



Evaluation of Mathematics, ICT and Technology (EVALMIT) 2023-2024

Self-assessment for research groups

Date of dispatch: 19 September 2023

Deadline for submission: 31 January 2024

Institution (name and short name): University of Oslo (UiO)

Administrative unit (name and short name): Department of Informatics (IFI)

Research group (name and short name): Networks and Distributed Systems (ND)

Date: 31.1.2024

Contact person: Tor Skeie

Contact details (email): tskeie@ifi.uio.no

Content

Introduction	3
1. Strategy and organisation	5
1.1 Research group's organisation.....	5
1.2 Research group's strategy.....	6
1.3 Relevance to the institutions	8
1.4 Research group's resources	9
1.5 Research group's infrastructures.....	10
1.6 Research group's cooperations	11
2. Research quality	12
2.1 Research group's scientific quality.....	12
2.2 Research group's societal contribution	23
3. Challenges and opportunities	25

1. Organisation and strategy

1.1 Research group's organisation

With a staff of more than 400, The UiO Department of Informatics (IFI) is a “powerhouse” for informatics training and research in Northern Europe. It is the largest such unit in Norway and the one with the strongest international rankings. Around a comprehensive core in computer science, IFI interprets informatics in substantial breadth: from microelectronics or signal processing, to participatory design or digital innovation. In 2023, IFI hosts five BSc and eight MSc study programmes, with close to 2500 students. The department is organized in four thematic sections, each of which comprising 2–5 research groups. Our group, Networks and Distributed systems (ND), is part of the section for Digital Infrastructure and Security (DIS).

ND was established in 1998 as it is running now. The group carries out cross-disciplinary research that encompasses activities in energy informatics (ranging from energy management through network architecture – the Green Internet– to protocols), blockchain technologies, multimodal systems, edge/cloud computing/IoT systems, High Performance Computing, digitalization for sustainability (i.e., intelligent environmental data processing models), and most of the layers of distributed systems and networking spanning all the way to quantifying the human experience. Research on digital security was spun out from ND in 2019, forming a separate research group that is also evaluated separately. The research interests in ND are very diverse, with individual members being most strongly invested in one interest. In spite of this, research collaborations are dynamically formed from mutual interests, and a subdivision of the group would be disruptive.

The broadness of scope is conducted by organizing ND into dynamically formed subgroups, usually represented by one or two professors. Typically, the research agenda of the various subgroups is organized into projects, each one led by a project manager (a professor or a postdoc). On top there is a group leader being responsible for the entire group both research-wise and taking care of the personnel policy and administration of the group. In that respect, the organization of ND is a combination of centralized and distributed leadership.

By the end of 2022 the group consisted of 5 professors, 4 associate professors (three of them have become full professors in 2023), 6 postdocs, one researcher, 12 PhD candidates, 1 adjunct professor, 3 adjunct associate professors, and 2 emeritus professors. An important role of the professors is to do training of the postdocs and PhD candidates. Occasionally and with approval from the Faculty, a postdoc might be the main supervisor of a PhD candidate.

Many research projects are externally funded, i.e. the PhD candidates and postdocs contributing to those projects receive their salaries from them. This is external funding from the Research Council of Norway, EU funding, as well as from companies (collaborators).

Table 1. List of number of personnel by categories

	Position by category	No. of researcher per category	Share of women per category (%)	No. of researchers who are part of multiple (other) research groups at the admin unit	No. of temporary positions
No. of Personnel	Professor (1013)	5		5	

by position	Associate professor (1011)	4	50		
	Researcher (1108)				
	Researcher (1109)	1			1
	Postdoctoral Fellow (1352)	6			6
	Doctoral Research Fellow (1017)	12	33.3		12
	Adjunct Professor (1013)	1		1	1
	Adjunct Associate Professor (1011)	3			3
	Adjunct Senior Lecturer (1198)	1			1

1.2 Research group's strategy

a) Describe the research group's main goals, objectives and strategies to obtain these (e.g. funding, plans for recruitment, internationalisation etc. within the period 2012-2022.

The strategy that ND adopted in 2012 was to establish itself as a prominent research group by proposing and delivering fundamental techniques within general networking and distributed systems. The main problem areas were scalability, resilience, self-adaptation, dependability, and data dissemination, including their applications to design digital services, with the objective of enhancing user experience and quality of services. In particular, the goal was to contribute to fundamental and applied research on Internet, High-performance computing, Edge/cloud computing, Internet of Things (IoT), and multi-multimodal systems. Along with this strategy, ND had the ambition to position itself as an attractive collaborator for prominent companies and standardization bodies, like Oracle, Mellanox Technologies, Nvidia, Apple, IETF, and ITU-T.

By taking on this strategy, ND was able to scale up the activities by attracting many more externally funded projects. We also had a clear goal of getting an SFI (center for research-based innovation) together with other research groups and a number of our industrial partners.

Around 2018, ND refined its strategy in order to be even more in line with the biggest challenges our society is facing, with the goal to turn our attention more on sustainability and digitalisation, by means of focusing on energy informatics, blockchain technology for network security and privacy, circular economy, and green Internet. The revised strategic focus was supported by employing two new associate professors focussing on Energy Informatics and Security, respectively. Finally, the Digital Security group was spun off from ND.

b) Please describe the benchmark of the research group. The benchmark for the research group should be written by the administrative unit in collaboration with the research group. The benchmark can be a reference to an academic level of performance (national or international) or to the group's contributions to other institutional or sectoral purposes.

As for IFIs strategy 2014-2017, one priority area was «Energy and Environment», herein production of oil & gas, analysis of large heterogeneous data volumes, research around sensor networks and aimed at Internet, smart grids, and further develop this research in collaboration with important business stakeholders. The ND has in particular contributed to this priority area, as we have been instrumental in getting the SIRIUS SFI, which is about enabling digitalization in and beyond the oil and gas industry, where we have done this together with key industrial players spanning from computer to oil & gas companies. Furthermore, we have been active and successful in carrying out research on cloud/edge computing, smart grids, and IoT.

When it comes to IFIs revised strategy for 2019-2021, ND followed the department's recommendation to focus more on digitalization and sustainability, by means kicking-off attention on energy informatics, blockchain, circular economy, and green Internet, as elaborated on in the previous section. Moreover, ND took a leading role in establishing UiO:Energy, which has been a fruitful “investment” both for the University and IFI.

c) Describe the research group contribution to education (master's degree and/or PhD).

ND takes a leading role in the Programming and System Architecture (PROSA) program, both at the bachelor and master level. ND led the PROSA program until professor Stein Gjessing retired. At the bachelor level, ND is considered the owner of the courses IN1020 “Introduction to Computer Technology” and IN2140 “Introduction to Operating Systems and Networks” (both with >300 students admitted per year). Additional bachelor courses are IN3230 – Nettverk and IN3260 – Prosjektoppgave i informatikk: datakommunikasjon. Teaching at the bachelor level is time-intensive but is an effective channel for the recruitment of master students to ND's research topics.

At the master level, ND takes the leading role in the PROSA specialization “Distribuerte systemer og nettverk”, where 4 out of 5 course in the category “strongly recommended” are owned by ND, including IN4230 (Networks), IN5020 (Distributed Systems), IN5030 (Protocols and routing in the Internet), and IN5060 (Quantitative performance analysis). Further recommended courses in the program are IN5150 (Recent advancements in Internet protocols), IN5050 (Programming heterogeneous multi-core architectures) and IN5410 (Energy informatics).

In the reporting period, 43 PhD students defended their thesis successfully under supervision from ND personnel. Approximately 30 master students have completed their master thesis successfully under supervision from ND members every year.

d) Describe the support the host institution provides to the research group (i.e., research infrastructure, access to databases, administrative support etc.).

The group has a room at its disposal, generally called the NDLab. This room hosts the various funded lab facilities. The group has been granted support for establishing and maintaining experimental facilities, which are physically hosted in the common NDLab.

NDLab hosted the CPSLab comprising the equipment and facilities for Cyber-physical systems research, supported by the ConSerns “endringsmiljø” project. NDLab hosts the ARLab, which is funded from an internal small equipment grant, funding equipment for VR, AR and XR research. This was merged into

SINLab, also an internal small equipment grant, funding robotic equipment to expand XR research to additional modalities.

1.3 Relevance to the institutions

The ND group has contributed severely to IFIs strategies and objectives during the evaluation period. As for IFIs strategy 2014-2017, ND has been instrumental in getting the SIRIUS SFI, which is about enabling digitalization in and beyond the oil and gas industry, where we have done this together with key industrial players spanning from computer to oil & gas companies. This was the first SFI awarded to the MATNAT faculty, which has been of top priority for years. Furthermore, our research on cloud/edge computing, smart grids, IoT has very much been in line with the department's strategy, where we have been highly successful both in getting external funding and publishing papers that are among the most cited papers both at IFI and UiO. For instance, one paper published in 2018 has got more than 2200 citations at the time of writing.

From 2018 to 2022, ND has taken a leading role at the department by turning our attention on digitalization and sustainability, by means of focusing on energy informatics, blockchain, and green Internet, in line with IFI's strategy. We have contributed to the objectives of conducting fundamental and applied research on these topics, and to position IFI as an attractive collaborator for prominent companies and standardization bodies, like Equinor, Oracle, Mellanox Technologies, Nvidia, Apple, Nokia, IETF, and IT-U. Furthermore, ND has contributed to IFI's objective in getting a substantial amount of external funded projects (income) within these strategic research areas. Another proof of success here, several of the more recent published papers within energy informatics have already got a high number of citations.

1.4 Research group's resources

The funding portfolio of ND is made up of several funding sources as follows: First, it consists of 12 external funded projects for the years 2018-2022, where those mainly are funded by the Research Council of Norway and EU – most of these projects are listed in Table 4 along with their budget numbers. In addition, we have received funding from the industry sector (the SIRIUS SFI), plus we have been granted government funded positions, called "KD" positions, where those are admitted by IFI. On top of this, we receive basic funding from IFI. All those budget numbers are included in Table 2 and Table 4. We would also like to mention that we recently have been granted three more projects that will run from 2023 until 2027, where the total budget is 212 MNOK.

Table 2. Describe the sources of R&D funding for the research group in the period 2018-2022.

	2018 (kNOK)	2019(kNOK)	2020 (kNOK)	2021(kNOK)	2022(kNOK)
Basic funding	9 375	10 210	10 415	10 198	10 383
Funding from industry and other private sector sources	200	200	200	200	200
Commissioned research for public sector					
Research Council of Norway	4 600	7 300	8 000	9 200	8 600
Grant funding from other national sources					

International funding e.g. NIH, NSF, EU framework programmes	1 500				
Other					

1.5 Research group's infrastructures

a) Describe which national infrastructures the research group manages or co-manages.

ND is host of the **Blockchain lab**, which serves as a centre of competence for the technical design and development of new blockchain applications. It is a collaboration of academia and industry heading by and located at UiO. It improves blockchain education, facilitates and catalyzes blockchain-related research at UiO, fosters new initiatives and promotes innovation and collaboration between academia and industry. It comprises facilities, hardware and software, and gives access to experts and an existing knowledge base. ND manages the Norwegian node of EBSI, the European Blockchain Services Infrastructure. The node is hosted by UiO.

More about EBSI: <https://ec.europa.eu/digital-building-blocks/sites/display/EBSI/Home>

b) Describe the most important research infrastructures used by the group.

The classical infrastructure that is essential to applied research in the ND group is the **Internet**. Group members have actively contributed to the development of protocols standardized at the IETF, with Michael Welzl taking formal roles (e.g. IRTF research group chair for 11 years) on several occasions. Unrestricted access to the Internet and a free connection to the European research backbone **Géant** is essential for a lot of research activities. The requirements of conducting world-leading Internet research are frequently colliding with the lack of separation from the institutional use of the Internet as a critical infrastructure for the entire university's office work.

We rely on data collections comprising Network measurement data. Several of these collections were created by ND group members, in particular traces of static and mobile network end systems in 3G, 4G and 5G networks. ND group members continue their involvement in extending these data collections.

The ND group also makes use of the national-wide infrastructure, eX3, related to our HPC activities, in particular the SIRIUS SFI. The goal of eX3 is to provide an experimental, heterogeneous computational cluster as a national infrastructure that will help Norwegian HPC researchers, HPC/Big Data users, data center management, and HPC industry prepare for the coming exascale era of computing. Further information can be found here: <https://www.ex3.simula.no/>

1.6 Research group's cooperations

Table 3. Reflect on the current interactions of the research group with other disciplines, non-academic stakeholders and the potential importance of these for the research (e.g. informing research questions, access to competence, data and infrastructure, broadening the perspectives, short/long-term relations).

Interdisciplinary (within and beyond the group)	As stated earlier (sec. 1.1), ND is teamed up as an interdisciplinary research group carrying out research in energy informatics including green Internet, blockchain technologies, multimodal systems, edge/cloud computing/IoT systems, High Performance Computing, and most of the layers of distributed systems and networking spanning all the way to quantifying the human experience. This is an important asset of our group enabling us to
--	---

	address the “bigger” societal challenges. We also have tight interactions with other research groups at IFI, such as the SEC (digital security), PSY (Reliable systems), ASR (Analytical solutions and reasoning), LTG (Language Technology Group), ROBIN (robotics and intelligent systems).
Collaboration with other research sectors e.g. higher education, research institutes, health trusts and industry.	Beyond collaborating with a high number of universities in our problem domain, we do also collaborate with other research sectors, in particular the institute sector in Norway and abroad (Fraunhofer, Eurecom) Furthermore, we collaborate with a substantial number of industrial partners, which is an important asset of our group: Activeeon, ADLink, Aker BP, Alpha Venturi, Altibox, AtomIQ, Bosch, DNV GL, Dolphin, Domos, Equinor, Eye Networks, Forkbeards AS, Fraunhofer, Green Mountain Data Center, Hafslund, InAccess, IOTA, Lefdal Mine Datacenter, Lyse Energi, Multinett, NCE Smart, NordPool, Numascale, NVE, Nvidia, OBOS, Oracle, PROSA Security, 7bulls, Softeam, Sonitor AS, Spotify, Statnett, Technicolor, Telefonica, and Telenor. We will also mention that ND has had a tight interaction with Simula Research Laboratory (since it was established back in 2002). The complete group had leave-of-absence from IFI to be at Simula at some time (~2004), and there has also been a strong recruitment of personnel from Simula, for instance to female researchers that today are professors.
<u>Transdisciplinary</u> (including non-academic stakeholders)	ND’s research aims to improve the performance of networked and distributed systems, which is frequently expressed by quantifying human experience of the systems. The pursuit has led to frequent collaboration with experts on human perception and perceptual psychology as well as several creative industries (including film and opera, since 2008). As the performance focus gives way to green computing, the scope of ND’s collaboration with psychology research was vastly expanded to explore the perception of transactive energy systems (since 2022). The research on energy informatics has led to close collaboration with energy systems companies and researchers (since 2018), but due to the status of the Norwegian energy regulation also with legal experts (since 2022). Blockchains replace trusted third parties in many processes with peer-to-peer audit-safe systems. This has led to several collaborations, including a medical registry, energy providers, and financial actors including the Norwegian national bank (since 2018).

2. Research quality

2.1 Research group's scientific quality

The research profile of ND is mainly within the following (cross-disciplinary) areas: 1) Networking, where we focus on enabling technologies (5G/6G, IoT, Tactile), performance capabilities (AV, AR/VR/XR), scaling of enabling HPC technologies (SoC, PCIe, InfiniBand, Ethernet), and network architectures (Internet, RINA) including green Internet. 2) Distributed systems, where we focus on cloud/edge computing, IoT, middleware, adaptivity, blockchain technology for network security and privacy. 3) Energy informatics, where we focus on smart grids, energy trading with machine learning and blockchain as enabling technologies, E2X/EV charging to support E-mobility. 4) Media technology, where we focus on the performance of systems on all levels up to human perception.

We will point to three metrics that prove the scientific quality of ND: Firstly, the group's research on Edge- and mobile computing and energy informatics has resulted in several highly cited papers, which are among the most cited papers at UiO in recent years. One paper published in 2018 has at time of writing more than 2200 citations, and two other papers published in 2013 and 2020 have received more than 800 citations - more information about these papers are included in Table 5. Additionally, a large number of papers have been published in highly ranked proceedings and journals, as also itemised in Table 5, as well can be found in our complete publication list <https://www.mn.uio.no/ifi/english/research/groups/nd/publications.html>. Of the 10 most cited papers in the NIFU report (8. January 2024, Table 1.3) supporting this evaluation, 8 papers originated in ND. Two of ND's members can be found on Clarivate's list of Highly Cited Researchers (since 2018 and 2022, respectively).

Secondly, the group can point to one prominent research activity that has shown impact on the outer world beyond academia, as one of IFI's five selected impact cases submitted to EVALMIT:

Transport Services (TAPS) is an IETF Working Group that seeks to replace the "Berkeley socket" API with a new standard. This standard should have an impact on the development of the Internet protocol stack altogether, as it offers much greater flexibility for the usage of Internet protocols and network interfaces. Apple has been implementing TAPS principles in their "Network.Framework" API, which they offer to all developers since the beta of iOS 12 and macOS Mojave, since 2018. As their implementation gradually takes more of the TAPS elements onboard, the flexibility of their implementation has been increasing. Rumours talk of at least one more large implementation being under development. The TAPS Working Group was created upon the initiative of Michael Welzl, who is a professor in the ND research group and one of the main contributors to this new standard.

As to have impact beyond academia, we can also mention that our research contribution on advancing the understanding of the subsurface, an activity within the SIRIUS SFI, has contributed both a new modelling methodology that quantifies heterogeneity and contention of MPI-based reservoir simulations and implementation of this concept in the OPM (Open Porous Media) open-source framework. This solution space has put Equinor in a position to achieve more efficient and faster reservoir simulations, which altogether will have a tremendous impact on their reservoir "business". This work has been done together with Simula Research Laboratory (main contributor), the SCML research group at IFI, and Equinor.

Thirdly, a final proof of ND's scientific quality is that we have been awarded a high number of external funded projects, from the Research Council of Norway, EU, as well as cash contributions from our industry partners, both nationally and internationally. These projects are listed in Table 4.

Please add a link to the research group's publication list at the research group's website

<https://www.mn.uio.no/ifi/english/research/groups/nd/publications.html>

Table 4. List of projects

Instructions: Please select 5-10 projects you consider to be representative/the best of the work in the period 1 January 2012 – 31 December 2022. The list may include projects lead by other institutions nationally or internationally. Please delete tables that are not used.

Project 1 <i>RCN StorIKT Verdione - Virtually Enhanced Real-life synchronizeD Interaction - ON the Edge (2008 - 2013)</i>	Owner	IFI/UiO
	Total budget and share allocated to research group	Total: 24 Mill. NOK Allocated share in review period: 2.5 Mill. NOK
	Objectives and outcomes (planned or actual) and link to website	Verdione targeted cooperative applications that merge virtual elements into the real world (XR). Verdione aimed at providing musicians, actors, singers and spectators in the context of a distributed opera stage to have meaningful, but not identical experiences. Besides working on the end-system performance, Verdione worked on the resources challenges with the objectives to create quantifiable resilience in networks and to improve content adaptivity, as well as the challenges also from the artistic perspective. https://prosjektbanken.forskningsradet.no/project/FORISS/187828
Project 2 <i>RCN Tidal News - a Middleware Platform for Adaptive and Dependable Data Dissemination in the Internet of Systems (2010-2014)</i>	Owner	IFI/UiO
	Total budget and share allocated to research group	Total: 12 Mill. NOK Allocated share: 12 Mill. NOK
	Objectives and outcomes (planned or actual) and link to website	The project focuses on properties of and mechanisms for large-scale data dissemination in the Internet including both cluster-based and infrastructure-less P2P systems. Applications of interest range from devising new technologies for online social networks to improving the protocols that power up large-scale clusters of companies like Google and Amazon.com. We emphasize non-functional properties of dissemination (including privacy, dependability, and adaptivity) while also considering dissemination semantics (such as a notification system and publish/subscribe for textual documents). https://www.mn.uio.no/ifi/english/research/projects/tidal/index.html
Project 3: <i>EU FP7 RITE - Reducing Internet Transport Latency (2012-2015)</i>	Owner	Simula Research Laboratory
	Total budget and share allocated to research group	total budget: € 4 974 399 total EU contribution: € 3 569 000 EU contribution to UiO: € 522 292

	Objectives and outcomes (planned or actual) and link to website	RITE locates and explores the root causes of Internet latency, specifies and implements new methods to significantly reduce - or even eliminate - the effects of latency when coupled with small, but significant, changes in end-system behaviour. Results were taken to the standardisation body IETFm and end-system solutions were implemented in open-source operating systems. RITE contributes to the evolution of the Internet and supports the next generation of applications that benefit from high interactivity. https://cordis.europa.eu/project/id/317700
Project 4: <i>SIRIUS SFI - Enabling digitalization in and beyond the oil and gas industry (2015-2023)</i>	Owner	IFI/UiO
	Total budget and share allocated to research group	Total: 373 Mill. NOK Allocated share IFI: 183 Mill. NOK Allocated share ND: 20 Mill. NOK Funding came from RCN and a number of industrial partners
	Objectives and outcomes (planned or actual) and link to website	To accelerate the development and adoption of innovative data access technology in the oil & gas industry via broad-based collaboration with a short feedback loop across the whole value chain. https://sirius-labs.no/
Project 5: <i>EU H2020 NEAT - A New, Evolutive API and Transport-Layer Architecture for the Internet (2015 – 2018)</i>	Owner	Simula Research Laboratory
	Total budget and share allocated to research group	Total: € 4 215 751 Allocated share ND: € 513 296
	Objectives and outcomes (planned or actual) and link to website	NEAT addresses two obstacles to Internet innovation: 1) It lowers the barrier to service innovation by developing a free open-source transport system that will allow SMEs to leverage the rich set of available transport protocols. 2) It paves the way for an architectural change of the Internet where new transport layer services can seamlessly be integrated and quickly made available, minimising deployment difficulties, and allowing Internet innovators to take advantage of them wherever possible. https://cordis.europa.eu/project/id/644334
Project 6:	Owner	Department of informatics, UiO

<i>RCN FRINATEK OCARINA - Optimizations to Compel Adoption of RINA (2016 – 2021)</i>	Total budget and share allocated to research group	Total: 16.6 Mill. NOK Allocated share ND: 16.6 Mill. NOK
	Objectives and outcomes (planned or actual) and link to website	OCARINA developed an entirely new way to do congestion control and load balancing, within the recursive structure of the RINA network architecture; the project has also worked on gradual deployment of RINA in the Internet. This has led to several top-tier publications, some during and some after the project. https://www.mn.uio.no/ifi/english/research/projects/ocarina/index.html
Project 7: SmartNEM - Smart Community Neighborhood - driven by energy informatics (2017-2022)	Owner	IFI/UiO
	Total budget and share allocated to research group	Total: 25 Mill. NOK Allocated share to ND: 10.3 Mill. NOK Funding from RCN Industrial partners: Statnett and Lyse Energy
	Objectives and outcomes (planned or actual) and link to website	Investigate an ICT driven decentralised grid infrastructure supported by prosumers. It would allow DSOs (Distribution System Operator) and TSOs (Transmission System Operator) to achieve community level grid reliability, peak shaving and secure supply. https://www.mn.uio.no/ifi/english/research/projects/smartnem/index.html
Project 8: <i>RCN SmartMed - Secure and accountable sharing of medical records using smart contracts and blockchain (2019-2023)</i>	Owner	IFI/UiO
	Total budget and share allocated to research group	Total: 20 Mill. NOK Allocated share to ND: 12 Mill. NOK
	Objectives and outcomes (planned or actual) and link to website	Facilitate solutions to the challenges in security and privacy that healthcare registries are facing today https://www.smartmed.no
Project 9:	Owner	Department of Informatics, UiO
	Total budget and share allocated to research group	Total budget: 13.13 Mill. NOK Allocated share ND: 7.19 MNOK

RCN AirQMan - Low Latency Air Quality Management (2021-2025)	Objectives and outcomes (planned or actual) and link to website	AirQMan is to develop intelligent computing methods, tools and techniques for the autonomous management of low-latency data fusion and analysis in Air Quality Management Systems. https://www.mn.uio.no/ifi/english/research/projects/airqman/
Project 10: <i>PriTEM (Privacy-preserving Transactive Energy Management)- UiO Energy Convergence Environment (2022-2026)</i>	Owner	IFI/UiO
	Total budget and share allocated to research group	ca. 23 Mill. NOK (5 PhD (KD stillinger) + 1 Postdoc (5 MNOK) from UiO-Energy)
	Objectives and outcomes (planned or actual) and link to website	PriTEM will develop new knowledge at the intersection of Energy technology, Energy Informatics, Psychology, and Data and Energy Law through collaboration and highly cross-disciplinary research synergy for privacy preserving and secure data sharing based transactive energy management. https://www.mn.uio.no/ifi/english/research/projects/pritem/index.html

Table 5. Research group's contribution to publications

Publication 1: <i>OCARINA</i> <i>LGCC: A Novel High-Throughput and Low Delay Paradigm Shift in Multi-Hop Congestion Control/ IEEE/ACM ToN / 2023 / 10.1109/TNET.2023.3301291</i> https://ieeexplore.ieee.org/document/10216921	Authors	Peyman Teymoori (group member at the time of writing), Michael Welzl (group member), David Hayes (prior group member)
	Short description	This paper introduces LGCC (Logistic Growth Chain Control), a stable congestion control with operation inside the network, for the sake of fluctuating-capacity links (mmWave etc.).
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Writing
Publication 2: <i>OCARINA</i>	Authors	Peyman Teymoori (group member at the time of writing), David Hayes (group member at the time of writing), Michael Welzl (group member), Stein Gjessing (group member at the time of writing)

<i>Estimating an Additive Path Cost With Explicit Congestion Notification / IEEE Transactions on Control of Network Systems / 2021/10.1109/TCNS.2021.3053179</i> https://ieeexplore.ieee.org/document/9329063	Short description	This paper establishes the theory to make the ECN signal additive, which is a ground-breaking result because it enables the use of ECN marking to truly convey how “full” a link is, e.g. using a shadow queue. There are similarities to the way DCTCP or L4S use ECN, but this is much more powerful.
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Software, Writing
Publication 3: <i>RITE Online Identification of Groups of Flows Sharing a Network Bottleneck / IEEE/ACM ToN / 2020 / 10.1109/TNET.2020.3007346 /</i> https://ieeexplore.ieee.org/document/9161279?source=authoralert	Authors	David Hayes (group member at the time of writing), Michael Welzl (group member), Simone Ferlin (prior group member), David Ros, Safiqul Islam (group member at the time of writing)
	Short description	This paper introduces an approach to identify shared bottlenecks in the Internet. Such knowledge can, for instance, be used by congestion control mechanisms.
	Research group's contribution	Conceptualization, Formal Analysis, Methodology, Investigation, Resources, Software, Writing
Publication 4: <i>SmartMed A Survey on Blockchain for Healthcare: Challenges, Benefits, and Future Directions / IEEE Communication Surveys and Tutorials / 2022 / 10.1109/COMST.2022.3224644/</i> https://ieeexplore.ieee.org/document/9963549	Authors	Mohammad Salar Arbabi , Chhagan Lal, Narasimha Raghavan Veeraragavan , Dusica Marijan, Jan F. Nygård, and Roman Vitenberg
	Short description	In this paper is a comprehensive survey of the state-of-the-art efforts that envision the use of blockchain-based solutions in the healthcare domain. A systematic framework for classifying and analyzing such systems is introduced, and 40 systems and solutions are analyzed.
	Research group's contribution	Conceptualization, Funding acquisition, Methodology, Investigation, Resources, Supervision, Writing
Publication 5:	Authors	Mohammad Hossein Tabatabaei, Roman Vitenberg, Narasimha Raghavan Veeraragavan

SmartMed <i>Understanding blockchain: Definitions, architecture, design, and system comparison / Computer Science Reviews / 2023 / 10.1016/j.cosrev.2023.100575</i> https://www.sciencedirect.com/science/article/pii/S1574013723000424	Short description	This paper provides a systematic and comprehensive study of four popular yet widely different blockchain systems: Bitcoin, Ethereum, Hyperledger Fabric, and IOTA. The systems are directly compared with each other, and compared with existing academic surveys and tutorials beyond the example systems.
	Research group's contribution	Conceptualization, Funding acquisition, Methodology, Investigation, Resources, Supervision, Writing
Publication 6: — <i>A Privacy-Preserving Framework for Outsourcing Location-Based Services to the Cloud / IEEE TDSC / 2019 / 10.1109/TDSC.2019.2892150/</i> https://ieeexplore.ieee.org/document/8607097	Authors	Xiaojie Zhu, Erman Ayday, Roman Vitenberg
	Short description	The paper proposes a privacy-preserving framework for outsourcing location-based services to the cloud. The framework supports multi-location queries with fine-grained access control, and search by location attributes, while providing semantic security and privacy. The viability of the proposed solution is shown experimentally.
	Research group's contribution	Conceptualization, Formal Analysis, Methodology, Investigation, Resources, Software, Supervision, Writing
Publication 7: SmartNEM <i>Intelligent Charging Management of Electric Vehicles Considering Dynamic User Behavior and Renewable Energy: A Stochastic Game Approach / IEEE Trans. on Intelligent Transportation Systems / 2021 / 10.1109/TITS.2020.3008279</i> https://ieeexplore.ieee.org/abstract/document/9153114	Authors	Hwei Ming Chung, Sabita Maharjan, Yan Zhang , Frank Eliassen
	Short description	Intelligent Charging Management of Electric Vehicles Considering Dynamic User Behavior and Renewable Energy: A Stochastic Game Approach
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Supervision, Writing
Publication 8:	Authors	Yunlong Lu, Xiaohong Huang, Yueyue Dai, Sabita Maharjan and Yan Zhang

— <i>Blockchain and Federated Learning for Privacy-Preserved Data Sharing in Industrial IoT / IEEE Trans. Industrial Informatics (IEEE TII) / 2020 / 10.1109/TII.2019.2942190</i> https://ieeexplore.ieee.org/abstract/document/8843900	Short description	This paper presents the design of a blockchain empowered secure data sharing architecture for distributed multiple parties. The data sharing problem is formulated into a machine-learning problem by incorporating privacy-preserved federated learning. Federated learning in the consensus process of permissioned blockchain is integrated. Has received more than 800 citations.
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Supervision, Writing
Publication 9: — <i>Dependable Demand Response Management in the Smart Grid: A Stackelberg Game Approach / IEEE Trans. Smart Grid / 2013 / 10.1109/TSG.2012.2223766</i> https://ieeexplore.ieee.org/abstract/document/6464552	Authors	Sabita Maharjan, Quanyan Zhu, Yan Zhang, Stein Gjessing and Tamer Basar.
	Short description	Demand Response Management (DRM) is a key component in the smart grid to effectively reduce power generation costs and user bills. This paper proposes a Stackelberg game between utility companies and end-users to maximize the revenue of each utility company and the payoff of each user. Has received more than 800 citations.
	Research group's contribution	Conceptualization, Formal Analysis, Methodology, Investigation, Resources, Supervision, Writing
Publication 10: — Mobile Edge Computing: A Survey / IEEE Internet of Things Journal / 2018 & 10.1109/JIOT.2017.2750180 https://ieeexplore.ieee.org/abstract/document/8030322	Authors	N. Abbas, Y. Zhang, A. Taherkordi, and T. Skeie
	Short description	Mobile edge computing (MEC) is an emergent architecture where cloud computing services are extended to the edge of networks leveraging mobile base stations. This paper presents a comprehensive survey of relevant research and technological developments in the field. It is the landmark paper in the field of mobile edge computing. The paper has been widely recognized by the research community. Has received more than 2200 citations.
	Research group's contribution	Conceptualization, Methodology, Investigation, Resources, Supervision, Writing

Publication 11: RITE, NEAT <i>Reducing Internet Latency: A Survey of Techniques and Their Merits</i> / IEEE Commun. Surv. Tutorials / 2016 / 10.1109/COMST.2014.2375213 https://ieeexplore.ieee.org/document/6967689	Authors	Bob Briscoe, Anna Brunström, Andreas Petlund, David A. Hayes, David Ros, Ing-Jyh Tsang, Stein Gjessing , Gorrry Fairhurst, Carsten Griwodz , Michael Welzl : 18(3): 2149-2196 (2016)
	Short description	This paper offers a broad survey of techniques aimed at tackling latency in the literature up to August 2014, as well as their merits. A goal of this work is to be able to quantify and compare the merits of the different Internet latency reducing techniques, contrasting their gains in delay reduction versus the pain required to implement and deploy them.
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Writing
Publication 12: — <i>Flexible device compositions and dynamic resource sharing in PCIe interconnected clusters using Device Lending</i> / Clust. Comput. / 2020 / 10.1007/s10586-019-02988-0 https://link.springer.com/article/10.1007/s10586-019-02988-0	Authors	Jonas Markussen, Lars Bjørlykke Kristiansen, Rune Johan Borgli, Håkon Kvale Stensland , Friedrich Seifert, Michael Riegler, Carsten Griwodz , Pål Halvorsen
	Short description	We propose Device Lending for PCI Express (PCIe) clusters to enable direct low latency access to remote devices. We prove that multiple remote devices can be used, achieving bandwidth and latency close to native PCIe, and without requiring any additional support in device drivers.
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Software, Supervision, Writing
Publication 13: SIRIUS SFI <i>Detailed Modeling of Heterogeneous and Contention-Constrained Point-to-Point MPI Communication</i> / IEEE Transactions on Parallel and Distributed Systems / 2022 / 10.1109/TPDS.2023.3253881	Authors	A. Thune, S.A. Reinemo, T. Skeie , and Xing Cai
	Short description	The network topology of modern parallel computing systems is inherently heterogeneous, with a variety of latency and bandwidth values. To get a detailed understanding of the individual communication cost per MPI process, we propose a new modelling methodology that incorporates both heterogeneity and contention.
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Software, Supervision, Writing

https://ieeexplore.ieee.org/document/10064025		
Publication 14: — <i>Experiencing Rotation and Curvature Gain for Redirected Walking in Virtual Reality / MMVE@MMSys / 2023 / 10.1145/3592834.3592874</i> https://dl.acm.org/doi/10.1145/3592834.3592874	Authors	Emil Magnar Kjenstad, Halvor Kristian Ringsby, Rahel Jamal Gaeb, Çağrı Erdem, Konstantinos Kousias, Ozgu Alay, Carsten Griwodz
	Short description	This paper studies the use of natural walking motion from the real environment into virtual environments. It explores to which extent redirected walking is achievable without being noticed by the users. Statistically significant differences between levels are discovered.
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Software, Supervision, Writing
Publication 15: — <i>Peekaboo: Learning-based multipath scheduling for dynamic heterogeneous environments / JSAC / 10.1109/JSAC.2020.300036</i> https://ieeexplore.ieee.org/abstract/document/9110610	Authors (Please highlight group members)	Hongjia Wu, Özgü Alay , Anna Brunstrom, Simone Ferlin, Giuseppe Caso
	Short description	A novel learning-based multipath scheduler that is aware of the dynamic characteristics of the heterogeneous paths. It was implemented in Multipath QUIC (MPQUIC) and compared with state-of-the-art multipath schedulers.
	Research group's contribution	Conceptualization, Formal Analysis, Funding acquisition, Methodology, Investigation, Resources, Software, Supervision, Writing

Table 6. Please add a list with the research groups monographs/scientific books. Max 10 listed: title, first three authors et al and link to webpage (if any). Please delete lines which are not used.

	Authors-Title (Please highlight group members) - link to webpage/review
1	Yan Zhang, "Mobile Edge Computing", Springer, 2022, https://link.springer.com/book/10.1007/978-3-030-83944-4

2.2 Research group's societal contribution

Most of ND's research is motivated by societal challenges, spanning from the direct impact on society that stems from contributions to Energy management, Sustainability, Digitalization of the Society to the more indirect contributions stemming from the support of widely available and deployed standards and (open source) software.

In the Energy Informatics area, ND brings together researchers from computer science, law and psychology to transform how the society thinks about energy production, consumption and trading, and to adapt the legal framework to ensure that a broad societal contribution to energy production becomes viable.

In the Digitalization area, one example is the Blockchain Lab's collaboration with important national actors including Norges Bank and the Norwegian Cancer Registry to assess blockchain technology as a basis for future financial tools.

In the field of software, AliceVision and its frontend Meshroom are examples. They have been downloaded tens of thousands of times, Meshroom has >10k stars on Github. It is used widely for private activities, cultural activities from performing arts to the creation of high-end commercial movies, is used to explore new computer vision algorithms, but also for unexpected use cases like microbiology research.

In the field of Sustainability, as an example, ND is working on intelligent and automated data processing models to connect different actors in electronic waste (e-waste) management systems to allow the customers to make fact-based decisions when purchasing EEE. The public will obtain better and more actionable information and allow consumers to make informed decisions to reduce e-waste generation, climate mitigation, and therefore the adverse effects on the environment and health.

Table 7. The research group's societal contribution, including user-oriented publications, products (including patents, software or process innovations

No.	Name of publication/product	Date of publication/product	Link to the document
1	AliceVision / 3D reconstruction software	2018/Software	https://github.com/alicevision/AliceVision
2	PopSift / real-time feature tracking	2016/Software	https://github.com/alicevision/popsift
3	Transport Services (TAPS) / replacement for the Berkeley socket API	2014-2022/Standard	https://github.com/apple/swift-nio-transport-services
4	SIRIUS SFI - a new modelling methodology that quantifies heterogeneity and contention of MPI-based reservoir simulations and implementation of this concept in the OPM (Open Porous Media) open-source framework.	2018-2022/Software+Process innovations	https://ieeexplore.ieee.org/document/10064025 https://opm-project.org
5	Method of computing balanced routing paths in fat-trees	2019/Patent	US10425324B2 https://patents.google.com/patent/US10425324B2/en?q=US10425324B2
6	System and method of computing Ethernet routing paths	2018/Patent	US20190149461A1 https://patents.google.com/patent/US20190149461A1

3. Challenges and opportunities

The Networks and Distributed systems (ND) group is carrying out cross-disciplinary research that encompasses activities in energy informatics and green Internet, blockchain technologies, multimodal systems, edge/cloud computing/IoT systems, High Performance Computing, and most of the layers of distributed systems and networking spanning all the way to quantifying the human experience. This broadness of scope has led to successful research results with impact beyond academia, where our solutions have been taken up by industrial partners as well as contributing to standards and open source, and getting external funding profusely.

In order to further develop and strengthen the research and the position of the group in the years to come, we believe we should achieve this goal by continuing to contribute to *sustainability* and *digitalisation*, which are among the biggest challenges our society is facing. ND's ambition is to be a major and recognized provider of technologies and research results in these problem domains.

To get there, we will continue on the path doing research on energy informatics for a sustainable future. Herein we will focus on Smart Grids, P2P energy trading between energy communities, V2X/EV charging to support E-mobility, green Edge/Cloud, herein Internet of vehicles and smart IoT. In order to lay the foundation of Edge intelligence and Smart Grids/IoT in general, we will also have a focus on machine learning, federated and deep reinforcement learning, being inventive about the way we apply these technologies.

ND also has the ambition, as we see an opportunity here, to contribute to transforming production of hydrogen so it becomes an environmentally friendly source of energy. Generation and consumption of hydrogen are under development and need further research to become reliable, scalable, and not harmful to the environment. We propose that this should be carried out by developing a digital twin concept, where we both take a bottom-up perspective for efficient use of material in the production, as well as a top-down perspective for a reliable, scalable, and efficient operation of such systems. This research agenda has been proposed to Equinor, and will also be discussed with Statkraft. Along these lines we can also mention that ND together with two other research groups at IFI has started to plan for submitting a new SFI application in 2025, related to development of a digital twin platform that can be applied to different sectors, where we will also benefit from our previous SFI (SIRIUS). A number of key industrial players will be part of this application.

Furthermore, we see an opportunity that blockchains should contribute even more to both sustainability and digitalisation. Regarding sustainability, we are evaluating the sustainability of blockchain-based systems, enabling secure energy trading, and improving blockchain technologies in order to make them more sustainable. Regarding digitalisation, we contribute to transforming the digital infrastructures in Norway and Europe (e.g., through our collaboration with the public sector in Norway) to increase the level of security, transparency and verifiability via integrating blockchain/smart contracts into digital infrastructures.

We will also have a sustainability focus when it comes to networking in general. Green Internet is a main research topic in ND, in particular to make the transport layer more energy efficient – a small protocol improvement will have a huge impact globally. Likewise, we focus on making HPC / data center networking solutions more energy efficient, e.g by introducing more in-network computing (offloading CPUs/GPUs), this we will do in collaboration with the partners Nvidia and Cornelis networks.

ND will in the years to come also have a considerable attention on developing and adopting 5G and beyond mobile networks, for instance by using pilots with vertical and cross-vertical industries to demonstrate the potential of advanced 5G/6G technologies and architectures. And in this way facilitating digitalisation and innovation of new services and applications important for the society.

When it comes to challenges, we would like to underline that in the future we will strive harder to capitalise even more on ND's cross-disciplinary research profile to obtain increased synergy by having more cross-activity projects, including projects with other research groups. By improving in that respect, there should be opportunities to address more overarching research topics.

We also see challenges in getting funded our future involvement in the IETF and other standardisation communities, as has proven very fruitful in the past (such as the TAPS Transport Services applied by Apple) - there are only very few funding opportunities for such involvement in the Research Council of Norway and EU.