or conversely we can effectively block the functioning of harmful networks (e.g. malfunctioning cells) without destroying them [5].

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Subproject 3:

New Network Architectures and Protocols

Subproject Leader: Csaba Attila Szabó

The main research objective of the subproject was investigation of new network architectures and protocols for the Future Internet. The research work was conducted in 6 separate but interrelated topics. Topic 3.1 dealt with transport protocols for the Future Internet. Within this topic, a concept of a new transport protocol without congestion control was proposed and investigated, which could present a viable alternative to the reliable transport protocol, TCP, for future networks. In Topic 3.2, new protection methods, based on network coding, were investigated. The results achieved could be significant contributions to creating the architectural foundations of the Future Internet. Topic 3.3 dealt with self-organizing networks, where new information distribution algorithms were proposed that are more efficient than the existing ones, and are important for the scalability of the whole network. In Topic 3.4, scalable mobile architectures, supported by distributed, dynamic and proactive mobility management, were dealt with. The results achieved are important as mobile broadband access will play a dominant role in the Future Internet presenting new challenges. Among radio access technologies, cognitive wireless infocommunications techologies are becoming increasingly important, these were investigated in Topic 3.5. Lastly, Topic 3.6 dealt with new network architectures and methods for media communications.

The research in this subproject was carried out by research teams of the Inter-University Centre for Informatics and Telecommunications. Researchers of University of Debrecen, while not being formally partners in this subproject, took part actively at the Subproject Workshop on 7 June, 2013, and several topics were identified for a potential joint research in the future.

Members of the research teams published the research results achieved in the topics of this subproject in 15 journal papers and 10 international conference papers.

This research helped several colleagues in successfully applying for research grants, including one researcher who was awarded a Bolyai prize. Two col-

leagues finished their PhD thesis based on the reseach conducted in this sub-project.

3.1. The Transport Protocols of Future Internet

Leader: Sándor Molnár

Since the first efficient reaction to the phenomenon of congestion collapse in the early Internet, congestion control, mostly performed by the Transmission Control Protocol (TCP), has played an important role in communication networks. Several TCP versions have been developed in order to fit the ever-changing requirements of communication networks [1]. Although, current high speed TCP variants provide efficient solutions for many network environments, they all fail to act as an universal mechanism considering heterogeneous and changing network conditions.

In this research project we have worked out the concept of a novel transport protocol without congestion control (DFCP, Digital Fountain based Communication Protocol), which can provide a serious alternative to the currently used TCP for future networks [2]. We have designed and built a multi-platform test environment (consisting of a laboratory testbed, the Emulab network emulation environment and the ns-2 simulator) in which our transport protocol and today's widely used TCP variants can be investigated. This environment made possible to study the operating mechanism of DFCP, as well as its validation and performance evaluation.

Unfortunately, most researchers choose only one way to investigate their proposed protocols, namely simulation or testbed measurements. However, especially for novel protocols and algorithms it can be misleading due to the unique nature of such environments. On the one hand, the main risk of relying only on simulation results is the fact that simulation environments are far from realistic in most cases, thus many real-world factors can easily be neglected. On the other hand, performing only testbed measurements can also lead to the loss of generality, because special hardware components can affect the results. In addition, building a network testbed is a time-consuming process, and measurements are very difficult to repeat as well. The multi-platform test environment enables performance evaluation both on complex topologies and in realistic network conditions. In this environment we studied many important properties of DFCP and TCP including the sensitivity to packet loss and round-trip time, the buffer space demand, the fairness behavior in case of competing flows, as well as the performance in networks with multiple bottlenecks [3]. The results pointed out that DFCP can provide efficient data transfer in various network conditions even when TCP suffers from performance degradation.

Beyond the previous features it is also interesting to investigate the data transfer efficiency in case of different flow types [4]. According to the scientific literature flows can be separated into groups from many aspects. One of the most frequently used classifications is based on the flow duration, which distinguishes between short-lived and long-lived flows. These flow categories carry different types of network traffic. While short-lived flows are typically originated from web applications, long-lived flows are mainly generated by downloading huge amount of data such as a movie or other multimedia content. In the last decade many researchers focused on the statistical analysis of flow parameters such as duration, size and rate. It has been found that most flows are short, but the most significant portion of data traffic is transferred by long-lived flows. Since it is important to investigate both flow classes for traffic engineering purposes, we analyzed their transfer efficiency by downloading a typical web object and a full DVD, respectively. Measurements were carried out in a testbed on various network topologies and under different conditions such as varying packet loss rate and delay. The results showed that DFCP guarantees faster operation than TCP for each flow type, which can highly improve the quality of experience (QoE). For example, in case of web objects DFCP can provide shorter download time by several orders of magnitude compared to TCP, which is unable to quickly achieve its maximum speed due to the limiting nature of the congestion control algorithm.

Our research highlighted that the currently used TCP responsible for transferring most of the Internet traffic cannot provide high network utilization and efficient data transfer under many conditions. Therefore, it is essential to design novel data transfer mechanisms for Future Internet, and DFCP can be a promising approach thanks to its beneficial properties.

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3.2. Reliable and Scalable Future Internet with Network Coding

Leader: Peter Babarczi

In the future, the reliability of all-optical networks will be crucial, as even the shortest disruption could cause the loss of enormous amount of data. In this topic, we investigated protection approaches in different layers of the Internet protocol stack, which could provide a cost efficient, reliable and scalable transport network infrastructure for future Internet services and applications. The topic is highly related to the research work of the MTA-BME Lendület Future Internet Research Group. Our results can be summarized as follows:

1. shared protection (restoration) with distributed unambiguous link failure localization (using supervisory lightpath in the optical layer) in order to reach better scalability,
2. general dedicated protection approaches for static and dynamic routing (using diversity and network coding in the MPLS layer),
3. fast IP restoration with pre-planned alternative routes.

In the physical layer of communication networks, one of the most important challenges is the fast and dynamic deployment of connections. This introduces several challenges into the control plane of current optical backbone networks, which was basically designed for static traffic. In order to make the control plane able to satisfy the high quality of service need of dynamic operation (e.g., high reliability, short disruption), we have investigated optical failure localization approaches from several aspects. In future communication networks, one of the main goals is to eliminate time consuming signaling from the restoration process. Thus, in [1] a distributed failure localization framework was proposed, where the routers are able to localize the failed links and recover the disrupted connections in a distributed fashion. This approach fully eliminates the electronic layer from the restoration process, which provides the possibility of a scalable all-optical protection framework.

In order to provide efficient and low complexity protection methods for connection reliability in the MPLS layer, network coding is a recently emerging and promising solution. In [2] new algorithms for static routing were proposed to satisfy the 1+1 path protection functionality. We have investigated these approaches from a theoretical perspective. It was shown that the protection methods based on network coding are NP-complete, therefore integer linear programs were presented to find the optimal capacity allocation. Furthermore, we proposed dynamic protection approaches with network coding, which provide the possibility of a smooth transition from current to future transport network capabilities. In order to reach this, we investigated the application of network coding based protection approaches, which are not only capacity efficient, but can significantly lower the complexity of coding and minimize the number of network coding nodes in the network. Based on the Software Defined Networking (SDN) infrastructure of the European GÉANT backbone network, we are working of the practical deployment of such a network coding based method using the OpenFlow protocol.

Beyond reliability, the proposed network coding architecture makes it possible to deploy further future Internet application. For example, the stateful approach of current IP multicast (states are stored at the intermediate forwarding elements) will not scale well with the proliferation of video streaming and online games. In this project, we proposed a network coding architecture, which can serve as the foundation of a stateless multicast application such as Information Centric Networking (ICN), only with a slight modification to current backbone routers. We have thoroughly investigated link identifier-based addressing schemes to support ICNs in the FIRST project 2.4 - „Scalable Resource Allocation and Traffic Management methods", which is related to the work of the MTA-BME Lendület Future Internet Research Group as well.

Providing protection in today's IP layer is based on a reactive approach, which means that disrupted connections are restored only after a failure has occurred. However, owing to the high speed of future Internet this could be a bottleneck. Thus, we investigated the possible extension of the only standardized proactive IP protection scheme, the so called Loop-Free Alternates (LFA), in order to fulfill the demands of the future Internet. In [3], the Remote Loop-Free Alternates (rLFA) method was investigated, which in contrast with LFA, allows the consideration of remote nodes instead of only adjacent ones in the protection path design through tunneling techniques. It was shown that from the aspect of reliability rLFA can provide almost full protection even in the most critical networks (odd and even rings).

Our theoretical results in this topic laid down the architectural basics of a „reliable and scalable future Internet". The first implementations show that the protection approaches using simple „network coding" operations are good candidates to form the basic model of the future Internet.

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3.3. Self-organizing networks

Leader: Vilmos Simon

In line with traditional communication systems, more and more attention is given to autonomous, self-organized networks with no central infrastructure, based on peer-to-peer communication, like mobile ad hoc networks. Designing multihop broadcast protocols for mobile ad hoc networks is a complex problem as the task of these protocols is to disseminate messages in a network effectively while avoiding unnecessary use of resources. The vast majority of these protocols (also as present day Inter-net) do not use the physical locations in space information of the network nodes to optimize the bandwidth and channel usage. Spatial computing implementations and languages do consider the physical location properties, however the communication protocols in these implementations are far from optimal, as they utilize oversimplied communication solutions.

Therefore we have examined the existing location based multihop communication protocols and concluded that a novel protocol should be developed for the communication in Proto, which was our choice for the spatial programming

system as it provides the most allround and general approach, furthermore it is very well suited to solve problems in a number of different domains (wireless mobile ad hoc and sensor networks, robotic swarms or biological systems). Our new communication protocol, the Direction Based Handshake Gossiping was implemented in our self-organizing network simulator, together with three other location based data dissemination protocols from the literature (Distance Adaptive Dissemination, the general probabilistic broadcast protocol, and Ni et al's location-based scheme). The results have shown that our solution overperforms the other three solutions in means of networking overhead and duplications, which is crucial for a radio resource and energy optimized functioning of self-organized mobile networks.

We have linked MIT Proto to OMNeT++, a well-established network simulator framework to see how Proto implementations deliver in a more realistic network environment. Our implementation runs Proto and OMNeT++ as separate processes, linked by extensions that use interprocess communication to synchronize the two simulators. We demonstrate this integration with an urban communications scenario, showing mobile devices using a spatial computing approach to create a communication channel along a path with ideal connectivity, as well as showing a tradeoff between speed and reliability of information sharing with neighbors. We have implemented of our DiBHG protocol in the Proto spatial computing system. With the presented protocol, we can achieve a more energy efficient functioning of the system when trying to disseminate static information in the network. Implementing the DiBHG protocol in Proto and making it available in an easy to use Proto plugin takes it one step further, to enable Proto become a real life spatial computing system and move it away from "simulator only" use.

In the second part of our work we have focused on collective movement of dynamic nodes called "flocking". The existing controlling mechanisms handle the group as a whole, no dynamic and autonomous regroupment or repartition is possible, when applying such schemes. Several uses cases would require to utilize 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 energy level of the nodes, the distance to the 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 supervi-

sion and directing them to the given destination, based on node interactions and a token mechanism. 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 center, when real-time surveillance is needed. Both algorithms were implemented and demonstrated in the Proto framework.

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3.4. Distributed, dynamic and proactive mobility management for scalable Future Mobile Internet architectures

Leader: László Bokor

Mobile Internet has recently started to become a reality for both users and operators. More and more people are willing to access Internet related services while being on the move, requesting seamless, ubiquitous connection anytime and anywhere. Based on the current trends in telecommunications, vendors prognosticate that overall mobile data traffic is expected to grow nearly 11 fold between 2013 and 2018. It is also expected, that the increase of mobile Internet traffic will be higher compared to the fixed Internet traffic in the forthcoming years, most dramatically due to new entrant, data-hungry mobile entertainment services and new application types. In order to accommodate the future

Internet to the anticipated demands, technologies applied in the radio and core networks must become scalable to advanced use-cases [1].

The growing number of mobile users, the increasing traffic volume, the complexity of mobility scenarios, and the development of new and innovative IP-based applications require network architectures able to deliver all kind of traffic demands seamlessly assuring high quality of service. However, the strongly centralized nature of current and planned mobile Internet standards prevents cost effective system scaling for the novel traffic demands [2]. Flat mobile or even ultra flat networks are to be designed and deployed where and distributed and dynamic mobility management (DMM) mechanisms form the key routines of the future mobile Internet designs. In order to contribute to this research work, we followed two distinct but close approaches. On one hand we extended a Loc/ID splitter solution called the Host Identity Protocol (HIP) with a distributed and proactive operation scheme. On the other hand we created a purely IPv6 solution based on the well-known MIPv6 family and integrated it with cross-layer optimized, flow-based, proactive handover technique.

The HIP-based Ultra Flat Architecture (UFA-HIP) system framework defines seven main building blocks: 1) several access networks, 2) an IP/MPLS transit network, 3) HIP capable UFA Gateways controlling main network functions, 4) an optimized terminal attachment scheme with cross-layer access authorization, 5) a session establishment protocol, 6) a handover initiation, preparation, decision and execution subsystem based on the IEEE 802.21 Media Independent Handover (MIH) standard and extended HIP functionalities, and 7) a HIP-based control network [2]. The proposed technology generally supports flat architectures, minimizes end-to-end path length for user traffic, and keeps the mobility signalling load in the backhaul and core segments. In the FIRST project our main goal was to further extend the functions of UFA-HIP, integrate the framework into 4G LTE/EPC architectures, and to develop a complex simulation environment where realistic mobility scenarios can be used for extensive evaluation of different DMM technologies. We designed and implemented a complex, INET/OMNeT++ based simulation framework where we compared DMM protocols (MIPv6-RO, MIPv6-ERO, FAMA, UFA-HIP and UFA-HIP-NEMO) with legacy mobility management solutions (MIPv6, GTP, HIP, NEMO-BS, HIP-NEMO) by four key parameter indicators: Handover Latency, UDP packet loss, TCP throughput and VoIP MOS [3]. We have analyzed existing LTE/EPC simulation models and extended our DMM simulation with a complete and well detailed LTE/EPC simulation model by integrating and ex-

tending INET's 4GSim/SimuLTE implementations. With the help of this comprehensive LTE/EPC-capable simulation framework we were able to study the already evaluated mobility management solutions in several different 4G and beyond architecture alternatives (like centralized, distributed, flat), and within different levels of distribution (e.g., core, backhaul, and access level distribution), such gathering valuable practical information about the feasibility and performance of different DMM schemes.

Our more conventional proposal is based on pure IPv6 and integrates MIPv6, Network Mobility, Multiple Care-of Addresses, Hierarchical Mobile IPv6, Global HA-HA, Source Address Selection, Enhanced Route Optimization, Fast Handover for MIPv6 and 802.21 Media Independent Handover protocols within a cross-layer optimized control framework. The solution offers a location information aided predictive mobility management scheme with an efficient handover execution technique for multihomed configurations. We combine the benefits of MCoA with a novel prediction-driven cross-layer management entity allowing mobile nodes/routers to operate using always the best available access networks and to perform smooth handovers when overlapping radio coverages are available [4]. In order to enhance scalability of this MIPv6-based solution and provide an advanced fine-grained offloading scheme for heterogeneous architectures, we extended the basic framework with a network-based IP flow mobility protocol aiming to enable operators to efficiently decide and execute the flow routing policies based on e.g., the available resources in the network [5]. Analytical evaluation and test-bed experiments proved that our proposals could efficiently support complex mobility scenarios of the Future Mobile Internet.

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3.5. Cognitive Wireless Infocommunications Technologies

Leader: László Csurgai-Horváth

Together with the development of wireless communications the user demands for higher bandwidth is increasing, whereas the available frequency bands are limited or became more saturated. Cognitive radio is a secondary system that can adaptively and intelligently utilize the selected frequency bands without disturbing the primary systems. In order to achieve this goal the data should be transferred in the free frequency band while the spectrum is sensed continuously. Cognitive radio is closely connected to the Software Defined Radio or SDR technologies, that is practically a radio that is capable to operate on several frequency bands and its settings can be freely selected and programmed by the user.

During our work we arranged the knowledge relating to cognitive radio, the state of the art technologies and the present research areas [1]. We were dealing with the question of spectrum management, algorithms and the tools for hardware implementation. We overviewed the IEEE 802.22 recommendation, which controls the operation of those cognitive radio-based opportunistic devices and is able to communicate in the TV bands without disturbing the incumbents (primary) users and without degrading they quality of service. Therefore we introduced particularly the frequency bands that become free after the change from analogue to digital terrestrial television transmitting (the "White Space", or unused frequency band), and we introduced its specialities in Hungary [2]. We summarized the knowledge about the sensor networks as cognitive radio systems and the future 5G networks as an example for efficient spectrum management systems.

Besides the overview of the literature our research are grouped around two main subjects. One of them is relating to spectrum sensing, its measurement devices, tools and the recording of fixed and mobile datasets. The second main subject was the investigation of the new modulation techniques that are used for cognitive radio [3].

Our wide band measurements were performed with the antenna developed within the frame of this project for the 0.5-3GHz band, where the measurement devices were a computer controlled software radio platform and a spectrum analyser. Our task was also the development of the data collecting and processing program. We performed measurements in the free TV bands after the digital transition, in the frequency bands of mobile radios and in the ISM band. We recorded time series on the board of moving vehicles in city area and statically in office environment [4]. Besides the received power time series we investigated the first and second order statistics as well (attenuation and fade duration distributions). During the evaluation of the received data we calculated the ratio of the spectrum usage and we were able to predict the possibility of using cognitive radio technologies by applying the different distribution functions.

In cognitive radio systems one of the greatest challenges is to develop the medium access technologies and the physical layer. In case of cognitive radios not only the measurement of the spectrum and the detection of primary users is problematical, but the selection of the right modulation mode. Considering the large number of users and the distortions due to the frequency-selective channel, a feasible solution could be a multicarrier system. In our research we were dealing with multicarrier modulation systems that are the most appropriate for cognitive radio. Nowadays the most widely used system is OFDM (Orthogonal Frequency Division Multiplexing), having many advantages but also some disadvantages. FBMC (FilterBank MultiCarrier) is also a multiple carrier modulation scheme that is an particularly important system and it was in the centre of our research [5]. This modulation mode is not standardized yet, but several project considered it as the base scheme for they cognitive radio system due to its very promising spectral properties. Its drawback is, similarly to OFDM that its Peak-to-Average Power Ratio (PAPR) is high, therefore it is sensitive to the nonlinear distortions. The reduction of PAPR was also one of our main research areas.

As the summary of the theme “Cognitive Wireless Infocommunications Technologies” we prepare a course material for university students as well. Besides the overview of the theme it will demonstrate our measurements and methods and new modulation modes as one of the key element of cognitive radio. We hope that this material can be used later in the education at universities.

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3.6. Novel Network Architectures and Methods for Media Delivery

3.6.1. 3D Free Viewpoint Video Delivery in IP Networks

Leader: Árpád Huszák

Free Viewpoint Video is special category of 3D video, allowing users to freely change their viewpoint. The new technology is still very new and includes number of research challenges regarding to delivery, viewpoint synthesis, system architecture, etc. due to huge amount of media data that must be handled. In our research works we focused on Free Viewpoint Video transmission over IP networks, viewpoint synthesis and distributed viewpoint generation architectural model and caching solutions in order to improve the efficiency of FVV systems. New methods were investigated in order to handle multi-camera streams and make FVV applications capable even for mobile devices based on predictive viewpoint estimation.

While virtual viewpoint synthesis is a resource hungry operation, it is worth to analyze the possibility of a distributed solution. In our work, we described a distributed FVV streaming model by introducing it elements, like proxy server and media server [1]. The proposed technique is capable to find the best topology setup and serve the clients requesting the lowest occupied bandwidth in the

network. This task is a NP-complete problem, therefore we were able to find optimal FVV setup only for low complexity network topologies. Using the developed FVV architecture optimization tool, the best network layout was able to be determined based on the client requirements, link characteristics, stream bitrates, etc.

Short-time storage of media content is essential in case of distributed viewpoint synthesis, therefore we proposed an energy efficient caching scheme that keeps balance between the consumed energy and the cache delay [2]. We analyzed the optimal cache size and the caused delay using the on-off based energy efficient method. By increasing the cache size, the consumption can be decreased, but on the other hand the higher delay has negative impact on the experimented quality. Our goal was to find the trade-off of these parameters. The proposed model is capable not for FVV systems, but for 2D streaming, too.

Viewpoint switching process in FVV services must be handled seamlessly, without interrupting the stream sequence that is displayed on the customer's device. We analyzed the acceptable delay thresholds of camera stream switching. In order to decrease the required time of new viewpoint stream playout in FVV streaming service, we proposed a multicast delivery scheme with viewpoint prediction [3][2]. The starvation of the viewpoint synthesizer algorithm can be avoided, if the camera views that will be requested in the future are prefetched. We analyzed the multicast group changing delays in the implemented NS2 simulation environment and developed a viewpoint predictive based multicast FVV streaming scheme that is able to prevent the FVV viewpoint synthesizer algorithm from starvation. Based on the obtained results, we were able to find the optimal parameter setup of the predictive multicast FVV streaming scheme and provide the highest FVV stream quality to the users.

3.6.2. Adaptive architectures and QoE measurements for media transmission

Leader: Róbert Schulcz

In this project, first, we focused our work on QoS measurement techniques relevant for HTTP-based services. We studied the behavior of SpeedTest application, which provides HTTP-level view on the available QoS. Then we analyzed the state-of-the-art of traffic management and the main goals of standardization efforts. Based on that we choose the ALTO problem in software-defined environments as an important research field. We call application-layer traffic optimization (ALTO) problem when someone is concerned with better-than-random peer selection for distributed services. The IETF ALTO protocol solves in a standardized way the problem of network-awareness for applications, i.e., it collects directly topology and network cost information from network providers, and endpoint and cache location information from content providers (e.g., peer-to-peer, content distribution network, in-network caching services). An ALTO-aware application can request network information for proper selection of service endpoint, without the need of making measurements, similar to what SpeedTest does when monitoring the available HTTP-level QoS.

We showed on a proof-of-concept implementation the integration of ALTO service into software-defined networks. The benefit of ALTO-SDN integration is that it makes ALTO transparent for the user, i.e., it has zero deployment cost in the user devices, and it enables dynamic, operator-driven assignment of flow-types to ALTO service [4][5].

We also analyzed QoS-enforcement possibilities using OpenFlow, and experienced that, both, the OpenFlow specifications and open-source implementations provide very limited QoS enforcement possibilities.

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Subproject 4:

Personalised Content Management

Sub-Project Leader: András Hajdu

With the co-operation of the Faculty of Informatics of the University of Debrecen (DE IK), the Inter-University Centre for Telecommunications and Informatics (ETIK) and the Budapest University of Technology and Economics (BME) the sub-project "Personalised content management" had the aim to find solutions to the tasks that we shall meet in the Internet of the future, first of all the storing and processing Big Data. The different themes of the sub-project were naturally linked together by the activities necessary for data-mining, data, query, data protection, effective data processing and visualisation. A special emphasis was put on the management of 3D content and the study of its collaborative and user-friendly recognisability. During our research we were using data deriving from several sources including image and genetic data and library content.

By the support of the FIRST we were able to develop an infrastructure which enabled us to do the examinations which ensures the sustainability of our researches. We use our results in functioning applications, including an automatic clinical screening system, a genome browser which is capable of representing Big Data, a 3D collaborative framework with a new content, e.g. library content and with online evaluation service of image processing algorithms.

We were accomplishing our work co-operating with several other teams, which was motivated by the given subject or the preparation of the joint proposals. We can mention as the beneficiaries of our results plenty of clinical fields like ophthalmology, dermatology, internal medicine and genomics, and other scientific fields like biology, biophysics and mathematics. The sub-project was utmost active in building international co-operations, including organising sections at international conferences and FP7/H2020 activities, amongst them a successful proposal.

As for the monitoring indicators, the sub-project fulfilled steadily the requirements, the outstandingly high number of publications, a successful FP7 proposal and an application for a patent connected to colleting Big Data are worth mentioning. The quality of the expert work can be characterised by the facts

that one of our publication was granted the Publication Award of the University Debrecen in the year 2014, the section organised by the sub-project at the IEEE CogInfoCom 2013 Conference was awarded the "Best Track Prize", furthermore, several members of the sub-projects received individual research award or a research scholar grant (János Kemény Grant, János Szentágothai Senior Researcher Scholarship, Zoltán Magyary Postdoctoral Grant, Ányos Jedlik Predoctoral Scholarship, János Apáczai Csere Grant for Doctoral Students). During this time one of our students obtained a PhD degree with a theme connected to the research topics.

4.1. Customizable and efficient processing of Big Data

Leader: András Hajdu

As originally planned, the theme was about problems requiring solution with large time complexity, which practically cannot be solved without the assistance of up-to date informatics infrastructure because of the quantity of the Big Data to be processed or the complexity of the chosen model. Accordingly, a distributed grid-based environment capable of effective processing of Big Data and a Hadoop system with an HBase database manager were developed. We proved the efficiency of the Hadoop environment by appropriate Map-Reduce-based implementation of algorithms already used on other platforms in tasks of bioinformatics dealing with the definition of species on the basis of DNA signature.

The need for large time complexity was justified in our research by the problems caused by Big Data and large time complexity was also needed because we used fusion techniques to some task solutions. This approach is based on the experience that we will be able to take a more accurate decision about a question which has arisen if we combine the outputs of the algorithms. As the demo applications of the sub-project are about solutions requiring image processing and aiming at automatic clinical screening, so in our case we had to solve problem of the effective combining the outputs of image processing algorithms. We managed to develop a method by the spatial generalisation of voting systems both for independent algorithms and for algorithms showing similar characteristics of function [1]. We extended the use of the classical diversity indices, so that the dependency can be examined.

In the sub-project's demo application of automatic screening the complication of diabetes the fusion method was proven outstandingly useful, so this is

the leading approach now at an international on-lien competition. Besides the fusion method, we developed several individual algorithms with special aims (see, e.g. [2]). Sorting the suitable member algorithms to our fusion systems is assisted by stochastic search algorithms, which are run in a grid-environment developed for the aims of the sub-project. This process is essentially an automatic generation of application. We made this complex application more accurate by defining the optimal adjustments of the system [3] as the adjustments belonging to best individual behaviour differ from the optimal adjustments at system level. We validated the prototype of our automatic screening system on clinically annotated data, which led to competitive results compared with results in the relevant literature [4].

During our researches we also managed to combine the joint usability of information deriving from image data and genomic data by methods based on machine learning and classification. Namely, beyond processing images taken of patients during clinical screening applications, we involved specific proteomic biomarkers in the decision-making process. We defined the relevant characteristics and the effective graders also on our system developed for large calculation performance. The importance of our approach is that we were able to develop a decision protocol based on non-invasive modalities for the scientific field [5].

Besides our researches described above we were dealing with processing videos in large quantity. The aim was the automatic quantitative characterisation of the cells' form. We designed an on-line system which automatically evaluates the output of algorithms to assist the method used in our clinical screening applications, which is meant to support testing made on public data-base. Because of the local clinical needs we started to operate a system used for browsing annotated genomic data. As an innovative element we integrated a component in the application of the genomic browser suitable for the visualisation of genomic Big Data. Defining the geometric models connected to this research is a serious tsk in the future. Taking into consideration the paradigm change in our society that people do their business more and more on-line, we examined how the systems that we had developed can accumulate the spread of use of mobile devices. We can collect data about our physical conditions by using sensors attached to cellular phones and we can forward these data to be processed to portals or server page applications. This method of application is supported by our prototypes and beside these we created a distributed processing system consisting of cell phones to implement simpler processes.

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4.2. Collaborative data mining framework

Leader: András Lukács

One of the most common requirements for a distributed data mining task performed on data sets of several parties is privacy, i.e. each participant's original data set should be hidden from the other parties during the calculations. This intuitively formulated confidentiality requirement can be made more specific by mathematical models. One of the most important privacy preserving models is the Secure Multiparty Computation (SMC), where the necessary calculations are carried out on encoded data. The information used for calculations or aggregation between the parties is hidden. Our results belong to this model of privacy preserving data mining.

During the project a framework for smooth implementation of algorithms under the SMC model has been developed. This tool also provides an environment for tests. It helps to use multiple data sources. An important feature of this framework is the extensive usage of modules during the improvements of distributed algorithms (eg. messaging, management of the parties). The framework also fits real life, industrial applications.

Moreover privacy preserving algorithms were implemented and improved for several important data mining tasks. For an improved privacy preserving k-means clustering algorithm a new exploits of geometrical arrangements of the data points is used. Our speed-up of the privacy preserving k-means clustering algorithm is based on the geometrical observation that it is not necessary to calculate all distances between cluster centres and the data points to determine the nearest neighbouring centres from each data if we know the geometric relations among the cluster centres. In this case the distances between the cluster centres can be applied in triangle inequalities to avoid large number of data points versus cluster centre distance computation. Important part of this result was to solve the reduced calculations in the SMC model based on the above considerations [1].

A different approach was used to improve privacy preserving k-NN and k-means algorithms with a better implementation of the nearest neighbour routine used in these algorithms. The reduction is based on random projections of the data vectors, reducing their dimensions. Since the calculation of the original distances in lower dimensions are faster, but also less accurate we measured the trade-off between the number of dimensions and the accuracy of the distances.

As a further result, the basic data mining algorithm, the Apriori frequent itemset mining in SMC model was accelerated by developing a new method based on the partition trick. The effectiveness of several versions of this method was demonstrated on different transactional databases [2].

During the study of privacy preserving algorithms we investigated and developed algorithms for networks, graphs given by distributed edge sets treated separately by the parties. To support this work on graph algorithms a special running environment was created. On one hand a variety of data sources can be processed this way, on the other hand it supports the testing and measuring of algorithms in the SMC model. Applicable data sources may be produced by using databases or can be generated on the basis of models. The compute-intensive graph routines were implemented in C ++ while simple data processing - typically building on former results - can be created in Python, thereby increasing the flexibility of the environment. The final implementation contains basic subroutines as examples for modules.

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4.3. User interface for multimodal human-machine interaction

Leader: Attila Fazekas

Nowadays, the role of information systems has increased significantly. Data stored in / served by these systems attracts more and more attention, so the design of appropriate user interface keeps being in focus in research / development, which influences the usability of the systems in positive direction.

Multimodal technologies provide significant opportunity to highlight up-to-date “access” known from human communication in the field of interaction between the user and information systems

The following research / development were carried out in the frame of this topic regarding the components of the above mentioned system:

- The development in the field of gesture control resulted a technology which supposes low-cost hardware (Microsoft Xbox 360 Kinect senzor) and its implementation, which can replace the mouse without restriction while focusing on the hand gestures. The right fingertips detection is of fundamental role in the realization of the control. To enhance this, an algorithm was developed to eliminate the deficiency of the technics discussed in the professional literature. An efficiency of 95-98% is achieved, which was proved by testing it using gesture databases recognized by professionals. [1]
- The demand of completing the multimodal communication implied research / development in the field of facial gesture recognition. The results make it possible to determine the look direction (including the head movement as well), which can be applied both to direct the system and to recognize the activity. [2]
- It was an important aspect of our multimodal human-machine communication system that it has a human-like output channel usage supported by a virtual avatar/ talking head. Among our objectives determined for the realization, there was a development of technology, which makes the photorealistic visualization based on models generated from existing persons possible. The theoretical background of issues like this is based on the generalized Szabo-theorem. [3]

- The avatar developed in the frame of this project uses graphical representation based on WebGL, and can be displayed in arbitrary web browsers without any obligation to set up additional plug-in. The speech facility of the avatar is implemented with the up-to-date platform independent open source software called TTS which can be supported from server-side as well enabling the effective handling the issues requiring much computation. [4]
- VirCA system was in focus in the project, like an already existing collaborative environment which facilitates the user to get the information he is interested in. Thus, a visual language were designed which promotes the integration of the modules. Although it served only demonstrative goals, a modul dealing with medical imagery got to integrate into VirCa. [5]

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4.4. Searching and disseminating digital library contents

Leaders: Mária Csernoch and Attila Gilányi

An important part of our investigations was related to three-dimensional visualization. Our representations were based on the Virtual Collaboration Arena (VirCA) developed by the Cognitive Informatics Research Group of the Computer and Automation Research Institute of the Hungarian Academy of Sciences. Related to this topic, we implemented a three-dimensional model of a virtual library created by exploiting the capabilities of VirCA. Based on the classification system elaborated by Callimachus we focus on the field of old Greek poetry and drama in the 3rd century BC, and select some illustrious ancient authors and texts for the content of a virtual library (cf. [1]). In order that the presented content should be appropriately searchable we attach certain (verbal or multimedia) metadata to the English translation of the selected ancient Greek texts and using them to form a well-searchable spatial hypertext system. We achieved our objective and implemented the elaborated model with a PhP/MySQL-based development. This model is presented in the VirCA system and certain components of the model are available on HTML interface. Further improvement of the model means that library contents stored in the database can be directly displayed on the web by using a Java Applet (Hypergraph) and an XSL style sheet. Among the possibilities of further improvement primarily we analyse how we can present additional three dimensional contents on the web search interface in an interactive way and integrate them into our developed system.

With an eye on the significance of the dissemination of scientific research results and based on the idea of open access philosophy, we performed a thorough examination of the homepages of large Visegrad-country universities, wondering 1) to what extent the library-built repository of a given institution is accessible and searchable in English; 2) how the predominance of national languages, as opposed to English, makes searchability and "visibility" difficult. Based on the assessment and comparative study of 28 university homepages, guided by the above principles and with the help of the VirCA system, we constructed a 3D "visibility model", whose virtual "rooms" are the university homepages of the individual countries. The essence of our proposal is that the DEA repository, built by the National and University Library of the University of Debrecen, could serve as a hub for this model. The model itself would aim at a greater degree of effectiveness in the dissemination of Visegrád-Four scientific results (that is, a better searchability of those databases), through a VirCA-based linking of the university repositories of the four countries in a single 3D space [3], [4].

Based on VirCA, we also developed a three-dimensional virtual system which visualizes some rooms of the University of Debrecen and makes the most cherished and carefully guarded treasures of the Collection of Rare and Early Printed Books of the University and National Library of the University of Debrecen virtually available [5]. Our general aim related to these investigations is to make

places (ancient buildings, monuments, etc.), that are not accessible for the public, virtually available.

As another direction of these studies, our aim was to develop a smart on-line virtual library with intelligent services in VirCA. We outlined the structure and the functions of an intelligent personal library called Ruza Breto that can detect the searches of its users, can make behavior patterns from the input data, and based on the results, it can suggest other relevant documents from libraries and from other reliable on-line repositories.

We examined the ways library catalogues are used in a university environment. We analyzed the log files of libraries to get appropriate data and give suggestion for a system (LibSearchNet) that can analyze semantically the contents of log files and gain data for making pattern of user behavior [2]. We gave suggestion for log file standardization to store and get necessary data for making the search of LibSearchNet more effective.

During the research project we studied the social influences of the Internet. Among others investigated the differences between the ages, qualification and genders in the field of reception's skill and capability of the digital competency, mainly focused on internet usage. Furthermore, we also examined if during the usage of applications, capacities on internet it is possible to determine specific national attitudes and in which applications they will have been noticed.

Besides the investigations above, in a joint research with Péter Baranyi we outlined the scope and goals of a new branch of cognitive infocommunications, which considers any combination of artificial and natural cognitive capabilities relevant to mathematics. This new field is referred to as mathability.

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4.5. Semantic multimedia content retrieval

Leader: Gábor Szűcs

In the research of multimedia search algorithms we have analysed the available search methods, applications, after that new ideas have been outlined, and we have developed the most promising ideas. Different search services have been investigated, some of them can be used in mobile platform to search mobile applications. We have given large emphasis on images among the multimedia types, and we have implemented an image browsing system. Besides the browsing, the search was the main topic of our research, especially the investigation of the search result list. We have worked out a method for clustering the search results; additionally improvement of classification methods was the aim of our work. We have used sophisticated classification method for the solution of image-based plant identification (international) challenge.

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 elaborated improved textual, visual features, and combination of them. Our results have indicated that this combination is better than the original two solutions. At the comparison with a known image search Web system it can be concluded that the results of our solution exceeds the Flickr results by using search result clustering and reordering.

A semantic image search system is developed, in which the end user can search by combination of names of more objects. State-of-the-art image processing, information extraction and machine learning methods were used for semantic analysis before searching. We have constructed more algorithms for combined image search, and we have focused on queries dealing with two and three objects.

An image browsing system is developed, which is easier and more transparent solution for the problem of browsing the huge amount of images, and where only visual information is available for users and computers as well. Large image set is structured in albums and the idea was to select the most representative image from each album in each level of hierarchy, and then the next upper level in the hierarchy consists of these representative images. Selection of the most representative image is based on semantic features, which helps end users in browsing process [1].

There are many different search services, and some of them can be used in mobile platform to find appropriate mobile applications. This recent topic, the search in mobile platform is also analysed in our research [2].

Search results clustering, which clusters returned documents, is the most preferred approach for re-organizing search results. Many parameters influence the inner mechanism of the well-known clustering algorithms, but an average user is not able to set these parameters accordingly. We have solved this problem by an iterative method based on the user feedback. In our solution some questions are generated for the user in order to offer the most appropriate result selected from the possible ones. We have developed a complex clustering algorithm, which automatically optimizes the parameter values based on the user answers. Our method calculates some possible results, which are probably one of the best results from the user's point of view. The main purpose of applying the user feedback is to give possibility to interact the search results and to achieve a better topic understanding about the given query [3].

A good classification method is important to produce accurate answer list for the users' query in the search, because this can help in ranking the answer set. Decision tree as classifier could be used for classification tasks, but Random Forest possessing more decision trees is more accurate. Further development of Random Forest was also a part of the research [4].

The image-based plant identification challenge was focused on tree, herbs and ferns species identification based on different types of images. The aim of the task was to produce relevant species for each observation of a plant of the test dataset. We have elaborated a viewpoints combined classification method for this challenge. We have applied dense SIFT for feature detection and description; and Gaussian Mixture Model based Fisher vector was calculated to represent an image with high-level descriptor. At classification the chosen classifier was the C-support vector classification algorithm with RBF kernel, in which we have optimized two hyperparameters by a grid search with two-dimensional

grid. We have constructed a combined classifier using the weighted average of reliability values of classifier at each viewpoint. The results show that our combined method exceeds our best classifier among the list of classifiers constructed for different viewpoints [5].

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4.6. 3D Internet and media content

Leader: Péter Baranyi

Goals of the subproject are promoted by the volunteer effort of BME as a catalytic background support providing the required technical and methodology related knowledge to the VirCA-based component development.

Within the subtask, a substantial descriptor structure and the corresponding design methodology has been developed that makes possible the representation the library and Information science-related content in the collaborative space of the VirCA framework [1-2].

The activity of the consortium resulted in additional significant advances in the theoretical and practical realization of virtual reality-based applications of complex information processing systems such as medical image processing [3]. The key point of the proposed method, that the already existing discrete image processing software components with special tasks and the internally definable

dataflow are organized in a unified structure, which allows for the manipulation of the processing workflow and the monitoring of the results.

The results and the underlying research and development process has been continuously supported by the workshop series that were held for the contributors of the 4th subproject. There were three events, in which the installation and the basic operations, content generation and VR space building and finally, the software development for the VirCA framework has been covered.

At BME a virtual wall has been installed, which allows for the testing and evaluation of basic algorithms related the 3D working environments. With the help of the device, the initial solutions has been delivered for testing the operation of everyday functionalities in 3D VR workspaces. Additionally the 3D reconstruction algorithms were overviewed which are usable for identification of real objects while the position and orientation of them can be tracked in real-time.

Significant progress were performed in the direction of a framework that provide input for the 3D content development based on a reference video database. In order to transform the video frames into 3D data an automatic annotation solution has been designed and developed as a stable software implementation. Based on the optical streams and the stereo camera records, various open source implementations of depth detection algorithms have been compared, separately investigated different combinations of the feature point extraction and feature point pairing. The results were evaluated via manual annotation of the records.

During the overall project, a continuous support were provided to the researchers and developers worjing with the VirCA platform. This activity has generated a very useful feedback loop, and as a result the 0.2.763 version of VirCA has been released [4- 5].

Besides the numerous small advances, the most significant added feature is the native support for the popular Oculus Rift head mounted immersive VR display.

All the results of the subproject have been demonstrated on International scientific forum (4th IEEE International Conference on Cognitive Infocommunications, CogInfoCom 2013) in the course of an online operating demo with the remote participation of multiple universities and research labs.

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Subproject 5:

Internet of Things

Subproject Leader: Zoltán Gál

The subjects of this subproject are in concordance with the R&D&I targets of the DG Connect (European Commission Directorate General for Communications Networks, Content & Technology) and with the development goals of the IERC cluster financed by the European Union. Because the Internet of Things represents significant part from the Future Internet, based on the limited human resources of the FIRST project only a subset of the Internet of Things research topic was possible to cover.

In the first subject integration possibilities of the objects into the Internet were analysed. Fundamental question is set by the seamless integration of several hundred billion objects into the IPv4 or IPv6 network. IPv4 utilizes shorter address format but for the usage requires NAT function. IPv6 has enough addresses to assign but the longer address format use more energy from the batteries of the wireless controllers and sensors. We analysed routing problems applied for multipath transmission, the effect of this to robustness of the packet arrival to the destination and the delay aspects introduced. We studied the effect of interference produced by different wireless technologies (WiFi, ZigBee, Bluetooth) working in the same frequency band. Based on this experience complex model was developed to determine the effect of noise distributed in space and time using measured noise values in several discrete points of the 4D space. We developed solution based on wavelets to create data clusters from the state data collected by sensor network. Usage aspects of sensor networks for transmitting bilateral commands were analysed, as well.

In subject two cyber physical problems were revealed. This Cyber-Physical System consists of a large number of embedded computing devices, with high speed interconnection among them through the Internet. Very diverse and complicated tasks can be solved based on the information which is collected on a distributed way. Our aim was to develop a universal system rather than a dedicated one. The applications developed by different users run on embedded devices, with high level of virtualization in order to provide portable code. For computationally very intensive tasks own method was developed to delegate jobs to the traditional cloud. Tasks developed by many users are dynamically allocated and reallocated among embedded processors in runtime.

In subject three context dependent behaviour (physical coordinates of a given device, state of the battery, signal intensity and ID reception of the WiFi and 3G microcells, data from accelerometer and light detector) was analysed in the IoT communication topic. We encoded context parameters in Bloom filters, considered a resource-efficient and easy-to-process solution to handle set operations. We described the idea of this context-aware addressing solution, and then analysed its efficiency through simulations. Another aspect of our research was therefore to provide a solution for filtering out these parameters based on the Hierarchical Temporal Memory approach (HTM).

In subject four we oriented to develop technologies for independent daily life assistance of elderly or sick persons and to improve the quality of human life using IoT techniques. We have developed an assistive assembly with three major components: smart and assistive environment; human activity/health monitoring and recognition system; and assistive/telepresence robot, together with assistive Android applications. Software method was implemented for indoor localization of the IoT objects. We have developed several modules for vital parameters monitoring (temperature, heart rate, acceleration). We designed and simulated in Matlab the recognition system for arm posture, body postures and simple activities, like standing, sitting, walking, running, etc.

In subject five statistical post-processing of ensemble forecasts was analysed, provided by the ECMWF leading organization and the Hungarian Meteorological Service (HMS). We tested the existing BMA models on ALADIN-HUNEPS ensemble forecasts of wind speed and temperature. We also developed a new BMA model for wind speed prediction and a bivariate BMA model for joint calibration of these data. A new EMOS model for wind speed prediction was also developed and tested. We also performed a detailed comparison of BMA and EMOS calibration of ALADIN-HUNEPS temperature and wind speed forecasts. We investigated optimal design problems of spatial Ornstein-Uhlenbeck processes, characterizations of bispectra of non-Gaussian homogeneous and isotropic random fields, predictions of spatio-temporal processes and estimation of the spectra of spherical random fields.

The subject six is a research and development work for sharp usage of the results as services in the Hungarian academic education and research network environment. The services, having been developed and being operated by the NIIF Institute, are available also for the Future Internet research communities,

and are extended to novel opportunities such as providing Virtual Research Environment (VRE) platforms and supporting Virtual Research Organizations (VRO) by making applications VO ready. As an e-Infrastructure service is the developped Shibboleth 2.x IdP X.509/LDAP authentication module. Application of a two-factor authentication module for simpleSAMLphp in the federated virtual networking environment and in the testbed system has been developed, in order to achieve increased security by pairing a time-based token with other credentials, such as a username and a password.
The subproject organized an international workshop with title „Advances in Wireless Sensor Networks" in 2013 and another workshop on the subproject level in 2014. Twenty seven seminars were organized during the two years subproject execution time where the research activity was demonstrated online for the public. More than 70 papers were published by the subproject. Two students granted scholarship in the National Excellence Program. Ten researchers were invited from Romanian universities and other three persons from Ukraine and United Kingdom.

5.1. Integrating the IoT with IPv4/v6 solutions

Leader: Zoltán Gál, Béla Almási

The integration of the IoT with the IPv4/v6 systems opens questions on the efficient bandwidth usage of the available multiple interfaces (e.g. WiFi, 3G, Bluetooth) of the hosts. This question appears more significantly on moving hosts (e.g. cars or other vehicles). The traditional IP communication infrastructure is restricted to a single IP address (and single interface) usage on the communication endpoints. Thus, the moving car may lost its communication session e.g. when leaving the WiFi cell. L3 roaming solution, or other kind of special solution (e.g. MPTCP) is necessary to keep the connection alive. The traditional L3 roaming solution suffers from the efficiency problem of "triangular inequality". A quite new solution could be established by using more than one interface in the same communication session.
In the FIRST IoT subproject a software library was developed (named as "MPT software library), which opens the possibility of using multiple interfaces (and multiple paths) inside a communication session between the endpoints. The individual paths can be turned off and on without losing the connection. The MPT introduces a new conceptual working mechanism, which differentiates

the identification of the communication session (i.e. the socket id) and the identification of the physical interfaces. The solution is based on creating a logical (tunnel) interface on the endpoint.
The logical interface is used to identify the node's communication sessions, and it is independent of the physical interfaces. The MPT software library maps the logical interface to multiple physical interfaces dynamically, so offering a L3 multipath working environment. Measurement results show, that the MPT library is able to aggregate the throughput of independent paths very efficiently (see [1]), even in the case of stream transmission (see [2]). As the logical interface and the physical interfaces are handled independently, it is also possible to use different IP versions on the logical interface (i.e. by the communication software) and in the physical network environment (see [3]), so the MPT library also offers a seamless IP version changing solution.
Analysis of the noise and the interference of the WiFi technology was executed based on data measured from a production system in university environment with 170 access points [4]. As an extension of this model was developed stochastic model for systems distributed in space and time and application of it in the description of radio channel noise characteristics in WiFi system with high number of base stations running as sensor nodes. The new kriging method is useful applicable to continuous extrapolation of the signal field intensity in 4D physical coordinates (space-time domains) not sampled by the discrete sensor nodes.
Clustering method was developed for information extraction from sensor network data sets and application for characterization of the resource usage of a supercomputer system [5]. This method based on cluster analysis and wavelets reduces by one order of magnitude the number of variables sampled and the amount of data and presaged surprise events at the CEP (Complex Event Processing) and ESP (Event Stream Processing) supported services based on huge number of logical and physical sensor nodes. The comparison of SGE and Slurm job schedulers made possible to enhance the Hungarian academic HPC system. The same clusterization method was applied for the state data sampled from the Hungarian WAN router network, as well. Network traffic load patterns were identified on the same network based on SAX (Symbolic Aggregate approXimation) representation.
Because the significant importance of the ZigBee technology in IoT services comprehesive summary was created about the IEEE 802.15.4 standard and the know-how generated here was applied at the new Wireless Sensor Labora-

tory created for the Faculty of Informatics, University of Debrecen. The IEEE 802.15.4 wireless communication technic was used to transmit high frequency, periodic signals for bilateral teleoperation [6]. The characteristics of the closed loop control were analysed in sensor network with mixed traffics.

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5.2. Cyber-Physical Systems

Leader: Tamás Dabóczi

Within the frame of this project we envisioned a special case of Internet of Things. This Cyber-Physical System consists of a large number of embedded computing devices, with high speed interconnection among them through the

Internet. The embedded devices (nodes) are connected to the physical world through sensors and actuators. On that way very diverse and complicated tasks can be solved based on the information which is collected on a distributed way. Our aim was to develop a universal system rather than a dedicated one. The cyber physical infrastructure serves as a universal computing farm and information provider about physical processes [1]. Many different users can develop applications for this universal infrastructure, very much like using a cloud, but with the extra feature to utilize knowledge about the real physical world. The applications run on embedded devices, with high level of virtualization in order to provide portable code [2]. In the case of computationally very intensive tasks there is a possibility to delegate certain jobs to traditional cloud [3]. Information collected from the world is semantically enriched and stored in databases using ontology. Tasks developed by many users are dynamically allocated and reallocated among embedded processors in runtime [4], [5].

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5.3. Context-aware communication in the Internet of Things

Leader: Rolland Vida

The 128-bit IPv6 addresses provide a huge address space for the IoT. However, the more relevant question is how can we use those addresses, how large will grow the routing tables, or how fast and efficient can be the routing and communication protocols. In the IoT we will very rarely use the individual IPv6 address of a sensor, we will rather target a group of smart "things" having in common some context-related characteristics. Thus, we proposed to use a context-aware addressing and routing scheme, in which the network routes the queries to the proper place(s) based on a set of context parameters, but without knowing the IP addresses of the concerned objects.

We encoded context parameters in Bloom filters, considered a resource-efficient and easy-to-process solution to handle set operations. IoT nodes will be grouped in smaller areas behind several edge nodes connecting them to the Internet. The devices behind an edge will build and maintain a multi-hop tree over which context information in Bloom-filters can be exchanged and aggregated. When a context-based query is initiated, it will be rapidly routed to areas where IoT nodes exist, conforming to the requested context. First we described the idea of this context-aware addressing solution [1], and then analysed its efficiency through simulations [2].

However, context-information can be very complex, involving temporal and spatial correlations between context parameters. Capturing the evolution of these parameters is important, but usually only a reduced set of them really affect the behaviour of a device, application or person. Another aspect of our research was therefore to provide a solution for filtering out these parameters based on the Hierarchical Temporal Memory approach (HTM), as described in [3].

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5.4. ICT tools for smart homes and assisted living for elders

Leader: István Oniga

Our research was oriented to develop technologies for independent daily life assistance of elderly or sick persons and to improve the quality of human life using Internet of things (IoT) techniques [1].

We have developed an assistive assembly with three major components: 1) A smart and assistive environment that allows environmental parameters monitoring and control, and also indoor localization using the wireless sensor network and Wi-Fi infrastructure; 2) A human activity/health monitoring and recognition system; 3) An assistive/telepresence robot, together with assistive Android applications.

In the direction of indoor localization we have developed a method and the software which implements the method [2]. For activity and health state recognition we developed several modules for vital parameters monitoring (temperature, heart rate, acceleration) [3, 4]. The acquired data is used to train neural network that allows recognition of activity or health status of the patient and trigger alert signal in case of unusual state detection. We designed and simulated in Matlab the recognition system for arm posture, body postures and simple activities, like standing, sitting, walking, running, etc. The recognition rate of the body postures was over 99 % on the data sets used for training [4]. We used FFT transform to determine the stepping rate in walking and running activities as the most dominating frequency in the acceleration signal's spectrum [5]. We also implemented and tested a real time recognition system using Raspberry Pi mini-computer.

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5.5. Weather prediction systems and analysis

Leader: Sándor Baran

The main direction of our research is statistical post-processing of ensemble forecasts which is a pioneering work in Hungary. Recently several meteorological services provide ensemble forecasts, the leading organization is the ECMWF, while the Hungarian Meteorological Service (HMS) operates the ALADIN-HUNEPS ensemble prediction system. However, the spread of these forecast ensembles is often too small, they are uncalibrated and statistical methods are needed to account for this deficiency. The most popular tools of post-processing are the Bayesian model averaging (BMA) and the ensemble model output statistics (EMOS).
As a first step we tested the existing BMA models on ALADIN-HUNEPS ensemble forecasts of wind speed [1] and temperature [2]. We found that statistical post-processing significantly improves the calibration of probabilistic and accuracy of point forecasts. We also developed a new BMA model for wind speed prediction [3] and a bivariate BMA model [4] for joint calibration of ensemble forecasts of wind speed and temperature. Both methods were tested on ALADIN-HUNEPS ensemble forecasts and on forecasts of the University of Washington Mesoscale Ensemble (UWME) and they outperform the existing methods. A new EMOS model for wind speed prediction was also developed and tested on wind speed forecasts of the UWME and of the ECMWF and ALADIN-HUNEPS ensemble prediction systems. Besides these new models we also

performed a detailed comparison of BMA and EMOS calibration of ALADIN-HUNEPS temperature and wind speed forecasts.
In order to include also the spatial interactions into the models one has to get a good overview of the statistics of random fields. We investigated optimal design problems of spatial Ornstein-Uhlenbeck processes, characterizations of bispectra of non-Gaussian homogeneous and isotropic random fields [5], predictions of spatio-temporal processes and estimation of the spectra of spherical random fields.

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5.6. Virtual service platforms and testbeds

Leader: István Farkas

More than 25 years of continuous development in the research networking area and later in the areas of those higher level e-Infrastructure services as grids, clouds, HPC, storage, collaboration and data infrastructures, have resulted in a leading edge e-Infrastructure system in Hungary that offers the provision of national and international services for the entire Hungarian research and education as well as public collection communities. The service portfolio includes, among others, communication, information access, and collaboration tools and platforms (e.g. remote co-operation and virtual community environments). The

country-wide Hungarian e-Infrastructure is connected into the European and global e-Infrastructures via GÉANT, the European backbone of the research and education community.
The services, having been developed and being operated by the NIIF Institute, are available also for the Future Internet research communities, and are extended to novel opportunities such as providing Virtual Research Environment (VRE) platforms and supporting Virtual Research Organizations (VRO) by making applications VO ready. An important special example of the major activities related to the e-Infrastructure is the development of a Shibboleth 2.x IdP X.509/LDAP authentication module. The basic motivation is to provide the opportunity of using hardware tokens as authentication source. SPs can decide if they want to force the X.509 authentication, or intend to simply keep a password based solution. Besides Shibboleth X.509 authentication (with or without PKI), also X.509 + LDAP certificate authentication and combining X.509 with username/password authentication are also possible options.
Based on GÉANT, also a specific, reconfigurable testbed operating in a federated virtual networking environment is provided by NIIFI, and its European partners, to the R&D community. The Hungarian segment of the testbed infrastructure is built on the high speed network of NIIFI and, together with its international connections, it is also available for supporting Future Internet research activities. Application of a two-factor authentication module for simpleSAMLphp in the federated virtual networking environment and in the testbed system has been developed, in order to achieve increased security by pairing a time-based token with other credentials, such as a username and a password. SimpleSAMLphp is used as a SAML2 Single-Sign-on solution based on php. Google Authenticator implements time-based one-time password (TOTP) security tokens from RFC6238 in mobile apps made by Google. The Authenticator provides a six digit one-time password users must provide in addition to their username and password to log into Google services. The Authenticator can also generate codes for third party applications, such as password managers or file hosting services.

Subproject 6:

Future Internet Social Applications

Subproject Leader: Gábor Fehér

The goal of the 6. subproject is to research and implement crowdsourcing and crowdsensing based smart city applications and services. The implemented prototypes are the results of the integration work among the three topics in this subproject. In topic 6.1 we planned and developed an open platform that is tailored to mobile based social applications and services based on crowdsourcing and crowdsensing. We have investigated the XMPP protocol, which is built on the publish/subscribe paradigm. In the given environment, the chosen protocol is found to be efficient both in terms of functionality and performance. Later we extended the platform with new functions beyond the XMPP capabilities. In the 6.2 topic we investigated the data management and knowledge discovery required to construct Future Internet social services. The research group analysed numerous data warehouse and analytic approaches. Many new algorithms were implemented and tested in real environment as well. The 6.3 topic integrates the results of 6.1 and 6.2 topics. Here we developed Future Internet social application prototypes. Several research groups contributed to this topic and as a result, we covered a wide range of smart city services and applications. The prototype works cover the following areas: public transportation, smart citizen avatar, smart campus, indoor WiFi positioning, real-time event detection on social networks.
This subproject was carried out as a joint work of ETIK, DE and SZTAKI research groups. The results of the individual groups were shared on internal workshops organized during the subproject's lifetime. On these events all members could meet and present their piece of work. The subproject organized an external workshop on the International Conference and Exhibition on Future RFID Technologies event. On the workshop we invited keynote presentations from companies leading the Hungarian Smart City developments and research.
During the subproject the research groups published several publications in journals and on scientific conferences. The most important ones are presented

here, after the description of each topic. The work of Dr. Farkas, a topic leader in the subproject, also contributed to his researches under the Bolyai János Research Fellowship of the Hungarian Academy of Sciences.

6.1. Open Application Platform for Smartphone Based Crowdsensing

Leader: Csaba Lukovszki

Within the confines of the theme we investigated the applicability of a crowdsensing framework. The main task of such a framework is to distribute and transport the information provided by sensors. The task is rather special in a couple of ways. First, there are a large number of sensors and users, thus we have to handle a large amount of data. It is essential to provide support for current popular devices (smartphones, integrated sensors, personal computers, etc.). Second, we have to make an effort to provide customizable and extendable data representation as the amount and format of the data can be changed in the future.

The aggregation and utilization of the data, and the publication of the outcome of data processing are an important aspect, as well. Sensor information can have a formal meaning (i.e. temperature, presence) or can have an informal meaning (magnetic field) passing by the framework and they can be reprocessed a couple of times. Nevertheless, the users require high-level services because that is the main motivation to use the whole system. The aggregation and distribution of data can happen in the well-known publish-and-subscribe way, which uses channels to collect subscriptions and forward messages from publishers to subscribers.

Additionally the framework shall be able to integrate newly joined sensors easily as this provides a way to collect more and more data to execute finer data analysis and offer more exact inference.

To do the job we started two threads: on the one hand we inspected a couple of existing solutions and on the other hand we implemented our own low-level framework. The most notable solution we inspected thoroughly is the XMPP (eXtensible Messaging and Presence Protocol) protocol.

The biggest benefit of the XMPP framework is that it runs on a number of platforms, it executes on Linux, Windows, iOS and Android as well. The XMPP consists of one or more server (node) entities, which the clients connect to with the help of a (optionally crypted) presistent connection. To identify the clients

and servers the XMPP uses DNS (Domain Name Service) domains and the clients can send messages directly over servers by forwarding. XMPP supports the publish-subscribe model as well, however, it is only a draft extension, which is not supported so widely as XMPP itself. Furthermore XMPP is pretty scalable and the data representation is robust and flexible thanks to the XML (eXtensible Markup Language) language.

As an application layer above XMPP we investigated the BuddyCloud solution, which provides a couple of method for integration and accessibility. Through the inspection we recognized that BuddyCloud makes the scalability deteriorate opposite to XMPP. The scalability analyses of XMPP confirmed that it is able to fulfill our needs to create a scalable crowdsensing framework.

Additionally to XMPP we refined the publish-subscribe model of XMPP and we created a channel management framework to Android platform by using the aSmack application programming interface.

In the case of our own framework we created a closed but extensible and scalable framework to serve the crowdsensing network. The most important aspect of designing such a framework was that the framework must be simple, efficient and scalable. Also, we put an effort on creating an unambiguous and flexible data representation. The result of the design is a three-layered framework which consists of nodes and client entities. The client and node communicate on TLS (Transport Layer Security) channels, authentication is made by SASL (Simple Authentication and Security Layer) and the E2E layer provides the direct client-client message exchange.

The data representation uses the state-of-the-art Apache Thrift technology that makes the data structure unambiguous and flexible. The actual coding on the channel can be customized as the function of performance and overhead. Apache Thrift has two notable advantages: we can send huge amount of data with little overhead and we can write and publish standardized data structures. The nodes of the framework are optimized to very fast message exchange and switching by the so-called “epoll” technology combined with the efficiency of the C++ language. The nodes are capable of providing publish-subscribe functions as well.

The client of the framework can be implemented on a numerous platforms, so we created client libraries for Linux, Android and Windows. The client libraries are able to provide services on Java platform or create synchronous or asynchronous service requests.

The scalability and performance of the framework were inspected in a number of configurations with different hardware and software combinations. The results show that the framework is able to comply with the requirements of a crowdsensing framework.

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6.2. Data Management and Knowledge Discovery for Smart City Applications

Leader: Márton Ispány

The research group, working on Task 6.2, investigated and implemented data warehouse and analytic solutions supporting crowdsourcing and crowdsensing. The research work were organized into three main topics: the development of the smart campus, the development of analytic models for smart city applications and finally the transportation and mobility studies. Within this Task, in correspondence with the integration effort of the subproject, we considered the use cases of the smart campus, smart public transportation and smart supporter applications from Task 6.3.

Within the Smart Campus research work we developed smart administration tools. We created an intelligent calendar for university and a crowdsourcing based system to evaluate seminar works and test cases. The description of the system's architecture is presented in [1]. The smart campus application is available under the www.smartcampus.hu address. This page is advertised with an online questionnaire, where the evaluation of the questions are based on crowdsourcing as well. This latter one is supported by an Android Smart Campus application. The application collects the sensor data of the smartphone (localization using GPS, WiFi and mobile base stations, temperature, magnetic fields, acceleration, humidity, gyroscope) as well. The bias, which presents due to the

unreliable sensors, is corrected using an analytic model. The investigations in the Smart Campus topic was extended with the research work of Smart Students. Here we applied the Computer Algorithmic and Debugging (CAAD) metacognitive approach. With this approach, the creation of textual documents are nothing more than defining, implementing and testing an algorithm.

We have evaluated numerous analytic, statistic and data mining models. Most of them were significantly different from the each other. We studied branching or periodically changing counting processes in order to develop statistic models for counting passengers, clients and students. Besides the theoretical investigations, such as described in [4], we fitted models into the simulated and real data.

In the analytic layer it is essential to analyse the social network relations. For this purpose we used the big graph mining. Such graphs are often analysed with graph evolution models. In [3] and other publications we have proven that using preference association models, counting with 4 vertices interaction we still get scale-free networks. We continued our studies considering N vertices random graph mechanisms. We succeeded in the description of the asymptotic behaviour of a fix vertex's weight and degree and the maximal weight and degree. An other tool to analyse social connections is the clustering of big graphs. We applied the spectral clustering method in a complex environment using multiple views. We created prototype implementations using Matlab. The tests using the density-based OPTICS clustering algorithm is presented in [5]. In the field of anomaly detection algorithms we investigated the feasibility of data mining with rare itemsets and rare rules. We extended the Apriori algorithm, which is the most well-known pattern searching algorithm for frequent itemsets. With our extension it possible to use Apriori on rare data as well. The algorithm was implemented in Java.

For the transportation analytics it is critical to give fast forecast with large volume mobility data. The algorithms handling the data processing are playing an important role. We have tested distributed algorithms and infrastructures using the D4D Challenge data source. To increase the size of the data source we added some noise to it. Instead of describing the users' accurate positions and movements, for which the data was not detailed enough, we examined global patterns on user level (home, workplace, daily routes) and public transport level (daily routes). The key metrics are the error of the short term forecast (5 min to 1 hour) and the long term forecast (daily or weekly) of the location and density of individual users on a given area. Creating a computing cluster from old servers, we were able to process ten thousands of records on-line. The results are published

in [2]. These results shows how to create real time mobility forecasts efficiently in big cities. Furthermore we developed a visual dashboard application, which could serve as a base to support emergency services, car sharing and traffic optimization, thus helps to protect natural resources.

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6.3. Smart City Applications

Leader: Károly Farkas

Task 6.3 is devoted for the design and development of use case smart city applications, where more research groups work on different fields. We have designed and implemented a crowdsensing based public transportation information system utilizing mobile phones. The communication of the system works on the XMPP protocol [1]. Later, this system was extended with a client side visualization application to display the relevant information [2]. Connected to the public transportation application, a research work was presented surveying the up to date and widely available public transportation information storage solutions, measurement techniques, statistical methods and mathematical models. The research report describes the best known DATEX2 data protocol, together with

available European wide on-line data sources. We studied the mathematical modelling of transportation networks in the view of smart cities' traffic related problems. Furthermore, we investigated and reported a noise pollution forecasting solution.

Connecting to the smart citizen avatar vision, the smart football fans concept was extended. With the contribution of other supporter groups, the current release of the Quantum Consciousness Soccer Simulator (QCSS) now offer the creation of own supporter agents. The QCSS mobile client was extended with a simple XMPP protocol implementation. This was tested locally in a LAN environment, and in a real scenario at the Nagyerdei stadium of Debrecen. We have designed the XML formats and schemes for the distributed supporter avatar system. Moreover the YANonymous system was designed and implemented. This application investigates the reproducibility of private, social information from anonymous connection graphs. [3] The YANonymous system supports political party preferences also.

A project report was presented about the indoor wireless positioning techniques. As a case study, we have designed and implemented an indoor positioning and navigation system for an underground car park [4]. In this system the positioning is performed with the help of WiFi reference points. The navigation is running on Android smartphones and began automatically as the car enters to the car park. Along with this work, we have worked out a simulator, which is capable of wireless sensor localization comparison. This WSASimulator supports the evaluation of cooperating mobile base stations as well.

In the smart campus environment, we designed and implemented a social course time schedule application for Android platform. The timetable application is capable of importing the users' timetable from the widely known NEPTUN system and storing, displaying it locally. Connecting to smarty city social applications, in a project report we gave details how to acquire the requested data in the two most popular social application: Twitter and Facebook. Moreover we gave recommendation on how to use these data sources in smart city applications. We created a prototype that uses the tweets of the Twitter application in order to detect events in real time [5]. Later on this was further developed with new descriptors and a simple graphical interface.

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Subproject 7:

Developing curricula

Subproject Leader: Márton Ispány

The subproject 7 implemented in the FIRST project has been devoted to develop curricula and a Future Internet training program. The knowledge of students who finish this program will be adapted to the challenges of the 21st century and the labor market requirements. The courses of this program provide students with international terms, competitive knowledge and skills when they enter to the labor market. The transfer of Future Internet research results into education is a brand new training direction. When the project started, in our country, there was no such a training program. As a result of the project a course on Future Internet has been accredited, first at the University of Debrecen, Faculty of Informatics, later at the Budapest University of Technology and Economics. This course started first time in the 2014 spring semester in the framework of MSc degree programs of University of Debrecen, Faculty of Informatics. The course had recorded more than 20 students who have passed on their exam.

The training program and its courses went through in several design phases. First, such subjects were concretized in the subproject of Future Internet, which could enable to educate in an MSc program. It was made by leaders of subproject who discussed their subjects with their colleagues. Then, the syllabus of teaching materials designed in the application was reviewed and reorganized, taking into account the latest achievements in the field of Future Internet research. Afterwards, the curriculum development methodology and its technical details were clarified during a series of meetings. Then, the authors have made the final commitment in the scope and content of their courses. After these steps, we signed the contracts on developing curricula. We finalized the technical format of teaching materials, which was deployed to the authors. The authors developed their presentations using a unified template which contains at least 240 slides and sometimes supplemented with exercises.

In the framework of the subproject the following training materials have been developed:

1. György Vaszil: Unconventional computational models based on chemical principles;

2. János Sztrik: New methods for modeling of the Future Internet;
3. Péter Orosz: New methods and tools for analyzing traffic of infocommunication networks;
4. András Hajdu: Distributed computing for Big Data;
5. Attila Buchmann: Wireless sensor networks;
6. Béla Almási: Performance evaluation of Multipath Communication Systems;
7. László Bokor: Mobility management in IPv6-based Future Mobile Internet architectures;
8. Lajos Kollár, László Szathmáry: Future Internet community applications;
9. András Kruppa: Quantum computers.

The Future Internet training program covers the main subjects of the Future Internet topic, from theory to applications. Parts of the syllabus are the current limitations of the Internet, future Internet extensions, models, mobility, scalability, quality and safety, adequately manageable network architectures and protocols, data management and content-centric solutions, services, platforms, and several applications for the communities in human-machine and machine-machine relationships supplemented with the social impacts.

Subproject 8:

Future Internet Research Coordination Center

Subproject Leader: Péter Bakonyi

The Future Internet Research Coordination Centre (FIRCC) has been established in January 2013, in the frame of the FIRST project, as the 8th subproject. The founders of the Research Coordination Centre are the University of Debrecen (UD), the Budapest University of Technology and Economics (BME), the Inter-University Centre for Telecommunications and Informatics (ETIK), the National Information Infrastructure Institute (NIIF) and the Institute for Nuclear Research of the Hungarian Academy of Sciences (ATOMKI). The basic role and function of the FIRCC is to co-ordinate the Future Internet research activity in Hungary and to promote the international cooperation in this field, particularly strengthen the participation of Hungarian researchers in EU programs, like Horizon 2020 in the coming years. The FIRCC is planning to organize workshops, conferences to demonstrate the results of the Hungarian research activity in the field of Future Internet.
The two years of operation can be summarized as follows:

Management activities:

- Establishment of the organizational units.
- Regular meetings of director and the head of units.
- The planned subproject meetings were held.
- Web development and maintenance
- A brochure of FIRCC was made in English and Hungarian languages.
- Managing the normal operation.
- Regularly organizing Future Internet National Technology Platform workshops

Deployment of Future Internet National Research Program

The Future Internet National Research Programme (JINKA) has been initiated by the FIRCC and the Future Internet National Technology Platform (FI NTP) in March 2013, and organised by the FIRCC. The National Research Pro-

gramme was based on the research programme of FIRST (JINKA1.0) and it was completed by all the research themes which are proposed by the participants of the National Programme (JINKA 1.1., 1.2, 1.3, 1.4, 2.0, 2.1, 2.1, 2.2.). Recently the Future Internet National Research Programme (JINKA 2.3) has 35 participating institutions and 138 registered research themes. It can be considered as a total coverage of the Hungarian research activities in this field.

The basic objectives of the Programme is to integrate all R&D&I activities in Hungary in the field of Future Internet and to support those activities which are in line with EU programmes and has an influence for the technological, economic and social developments in Hungary. In the frame of the program we intend to:

- co-ordinate and support the ongoing research and innovation activities in Hungary,
- to initiate new research directions,
- to search for synergies,
- to strengthen the Hungarian participation of international research programmes especially in Horizon 2020,
- to support the co-operation among academic-university institutions,
- to support the co-operation with the business sphere, and
- to promote the Internet Science and Engineering in Hungary.

The registered research themes are clustered into nine chapters and each chapter contains 5-7 ranges of themes. The research chapters are the followings (in bracket the number of registered research themes and number of ranges):

1. Internet basic research (18, 7)
2. Future Internet modelling, analysis and design (9, 6)
3. Future Internet network architectures (13, 7)
4. Data and content technologies (21, 5)
5. 3D Internet and cognitive infocommunications (15, 5)
6. Internet of Things (11, 5)
7. Cyber-physical systems and applications (16, 5)
8. Future Internet community applications (22, 7)
9. Experimentation, standardization, regulation (13, 5).

Research results of the Programme were summarized in FIRCC Report 2014, financed by the FIRST project, edited by P. Bakonyi and Gy. Sallai, published in September 2014, in English (128 pages) and in Hungarian (180 pages). The FIRCC Report presents the results of 83 research themes, selected from JINKA 2.1. FIRCC Report is also accessible at the FIRCC web site.

We initiated and organized the First Hungarian Future Internet Conference, in the frame of Innotrends, at 17 October 2014. The Conference provided a broad overview on the trends of the Internet technology, the emerging opportunities, the domestic research teams in the field and their research results. The Conference paid attention to the achievements of the FIRST project and reviewed the FIRCC Report.

Organizing conferences and workshops:

- EU initiated workshop in Budapest in the frame of IEEE ICC Conference, titled “Building an Eco-System for Delivering Innovative Future Internet Services” (June, 2013)
- In the frame of IEEE CogInfoCom conference, a one day workshop was organized titled: „ Workshop on Future Internet Science and Engineering” (6 December 2013). Hungarian and Foreign lecturers took part in the workshop
- First Hungarian Future Internet Conference. Innotrends, Budapest, 17 October 2014.

International activity: Inter alia we participated on:

- Future Internet Assembly and Forum in Dublin, 8-10 May 2013, organized by EU and presentation was held entitled “Future Internet Research Projects in Hungary”;
- Future Internet PPP workshop on „Building an Eco-System for Delivering Innovative Future Internet Services and Applications” in Budapest, 13 June 2013, and presentation was delivered entitled „The FIRST Project and the Future Internet National Research Programme”;
- Internet of Things (IERC) cluster meeting, announcement of our joining intent.
- Participation in the IEEE ICC Conference in Budapest, 9-13 June, 2013
- Participation in the Workshop on Probabilistic and Statistical Techniques for Cosmological Applications, Rome, 04-08 June, 2013
- Participation in the IERC Cluster meeting in Helsinki, 16-20, June, 2013
- Presentation in the EU FI-PPP Conference in Poznan, 18-19 September, 2013
- Participation in the EU ICT 2013 Conference on Horizon 2020 – 2014/2015 call for tenders in Vilnius, December, 2013.
- Participation in the Future Internet Assembly Conference, Athens, 18-20

March 2014.

- Participation in the First European Future Internet Conference, 2014. Brussels.
- Participation in the 3rd IEEE International Cloud Networking Conference (CloudNet 2014) in Luxembourg.
- Participation and plenary talk on the First International Conference on Future RFID Technologies (FutureRFID) in Eger, 6- 7 November 2014.

Educational activity:

- Development of the Future Internet course, jointly presented by UD and BME.

Indicators:

- All indicators have been performed.

Selected publications:

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