NETWORKS

NETWORKS is a project of University of Amsterdam, Eindhoven University of Technology, Leiden University and Center for Mathematics and Computer Science (CWI) and receives funding from OC&W through NWO

THENETWORKCENTER.NL

ANNUAL REPORT 2017

The year 2017 was NETWORKS' fourth year of operation. The program is at full speed, both scientifically and organizationally. Two important events took place in 2017: the midterm review and the first international NETWORKS conference.

The preparations for the midterm review started by the end of 2016 when a self-evaluation document was written. In February 2017, a committee of 'Critical Friends' visited us in Amsterdam to discuss the progress of the program as a whole, with a focus on scientific and strategic aspects. Their report was highly positive and included a set of helpful and constructive recommendations. It served as one of the main ingredients for the formal midterm evaluation by NWO, which took place in June. In December, we were pleased to be informed that the Dutch Minister of Education, Culture and Science had decided to extend the funding for the program until 2024.

On June 7–9, 2017, the first international NETWORKS conference took place. Over 200 participants found their way to the Science Park Amsterdam. The conference consisted of a technical program on June 7 and 9 (with tracks on Mathematical Physical Aspects of Complex Networks, Communication Networks, Logistics and Scheduling, and Scheduling under Uncertainty), and a public event on June 8. The public event included a panel discussion with Dutch science policy leaders and an award ceremony for the winners of the NETWORKS Challenge 2017.

Scientifically, major progress has been made. Both qualitatively and quantitatively, scientific output has been overwhelming, with over 400 publications in leading journals and presentations at conferences on probability, combinatorics, operations research and algorithms since the start of the program in 2014. The interactions between the different research groups within NETWORKS have continued to take shape, most notably between the groups with an algorithmics orientation on the one hand and those focusing on stochastics on the other. Collaborations within algorithmics and stochastics have intensified as well, which is an important added value of the program, too.

Second-year PhD students do an internship at one of the other participating institutes, which also strengthens the ties between the teams. In addition, the PhD students organize their PhD days, during which they meet and talk about their research projects. The training weeks, intended for the junior program members as well as the staff members involved, consist of intensive courses given by NETWORKS staff members (both junior and senior) and vivid open-problem sessions.

The interaction with partners from outside the consortium has been further expanded. In December 2017, the first joint doctorate between NETWORKS (University of Amsterdam) and the ARC Center of Excellence for Mathematical and Statistical Frontiers (University of Queensland, Australia) was

realized. With the Indian Statistical Institute (ISI), preparations for a joint workshop in Kolkata (India) early 2018 have been started; a second workshop will take place in Leiden later in 2018. Interaction with the Institute for Advanced Study of the University of Amsterdam is being explored. At UvA, a PhD student has been appointed on a joint project with TNO, working on quantitative models for transport and logistics. In addition, together with the Science Communication group of the University of Leiden, a PhD student has been appointed at TU/e working on a citizen science project.

Once it was clear that the NETWORKS program is to be continued until 2024, we started making concrete plans for the second funding period. By the end of 2017, a first meeting of the principal investigators and tenure trackers was organized with the objective of creating a list of potentially interesting research projects. A meeting with the Scientific Advisory Board planned for early 2018 will be an important moment to further develop these research lines. The program's portfolios will also be discussed in detail.

This annual report provides an overview of the NETWORKS activities in 2017. Additional information can be found on our website (www.thenetworkcenter.nl) and on the Network Pages (www.networkpages.nl).

Michel Mandjes (Project Leader)
Marieke Kranenburg (Project Manager)

Winners of the Networks Challenge 2017, photo Eric Daams

RESEARCH THEMES

NETWORKS follows an integrated approach combining stochastic modeling (essential to capture the uncertainty and variability of networks) and algorithmics (needed to control and optimize networks). The overarching research objectives of the program are to gain a better understanding of the relevant structural properties ('Network Structure') and to use these insights in the control and optimization of complex networks ('Network Shaping'). To structure these objectives, we defined seven research themes. These research themes are not independent: many of the ongoing projects relate to multiple themes. The research themes act as different lenses through which we can view our networks of interest. They help us to distribute our research efforts in a balanced way over the various questions arising from these networks. Below, we give the highlights of each research theme.

THEME 1: APPROXIMATE AND EXACT NETWORK METHODS

The design, optimization, and control of networks lead to a large variety of challenging algorithmic problems. Unfortunately, many of these problems are NP-hard, which means that there are no efficient algorithms that solve these problems optimally on all possible instances. Nevertheless, NP-hard network problems need to be dealt with in practice. One approach to is to develop approximation algorithms, which are guaranteed to compute solutions that are very close to an optimal solution. Another approach is to exploit the fact that not all input instances are equally hard: some instances enjoy structural properties that make it possible to compute an optimal solution in an efficient manner. In Theme 1 we explore these and other approaches to algorithmic network problems.

HIGHLIGHTS

Among the many results that were obtained in Theme 1 in 2017, we briefly discuss two.

- Several hard optimization problems become substantially easier on special classes of graphs, such as planar graphs and bounded-treewidth graphs. Unfortunately, algorithms that have been designed for these special graph classes are usually not robust: they fail even for graphs that are 'almost' in the given class. This led Nikhil Bansal (TU/e), together with Daniel Reichman and William Umboh (Berkeley), to study algorithms for so-called noisy planar graph classes, which allow the addition of a relatively small number of extra edges to a planar graph. They present a general LP-based framework that yields (1+Ɛ)-approximation algorithms for a large class of problems on such graphs.

  See: N. Bansal, D. Reichman and S.W. Umboh. TSP: *LP-Based robust algorithms for noisy minor-free and bounded treewidth graphs*. Proceedings of the Twenty-Eighth Annual ACM-SIAM Symposium on Discrete Algorithms (SODA 2017), pp. 1964-1979 (2017).

- Counting the number of independent sets, proper colorings and other structures in a graph is a fundamental question that has received ample attention in mathematics and computer science. Often, computing the exact number of such structures is #P-hard. Hence, approximation algorithms are needed. So-called graph polynomials, which are also called partition functions and have applications in statistical physics, are a powerful tool for this. UvA researchers Viresh Patel and Guus Regts

developed a novel way of constructing approximation algorithms for evaluating graph polynomials. Their method yields deterministic algorithms and works on a large class of graph polynomials.

See: V. Patel and G. Regts. *Deterministic polynomial-time approximation algorithms for partition functions and graph polynomials*. SIAM Journal of Computing, Vol. 46, pp. 1893-1919 (2017).

THEME 2: SPATIAL NETWORKS

In many applications, the networks under consideration are embedded in space, leading to geometric networks. This is for example the case in railway networks, where nodes correspond to stations and edges to railway tracks. Another example is given by large molecules, where nodes correspond to atoms and edges to chemical bonds. In many real-world networks, the geometry is an important feature that is hard to treat mathematically. Typically, connections between nearby nodes are more abundant than connections between distant nodes. Yet long-range connections play a crucial role in the small-world behavior these networks exhibit in the sense that all vertices are connected via short connecting chains. A key spatial stochastic model is percolation, while a well-known algorithmic problem where geometry plays a key role is the Euclidean traveling salesman problem.

HIGHLIGHTS

Three important research lines within the second theme are summarized below.

- Sem Borst and Francesca Nardi (TU/e), and Mateo Sfragara and Frank den Hollander (UL) have studied queue-based activation protocols in random networks, where the network structure is modeled by an interference graph. Each node of the graph represents a server with a queue. Packets arrive at the nodes as independent Poisson processes and have independent exponentially distributed sizes. Nodes can be active or inactive. Active nodes deactivate at unit rate, inactive nodes are activated at a rate depending on their current queue length, provided none of their neighboring nodes are active. This situation arises in random-access wireless networks where servers that are close to each other cannot use the same frequency band. In the limit as the queues at the nodes become very long, the authors have computed the transition time between the two states where one half of the network is active and the other half is inactive in the case of bipartite interference graphs, using ideas from metastability.

- Tim Hulshof (TU/e), together with Markus Heydenreich (LMU Munich) and former TU/e master student Joost Jorritsma, investigated the structure of scale-free percolation, a long-range inhomogeneous percolation model showing power-law degree sequences, as well as the behavior of random walks on them. They showed that the diameter of the infinite cluster is finite in the case where the degrees are infinite almost surely and identified the constant. They further identified the transience versus recurrence transition fully in dimensions 2 and 3, and gave necessary conditions for transience in dimensions 3 and higher. One of the key tools in this work is the hierarchical structure of the giant component in the case where the degrees have infinite variance, a description that is highly interesting in its own right.

- Further investigated topics include the study of bond percolation on the d-dimensional Hamming graph (the Cartesian pro-

duct of d copies of the complete graph) by Lorenzo Federico (TU/e), Remco van der Hofstad, Frank den Hollander, and Tim Hulshof; conflict-free colorings arising in frequency-assignment problems in cellular networks by Aleksandar Markovic and Mark de Berg (TU/e), together with colleagues from RWTH Aachen and Tohoku University; and improved mean-field approximations for random sequential adsorption on random geometric graphs studied by Souvik Dhara, Johan van Leeuwaarden, and Debankur Mukherjee (TU/e).

GRANTS, AWARDS AND OTHER ACHIEVEMENTS

A monograph on high-dimensional percolation of Van der Hofstad, jointly with Markus Heydenreich, appeared in the CRM Short Courses Series by Springer. This monograph was based on a 24-hour lecture series by Van der Hofstad in the 2015 CRM-PIMS Summer School in Probability in Montreal, Canada.

THEME 3: QUANTUM NETWORKS

Quantum computers hold great promise as the next generation of hardware. The question that we address is how networks and network algorithms are affected by the quantum world. New steps have been made in understanding which problems allow for a substantial speed-up by using quantum computation.

HIGHLIGHTS

- Srinivasan Arunachalam (CWI), Jop Briët (CWI) and Carlos Palazuelos (UC Madrid) proved an exact characterization of quantum query algorithms in terms of the unit ball of a space of low-degree polynomials. Relevance to NETWORKS stems from the fact that quantum walk algorithms are special instances of quantum query algorithms. This work was accepted to the 2018 'Innovations in Theoretical Computer Science' conference.

- Jop Briët and Sivakanth Gopi (Princeton) made progress on a problem from non-linear large deviations, related to the count of arithmetic progressions in Bernoulli random sets. This problem is of interest to NETWORKS due to connections with the infamous triangle count problem in Erdos-Renyi random graphs. This work was presented at a Harvard workshop on Additive Combinatorics in October 2017.

- Tom Bannink (CWI), Jop Briët, Harry Buhrman (UvA/CWI), Farrokh Labib and Troy Lee (National University of Singapore) established new connections between quantum entanglement in the context of nonlocal games and measures of pseudo-randomness originating from Szemeredi's theorem, in particular Gowers norms. This was used to prove to bound advantage of entanglement in certain classes of games and study the value under parallel repetition.

DEVELOPMENTS OUTSIDE NETWORKS

- The importance and urgency of developing theory and software for quantum computers was recognized nationally through the start of the Quantum Software Consortium (QSC), led by Buhrman, funded by an NWO Gravitation grant in parallel to NETWORKS. The QSC consists of research groups from CWI, Leiden University and TU Delft. Fruitful interaction between NETWORKS and QCS is expected to take place over the course of the two projects.

- In response to the billion-Euro EU flagship on quantum technologies, a quantum software manifesto was written to stress

the importance of the 'software' and theoretical aspects of quantum computation. A special issue of ERCIM news (edited by Briët and Perdrix) was devoted to current research on these topics.

THEME 4
DYNAMICS OF NETWORKS

In virtually all sectors of society we are faced with issues regarding the design, operation, and control of highly complex networks. In this research theme we specifically focus on networks that evolve over time. The way in which this happens is often closely related to their functionality. Random graphs are essential tools to model real-life network structures as stochastic objects that grow in time according to certain local growth rules. By adapting these rules, different types of dynamic network behavior can be captured and analyzed.

HIGHLIGHTS

- Paulo Serra (TU/e) and Michel Mandjes (UvA) have finished a paper that describes a procedure to estimate the intrinsic dimension of a dataset. The estimator is based on the underlying adjacency matrix only, meaning that it does not use explicit distance information. The underlying graph is modeled according to a subset of a specific random connection model. As it turns out, the estimator scales like n log n and its asymptotic distribution as well as the corresponding rate of convergence is explicitly identified. In follow-up work, Serra and Mandjes consider local degree estimation procedures.

NEW PERSONNEL

prof. dr. Nikhil Bansal
PI, TU/e

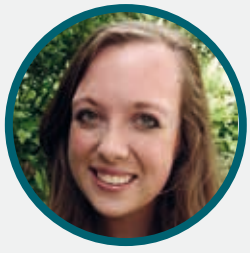
dr. Sudeshna Kolay
Postdoc, TU/e

Farrokh Labib, MSc
PhD-student, CWI

Daniel Olah, MSc
PhD-student, TU/e

Youri Raaijmakers, MSc
PhD-student, TU/e

Dr. Liron Ravner
Postdoc, TU/e, UvA



Marjolein de Vries, MSc
PhD-student, UL, TU/e

See: P. Serra and M. Mandjes. *Dimension estimation in random connection models*. Journal of Machine Learning Research, Vol. 18, paper no. 138 (2017).

- Mariska Heemskerk (UvA) and Michel Mandjes completed a paper on exact large deviations results of compositions of Lévy processes. The results can be used to analyze stochastic systems facing arrivals that are dictated by some random environment. This environment creates correlation and fascinating limit theorems related to system occupancy and rare events. The results described in this paper directly relate to the analysis of the overdispersion phenomenon exhibited by arrival processes of a broad range of service systems (e.g. in call centers and in various healthcare applications), and will be used in follow-up work with Johan van Leeuwaarden.

- Remco van der Hofstad and Johan van Leeuwaarden, together with PhD student Clara Stegehuis, continued working on epidemics on networks with communities. In a series of multiple papers, they introduced and studied new classes of random graphs models that allow for hierarchy and clustering. Attention is also paid to the rigorous underpinning of the occurrence of motifs (such as triangles) in network infrastructures.

  See: C. Stegehuis, R. van der Hofstad and J. van Leeuwaarden. *Epidemic spreading on complex networks with community structures*. Scientific Reports, Vol. 6, paper no. 29748 (2016).

THEME 5
DYNAMICS ON NETWORKS

While random processes on static random structures are well understood, the understanding of their behavior on dynamic random structures poses many challenges. Sometimes the dynamics alter their qualitative behavior, sometimes they do not. It is important to classify the interplay between the dynamics of the process and the dynamics of the network. It is believed that local conservation laws in the dynamics play a crucial role.

HIGHLIGHTS

- Both the social and economic cost of unexpected breakdowns can be very high, depending on the infrastructure it affects. This motivates the development of methodologies that can prescribe maintenance policies in order to achieve an optimal balance between cost and risk. Sandor Kolumban, jointly with Onno Boxma and Stella Kapodistria (TU/e), developed a flexible model and algorithm that can be used for maintenance planning in situations that are typical in case of high-stake assets. This in particular concerns cases where large amounts of data are available about the very well instrumented and monitored normal operation, but actual failure data is scarce due to the costs associated with unexpected failures. This model was developed while keeping in mind that it is not the reliability of single assets that matters the most, but rather the reliability of a network of assets. Continuation of the work is aimed at developing the models and algorithms towards this network perspective.

- Haralambie Leahu and Michel Mandjes (UvA) continued their work on automated and simulation-based stability detection for a general class of stochastic networks.

This class covers nearly all relevant queueing network structures, including for instance re-entrant lines (which are notoriously hard to analyze and for which no explicit stability criterion is known). This year, earlier results on monotonicity of FIFO networks (with respect to the external arrival rates) were extended to the processor sharing case.

See: H. Leahu, M. Mandjes and A. *Oprescu. A numerical approach to stability of multiclass queueing networks*. IEEE Transactions on Automatic Control, Vol. 62, pp. 5478-5484 (2017).

- Michel Mandjes, Brendan Patch and Nicos Starreveld (UvA) looked at various models for population processes on randomly evolving graphs. In such models either the nodes or the edges alternate between a present and an absent state. The moments of the network population vector were determined, and in addition diffusion limits were derived. A model developed by Mandjes and Patch (jointly with Dieter Fiems, Ghent) has applications in the design of storage systems, an area that is currently being explored.

- With David Koops (UvA), Onno Boxma and Michel Mandjes have studied infinite-server systems fed by various types of overdispersed input processes, most notably Hawkes processes. Such self-exciting processes received substantial attention over the past few years, owing to their ability to realistically model counting processes. With Liron Ravner (UvA), Boxma and Mandjes studied problems concerning the inference of input characteristics from workload observations. For special classes of queueing systems, efficient algorithms were developed. With Birgit Sollie (VU) and Mathisca de Gunst (UvA), Mandjes considered similar issues for population processes in a Markov-modulated environment. The fact that the environment process is not observed causes substantial complications.

- Andrea Roccaverde, together with Frank den Hollander and Diego Garlaschelli (UL), continued his research on the comparison of the microcanonical ensemble and the canonical ensemble for large random graphs subject to constraints. The goal is to classify for which classes of graphs and constraints breaking of ensemble equivalence occurs. An approximate formula for the relative entropy, recently put forward by Garlaschelli and Squartini and based on covariance matrices, was analyzed in the setting where the constraint is on the degree sequence. A paper was accepted by the Journal of Statistical Physics.

- Andrea Roccaverde, together with Frank den Hollander, Michel Mandjes and Nicos Starreveld, also analyzed the situation where the constraint is put on the total number of edges and triangles in the dense regime. The main result is that breaking of ensemble equivalence occurs when the constraints satisfy a certain 'frustration condition'". The proof extensively uses large deviation theory for graphons.

  See: F. den Hollander, M. Mandjes, A. Roccaverde and N. Starreveld. *Ensemble equivalence for dense graphs*. Electronic Journal of Probability, Vol. 23, paper no. 12 (2018).

THEME 6: TRANSPORTATION AND TRAFFIC NETWORKS

As mentioned before, virtually all sectors of society are facing issues regarding the design, operation, and control of highly complex networks. In this theme the focus is on a key application area that is of primal societal interest, namely, transportation and traffic networks.

Various network-related problems are studied, shedding light on different aspects. In some of these the network structure is fixed and the focus lies on the effect of the randomness involved in user behavior, while in others the main objective concerns the shaping of the network structure. The emphasis is both on structure-related issues (planning and dimensioning of transportation and traffic networks) and the operations on existing networks (routing and scheduling and other traffic management mechanisms that relate to shorter time scales).

HIGHLIGHTS

- Marko Boon, Guido Janssen and Johan van Leeuwaarden (TU/e) introduced a novel method to analyze the fixed-cycle traffic-light (FCTL) queue, which is the standard model for intersections with static signaling, where vehicles arrive, form a queue and depart during cycles controlled by a traffic light. Classical analysis of the FCTL queue based on transform methods requires a computationally challenging step of finding the complex-valued roots of a certain characteristic equation. Building on the recent work of Oblakova, they obtain a contour-integral expression, reminiscent of Pollaczek integrals for bulk-service queues, characterizing the steady-state distribution of the FCTL queue. Through the asymptotic evaluation of this Pollaczek-type integral, it is possible to study the system in heavy-traffic. A capacity sizing rule is determined, ensuring that the specified traffic flow will operate in the Quality-and-Efficiency Driven (QED) regime.

- During the past year, Wouter Kager (VU), Michel Mandjes, Sandjai Bhulai (VU), and Jaap Storm (VU) studied a cellular automaton model of a roundabout. They proved that this model is stochastically equivalent to a work-conservative multiclass queueing network with priorities, which opens up a methodology for studying traffic cellular automata in a more rigorous way. In order to study non-trivial stability issues with these traffic cellular automata, the fluid models related to these queueing networks have been examined. In addition, closed-form expressions for various performance quantities have been derived and relevant probabilistic properties of the model were discovered.

THEME 7: COMMUNICATION AND ENERGY NETWORKS

Communication and energy networks are both prominent instances of highly complex large-scale networked systems which are of critical importance to society. Because of their vital interest, these systems need to be designed to achieve consistently high levels of performance as well as reliability, and yet be cost-effective to operate. This involves huge challenges, especially since both communication and energy networks are subject to inherent uncertainty and random variation in demand as well as supply.

HIGHLIGHTS

- Murtuza Ali Abidini and his supervisors Onno Boxma, Ton Koonen, and Jacques Resing (TU/e) have worked with Nicola Calabretta (Electrical Engineering department at TU/e) on a study of the behavior of an all-optical datacenter switch. A queueing model was developed to mimic the simulation results obtained by researchers in the group of Koonen. Furthermore, Ali Abidini, his supervisors, and Cor Hurkens (Combinatorial Optimization group at TU/e) have studied a revenue optimization problem for optical nodes with multiple wavelengths. Besides these research activities, a significant effort was devoted to the organization of the workshop "Mathematical Techniques in Optical Networks" which will take place in April 2018.

- Bart Post and Sem Borst completed a second paper on optimal cell assignment algorithms for wireless pico-cell networks, which he presented at the ITC 29 conference in Genoa, Italia held in September. With Ton Koonen, Post and Borst have also initiated the study of load-aware dynamic resource allocation schemes. These schemes are specifically designed for dense cellular networks enabled by Radio-over-Fiber technology, as a promising architecture paradigm for future 5G networks. This work has led to two further conference papers accepted for ICC 2018 and WiOpt 2018.

GRANTS AND AWARDS

GRANTS

RC Proof of Concept Grant

Ton Koonen - BROWSE_PLUS: Beam-steered Reconfigurable Optical-Wireless System for Energy-efficient communication — Proving the Concept.

Australian ARC Discovery Grant

Michel Mandjes - Time Consistency, Risk-Mitigation, and Partially Observable Systems.

Gravitation Grant

Harry Buhrman — Gravitation programme "Quantum Software Consortium".

AWARDS

Best-in-Session Presentation award

Mark van der Boor 2017 IIEEE International Conference on Computer Communications in Atlanta, GA, USA (IEEE INFOCOM 2017) — title "Load Balancing in LargeScale Systems with Multiple Dispatchers".

Excellent Student Paper Award ↑

Bart Jansen and Astrid Pieterse - 12th International Symposium on Parameterized and Exact Computation (IPEC 2017) - title "Optimal Data Reduction for Graph Coloring Using Low-Degree Polynomials".

Honorary doctorate

Onno Boxma, - The Heriot-Watt University in Edinburgh (Scotland).

ACM SIGMETRICS Achievement Award

Sem Borst.

See: B. Post and S. Borst. *Load-Driven Cell Assignment Algorithms for Dense Pico-Cell Networks*. Proceedings of the 29th International Teletraffic Congress (ITC 2017), pp. 37-45.

- The work of Fiona Sloothaak, with her supervisors Sem Borst and Bert Zwart (CWI, TU/e), focuses on the performance and reliability of network systems operating under a certain form of criticality. One specific thread of research involves cascading failure models, where the effect of a small disturbance on the reliability of the entire network is studied. In 2017, the first journal paper on a stylized model was published as well as an extension in a conference paper (IEEE Power & Energy Society General Meeting).

  See: F. Sloothaak, B. Zwart and S. Borst. *Robustness of power-law behavior in cascading line failure models*. Stochastic Models, Vol. 34, pp. 45-72 (2018).

- Mark van der Boor and Debankur Mukherjee (TU/e) have actively pursued the analysis and design of scalable load-balancing algorithms, and wrote a survey together with their supervisors Sem Borst and Johan van Leeuwaarden which will appear in the proceedings of ICM 2018. Van der Boor introduced a novel class of load balancing schemes where the various servers provide occasional queue updates to guide the load assignment. He showed that the proposed schemes strongly outperform JSQ(d) strategies with comparable communication overhead per job and can achieve a vanishing waiting time in the many-server limit with just one message per job. Mukherjee explored the performance of load balancing algorithms in network scenarios as represented by some underlying graph topology and identified a broad class of asymptotically optimal topologies, resulting in a paper which he will present at ACM SIGMETRICS 2018.

  See: D. Mukherjee, S. Borst and J. van Leeuwaarden. *Asymptotically Optimal Load Balancing Topologies*. Proc. SIGMETRICS '18 (2018). Journal version: PACM on Measurement and Analysis of Computing Systems, Vol. 2, paper no. 14 (2018),

PORTFOLIOS

EDUCATION

Two main components of the NETWORKS educational program are the Training Weeks and the internships.

In the Training Weeks, researchers from NETWORKS gather to learn more about the research topics studied within the entirety of the NETWORKS project. The Training Weeks not only play an important role in the education of PhD students, but they also help to connect (the researchers from) stochastics and algorithms. The first three Training Weeks, organized in previous years, consisted of two mini-courses each, taught by NETWORKS PIs: one on a topic from algorithmics, and one on a topic from stochastics. Now that the NETWORKS program is well on its way, the focus has been shifted slightly: the Training Weeks still have mini-courses, but in addition there are talks by PhD students and other NETWORKS researchers. Moreover, there is an open problem session and there are working sessions where participants can work together in new or existing research collaborations. Another change is that the mini-courses are no longer given by the PIs but by NETWORKS tenure-trackers.

In 2017 we organized two Training Weeks in the new format. For the Training Week that was held January 30 – February 3, we returned to Kaap Doorn, where we also had a Training Week in 2016. Time Hulshof gave a mini-course on percolation, while the other mini-course on structural graph parameters was given by Bart Jansen. From October 30 – November 3, another Training Week took place in De Schildkamp in Asperen. Viresh Patel gave a mini-course on expansion properties of networks and Luca Avena on random walks, forests and network analysis. Both weeks were well attended (on average 45 participants) and the new format led to several new collaborations.

The NETWORKS internships are small (2-3 months) research projects. Many PhD students do their internship with another research group in NETWORKS, but it is also

INTERNSHIPS

PHD STUDENT	INTERNSHIP AT	SUPERVISOR	TITLE INTERNSHIP
Mukherjee, Debankur (TU/e)	TU/e	Berg, Mark de Jansen, Bart	Reconfiguration thresholds for independent sets
Federico, Lorenzo (TU/e)	Budapest University of Technology and Economics	Gabor Pete Balasz Rath	High-dimensional percolation under free boundary conditions
Heemskerk, Mariska (UvA)	TU/e	Boxma, Onno	Asymptotics of doubly stochastic infinite-server queues
Kleer, Pieter (CWI)	UvA	Carstens, Jacobien	The Curveball algorithm
Markovic, Aleksandar (TU/e)	Tohoku University, Sendai, Japan	Takeshi,Tokuyama	Rectilinear Link Diameter and Radius in a Rectilinear Polygonal Domain
Kisfaludi-Bak, Sándor (TU/e)	CWI	Briët, Jop	Representing quantum algorithms with low degree polynomials

an option to visit a research group abroad or an applied research institution. Examples of host institutions are: the University of Haifa (Israel), IBM Research Yorktown Heights (USA), and INRIA/Microsoft Research (Paris, France). By now, most PhD students who started in 2014 or 2015 have done their internship.

OUTREACH

The main outreach activity of this year was the NETWORKS 2017 Conference, with two days of technical talks as well as a public day. During the public day a panel discussion was organized on the role of networks in our society, and the need for mathematical tools to understand and design such networks. For a detailed report on the conference, see page 20.

From 2016 onwards, Bart Groeneveld has been appointed as NETWORKS' outreach coordinator. His primary task is to enhance the program's visibility. The policy adopted is to organize outreach activities in the form of short projects with a clear goal. This year the focus was on the development of a NETWORKS challenge for secondary schools, with the key question 'What would you like to know about Networks?'. The challenge was part of the NETWORKS 2017 Conference.

During the Fall of 2017 a web class has been run. In this web class, high-school students do exercises on complex networks in an online environment. The course has been developed by NETWORKS postdoc Jacobien Carstens, jointly with Kees Temme and Jeroen Eijkens (UvA). The web class was concluded by a closing event on Thursday December 21st, 2017, which also included a public lecture by Michel Mandjes. The course was highly appreciated by both students and their teachers.

Next to this, the NETWORKS members are involved in several outreach activities. Johan van Leeuwaarden is strongly involved in out-

PHD STUDENT	INTERNSHIP AT	SUPERVISOR	TITLE INTERNSHIP
Patch, Brendan (UvA)	IBM Thomas J. Watson Research Center	Squillante, Mark	Optimal Resource Management for Networks of Erlang B Loss Systems: A Functional Form Approximation Approach
Pieterse, Astrid (TU/e)	CWI	Schaefer, Guido	Coordination games on graphs
Bannink, Tom (CWI)	TU/e	Hofstad, Remco van der	Switch chain mixing times through triangle counts
Dhara, Souvik (TU/e)	UvA	Mandjes, Michel	Efficient simulation of the scaling limits for critical random graphs
Starreveld, Nicos (UvA)	UL	Hollander, Frank den	Equivalence of random graph models
Roccaverde, Andrea (UL)	UvA	Mandjes, Michel	Ensemble Equivalence for Dense Graphs
Garavaglia, Alessandro (TU/e)	CWTS, Leiden	Traag, Vincent	Temporal dynamics in citation networks
Güldas, Hakan (UL)	TU/e	Berg, Mark de	The conflict-free coloring problem of unit disk regions
Meylahn, Janusz (UL)	CWI	Buhrman, Harry	Quantum Boltzmann machines

reach in his role as a member of De Jonge Akademie of KNAW. Public lectures were given by Jop Briët, Harry Buhrman, Frank den Hollander, Remco van der Hofstad, and Michel Mandjes. Van Leeuwaarden and Ionica Smeets (UL) jointly supervise a PhD student who is working on a citizen science project.

INTERNATIONALIZATION

In 2017, the ties that NETWORKS has with international partners have been further strengthened as well.

Within the framework of the Memorandum of Understanding (MoU) with the Australian Research Council Centre of Excellence for Mathematical and Statistical Frontiers (ACEMS) signed in 2015, Michel Mandjes made an extended visit to Melbourne in the Fall of 2017, collaborating with Australian researchers and participating in strategic discussions about the scope and the organization of ACEMS. He was keynote speaker at the ACEMS annual retreat. One joint doctorate (University of Queensland/University of Amsterdam) was awarded in 2017 and a second one is expected early 2019. Mandjes received, together with colleagues of the University of Queensland, an ARC Discovery Grant.

There is also an MoU with the Indian Statistical Institute (ISI), signed in 2016. Frank den Hollander visited Bangalore in the Summer of 2017, co-organizing a 2-months program on Large Deviations at the International Center for Theoretical Sciences, collaborating with Indian researchers, and making preparations for an ISI-NETWORKS workshop in January 2018 in Kolkata. Four PhD-students from NETWORKS participated in this program as well. A one-day meeting (which was called ISI-NETWORKS Day) was held in Leiden on June 23, 2017.

WORKSHOPS

WORKSHOP	PERIOD	LOCATION	INVOLVED FROM NETWORKS
SEMSTAT	Eurandom, Eindhoven	March 7–10, 2017	Hofstad, Remco van der
43rd International Workshop on Graph-Theoretic Concepts in Computer Science	Kapellerput Conference Hotel, Heeze	June, 21–23, 2017	Berg, Mark de
Random Structures on the Brain	Lorentz Center, Leiden	July 3–8, 2017	Avena, Luca Hollander, Frank den
Stochastic Activity Month on "Random Graphs and Complex Networks"	Eurandom, Eindhoven	September 3–22, 2017	Avena, Luca Briët, Jop Patel, Viresh Hulshof, Tim
Israeli–Dutch Workshop on Applied Probability and Queues	Eurandom, Eindhoven	October 2–4, 2017	Boxma, Onno
Traffic Logistics	Eurandom, Eindhoven	November 8, 2017	Boon, Marko Boxma, Onno
YEQT XI: "Winterschool on Energy Systems"	Eurandom, Eindhoven	December 11–15, 2017	Sloothaak, Fiona

NETWORK PAGES

The Network Pages (www.networkpages.nl) are an interactive web portal aimed at a broad audience interested in network science. The slogan 'The math and algorithms that keep us connected. Network science for students, teachers and researchers' describes the content as well as target audiences of the site.

From December 2016 onwards, the aim was to publish an article every month and a blog bi-weekly. The Network Pages' team consists of Mark de Berg (education), Robert Fitzner (demo designer), Tim Hulshof (blog editor), Marjolein de Vries and Bart Groeneveld, with Remco van der Hofstad as editor-in-chief. Bart Post has helped tremendously in the past three years to set up the design of the WordPress website, but due to being in the last year of his PhD project, he is slowly gearing down his activities for the Network Pages. While much of the content is produced by members of the NETWORKS project, we welcome contributions from everyone. We provide an incentive for authors in the form of demos designed by Robert Fitzner, that enliven contributions. Such demos can subsequently also be used in the author's presentations. The Network Pages also provide a forum to reach high-school teachers and students, which has been used for the Networks Contest at the NETWORKS conference in June 2017. The coming year, we plan to enhance the visibility of the site, by relying on frequent communications about additions to the site through the social media teams of the UvA and TU/e. Furthermore, in 2018, we plan to organize a workshop on how to write popular-scientific articles for a broad audience, so as to activate authors for the Network Pages and help them to reach an appropriate audience, as well as to increase the number of videos on the site.

YOUNG TALENTED SCIENTISTS

MATHEMATICIAN CLARA STEGEHUIS ONE OF THE NEW 'FACES OF SCIENCE'

PhD student Clara Stegehuis, affiliated to NETWORKS, has been chosen as one of the twelve new 'Faces of Science'. These young talents, chosen by the Royal Netherlands Academy of Arts and Sciences (KNAW), will relate about their daily ins and outs as a scientist in movies and blogs.

Faces of Science is a project initiated by 'KNAW', 'De Jonge Akademie' and 'NEMO Kennislink' with the purpose of highlighting young talented scientists. In their blogs, to be found on Facesofscience.nl, they share their experiences and passions to give a realistic picture of being a scientist, mainly to young potential students. Besides this they perform regularly at meetings and in the media.

Clara is looking forward to the opportunities that this stage will offer: "I love to show people, and particularly high-school students, how beautiful mathematics and science are. www.nemokennislink.nl/facesofscience/wetenschappers/clara-stegehuis/

VALORIZATION

The research activities in NETWORKS are not only driven by intriguing scientific quests, but also strongly inspired by urgent challenges involving complex dynamic networks that industry and society are increasingly being confronted with. Several paths are pursued to accomplish the transfer of novel insights and results and translate fundamental concepts into actual implementations. Specifically, the main vehicles for knowledge transfer and utilization are: (i) a long-term flux of young talented professionals who have been and will continue to be trained in the various groups of which NETWORKS is comprised; (ii) active engagement of the various groups in NETWORKS in several broader efforts to

promote the application of advanced knowledge in mathematics and computer science to solve problems of industrial and societal relevance; (iii) close ties maintained by many of the principal investigators in NETWORKS with various companies and societal organizations, and involvement in application-oriented multi-disciplinary projects; (iv) open and high-visibility channels towards companies and societal organizations that face challenges relating to complex dynamic networks and seek innovative solution approaches.

There is a fruitful interaction with TNO, which is a semi-public organization in technology research with an active interest in the various application areas pursued by NETWORKS, and in particular societal infrastructure networks. Michel Mandjes and Sem Borst have had contacts with Hans Van den Berg (TNO), discussing common research interests. Hans van den Berg and Daniël Worm gave well-received talks at NETWORKS days (in Eindhoven on April 19, and in Den Bosch on December 8, respectively), whereas Michel Mandjes, Harry Buhrman, Bart Post and Sem Borst have given seminars at TNO. There are plans for other NETWORKS researchers to give similar seminars at TNO and for TNO scientists to give presentations at NETWORKS events. The possibility of launching a possible broader NETWORKS-wide strategic alliance with TNO under the umbrella of a formal Memorandum of Understanding remains under investigation. NETWORKS played an active role in the organization of the annual 'Study Group Mathematics with Industry' event at CWI and UvA in January 2017, and also took the lead in organizing the January 2018 edition at TU/e. Both editions featured a specific networks-oriented problem, formulated in 2017 by TNO and in 2018 by CQM (Consultants in Quantitative Methods, Eindhoven).

Several principal investigators of NETWORKS are engaged in application-oriented projects which are typically carried out in the framework of the top-sector themes of the Dutch government, special industrial partnerships or various local initiatives. Frank den Hollander, Remco van der Hofstad, and Michel Mandjes met with Louise Gunning, member of the Critical Friends Committee and Chair of the Dutch National Research Agenda (Nationale Wetenschapsagenda, NWA) initiative, to explore connections between the NETWORKS research activities on one hand and various routes and themes as defined in the NWA on the other hand.

NETWORKS 2017 CONFERENCE

From June 7 to June 9, the NETWORKS 2017 conference took place in Amsterdam. This conference was the first large conference in the framework of the NETWORKS program and was organized by NETWORKS members. Scientific presentations took place on June 7 and June 9, split over four tracks in two parallel sessions. The tracks, each covering an important subtheme within networks, featured a keynote lecture as well as other lectures by experts in the field. Next to this, on June 8, a public event was organized to highlight the importance of research in networks to a broad audience.

The first of June 7's tracks, on mathematical physical aspects of complex networks, viewed networks from the combined perspective of mathematics and physics. The keynote lecture in this track was delivered by M. Ángeles Serrano (Universidad de Barcelona). The second track that day covered logistics and scheduling, which form central issues within networks. The keynote lecturer Gerhard Woeginger

(Rheinisch-Westfälische Technische Hochschule Aachen) as well as the other lecturers discussed logistic and scheduling problems and methods from an algorithmic and mathematical view point.

The public event on June 8 sought to display the role of networks in our present-day society as well as the importance of understanding this role to a broad audience. In the morning, a panel discussion on this topic took place between several political and strategic leaders of Dutch science. Moderated by Isolde Hallensleben, who is known for presenting programs for radio and television, Wim van Saarloos (vice-president of the Royal Netherlands Academy of Arts and Sciences, KNAW), Stan Gielen (Head of the Netherlands Organisation for Scientific Research, NWO), Louise Gunning (Chair of the National Research Agenda, NWA), Frank van der Duyn Schouten (Chair of the National Mathematics Council) and Ionica Smeets (Professor of Science Communication, UL) shared and discussed various interesting viewpoints on the role and impact of complex networks in modern society.

After the discussion the winners of the NETWORKS Challenge 2017, a competition for high school students, were announced. The question the students were asked to reflect upon was: “What would you like to know about networks?” Kim and Marit Tijhuis made a short movie on the puzzle Tectonics, and the relation of these types of puzzles with social geography, whereas Marit Bonne, Bariya Boskma, Blanca van Duijn, Noa Boon and Roos Tijssen visualized “What is the purpose of life and how do networks influence that purpose”. Ionica Smeets handed out the prizes to the winners.
In the afternoon, four international experts in networks theory gave lectures, each highlighting a particular aspect of network research and its impact on society.

The conference concluded by another two parallel tracks with scientific presentations. The first of these tracks focused on com-

Panel discussion during Public Event of the NETWORKS 2017 conference, photo Eric Daams

munication networks, which are prominent examples of highly complex large-scale networked systems that are of critical importance to society. Keynote lectures in this track were delivered by NETWORKS-tenure trackers Jan-Pieter Dorsman (UvA/UL) and Stella Kapodistria (TU/e). Concurrently, the second track centered on scheduling problems arising in the context of complex networks where uncertainty plays a critical role. The track featured a keynote presentation by a world-renowned expert, Kirk Pruhs (University of Pittsburgh).

The conference attracted enormous interest, as witnessed by the involvement of more than 200 participants from the Netherlands and abroad.

INVITED SPEAKERS OF THE NETWORKS 2017 CONFERENCE

TRACK	MATHEMATICAL PHYSICAL ASPECTS OF COMPLEX NETWORKS	LOGISTICS AND SCHEDULING	COMMUNICATION NETWORKS	SCHEDULING PROBLEMS
KEYNOTE	M. Ángeles Serrano (Universidad de Barcelona)	Gerhard Woeginger (Rheinisch-Westfälische Technische Hochschule Aachen)	Jan-Pieter Dorsman (UvA/UL) Stella Kapodistria (TU/e)	Kirk Pruhs (University of Pittsburgh)
OTHER	Ginestra Bianconi (Queen Mary University of London) Tiziano Squartini (Universita di Roma "La Sapienza") Dmitri Krioukov (Northeastern University, Boston)	Rolf Möhring (Technische Universität Berlin) Guido Schaefer (CWI/VU) Vincenzo Bonifaci (IASI-CNR)	Nelly Litvak (University of Twente) Laurent Massoulie (Microsoft Research – INRIA Joint Centre) Mark Squillante (IBM Thomas J. Watson Research Center)	Marc Uetz (University of Twente) Rene Sitters (VU/CWI) Bert Zwart (CWI/TU/e)

ORGANISATIONAL ASPECTS

In 2017, 4 PhD students, 2 postdocs have been appointed. Nikhil Bansal (TU/e) succeeded Gerhard Woeginger in the Project Team of NETWORKS. By the end of 2017, NETWORKS counted 62 members and 36 affiliated members (affiliated members are not paid by the grant, they are strongly connected to the NETWORKS program).

NETWORKS members and affiliated members convene two or three times a year during the so-called NETWORKS days. As of 2017, the NETWORKS days are more focused on current research within the program, rather than on organizational aspects and the overall progress of the program.

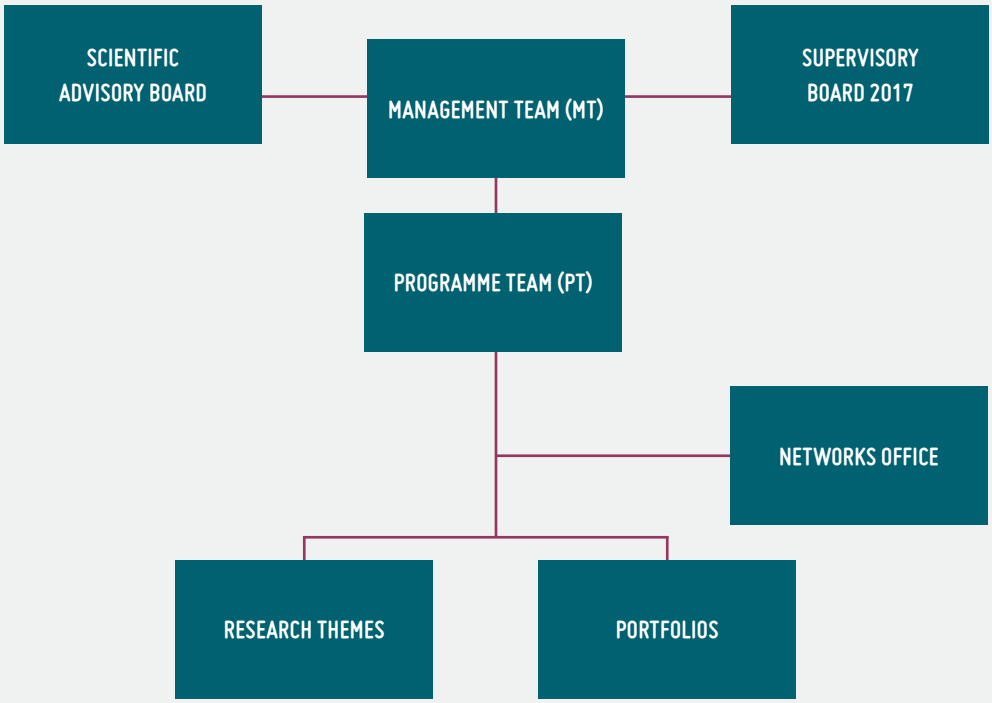
In 2017, two such meetings were organized:

- **April 19, 2017**. Scientific presentations by keynote lecturer Hans van den Berg (TNO) and affiliated members on application-oriented topics. Location: Speco Sportslab, Eindhoven.
- **December 8, 2017**. Scientific presentations with the main focus on current research within the research themes and introductory talks of the new hires. Location: Congress center 1931, Den Bosch.

In 2017 NETWORKS underwent its midterm review with the purpose of assessing whether the second half of the funding period should be granted. Specific attention was paid to the organizational structure and to the perspectives of the consortium after the funding period. To this end, we were first visited by a team of internationally renowned colleagues, referred to as 'Critical Friends'. Based on our self-evaluation document and the interviews they had with researchers from the consortium, they wrote an in-depth assessment of the program. This review, as well as our self-evaluation and the annual reports, was input for an NWO committee who did the final assessment.
The reviews of the Critical Friends as well as the NWO committee focused on a variety of aspects. Of course, attention was paid to the scientific progress, but various other aspects were looked at in detail. An important issue concerned the interaction between the algorithmically oriented and the stochastically oriented researchers in the team, and more specifically, the policies we adopted to foster this interaction (training weeks, internships, dual supervision, etc.). Another issue related to the interaction with other scientific disciplines in which networks play a prominent role, and also the link with industry. We discussed our policy to disseminate the findings of the program towards more applied fields, and various suggestions were made to further enhance this. Other topics that were assessed concerned the support provided towards the tenure-track employees, diversity and gender balance, as well as various organizational aspects. In addition, a substantial amount of attention was paid to the issue of our legacy: what do we do to make sure that after 2024 the research efforts in this direction will be continued, building on the connections between the partners.

Both the Critical Friends and the NWO committee were highly positive about the scientific achievements of the program, as well as the way the program is run. We were in particular pleased to learn that it was noted that we succeed in building bridges between previously separated research branches. Indeed, rather than just scaling up the research agendas of the individual PIs, we have managed to create a substantial synergy. In December we received the formal letter from our Minister of Education, Culture and Science, I.K. van Engelshoven, informing us that she had decided to grant us the second tranche. The letter consisted of more specific feedback on our performance so far, based on the evaluation of the NWO committee. The sole formal recommendation made concerned a systematic procedure for storing code and data.

ORGANOGRAM



SCIENTIFIC ADVISORY BOARD

prof. dr. Jan van Leeuwen (Utrecht University)
prof. dr. David Gamarnik (MIT)
prof. dr. Peter Glynn (Stanford)
prof. dr. Catholijne Jonker (TU Delft)
prof. dr. Joel Spencer (NYU)
prof. dr. Rolf Niedermeier (TU Berlin)
prof. dr. Dorothea Wagner (Karlsruhe Institute of Technology)

SUPERVISORY BOARD 2017

prof. dr. P.H. van Tienderen (UvA)
prof. dr. Barry Koren (TU/e, till March 2017)
prof. dr. Johan Lukkien (TU/e, from 1 April 2017)
prof. dr. Geert de Snoo (UL)
prof. dr. Jos Baeten (CWI)

MANAGEMENT TEAM (MT)

prof. dr. Mark de Berg (TU/e)
prof. dr. Sem Borst (TU/e)
prof. dr. Remco van der Hofstad (TU/e)
prof. dr. Frank den Hollander (UL)
prof. dr. Michel Mandjes (UvA, chair)
prof. dr. Lex Schrijver (UvA, CWI)

PROGRAMME TEAM (PT)

prof. dr. Nikhil Bansal (TU/e)
prof. dr. Mark de Berg (TU/e)
prof. dr. ir. Sem Borst (TU/e)
prof. dr. ir. Onno Boxma (TU/e)
prof. dr. Harry Buhrman (UvA, CWI)
prof. dr. Remco van der Hofstad (TU/e)
prof. dr. Frank den Hollander (UL)
prof. ir. Ton Koonen (TU/e)
prof. dr. Johan van Leeuwaarden (TU/e)
prof. dr. Michel Mandjes (UvA, chair)
prof. dr. Lex Schrijver (UvA, CWI)

NETWORKS OFFICE

Marieke Kranenburg, project manager
Patty Koorn, workshop officer
Petra Rozema, secretary
Monique Onderwater, webmaster
Bart Groeneveld, outreach

PORTFOLIOS

Workshops, Frank den Hollander
Outreach, Michel Mandjes / Johan van Leeuwaarden
Internationalisation, Frank den Hollander
Education, Mark de Berg
Valorisation, Sem Borst
Network Pages, Remco van der Hofstad

RESEARCH THEMES

Approximate and exact network methods
Spatial networks
Quantum networks
Dynamics of networks
Dynamics on networks
Transportation and traffic networks
Communication and energy networks

NETWORKS MEMBERS

AFFILIATIONS ABBREVIATED	FULL NAME WITH TITLE	FUNCTION PROFILE
TU/e	Murtuza Ali Abidini, MSc	PhD
UL	dr. Luca Avena	Tenure Track
CWI	Tom Bannink, MSc	PhD
TU/e	prof.dr. Nikhil Bansal	Professor
UvA	Abishek BegRaj, MSc	PhD
TU/e	prof.dr. Mark de Berg	Professor
TU/e, UU	prof.dr. Hans Bodlaender	Professor
TU/e	Mark van der Boor, MSc	PhD
TU/e	prof.dr.ir. Sem Borst	Professor
TU/e	prof.dr.ir. Onno Boxma	Professor
CWI	dr. Jop Briët	Tenure Track
UvA, CWI	prof.dr. Harry Buhrman	Professor
UvA	dr. Jacobien Carstens	Postdoc
TU/e	Souvik Dhara, MSc	PhD
UvA, UL	dr. Jan-Pieter Dorsman	Tenure Track
TU/e	Lorenzo Federico, MSc	PhD
TU/e	dr. Robert Fitzner	Programmer
TU/e	Alessandro Garavaglia, MSc	PhD
UvA	drs. Bart Groeneveld	Support Staff
UL	Hakan Güldas, MSc	PhD
UvA	Mariska Heemskerk, MSc	PhD
TU/e	prof.dr. Remco van der Hofstad	Professor
UL	prof.dr. Frank den Hollander	Professor
TU/e	dr. Tim Hulshof	Tenure Track
TU/e	dr. Bart Jansen	Tenure Track
UL	dr. Oliver Jovanovski	Postdoc
TU/e	dr. Stella Kapodistria	Tenure Track
UvA	Madelon de Kemp, MSc	PhD
TU/e	Sándor Kisfaludi-Bak, MSc	PhD
CWI	Pieter Kleer, MSc	PhD
TU/e	dr. Sudeshna Kolay	Postdoc
TU/e	dr. Sándor Kolumbán	Postdoc
TU/e	prof.ir. Ton Koonen	Professor
UvA	David Koops, MSc	PhD
TU/e	Patty Koorn	Support Staff
UvA	dr.ing. Marieke Kranenburg	Support Staff
CWI	Farrokh Labib, MSc	PhD
TU/e	prof.dr. Johan van Leeuwaarden	Professor
UvA	prof.dr. Michel Mandjes	Professor
TU/e	Aleksandar Markovic, MSc	PhD
UL	Janusz Meylahn, MSc	PhD
UvA	prof.dr. Sindo Núñez Queija	Professor
TU/e	Daniel Olah, MSc	PhD
UvA	Monique Onderwater	Support Staff
UL	Margriet Oomen, MSc	PhD
UvA	Brendan Patch, MSc	PhD
UvA	dr. Viresh Patel	Tenure Track
TU/e	Astrid Pieterse, MSc	PhD
TU/e	Bart Post, MSc	PhD
TU/e	Youri Raaijmakers, MSc	PhD
TU/e, UvA	Dr. Liron Ravner	Postdoc
UvA	dr. Maria Remerova	Postdoc
UL	Andrea Roccaverde, MSc	PhD
TU/e	Petra Rozema-Hoekerd	Support Staff
CWI, UvA	prof.dr. Lex Schrijver	Professor
UL	Matteo Sfragara, MSc	PhD
TU/e	Fiona Sloothaak, MSc	PhD
VUA	Birgit Sollie, MSc	PhD
NYU	prof.dr. Joel Spencer	Professor
UvA	Nicos Starreveld, MSc	PhD
VUA	Jaap Storm, MSc	PhD
UL, TU/e	Marjolein de Vries, MSc	PhD

See www.thenetworkcenter.nl/people/people-overview for extended profiles

AFFILIATED MEMBERS

AFFILIATIONS ABBREVIATED	FULL NAME WITH TITLE	FUNCTION PROFILE
TU/e	prof.dr.ir. Ivo Adan	Staff
VUA	dr. René Bekker	Staff
VUA	prof.dr. Sandjai Bhulai	Staff
UvA	dr. Arnoud den Boer	Tenure Track
TU/e	dr.ir. Marko Boon	Staff
TU/e	Dr. Kevin Buchin	Staff
CWI	dr. Daniel Dadush	Tenure Track
UU	prof.dr. Roberto Fernandez	Staff
UL	dr. Diego Garlaschelli	Staff
TU Delft	dr. Dion Gijswijt	Staff
VUA	prof.dr. Mathisca de Gunst	Staff
CWI	dr. Stacey Jeffery	Tenure Track
VUA	dr. Wouter Kager	Staff
VUA	dr. Bartek Knapik	Staff
TU/e	dr. Júlia Komjáthy	Tenure Track
CWI	prof.dr. Monique Laurent	Staff
UT	dr. Nelly Litvak	Staff
TU/e	Debankur Mukherjee, MSc	PhD-student
TU/e	dr. Jan Nagel	Postdoc
VUA, CWI	dr. Neil Olver	Staff
UvA	dr. Guus Regts	Tenure Track
TU/e	dr. Jacques Resing	Staff
CWI	prof.dr. Guido Schäfer	Staff
UL	prof.dr.ir. Ionica Smeets	Staff
TU/e	prof.dr. Bettina Speckmann	Staff
UL	dr. Floske Spieksma	Staff
TU/e	Clara Stegehuis, MSc	PhD-student
VUA	prof.dr. Leen Stougie	Staff
TU/e	Viktória Vadon, MSc	PhD-student
UL	prof.dr. Evgeni Verbitskiy	Staff
TU/e	dr. Maria Vlasiou	Staff
UvA	dr. Neil Walton	Staff
Germany	prof.dr.ing. Gerhard Woeginger	Staff
UU	Tom van der Zanden, MSc	PhD-student
UL	Qi Zhang, MSc	PhD-student
CWI, TU/e	prof.dr. Bert Zwart	Staff

PHD PROJECTS

PROJECT TITLE	LOCATION	SUPERVISORS	PHD STUDENT
Algorithms for Range- and Frequency-Assignment Problems in Wireless Networks	TU/e	Woeginger, Gerhard Berg, Mark de	Markovic, Aleksandar
Breaking of ensemble equivalence for complex networks	UL	Garlaschelli, Diego Hollander, Frank den	Roccaverde, Andrea
Citation networks and performance measures	TU/e	Hofstad, Remco van der Woeginger, Gerhard	Garavaglia, Alessandro
Correlated sources in networks	UvA	Mandjes, Michel Leeuwaarden, Johan van	Heemskerk, Mariska
Dynamic behavior of interacting-particle systems with hard-core interaction	UL	Hollander, Frank den Borst, Sem Nardi, Francesca	Sfragara, Matteo
Dynamic interaction and volatility in future energy networks	TU/e	Borst, Sem Zwart, Bert	Sloothaak, Fiona
Dynamic resource allocation and user association in pico-cell networks	TU/e	Borst, Sem Koonen, Ton Woeginger, Gerhard	Post, Bart
FPT algorithms for geometric network problems	TU/e	Berg, Mark de Bodlaender, Hans	Kisfaludi-Bak, Sándor
Hamilton cycles in sparse graphs	UvA	Patel, Viresh	Stroh, Fabian
Information diffusion and epidemics on random graphs	TU/e	Hofstad, Remco van der Leeuwaarden, Johan van	Dhara, Souvik
Interpretation of measurements for distributed control	TU/e	Mandjes, Michel Bekker, René	Starreveld, Nicos
Invasion percolation and minimal spanning trees on spatial graphs	TU/e	Hofstad, Remco van der Hollander, Frank den	Federico, Lorenzo
Learning Algorithms for Optimal Task Replication and Server Selection	TU/e	Borst, Sem Boxma, Onno	Raaijmakers, Youri
Load Balancing Algorithms in Networked Systems	TU/e	Borst, Sem Leeuwaarden, Johan van	Boor, Mark van der
Optical Networks	TU/e	Boxma, Onno Koonen, Ton Resing, Jacques	Abidini, Murtuza Ali
Optimisation of polling networks with limited service disciplines	UvA	Núñez Queija, Sindo Boon, Marko	BegRaj, Abishek
Optimized Appointment Scheduling	UvA	Mandjes, Michel Olver, Neil	Kemp, Madelon de

More PhD projects on the next page »

PHD PROJECTS (CONTINUATION)

PROJECT TITLE	LOCATION	SUPERVISORS	PHD STUDENT
Parameterized Preprocessing for Network Analysis Problems	TU/e	Jansen, Bart Berg, Mark de	Pieterse, Astrid
Quantum Walks and Quantum Algorithms	CWI	Buhrman, Harry Hollander, Frank den	Bannink, Tom
Random processes on dynamic random graphs	UL	Hollander, Frank den Hofstad, Remco van der Avena, Luca	Güldas, Hakan
Refined Models and Coordination Mechanisms for Network Games	CWI	Schäfer, Guido Schrijver, Lex	Kleer, Pieter
Robust Spanner Networks in the Face of Uncertainty	TU/e	Berg, Mark de Hofstad, Remco van der Hulshof, Tim	Olah, Daniel
Scaling limits of random walks	UvA	Mandjes, Michel Boxma, Onno	Koops, David
Spatial populations with seed-bank	UL	Hollander, Frank den Andreas Greven (Erlangen)	Oomen, Margriet
Spontanenous synchronization in complex networks	UL	Hollander, Frank den Garlaschelli, Diego Meijer, Joke	Meylahn, Janusz
Stability and control of transportation and communication networks	UvA / UQ	Mandjes, Michel Thomas Taimre	Patch, Brendan
Statistical inverse problems for network dynamics	VU	Mandjes, Miche, Gunst, Mathisca de Knapik, Bartek	Sollie, Birgit
Stochastic models for road traffic	VU	Mandjes, Michel Bhulai, Sandjai Kager, Wouter	Storm, Jaap
Structure and randomness in quantum networks	CWI	Briët, Jop	Labib, Farrokh

SELECETION OF JOINT PUBLICATIONS

Below a selection of joint publications in 2017. For the complete list, see our website www.thenetworkcenter.nl/Output/Articles-2017/

- A single-server queue with batch arrivals and semi-Markov services
  Abhishek, Boon, M., Boxma, O., Núñez-Queija, R., *Queueing Systems 86* (3-4), 2017, pp 217-240

- Critical window for the configuration model: finite third moment degrees
  Dhara, S., van der Hofstad, R., van Leeuwaarden, J., Sen, S., *Electronic Journal of Probability 22*, 2017, paper no. 16, 33 pp

- The dynamics of power laws : fitness and aging in preferential attachment trees
  Garavaglia, A., van der Hofstad, R. & Woeginger, G., *Journal of Statistical Physics, 168* (6), 2017, pp 1137-1179

- Ensemble nonequivalence in random graphs with modular structure
  Garlaschelli D., den Hollander, F., Roccaverde A., *Journal of Physics A: Mathematical and Theoretical 50*: 015001, 2017

- Scaling limits for infinite-server systems in a random environment
  Heemskerk, M., van Leeuwaarden, J., Mandjes, M., *Stochastic Systems* 7 (1), 2017, pp 1-31

- Fine-Grained Parameterized Complexity Analysis of Graph Coloring Problems
  Jaffke, L., Jansen, B.M.P., In: D. Fotakis, A. Pagourtzis & V.T. Paschos (Eds.), *Algorithms and Complexity* (Lecture notes in computer science, No. 10236). Dordrecht: Springer Netherlands, 2017, pp 345-356

- Networks of ·/G/∞ queues with shot-noise-driven arrival intensities
  Koops, D., Boxma, O., Mandjes, M., *Queueing Systems 86* (3-4), 2017, pp 301-325

- Two queues with random time-limited polling
  Saxena, M., Boxma, O., Kapodistria, S., Núñez-Queija, R., *Probability and Mathematical Statistics 37* (2), 2017, pp 257-289

- Occupation times for the finite buffer fluid queue with phase-type ON-times
  Starreveld, N., Bekker, R., Mandjes, M., *Operations Research Letters*, 2017

NETWORKS

by address: University of Amsterdam
Faculty of Science – Korteweg-de Vries Institute
PO Box 94248
1090 GE Amsterdam
the Netherlands
+31 (0)20 525 6499
info@thenetworkcenter.nl
www.thenetworkcenter.nl

NETWORKS is a project of University of Amsterdam, Eindhoven University of Technology, Leiden University and Center for Mathematics and Computer Science (CWI) and receives funding from OC&W through NWO

Universiteit van Amsterdam

TU/e Technische Universiteit Eindhoven University of Technology

Universiteit Leiden

CWI Centrum Wiskunde & Informatica

NET WORKS

THENETWORKCENTER.NL