STAND-ALONE PROJECT - FINAL REPORT

Project number	P28182
Project title	**Gracefully Degrading Agreement in Directed Dynamic Networks**
Project leader	**Ulrich Schmid (Embedded Computing Systems Group, TU Wien)**
Project website	**http://ti.tuwien.ac.at/ecs/research/projects/adynnet**

Final project report

1 Report on research work

1.1 Information on the development of the research project

The main focus of ADynNet (Gracefully Degrading Agreement in Directed Dynamic Networks) has been on the precise characterization of conditions that render consensus and other agreement problems solvable in directed dynamic networks, and on the design, correctness proof and performance analysis of solution algorithms. Certain application-oriented aspects like assumption coverage were also addressed.

As already foreseen in the project proposal, the project work was split into three reasonably independent main tasks:

(1) Development of network assumptions and solvability conditions. This work essentially followed the original project plan (albeit we considerably expanded the knowledge-based analysis part), and we are happy to say that its development exceeded our expectations considerably. A noteworthy fact, which confirms the inherently unpredictable nature of real scientific research, is that it took us many years to identify the right method (= point-set topology) for achieving our ultimate goal, namely, a precise characterization of the consensus impossibility/solvability border.

(2) Development of algorithms, correctness proofs and performance analyses. The work on this task also followed the original plans, and also developed excellently.

(3) Investigation of assumption coverage and other application-oriented aspects. Whereas we obtained very interesting results, it became apparent fairly early that the resources assigned to this task in ADynNet itself were not adequate. Since our attempts to fix this problem thoroughly by means of a follow-up project (that has already been suggested in the proposal) did not work out (see Sec. 1.3 for details), we decided to drop some of the goals of this task and focus more on the remaining ones. The existence of our transdisciplinary follow-up FWF project ByzDEL (Reasoning about Knowledge in Byzantine Distributed Systems, P33600, led by Dr. Roman Kuznets) is probably the most significant consequence of this shift.

1.2 Most important results and brief description of their significance

As far as the envisioned accomplishments are concerned, we are happy to say that the work in ADynNet developed excellently: The scientific results obtained in ADynNet are documented in 6 journal papers, 15 papers in international conference proceedings, 2 PhD theses and 3 Master theses. At least two additional conference papers and 3 Master theses on ADynNet core topics are expected to appear in 2021. Moreover, one follow-up FWF project has already been lauched.

Key accomplishments:

(i) We developed a precise characterization of the solvability/impossibility border for consensus in directed dynamic networks controlled by arbitrary message adversaries. “Classic” distributed computing analysis approaches (in particular, combinatorial, knowledge-based and algebraic topology-based ones) turned out to be successful in the restricted case of limit-closed message adversaries. Particularly interesting examples are the consensus characterization in the joint

work with our external collaborator Yoram Moses (Technion Haifa) [WSM19], and the notion of a strongest message adversary based on message adversary simulations [SSW18a], which was inspired by weakest failure detectors in asynchronous crash-prone systems.

It took us years, however, to discover that point-set topology was the right approach to also cover non-limit closed message adversaries [NSW19]. This joint work with our external collaborator Thomas Nowak (Université Paris-Saclay) opened up exciting new research avenues, which we are currently exploring in the context of our follow-up project ByzDEL.

Most related findings are documented in the PhD thesis [Win19] by Kyrill Winkler, which was honored by an invited survey article in the EATCS Bulletin [WS19] and officially nominated by TU Wien for the Dissertation award of the German GI and the Heinz Zemanek dissertation award of the Austrian OCG.

(ii) We developed novel consensus algorithms for very powerful message adversaries: Our eventually stabilizing message adversaries do not restrict the network topology at all, except for a very short period of time, where some reasonably stable interconnect topology must exist. For example, our provably optimal optimal algorithm [WSS19] for rooted graphs requires only D+1 rounds where a vertex-stable root component (consisting of the same set of nodes, with a possibly varying interconnect that guarantees dynamic diameter D) exists. For the general case, where the message adversary can even completely disconnected the network most of the time, we developed an optimal algorithm [SWS16] that requires 2D+1 rounds of stability.

In addition, we also developed algorithms for weaker agreement problems, like gracefully degrading k-set agreement [BRS+18], as well as for asymptotic and approximate agreement [FNS18].

Most of these algorithmic results are documented in the PhD thesis [Sch18] by Manfred Schwarz.

(iii) Our attempts to develop a precise characterization of the consensus impossibility/solvability border also led us to the knowledge-based approach in distributed computing (Halpern and Moses, JACM 1990). In particular, action models from dynamic epistemic logic were found to be very suitable for modelling dynamic networks controlled by message adversaries [PS18].

We realized, however, that the existing state of the art in epistemic logic did not fully exploit the power of this approach, since it did not properly incorporate faulty agents. We therefore ended up with the first multi-agent epistemic modelling and analysis framework, which even allows to deal with arbitrarily misbehaving (byzantine faulty) agents [KPSF19a, KPSF19b].

This direction of work not only caused the project leader Ulrich Schmid to join the second period of the FWF doctoral college LogiCS (Logical Methods in Computer Science, W1255) as a full faculty member, but also laid the grounds for our successful application of the FWF project ByzDEL (Reasoning about Knowledge in Byzantine Distributed Systems, P33600).

(iv) In our attempts to also address application-oriented aspects like assumption coverage, we conducted a thorough experimental evaluation of the assumption coverage of the vertex-stable message adversary in a custom wireless sensor network [PS16]. Since we could not find an existing testbed that would have supported the required continuous connectivity monitoring feature, we had to delvelop the whole experimental setup from scratch. In addition, in a later phase of the project, we reached out to some applications [ZS20, TNL19+].

On the theoretical side, we conducted a thorough theoretical analysis of the pivotal problem of data dissemination in directed dynamic networks [ZSS19] and managed to improve the known dissemination time upper bound from O(n log n) to O(n loglog n) in [FNW20].

1.3 Information on the running of the project, use of the available funds and (where appropriate) any changes to the original project plan

The project ran from January 2016 until December 2020, which is longer than the originally projected 36 months. This (cost-neutral) extension was possible, since (a) the main project members Manfred Schwarz and Kyrill Winkler were partly funded by TU Wien for some time, and (b) the FWF-funded project member Dr. Martin Zeiner moved to some other place in 2018 while continuing work on ADynNet-related topics.

The project work in ADynNet essentially followed the original work plan in the proposal for tasks (1) and (2) (see Sec. 1.1), except for task (3), which was originally planned to cover both analytical and simulation-based experimental coverage analysis. In the course of the project work, however, it became apparent that it could not be performed by the single PhD student originally foreseen for this task: Developing analysis techniques for time-evolving structures in random graph models would have required a skilled mathematician, who unfortunately does not typically have the required background and programming skills for developing representative simulations and experiments. Consequently, we were not able to fill this PhD position in 2016.

We hence decided to go for the experimental coverage analysis first, by means of a capable (Bachelor/Master) student (Daniel Pfleger), until we could fill the PhD position. Unfortunately, this turned out to be more difficult than expected, due to the unforeseen lack of an openly accessible wireless sensor network testbed for the experimental evaluation of topology-related properties in time-varying communication graphs: None of the available platforms, including the ones of our external collaboration partners Christian Bettstetter and Kay Römer, provided sufficient capabilities for the required continuous and mid- to long-term topology monitoring. As a consequence, we had to develop a suitable experimental setup [PS16] from scratch ourselves. Whereas it has been used successfully for the coverage assessment of the adversarial model used in [SWS16], the limited generality and reproducibility of our measurement results suggested that “local” experiments were not the right way to proceed here. Moreover, as we still did not find a PhD student with the required skill set, we eventually hired a 50% PostDoc (Dr. Martin Zeiner) for performing (some of) the theoretical work in task (3).

To possibly fix all these problems satisfactorily, we decided to try and launch an extended version of the follow-up project already suggested in the ADynNet proposal (devoted to the experimental evaluation of our models and algorithms) in 2016/17. The FWF project proposal SPRG (P30083, Structural Properties of Random Graphs), which came out of these efforts, was a joint application with Christian Bettstetter and Udo Schilcher (AAU Klagefurt). Since the rules of the FWF did not allow me to also lead this project (I was leading too many FWF projects already), Dr. Martin Zeiner was supposed to lead this project. Unfortunately, however, the proposal was finally rejected by the FWF.

Consequently, at the end, we decided to drop the goal of a thorough theoretical coverage analysis from task (3).

2. Career development – Importance of the project for the research careers of those involved (including the principal investgator)

Nonwithstanding the general difficulty of assessing scientific recognition, we can safely say that the work on ADynNet was very important for increasing the international reputation of our group as a whole, and for the project members in particular.

- For the project leader *Ulrich Schmid*, ADynNet was important for increasing the reputation of his ECS group at TU Wien, in particular, w.r.t. the topological [NSW19, GWSR19] and epistemic [WSM19,KPSF19a] analysis of distributed algorithms. One equally important aspect of this work was the opportunity to establish new collaborations with leading international researchers, namely, Yoram Moses and Sergio Rajsbaum. Last but not least, the launch of the follow-up project ByzDEL is likely to re-shape the future of a substantial part of the research activities of the ECS group for the next 5 years.

- ADynNet was definitely instrumental for the career of Kyrill Winkler, as his PhD thesis [Win19] (reviewers: Sergio Rajsbaum/UNAM, Stefan Schmid, University of Vienna) was honored by an invited contribution in the EATCS Bulletin [WS19] and officially nominated by TU Wien for the Dissertation award of the German GI and the Heinz Zemanek dissertation award of the Austrian OCG. In October 2020, Kyrill moved to Stefan Schmid's group, where he still continues to contribute substantially to ADynNet core topics.

- ADynNet was vital also for the PhD thesis [Sch18] (reviewers: Emmanuel Godard/U. Marseille, Jesper Träff/TU Wien) of Manfred Schwarz. After completing his thesis, Manfred finally moved to industry, however.

- Dr. Martin Zeiner, who contributed substantially to the theoretical work in task (3), substantially expanded and broadened his scientific profile in the course of his work in ADynNet. Since the follow-up project SPRG was unfortunately not accepted by the FWF, he eventually decided to move to industry already in 2018.

Finally, ADynNet was also an important additional driver for advancing the career of our closest collaboration partners *Matthias Függer* (ENS Paris-Saclay) and Thomas Nowak (University Paris-Saclay), who contributed substantially to the project.

3 Effects of the project beyond the scientific/scholarly field

As already mentioned, ADynNet was instrumental for our transdisciplinary follow-up project ByzDEL, and also caused the project leader Ulrich Schmid to join the faculty of the FWF Doctoral College LogiCS in its second period.

With respect to teaching, some of the results of ADynNet are used in advanced courses (like 182.703 Problems in Distributed Computing[1]) in our computer engineering Master program. Experience tells that this is a very effective means for educating students for current and future research projects.

Given the quite specialized and theoretical nature of ADynNet, we cannot report any public relation-related activities within the project.

[1] Course web page: *http://ti.tuwien.ac.at/ecs/teaching/courses/prdc/*

4 Other important aspects

4.1 Participation in scientific conferences

See 2.2 in the Appendix (List 2) for details.

4.2 Organization of conferences

- General chair and organizer of DISC'17 (Vienna)
- PC chair DISC'18 (New Orleans)

4.3 Honors, prizes etc.

- invited paper for the EATCS Bulletin [WS19]
- Kyrill Winklers PhD thesis [Win19] officially nominated by TU Wien for the Dissertation award of the German GI and the Heinz Zemanek dissertation award of the Austrian OCG
- Thomas Schlögl became our faculty's Distinguished Young Alumnus for his Master thesis [Sch20]

4.4 Relevance of the project in the organization of the relevant scientific discipline

- Transdisciplinary input of distributed computing expertise to the logic community, primarily in the context of the FWF LogiCS doctoral college and the follow-up ByzDEL project.

4.5 Applications for follow-up projects

- Rejected: Structural Properties of Random Graphs (SPRG, P30083)
- Approved: Doctoral college Logical Methods in Computer Science (2nd period LogiCS, W1255)[2]
- Approved: Reasoning about Knowledge in Byzantine Distributed Systems (ByzDEL, P33600, project leader: Dr. Roman Kuznets)[3]

[2] *https://logic-cs.at/phd/*

[3] *http://ti.tuwien.ac.at/ecs/research/projects/byzdell*

Appendix: Additional Information
List 1

1.a. scientific publications
with an indication of the status (published, in press, submitted, in preparation)

ADynNet followed the FWF open access rules, by providing draft versions of all publications as technical reports. Moreover, where available, we negotiated open access with the publishers.

1.a.1. Peer-reviewed publications (journals, contribution to anthologies, working papers, proceedings etc.)

All listed publications have already appeared, unless otherwise noted.

1. [NSW21a] Thomas Nowak, Ulrich Schmid, and Kyrill Winkler. Topological characterization of consensus with Arbitrary Process and Communication Faults, 2021. (submitted)

2. [NSW21b] Thomas Nowak, Ulrich Schmid, and Kyrill Winkler. Valency-based Consensus under Message Adversaries without Limit-Closure, 2021. (submitted)

3. [SSK21] Thomas Schlögl, Ulrich Schmid, and Roman Kuznets. The persistence of false memory: Brain in a vat despite perfect clocks. In Takahiro Uchiya, Quan Bai, and Ivan Marsa Maestre, editors, PRIMA 2020: Principles and Practice of Multi-Agent Systems, pages 403–411, Cham, 2021. Springer International Publishing. https://doi.org/10.1007/978-3-030-69322-0_30

4. [FNW20] Matthias Függer, Thomas Nowak, and Kyrill Winkler. On the radius of nonsplit graphs and information dissemination in dynamic networks. Discrete Applied Mathematics 282:257-264, 2020. https://doi.org/10.1016/j.dam.2020.02.013

5. [ZS20] Martin Zeiner and Ulrich Schmid. Upper and lower bounds for the synchronizer performance in systems with probabilistic message loss. Methodology and Computing in Applied Probability, 2020. https://doi.org/10.1007/s11009-020-09792-z

6. [GWSR19] Hugo Rincon Galeana, Kyrill Winkler, Ulrich Schmid, and Sergio Rajsbaum. A topological view of partitioning arguments: Reducing k-set agreement to consensus. In Stabilization, Safety, and Security of Distributed Systems - 21st International Symposium, SSS 2019, Pisa, Italy, October 22-25, 2019, Proceedings, volume 11914 of Lecture Notes in Computer Science, pages 307-322. Springer, 2019. https://doi.org/10.1007/978-3-030-34992-9_25

7. [KPSF19a] Roman Kuznets, Laurent Prosperi, Ulrich Schmid, and Krisztina Fruzsa. Causality and epistemic reasoning in byzantine multi-agent systems. In Proc. TARK 2019: Theoretical Aspects of Rationality and Knowledge, pages 293-312. Open Publishing Association, 2019. https://doi.org/10.4204/EPTCS.297.19

8. [KPSF19b] Roman Kuznets, Laurent Prosperi, Ulrich Schmid, and Krisztina Fruzsa. Epistemic reasoning with byzantine-faulty agents. In Proc. FroCoS 2019: Frontiers of Combining Systems, pages 259-276. Springer, 2019. https://doi.org/10.1007/978-3-030-29007-8_15

9. [Fru19] Krisztina Fruzsa. Hope for epistemic reasoning with faulty agents! In Proc., 31st European Summer School in Logic, Language and Information (ESSLLI'19) Student Session, Riga, Latvia, p. 169-180, 2019. http://esslli2019.folli.info/wp-content/uploads/2019/08/tentative_proceedings.pdf

10. [NSW19] Thomas Nowak, Ulrich Schmid, and Kyrill Winkler. Topological characterization of consensus under general message adversaries. In Proceedings of the 2019 ACM Symposium on Principles of Distributed Computing, PODC 2019, Toronto, ON, Canada, July 29 - August 2, 2019, pages 218-227, 2019. https://doi.org/10.1145/3293611.3331624

11. [TNL+19] Christos Tsigkanos, Laura Nenzi, Michele Loreti, Martin Garriga, Schahram Dustdar, and Carlo Ghezzi. Inferring analyzable models from trajectories of spatially-distributed internet-of-things. In 14th International Symposium on Software Engineering for Adaptive and Self-Managing Systems, SEAMS 2019, Montreal, Canada, May 25-26, 2019, 2019. https://doi.org/10.1109/SEAMS.2019.00021

12. [WS19] Kyrill Winkler and Ulrich Schmid. An overview of recent results for consensus in directed dynamic networks. Bulletin of the EATCS, 128, 2019. http://bulletin.eatcs.org/index.php/beatcs/article/view/581/585

13. [WSM19] Kyrill Winkler, Ulrich Schmid, and Yoram Moses. A characterization of consensus solvability for closed message adversaries. In 23rd International Conference on Principles of Distributed Systems, OPODIS 2019, December 17-19, 2019, Neuchatel, Switzerland, volume 153 of LIPIcs, pages 17:1-17:16. Schloss Dagstuhl - Leibniz-Zentrum für Informatik, 2019. https://doi.org/10.4230/LIPIcs.OPODIS.2019.17

14. [WSS19] Kyrill Winkler, Manfred Schwarz, and Ulrich Schmid. Consensus in directed dynamic networks with short-lived stability. Distributed Computing 32(5):443-458, 2019. https://doi.org/10.1007/s00446-019-00348-0

15. [ZSS19] Martin Zeiner, Manfred Schwarz, and Ulrich Schmid. On linear-time data dissemination in dynamic rooted trees. Discrete Applied Mathematics, 255:307-319, 2019. https://doi.org/10.1016/j.dam.2018.08.015

16. [FN19] Thomas Nowak and Joel Rybicki. Byzantine Approximate Agreement on Graphs. In Jukka Suomela, editor, Proceedings of the 33rd International Symposium on Distributed Computing (DISC'19), volume 146 of Leibniz International Proceedings in Informatics (LIPIcs), pages 29:1-29:17, Dagstuhl, Germany, 2019. Schloss Dagstuhl/Leibniz-Zentrum fuer Informatik. http://drops.dagstuhl.de/opus/volltexte/2019/11336

17. [BRS+18] Martin Biely, Peter Robinson, Ulrich Schmid, Manfred Schwarz, and Kyrill Winkler. Gracefully degrading consensus and k-set agreement in directed dynamic networks. Theoretical Computer Science, 726:41-77, 2018. https://doi.org/10.1016/j.tcs.2018.02.019

18. [PS18] Daniel Pfleger and Ulrich Schmid. On knowledge and communication complexity in distributed systems. In Structural Information and Communication Complexity - 25th International Colloquium, SIROCCO 2018, Ma'ale HaHamisha, Israel, June 18-21, 2018, Revised Selected Papers, pages 312-330, 2018. https://doi.org/10.1007/978-3-030-01325-7_27

19. [SSW18a] Ulrich Schmid, Manfred Schwarz, and Kyrill Winkler. On the strongest message adversary for consensus in directed dynamic networks. In Structural Information and Communication Complexity - 25th International Colloquium, SIROCCO 2018, Ma'ale HaHamisha, Israel, June 18-21, 2018, Revised Selected Papers, pages 102-120, 2018. https://doi.org/10.1007/978-3-030-01325-7_13

20. [FNS18] Matthias Függer, Thomas Nowak, and Manfred Schwarz. Tight Bounds for Asymptotic and Approximate Consensus. In Proceedings of the 2018 ACM Symposium on Principles of Distributed Computing, July 2018, p. 325–334. https://doi.org/10.1145/3212734.3212762

21. [FN18] Matthias Függer and Thomas Nowak. Fast Multidimensional Asymptotic and Approximate Consensus. In Ulrich Schmid and Josef Widder, editors, Proceedings of the 32nd International Symposium on Distributed Computing (DISC'18), volume 121 of Leibniz International Proceedings in Informatics (LIPIcs), pages 27:1-27:16, Dagstuhl, Germany, 2018. Schloss Dagstuhl/Leibniz-Zentrum fuer Informatik. http://drops.dagstuhl.de/opus/volltexte/2018/9816

22. [FNS17a] Matthias Függer, Thomas Nowak, and Manfred Schwarz. Brief Announcement: Lower Bounds for Asymptotic Consensus in Dynamic Networks. In Andrea W. Richa, editor, 31st International Symposium on Distributed Computing (DISC 2017), volume 91 of Leibniz International Proceedings in Informatics (LIPIcs), pages 51:1-51:3, Dagstuhl, Germany, 2017. Schloss Dagstuhl/Leibniz-Zentrum fuer Informatik. http://drops.dagstuhl.de/opus/volltexte/2017/7992

23. [CBFN16] Bernadette Charron-Bost, Matthias Függer, and Thomas Nowak. Fast, Robust, Quantizable Approximate Consensus. In Proceedings 43rd International Colloquium on Automata, Languages, and Programming (ICALP 2016), volume 55 of Leibniz International Proceedings in Informatics (LIPIcs), pages 137:1-137:14. Schloss Dagstuhl/Leibniz-Zentrum für Informatik, 2016. https://drops.dagstuhl.de/opus/volltexte/2016/6281/

24. [PS16] Daniel Pfleger and Ulrich Schmid. A framework for connectivity monitoring in wireless sensor networks. In Proceedings 10th International Conference on Sensor Technlogies and Applications (SENSORCOMM'16), pages 40-48. IARIA, 2016. https://www.thinkmind.org/download.php?articleid=sensorcomm_2016_3_10_10013

25. [SWS16] Manfred Schwarz, Kyrill Winkler, and Ulrich Schmid. Fast consensus under eventually stabilizing message adversaries. In Proceedings of the 17th International Conference on Distributed Computing and Networking, ICDCN '16, pages 7:1-7:10, New York, NY, USA, 2016. ACM. http://doi.acm.org/10.1145/2833312.2833323

1.a.2. Non peer-reviewed publications (journals, contribution to anthologies research reports, working papers, proceedings, etc.)

None.

1.a.3. Stand-alone publications (monographies, anthologies)

None.

1.b. publications for the general public and other publications

None.

List 2 project-related participation in international scientific conferences

2.1. Conference participations - invited lectures

[Sch16a] Ulrich Schmid. Easy impossibility proofs for k-set agreement. In Dmitry Feichtner-Kozlov and Damien Imbs, editors, Report Dagstuhl-Seminar 16282 Topological Methods in Distributed Computing, volume 6(7), page 39, Dagstuhl, Germany, 2016. Schloss Dagstuhl/Leibniz-Zentrum für Informatik.

2.2. Conference participations - lectures

Lectures for conference proceedings publications (numbering according to 1.a.1 above):

[3, 6, 7, 8, 9, 10, 11, 13, 16, 18, 19, 20, 21, 22, 23, 24, 25]

Additional presentations (without publication):

[ZSS17] Martin Zeiner, Ulrich Schmid, and Manfred Schwarz. On linear-time data dissemination in dynamic rooted trees. Presentation 19th MG Congress and Annual DMV Meeting, Salzburg, September 11-15, 2017 2017.

[ZSWS16] Martin Zeiner, Manfred Schwarz, Kyrill Winkler, and Ulrich Schmid. Broadcasting in random trees. Presentation at ALEA in Europe - Young Researchers Workshop, Vienna, Austria, September 6-9 2016.

2.3. Conference participations - posters

None.

2.4. Conference participations - other

None.

List 3 “Habilitations” (professorial qualifications) / PhD theses / diploma theses

3.1. Professorial Qualifications

None.

3.2. PhD Theses

[Win19] Kyrill Winkler. Characterization of Consensus Solvability under Message Adversaries. PhD thesis, TU Wien, Fakultät für Informatik, 2019. (Nominated for Dissertation award of the German GI and the Heinz Zemanek dissertation award of the Austrian OCG)

[Sch18] Manfred Schwarz. Agreement Algorithms in Directed Dynamic Networks. PhD thesis, TU Wien, Fakultät für Informatik, June 2018.

3.3. Diploma/Master Theses

[Sch20] Thomas Schlögl. An Extension Framework for Epistemic Reasoning in Byzantine Distributed Systems. Master's thesis, TU Wien, Institut für Computer Engineering E191-02, January 2020. (Distinguished Young Alumnus Award @ Faculty of Informatics EPILOG, June 2020)

[Fim18] Patrik Fimml. Temporal-epistemic logic in byzantine message-passing contexts. Master's thesis, TU Wien, Institut für Computer Engineering E191-02, January 2018.

[Pfl18] Daniel Pfleger. Knowledge and communication complexity. Master's thesis, TU Wien, Institut für Computer Engineering E191-02, April 2018. (Nomination for Distinguished Young Alumnus Award @ Faculty of Informatics EPILOG, June 2018)

List 4 Information on project participants

not funded by the FWF			**funded by the FWF (project)**		
co-workers	**number**	**Person-months**	**co-workers**	**number**	**Person - months**
non-scientific co-workers			non-scientific co-workers		
diploma students	2	10	diploma students	5	24
PhD students	2	27	PhD students	5	65,5
post-doctoral co-workers	4	29	post-doctoral co-workers	3	24
co-workers with “Habilitation”			co-workers with “Habilitation”		

(professorial qualifications)			(professorial qualifications)		
professors	1	15	professors		

List 3 Development of collaborations

Indication of the most important collaborations (maximum 5), that took place (initiated or continued) in collaboration please give the name of the collaboration partner (name, title, institution) and a few words about the scientific content. Please also assign one of the following **categories** to each collaboration:

N			Nature	**N**	(national);
				E	(European);
				I	(other international cooperation)
	E		Extent	**E1**	**low** (e.g. no joint publications but mention in acknowledgements or similar);
				E2	**medium** (collaboration e.g. with occasional joint publications, exchange of materials or similar but no longer-term exchange of personnel);
				E3	**high** (extensive collaboration with mutual hosting of group members for research stays, regular joint publications etc.)
		D	Discipline	**D**	within the discipline
				T	transdisciplinary

N	**E**	**D**	**Collaboration partner / content of the collaboration**
I	E2	T	1) Name: Yoram Moses Title: Prof. Institution: Technion Content: Knowledge-based analysis of distributed algorithms
E	E2	D	2) Name: Bernadette Charron-Bost Title: Dr. Institution: Ecole Polytechnique Paris Content: Asymptotic and approximate agreement
E	E3	D	3) Name: Matthias Függer Title: Dr. Institution: ENS Paris-Saclay (ex Cachan) Content: Approximate agreement
E	E3	D	4) Name: Thomas Nowak Title: Ass. Prof. Institution: Universitè Paris-Saclay Content: Topology in distributed computing
I	E3	D	5) Name: Sergio Rajsbaum Title: Prof. Institution: UNAM (Mexico) Content: Algebraic topology

Note: general scientific contacts and occasional meetings should not be considered as collaborations in the above sense.

Zusammenarbeit mit dem FWF

Sie werden gebeten folgende Aspekte der Zusammenarbeit mit dem FWF zu bewerten. **Anmerkungen (Ausführungen)** unter Verweis auf den entsprechenden Referenzpunkt bitte auf Beiblatt.

Skala
-2 sehr unzufriedenstellend,
-1 unzufriedenstellend;
0 angemessen;
+1 zufriedenstellend;
+2 sehr zufriedenstellend.
X nicht beansprucht

Regelwerk
(Richtlinien für Programm, Antrag, Verwendung, Bericht)

		Wertung
Antragsrichtlinien	Umfang	**+2**
	Übersichtlichkeit	**+2**
	Verständlichkeit	**+2**

Verfahren (Einreichung, Begutachtung, Entscheidung)

	Beratung	**X**
	Dauer des Verfahrens	**0**
	Transparenz	**+1**

Projektbegleitung

Beratung	Verfügbarkeit	**+2**
	Ausführlichkeit	**+1**
	Verständlichkeit	**+2**

Durchführung Finanzverkehr (Überweisungen, Gerätebeschaffungen, Personalwesen)	**+2**

Berichtswesen/ Prüfung/ Verwertung

	Aufwand	**+1**
	Transparenz	**+2**
	Unterstützung bei Öffentlichkeitsarbeit/ Verwertung	**X**

Anmerkungen zur Zusammenarbeit mit dem FWF:

Zusammenarbeit funktioniert seit vielen Jahren ausgezeichnet.

Summary for public relations work

English:

ADynNet (Gracefully Degrading Agreement in Directed Dynamic Networks) has been devoted to the development of the theoretical foundations, models, algorithms and analysis techniques for distributed agreement in directed dynamic networks. Such networks are characterized by sets of participants that are a priori unknown and potentially time-varying, a rapidly changing uni-directional connectivity between participants, and the absence of any central control. Instantiated, e.g., by wireless sensor networks and ad-hoc networks, such dynamic networks are ubiquitous in many applications nowadays. A natural approach to build robust services in such networks would be to use distributed consensus to agree system-wide on fundamental parameters like schedules, operating frequencies, operating modes etc. In larger-scale dynamic networks, however, this has been considered infeasible, as solving consensus was believed to require a well-connected and temporarily stable network topology.

In ADynNet, we showed that this is not necessarily the case: We thoroughly studied consensus solvability in directed dynamic networks controlled by message adversaries, and developed solution algorithms for surprisingly strong message adversaries. Some highlights of our accomplishments are:

(i) We developed a precise characterization of the solvability/impossibility border for consensus in such dynamic networks. Surprisingly, point-set topology turned out to be the method of choice for this purpose.

(ii) We developed consensus algorithms for several stabilizing message adversaries, including optimal ones that require very short durations of stability. Moreover, we also provided relaxed agreement algorithms such as gracefully degrading k-set agreement and approximate agreement for message adversaries that do not allow consensus.

Apart from its primary research results, the work in ADynNet also revealed the utility of knowledge-based analysis and epistemic logic for studying the problems at hand, which stimulated a transdisciplinary follow-up FWF project ByzDEL (Reasoning about Knowledge in Byzantine Distributed Systems, P33600).

German:

Das Projekt ADynNet (Gracefully Degrading Agreement in Directed Dynamic Networks) war der Entwicklung von theoretischen Grundlagen, Modellen, Algorithmen und Analysetechniken für verteiltes Agreement in gerichteten dynamischen Netzwerken gewidmet. Derartige Netzwerke zeichnen sich durch eine a priori unbekannte und potentiell

zeitvariante Anzahl von Teilnehmern, eine stark schwankende, richtungsabhängige Konnektivität zwischen den Teilnehmern, und das Fehlen einer zentralen Kontrollinstanz aus. In Form von drahtlosen Sensornetzwerken und ad-hoc Netzwerken sind derartige dynamische Netzwerke immer häufiger in praktischen Anwendungen anzutreffen. Ein natürlicher Ansatz zur Realisierung robuster Services in solchen Systemen ist die Verwendung von Consensus-Algorithmen für die Festlegung kritischer Systemparameter wie Zeitplänen, Ausführungsfrequenzen und Betriebsarten. In größeren dynamischen Netzwerken wurde dies jedoch als praktisch unmöglich angesehen, da man davon ausging, daß Consensus eine gut verbundene und zeitlich stabile Netzwerktopologie erfordert.

Das Projekt ADynNet hat gezeigt, daß dies nicht notwendigerweise der Fall ist: Unsere Untersuchungen haben neue Einsichten in die fundamentalen Beschränkungen sowie neue Algorithmen für verteiltes Agreement in unidirektionalen dynamischen Netzwerken geliefert, die von starken Message Adversaries kontrolliert werden. Einige zentrale Ergebnisse sind:

(i) Eine präzise Charakterisierung der Grenze zwischen Unmöglichkeit und Lösbarkeit für Consensus in solchen dynamischen Netzwerken. Überraschenderweise hat sich Punktmengentopologie als die hierfür geeignete mathematische Disziplin erwiesen.

(ii) Mehrere neue Consensus-Algorithmen für stabilisierende Message Adversaries, inklusive optimaler Lösungen für sehr kurze Phasen der Stabilität, sowie schwächere Agreement-Algorithmen wie etwa degradierendes k-Set Agreement und Approximate Agreement für Message Adversaries, die keine Lösung von Consensus erlauben.

Zusätzlich zu diesen primären Forschungsergebnissen hat die Projektarbeit in ADynNet auch die Nützlichkeit einer wissensbasierten Analyse und epistemischer Logik für die relevanten Probleme zutage gefördert, die schlußendlich ein transdisziplinäres FWF-Folgeprojekt ByzDEL (Reasoning about Knowledge in Byzantine Distributed Systems, P33600) stimuliert haben.