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6G Flagship is part of the Finnish Flagship Programme funded by the Academy of Finland.
6G Flagship has come a long way in a relatively short time, and I am proud to be leading this world-class research programme. We announced our research strategy at the first 6G Summit in early 2019, emphasising the importance of UN SDGs in defining the 6G requirements. This message has not changed during the first four years of Flagship. On the contrary, it has become even more important in the current turbulent world. The key technology enablers identified in the 6G White papers published in 2020 are also still valid, and the popularity of the White Papers has been overwhelming – they have been downloaded already more than 1 million times.

The second phase of 6G Flagship started at the beginning of May 22. The next four years will be the most intensive in 6G research. At the time of ending the programme in mid-2026, 6G standardisation can be expected to be progressing at full speed. Until then, we will have a lot of fun investigating all possible venues making 6G possible. Our key research directions remain somewhat unchanged, and the focus will gradually shift toward defining key building blocks and the overall 6G system concept. The European Hexa-X project will enter its second phase at the beginning of 2023 with a clear mission to define the European 6G system concept. 6G Flagship is a member of the Hexa-X-II consortium and is fully committed and ready for this great mission.

Global collaboration is becoming more important than ever before to respond to ever-increasing challenges in mobile communications research. With great pleasure, we can see increasing discussions with the key players from the US, Europe and Asia. 6G Flagship has been actively fostering this dialogue and has initiated several new collaborations in Japan, Korea, India and the US. New 6G programmes and fora are emerging. 6G Finland was initiated recently to involve all critical ICT players in Finland in the 6G development. As a next step, it would be imperative to get critical vertical sectors like health, automotive, energy and industries involved with defining the 6G requirements. It will be a real challenge to develop a superior mobile technology satisfying future sustainability criteria from different perspectives. Hopefully, we won’t need 7G and beyond to make it real, but 6G would already satisfy the majority of the UN SDGs.

Matti Latva-aho
Director of 6G Flagship
University of Oulu, Finland
6G FLAGSHIP – THE SECOND PHASE

EXPERT TEAMS SPEEDING UP IN CREATING POSSIBLE SOLUTIONS
The second phase of 6G Flagship started at the beginning of May. The next four years will be the most intensive in 6G research. At the time of ending the programme in mid-2026, 6G standardization can be expected to be progressing at full speed.

“Until then, we will have a lot of fun investigating all possible alternatives making 6G possible. Although it isn’t clear at all yet what will eventually make 6G a reality, the global research community has made significant steps forward since we started in 2018. Our seminal work on identifying key research challenges and directions in the 6G White Papers series is still valid. More open questions remain than mature answers,” defines Professor Matti Latva-aho, the Director of 6G Flagship.

Four main research areas will continue their work, namely wireless connectivity, device technologies, distributed intelligence and human-centric wireless services.

Key challenges for the second term

6G must provide increased transmission capabilities and safe and dependable global service delivery. These will help bridge the existing digital divide. We are developing new connectivity techniques to accommodate higher spectrum bands towards the THz regime. We also integrate sensing capabilities into the communication systems and create novel connectivity strategies and solutions that work at various frequencies for the demands of different verticals. Our research is governed by the United Nations’ Sustainable Development Goals, which provide us with an entirely new and unforeseen set of additional requirements for wireless connectivity.

Transceiver and antenna implementations will be the foundations for future communication systems. Experimental research on new and innovative solutions ranging from materials to hardware architectures can address their technological limitations. The research will evolve from individual enablers to entire RF transceivers/systems and mechanisms to further advance technologies around core areas, from RF and antennas to digital solutions, including AI/ML solutions, to support HW platform optimization. However, as the technologies are still at a low maturity level in many core concepts, advancements are needed before standardization can ramp up and continue to validate assumptions.

Data is the future digital society’s foundation. Ultra-densified communications and sensing overwhelm the current data and computing infrastructures. Massive volumes of locally produced data need the dispersion of computations throughout an edge-cloud continuum. AI/ML models need new distributed paradigms that use modern 6G networks to boost privacy and data locality. Distributed computing and AI/ML will enable distributed sensing, modelling, and unique user interfaces. These will need integration into complex system architectures that operate independently and in dynamic contexts and will lay the groundwork for the future society’s needs.

Commercial-grade test environments are needed for vertical applications to have sufficiently realistic testing conditions. 6GTN will provide a solution for this purpose. Testing across many verticals will give a complete examination of interoperability challenges and requirements than testing across a single vertical. 6G is an upcoming general-purpose technology that will influence how value and profit are built from technological advancements. Considerations for business, technology, economics, and sustainability are critical for creating future 6G systems and technologies and associated legislation. Research is also needed to investigate the empowerment of users as active participants of the 6G ecosystem.

New 6G programmes and fora emerging

In order to be able to respond to ever-increasing challenges in mobile communications research, global collaboration is becoming more important than ever before.

“It’s a pleasure to see increasing discussions with the key players from the US, Europe and Asia. New 6G Programmes and Fora are emerging. As a next step, it would be imperative to get critical vertical sectors like health, automotive and energy besides industry involved with the definition of the future requirements. It will be a real challenge to develop a superior or mobile technology satisfying future sustainability criteria. Hopefully, we won't need 7G and beyond making it real, but already 6G would satisfy the new sustainability requirements,” muses Latva-aho.
NETWORLD EUROPE OUTLINES 6G RESEARCH AND INNOVATION PRIORITIES
Networld Europe, an ICT technology platform in Europe, has helped the EU Commission write the next ICT work programme by offering its Strategic Research and Innovation Agenda (SRIA) as a baseline document and European take on necessary technology areas representing the views of more than 1000 members of Networld Europe. The objective of this task is also to make Information and Communications Technology research, development, and innovation (R&D&I) more available throughout all of Europe for both citizens and businesses.

The SRIA was also developed to support the Smart Networks and Services Joint Undertaking (SNS)* members in charge of writing the draft proposal for the SNS JU work programme and is produced in consultation with key stakeholders. The SRIA is a roadmap and a joint vision of European ICT players that outlines the research and innovation priorities as Europe moves toward 6G. It will help the EU meet its digital economy and society goals and support industrial policy objectives.

“SRIA 2022 is an ambitious and wide-ranging living document which contains a white paper and a technical annex that will be updated regularly to reflect changes in technology and market developments. It captures the current thinking of the Networld Europe members on where ICT R&D&I should be heading in order to enable a fully digitalised and decarbonised European economy and society. It will help the European Commission to formulate its next ICT work programme in a way that is aligned with the ambitions of the EU. The plan is to update it already in 2024,” says Ari Pouttu, 6G Flagship’s Vice Director and chairperson of the Expert advisory group of Networld Europe that is in charge of producing the SRIA.

The white paper of the SRIA discusses the ICT impact on European business and highlights the major EU and EC policies affected and supported. The white paper describes the EU plans and methods and highlights some member state initiatives in the ICT domain towards 6G. The document gives Networld Europe’s vision on 6G before briefly highlighting the nine technology R&D&I areas, which are more deeply described in the technology annex of the SRIA. The white paper then describes the time plan for different technology R&D&I areas and discusses the metrics usable to evaluate the progress in different areas.

The technical annex, on the other hand, is a comprehensive review of more than 300 pages on important R&D&I topics as we move towards 6G. The document provides insight into nine technology areas, namely:

1. System services description,
2. System and Network Architecture (incl. edge computing),
3. Network and Service Security,
4. Software technologies for telecommunications,
5. Radio Technology and Signal Processing,
6. Optical Networks and System Components,
7. Non-Terrestrial Networks and System Components.
8. Devices and Components for 2030, and

There is still plenty of room for improvement in digitising different industries. Standardisation bodies still need to comprehensively examine most areas to identify which requirements are crucial and would be meaningful. Without full mobility data integration, existing network solutions cannot support the most advanced cases. As industries change, so must the networks that support them. Smart Networks and Services JU ICT work programme will enable several vertical domains to evolve. Ecosystems connected to digital platforms and marketplaces create value for all members and have the potential to disrupt entire industries, having a significant economic and social impact.

SRIA 2022 is an ambitious and wide-ranging living document which contains a white paper and a technical annex that will be updated regularly to reflect changes in technology and market developments.
Already 190 organisations cooperating on 6G research

Finland’s global reputation as a top ICT talent and investment destination will gain robustness with 6G BRIDGE. The programme will also support Finnish stakeholders in forming tangible partnerships with key countries such as the United States, Japan, the United Kingdom, and Canada and assist with EU partnerships. By the end of the 6G BRIDGE programme, Finland will have established the world’s first widely acknowledged 6G test network.

The 6G BRIDGE programme has a Strategic Research & Innovation Agenda (SRIA) whose aim is to generate new knowledge and understanding about the interactions between the built environment, society, economy and nature. The total budget for the SRIA is €130 million, €63 million of which comes from Business Finland (BF).

The application deadline for the SRIA was in mid-October 2022. After the application deadline, BF will inform customers of its decision before the year-end.

The 6G BRIDGE programme has a Strategic Research & Innovation Agenda (SRIA), a brief white paper that aims to define the general development and innovation activities and the upcoming Business Finland program.
The four main SRIA topics are:
1. Utilising existing 5G technology to its full potential.
2. Developing 5G Advanced to push the boundaries of what is possible with this new technology.
3. Researching and developing 6G technology.

In SRIA, 6G Flagship is responsible for topics 3 & 4. Those appointed to SRIA create a roadmap where each of the four main topics will have a coordinating organisation in charge of the SRIA writing process.

These carefully defined strategic research and innovation focus areas will ensure that Finland remains at the forefront of mobile communications technology, reaping the benefits of economic growth and productivity.

Keeping Finland in the 6G lead
6G BRIDGE is a Business Finland-funded programme to advance 5G and 6G technologies. The programme has a budget of 130 million euros and is scheduled to run from 2022 to 2026, with a possible extension depending on progress. On the 3GPP timeline, this means releases R17 through to R20 or even R22.

The programme’s main stakeholders and customers include ICT mammoths such as Nokia and Ericsson and 190 other organisations, including 6G Flagship, Allied ICT Finland, 6G Finland, 5G Momentum. The programme aims to keep Finland a global leader in ICT technologies.

The outcomes Business Finland expects of 6G BRIDGE are many. One of the main expectations is to generate more intellectual property in Finland than 5G technology has generated. The programme also aims to maintain Finland’s position as a global leader in 6G, and its market impact is undeniable. Maintaining strong influence in ITU-R 6G Requirements definition as well as the later 6G standards process is also essential.
EU HORIZON WINDFALL FOR

6G FLAGSHIP RESEARCH

6G Flagship’s reputation as the European Union’s leading 6G research entity gets confirmation as Horizon Europe, the EU’s most significant investment in European research and innovation, approves fifteen new project proposals. The 6G Flagship proposal acceptance rate was outstanding, at approximately 50%.

The total budget for twelve SNS projects, one infrastructure project, and two MSCA projects will be roughly 110 million euros, with the 6G Flagship research receiving over 10 million euros. The projects will begin in early 2023. They cover a wide range of research topics, including Terahertz (THz) integrated systems that enable 6G Terabit-per-second ultra-massive MIMO wireless networks, truly sustainable IoT, light-based energy harvesting, and THz Reconfigurable Intelligent Surface (RIS) assisted ultra-high data rate wireless and many more. This means a great many opportunities for talented doctoral and postdoctoral researchers and professors to join the 6G Flagship’s research efforts.

The European Union launched its most extensive-ever research and innovation program to support its industrial transformation. Horizon Europe seeks to stimulate growth, trade, and investment while having a significant social and environmental impact. It aims to deliver on the Paris Agreement through the green transition and to foster the development of the digital economy by investing in key enabling technologies. The total budget of Horizon Europe is €95.5 billion.

“One of 6G Flagship’s missions is industry-driven R&D, so we are delighted that the EU has endorsed this approach. We can now proceed at an even wider front to create a competitive
The new Horizon Europe projects:
- CENTRIC
- Hexa-X-II
- DESIRE6G
- 6G-XR
- RIGOUROUS
- VERGE
- TERRAMETA
- SUPERIOT
- TERA6G
- CRITICAL CHANGELAB
- ADROIT6G
- 6G-SANDBOX
- CONVERGE
- RE-ROUTE
- EVOLVE

Horizon Europe is the EU’s key funding programme for research and innovation with a budget of €95.5 billion. It tackles climate change, helps to achieve the UN’s Sustainable Development Goals, and boosts the EU’s competitiveness and growth.

Read more:
research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

European digital industrial ecosystem and make Europe the global leader in 6G,” says Professor Ari Pouttu, Vice Director of 6G Flagship.

“Working side-by-side with the leading European industry is very important for 6G Flagship. It is crucial to build general-level consensus on 6G key technical solutions jointly. The role of academia is more forward-looking, industry and those deploying 6G will jointly define the 6G standard later on, after these European projects,” affirms Professor Matti Latva-aho, Director of 6G Flagship.
EUROPE’S LARGEST 6G RESEARCH PROJECT
HEXA-X-II
**We need a technology vision that will enable a seamless interaction between the physical and digital worlds to make our societies more sustainable, inclusive, and safe.**

Hexa-X-II is the next version of the EU project Hexa-X, which set out to create wireless technologies that will be able to meet society’s needs in the 2030s. The project builds on the research and findings of Hexa-X. It works towards creating an intelligent fabric of technology enablers connecting the human, physical, and digital worlds.

The project’s main objective is to identify and address concerns relating to green deal efficiency, digital inclusion, and assurance of trustworthiness in a post-pandemic world. The development of essential components, such as new radio access technologies that operate at high frequencies and localisation/sensing capabilities driven by AI-driven air interfaces, flexible infrastructure, and smart network management, will also be addressed.

“Digitalization has been one of the most important global trends even before the Covid-19 pandemic. Now it is accelerating at an unprecedented pace as the pandemic made people find new ways to work, study and socialise online. We need a technology vision that will enable a seamless interaction between the physical and digital worlds to make our societies more sustainable, inclusive, and safe. Hexa-X-II will help us achieve that,” says Mikko Uusitalo, Head of Research at Nokia Bell Labs and coordinator of Hexa-X and Hexa-X-II.

“The Hexa-X-II is exactly what the doctor ordered. It fulfills the intent of the NetworldEurope SRIA 2020 as a EU light-house project for 6G research,” indicates Professor Ari Pouttu, Editor of the NetworldEurope SRIA.

“Hexa-X-II is a holistic flagship towards the 6G platform and system to inspire digital transformation for the world to act together in meeting needs in society and ecosystems with novel 6G services. Hexa-X-II will increase the competitiveness of Europe by bringing industry and academia together in the right way,” adds Mikko Uusitalo.

**A comprehensive European 6G project**

The work is scheduled to get underway on the Hexa-X-II project in January 2023. It is an ambitious task that is expected to take 2.5 years.
Since the very beginning of the 6G research endeavour, sustainability has been considered as the single most important new driver. Decades old definitions of sustainability as the principle of ensuring that our actions today do not limit the range of economic, social, and environmental options open to future generations continues to be timely. Developing sustainable ICT services and solutions to solve major sustainability challenges is the shared goal.

Energy efficiency has been a design-criteria throughout mobile communication generations, but still today consumers do not know the environmental footprint of their choices as this information is not available.

“Sustainability is still not the mainstream, which is why I keep on bringing it up in different fora”, Marja Matinmikko-Blue states. After being appointed as Director of Sustainability
and Regulation at 6G Flagship a year ago, she took a parallel position as Research Director of Infotech Oulu Focus Institute, which broadens her work to the entire strategic focus area of “Digitalization and Smart Society” at the University of Oulu.

“Despite reaching the consensus on 6G being driven by sustainability almost four years ago, we are still in the stage of raising awareness in the large scale,” she emphasizes.

**Triple bottom line of sustainability in focus**
The triple bottom line of sustainability, widely used in different fields, emphasizes social, environmental and economic perspectives of sustainability. They are interlinked and promoting one should not come at the expense of another. “If we had all the money in the world, many social and environmental sustainability challenges would have been solved by now”, Matinmikko-Blue says.

6G Flagship has adopted sustainability into its multi-disciplinary research agenda that combines technology, business and regulation related research. Examples of 6G and sustainability include White Paper on 6G Drivers and the UN SDGs, solutions to connect the unconnected, energy efficient algorithms, and energy harvesting solutions, accompanied with inputs to regulatory fora.

In general, enablement effect has received attention denoting ICT sector’s role to help other sectors of society to cut their green-house gas (GHG) emissions and reduce their environmental sustainability burden as well as reach societal sustainability targets (handprint). Estimates of ICT sector’s own energy consumption and GHG emissions (footprint) vary according to sources. What is clear is that the ICT sector’s emissions keep increasing. For example, countries are ranked according to the higher their mobile data consumption is. “How sustainable is that?” Matinmikko-Blue questions.

**Importance of regulations**
“Researchers are good at linking their work with the UN SDGs”, Matinmikko-Blue says. “When this became a requirement by many funding agencies in funding applications, researchers took it seriously and developed ways to contribute to the targets within the UN SDG framework,” she continues. A similar approach would work for the ICT sector. External pressure will change traditional ways of doing business.

Regulators admit to facing a new situation when incorporating sustainability principles into telecommunication regulation. But stakeholder management continues to be a bottleneck. “What is characteristic of this development is that the research community is not yet taken seriously in the game”. Recent examples include collecting information about environmental sustainability indicators only from the ICT industry in Europe excluding academia. “There is a strong need for unbiased research results in addition to what the industry and the operators provide”, Matinmikko-Blue urges.

Sustainability is a visible design criteria in global 6G vision building at the UN based International Telecommunication Union Radiocommunication (ITU-R) in defining International Mobile Telecommunications (IMT) towards 2030 and beyond. Concrete requirements will be specified in the coming years.

**Time for proper stakeholder management**
Incorporating sustainability principles into work and life is everybody’s responsibility. Sustainability can be seen as a mindset that we all as developers and users of ICT services and solutions need to take. The next generation will be native in sustainability whether we mean the human or communications generation.

“A good starting point would be to give consumers quantified information on their ICT footprint which would allow them to make sustainable decisions”, Matinmikko-Blue says. “Those, who will come up with sustainable ICT solutions to solve major sustainability challenges, will be the heroes of the future,” she continues. “Our preliminary action plan for stakeholders to act from the White Paper on 6G Drivers and the UN SDGs still holds,” she concludes.

**Read more:**
6gflagship.com/white-paper-on-6g-drivers-and-the-un-sdgs
6G Flagship research is divided into four interconnected areas: Wireless Connectivity Solutions, Devices and Circuit Technology, Distributed Intelligence, and Human-centric Wireless Services. Each research area employs dozens of scientists who seek breakthroughs in core 6G technology and component development. We talked with Dr Nurul Huda Mahmood to find out what’s happening in the Wireless Connectivity team, which forms 6G Flagship’s biggest research area.

Mahmood greets us at the Centre for Wireless Communications, where 6G Flagship resides. “In the Wireless Connectivity team, we develop new connectivity techniques to meet the diverse requirements of eMBB, URLLC and mMTC services. These areas cover the range from the physical layer to the networking layer. We aim to accommodate higher spectrum bands towards the THz regime and integrate capabilities beyond communications, such as sensing, to create novel connectivity strategies and solutions. Such a wide research focus enables people with any related background to contribute with their skills and know-how while benefitting from the broad scope to increase their knowledge base.”

Working with futuristic and long-term research problems
When we inquire about the team’s work environment, Mahmood nods enthusiastically: “6G Flagship gives an ambitious scientist a genuinely nurturing environment where you can solve complex challenges and network with the right individuals who support your progress into an independent research leader. If you join our team, you’ll work alongside famous scientists like Professor Matti Latva-aho, the Director of 6G Flagship, and Professors and IEEE fellows Tarik Taleb, Markku Juntti, and Mehdi Bennis, to name a few.”

Working at 6G Flagship means working with futuristic and long-term research problems expected to materialise around 2030. Instead of being constrained by practical limits, this allows researchers to take measured risks and investigate ambitious ideas. At the same time, 6G Flagship is very much grounded in reality. It interacts closely with the vertical sectors it aims to serve, as evinced by the 6G Flagship’s ecosystem arm and its strategic vertical areas. As the world’s first, largest, and most well-known 6G research project, one is at the vanguard of 6G development worldwide, providing researchers with unparalleled visibility and exposure.

Independent diversity, merged expertise
The research group comprises professors, researchers and graduate students from different engineering disciplines, such as Electrical and Electronic Engineering, Computer Science and Statistics. They work together to develop those cutting-edge technologies that would make 6G a reality in the 2030s. Most university research projects have an autonomous group leader but not the 6G Flagship. “When working
on larger projects, like EU projects, the leaders work independently and merge their outputs to create project reports and deliverables,” Mahmood declares.

**Discovering and paving the way over challenges**

Dr Mahmood, the coordinator of the Wireless Connectivity research group, is very clear about what the Wireless Connectivity research group aims to achieve by the time the 6G Flagship programme ends. “Before the program concludes in 2026, we aim to create a comprehensive idea for a 6G system. This will include all the necessary enablers and solutions,” Mahmood underlines.

**Developing new technologies always comes with challenges, but that is what makes this work interesting and exciting.**

“What we have discovered so far are solutions for wireless energy transfer, which will pave the way toward sustainable MTC networks,” Mahmood gets excited in relating their achievements. “We’ve also been pioneering the application of machine learning and artificial intelligence to wireless systems, which allows efficient solutions for complex optimisation problems. And we’ve developed mobile network softwarization and service customisation concepts as an enabler of autonomous telco cloud service architecture.”

On the challenges facing his team in their research journey toward 6G, Mahmood comments, “Developing new technologies always comes with challenges, but that makes this work interesting and exciting. We are confident that our team will be able to overcome those challenges and deliver on our promise of creating a vision for 6G by 2026.”

Exciting times lie ahead for wireless connectivity, especially with programmes like this at the University of Oulu.
**ENABLING UNLIMITED CONNECTIVITY**

Transceivers will power next-generation communication and sensor systems. Included will be semiconductor and material breakthroughs that determine the devices’ physical data speeds, bandwidth, and 6G radio frequencies.

Before standardising a new generation of communications with better hardware awareness, the mix of various HW technologies and their maturity must be carefully considered. Frequencies of 300 GHz or even higher frequencies are targeted for 6G enablement. The core technological opportunities and limitations will be addressed through experimental research on new and innovative solutions ranging from components to hardware architectures.

Professor Aarno Pärssinen’s Devices and Circuit Technology team are working to prepare us for the move into 6G. Associate Professor Ping Jack Soh, the research area coordinator, invited us to meet with him at the University of Oulu’s Linnanmäki campus.

Jack greets us on Tietotalo’s 4th floor at the University of Oulu’s Faculty of Information Technology and Electrical Engineering. He gets animated when we approach the topic of what it takes to work in his team. 6G Flagship have just been given considerable EU Horizon funding, and new projects will be starting. New hands are soon needed on deck.

Devices and Circuit Technology concentrates on radio front-ends, which are expected to be the last physical sub-system before signals (in the form of waves) are transmitted into the air,” Jack explains what the team does. “Conversely, they are also the first sub-system reached by signals when information arrives at its destination. The radio front-ends must be designed carefully and optimised to ensure reliable and high-speed wireless links. This involves joint optimisation efforts between researchers of different expertise within the research area, as well as in collaboration with other 6G Flagship research areas and external partners. Our part of the whole becomes increasingly essential in the near future when we move to make 6G systems a reality.”

There has been quite a number of ground-breaking research in this research area, particularly with the design of transceiver components. Several examples include an amplifier that can operate at two-thirds of its theoretical limits at 300 GHz and a digital phase shifter that can provide excellent tuning resolution at the same frequency.

“IT always feels like we’re competing in the research Olympics of RF hardware for next-generation communications,” Jack beams. “Everyone is trying to break the next record with their design — get the fastest speed, the highest gain, etc. A bit of competition definitely adds to the excitement of researching in this area,” he nods vigorously.
“By the end of the 6G Flagship programme, we aim to have both the knowledge and models in designing and optimising a sub-THz transceiver. In terms of deliverables,” Jack continues, “having a demonstrator system capable of high speed and reliable communications within the sub-THz band is what we’re aiming for.”

Collaboration on another level
Working at 6G Flagship has been one of the most collaborative experiences Jack says he has ever had. “Everyone is open to sharing their knowledge and experience and providing constructive feedback. Our team take an interest in each others’ research and ask how they can contribute to it.” The way of working can, of course, have something to do with the Finnish working culture, Jack thinks, “but where ever it stems from, it’s very much needed in RF hardware development.

Any variations in behaviour originating from different components in the RF chain, no matter how minor, can significantly affect the adjacent/linked component’s performance. This is unique, so discussing and addressing issues throughout the design and development stages is critical. It ensures that satisfactory results are obtained at the end of the day.

The ideal candidate
We then talk about the type of researchers the team is looking for. “Although solid knowledge in the field is needed, having the right attitude is even more critical,” Jack explains what they’d like to see in a team member. “You don’t need perfect grades from your previous study to join us. Willingness to learn and being proactive is what is more important to the team. We also cannot micromanage anyone, so having an independent mindset to see your research through is essential. “Besides that,” Jack emphasises how “all team members need to have a good team spirit. Not teen spirit,” he laughs jokingly. “And it’s essential that you can communicate what is on your mind and not sit on any ideas. We work in a collaborative environment, after all.”

As the majority of research in this area necessitates a complete development cycle — from design to fabrication to experimental evaluations — progress in discovering new knowledge always takes significant time and effort from various experts. For example, one of our largest research teams works together to design integrated circuits (ICs), and once optimised based on input from each member, it can only be built once or twice a year.

“If you’re looking for a research position that will allow you to think outside the box and give you a lot of autonomy, 6G Flagship ticks all the boxes,” Jack ends with a firm nod.
It is safe to say that data will serve as the future bedrock of digital society. However, ultra-dense networks of communication and sensing are already straining today’s information and computational systems to their limits.

A large amount of new local data requires edge-cloud computations. We’ll need new distributed AI/ML models that use 6G network capabilities to increase security and by doing the computations locally. Distributed computing and AI/ML will advance sensing, modelling, and even user interfaces. These must be included in complex system designs that can run autonomously and adapt to new situations to serve as the basis for tomorrow’s society.

6G Flagship’s Distributed Intelligence research area, led by Professor Olli Silvén, lays on several initiatives that address these issues. The projects range from partnering with industry to tackle specific challenges to building fundamental distributed intelligence technologies. Distributed Intelligence specialists often work on numerous projects at once.

Associate Professor Miguel Bordallo López, the team’s coordinator and second-in-command, sat with us to discuss the team’s day-to-day operations and elaborate on their long-term aim of seeing the 6G Flagship programme through to its conclusion in 2026.

New ambitious researchers are needed onboard
The research team is always on the lookout for new talent. Bordallo López guides to discussion to funding.

“We're always looking for new bold ideas and people who can make them a reality.

Over 30 senior researchers and professors have already joined Flagship’s Distributed Intelligence research. Their expertise ranges from fundamental research to more applied areas. Researchers who join the team have many options for finding suitable mentors or collaborators.

As the name of our research team may suggest (Distributed Intelligence), the research area is distributed into several research groups that coordinate their work under one vision. A researcher can join one of the many topics and collaborate closely with others working on related topics. They can also collaborate with researchers focusing on themes in a multidisciplinary manner. “The ability to move across topics and address the many challenges of complex systems allows us to conduct research in a truly unique way,” delights Bordallo López.

“We're always looking for new bold ideas and people who can make them a reality. We especially like self-driven people who get excited about the multifaceted research in dis-
tributed intelligence and contribute novel solutions to these challenging problems,” Bordallo López confirms.

Since collaboration across different disciplines is needed, people with a broad understanding of the technology and the will to interact with multiple players are very much wanted onboard.

Distributed Intelligence research focus
Bordallo López turns the conversation to what the team want to achieve. “We focus on the effects of device ultradensification in computing, sensing, and AI. We address three major themes: edge-to-cloud computing, distributed AI, and multimodal sensing and modelling.”

Edge-to-cloud computing focuses on the distribution of computations and data through a computing continuum composed of a massive number of devices. The focus of distributed AI is on new algorithms and learning paradigms for developing AI models with increased explainability, privacy, and data locality. Multimodal sensing and modelling are concerned with integrating a large number of highly heterogeneous sensors to convert a large flow of data into useful information. “The goal is to integrate communications, sensing, and 3D modelling of the environment in a coordinated manner,” he emphasises.

“We specifically invest in researching complex distributed systems that operate autonomously in dynamic environments. A new generation of fast and reliable 6G wireless connections will enable this distributed intelligence,” Bordallo López concludes.

Goals for the end of the 6G Flagship programme
Since the start of the 6G Flagship, Distributed Intelligence research team have been discovering new ways of manipulating the addition of multiple computing and sensing devices with novel state-of-the-art algorithms for edge server placement, distribution of AI training and inference, and 3D modelling from multimodal sensors.

“Especially interesting has been the discovery that AI-based reinforcement learning algorithms can help us learn new ways of efficient communications, discovering new strategies for beamforming, creating new communication protocols or devising new strategies for cooperative sensing,” says Bordallo López with eyes beaming and continues. “By the end of the program, we want complex, self-organising networks made of wireless 6G devices that can act without human intervention. Such systems should be robust, responsive to environmental changes, and allow smooth addition or removal of sensing and computing components.”

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- Coordinated sensing & communication
- Multimodal 3D modeling
- Data locality

Read more
6gflagship.com/research/strategic-research-areas/distributed-intelligence
Emerging in the not-too-distant future, 6G is a general-purpose technology that will affect how technological progress is turned into economic value.

“We have three research themes: 5G test network to 6G test network, Strategic vertical areas, and Sustainability, business, and regulation” Dr Tuomo Hänninen, the coordinator of 6G Flagship’s Human-centric Wireless Services team starts his tour of the research area. “Vertical application requires commercial-grade test environments to ensure realistic testing conditions. This is why building a 6G test network (6GTN), which can be widely used by research facilities and companies alike, is one of the main themes of this research area. Our 5G test network (5GTN) platform evolves in tandem with 6G research progress, technology development, and applications.”

Interoperability issues and requirements can be better understood by testing across multiple verticals. To build an experimental platform for testing 6G solutions Human-centric Wireless Services team actively draws on the new research done in all four research areas in 6G Flagship.

**Strategic Vertical Areas**

6G Flagship has identified four strategic verticals. “Transportation, healthcare, energy, and industry sectors were selected as strategic verticals after considering revenue growth potential and market size,” explains Hänninen describing the second theme of his research area.

The time when one solution fits all possible problems is changing. For the 6G, many key performance indicators (KPIs) exist and, often, contradictory requirements. We cannot have really high throughput, low latency, and extreme energy efficiency simultaneously. We can, however, have a combination of these requirements while remembering that there is always a trade-off.

**Often the challenges faced in wireless technology development are not technological in nature.**

“What is critical to determine for 6G is how much customisation is required for the benefit of various vertical use cases and business cases and what other requirements may exist,” Hänninen explains. “We accomplish this by collaborating
with various vertical players and researching various vertical use cases.”

**A sustainable stage for a new era of technology**
The United Nations’ sustainable development goals (UN SDGs) have laid the groundwork for technology in which everyone can participate. As the wireless industry looks ahead to 6G, the UN SDGs will play an essential role in shaping the design of next-generation networks. “One goal is to ensure universal access to communication services. Another is to promote sustainable economic growth, which will drive innovation in energy-efficient network technologies. And finally, the goal of preserving our planet for future generations will require a concerted effort to reduce the environmental impact of wireless communications. By taking these type of goals into account, the wireless industry can ensure that 6G technologies are not only technologically advanced but also socially responsible,” Hänninnen says emphatically.

**Preparing regulations for the next G business**
6G Flagship researchers pioneered the development of local 5G concept and introduced it widely to academic, industry and regulatory fora. The successful deployment of this new business opportunity is already seen in Germany, Japan and Finland. The local 5G concept implies a variety of new use cases: some public networks but many private.

Often the challenges faced in wireless technology development are not technological in nature. Policy-level issues are often more complicated to change and adjust than technology. An example of successful policy-level impact making is the local 5G concept with local spectrum licensing.

Bringing together business, regulation, and technology perspectives is essential for developing future sustainable mobile communication systems. “Our research aims to identify new business opportunities and their consequent impact on policy-making, focusing on sustainability’s triple bottom line (economic, social, and environmental) and the UN SDG framework. Our expertise areas include future research, business models, business platforms and ecosystems, stakeholder analysis, telecommunication regulation, and techno-economics. We believe that by integrating these perspectives, we can enable mobile communication systems to play a significant role in solving some of the world’s most pressing sustainability challenges,” Hänninnen concludes.
Interest in portable medical diagnosis and monitoring systems has grown dramatically in scientific circles and in the mainstream media. The attention is partially driven by the portable devices’ potential to address well-acknowledged concerns such as overburdened healthcare in growing cities, assistance for an ageing population, and equality in rural health care. Portable medical monitoring also supports diagnosis and medical treatments in hospitals and can be used for diagnosis in exceptional situations like pandemics when hospital visits are limited.

Recently, researchers have turned their attention to new microwave-based techniques that can be used for various medical monitoring and diagnosis applications. These techniques give new promise to developing portable, low-power, low-cost diagnostic devices.

“In cases of serious physical illnesses, like a stroke, which can result in severe disability or even death, prompt diagnosis is needed. For example, if we could confirm a stroke already while the patient is in the ambulance, the treatment could begin sooner, and the patient’s chances of survival would dramatically improve. Also, detecting blood clots early is critical for avoiding major thrombosis. Currently, all the detection methods we use – magnetic resonance imaging (MRI), computer tomography (CT), and ultrasound – require a hospital visit. Patients with suspected blood clots in rural locations may travel for hours to undergo blood clot verification. Therefore, there is an obvious need for portable blood clot detecting instruments,” says Mariella Särestöniemi, a postdoctoral researcher at the University of Oulu who works in the 6G-enabled sustainable society (6GESS) project as a Docent in WBAN radio channel modelling for medical diagnosis and monitoring.

Another timely and significant research area Särestöniemi reveals is tumour detection using portable devices. Microwave-based brain tumour detection techniques are of interest to researchers because they would allow portable tumour diagnosis equipment to be utilized as a preliminary diagnosis approach in remote locations. Because microwaves can permeate the entire head, microwave-based techniques can be used to image the brain through the skull. The method is based on detecting changes in signal propagation caused by heterogeneous tissue.

Detecting breast tumours has also been studied intensively for years. Recently, there’s been renewed interest in devel-
oping a self-monitoring vest for microwave-based breast cancer diagnosis. With easily accessible devices, we may be able to reach women who decline in participate in routine screenings like mammography due to distance or fear of pain.

**How are body abnormalities detected using radio channel analysis?**

Abnormalities like tumours, blood clots, or haemorrhages can be detected using radio channel analysis because their dielectric properties (e.g., relative permittivity and conductivity) differ from those of the surrounding tissues. Tumour detection, for example, is predicated on the notion that tumours have significantly greater relative permittivity values than surrounding tissues. Consequently, dielectric properties cause differences in propagation time, and power loss as the signal passes through the anomalous areas.

Intelligent channel analysis detects and localises anomalies by analysing radio channel characteristics between many antennas situated in the area where irregularities are presumed to be present and comparing them to reference data. With sensitive receivers, changes in radio channel data can be noticed, and the data can be evaluated in a server computer using AI-based algorithms. AI is employed to obtain an extensive reference data set to determine which changes in channel responses are attributable to variances in the physical parameters of the area under study and which are due to tumours of varying sizes.

One suggested approach for realising medical monitoring systems and remote healthcare is to merge Wireless Body Area Networks (WBAN) and 5G/6G connection so that WBAN captures in-body sensor data, which is then communicated to a hospital, for example, via 5G/6G networks. WBAN standard IEEE802.15.6 includes e.g., the UWB frequency band 3.1-10.6 GHz, a strong alternative for in-body, on-body, and off-body communications.

The 6G-enabled sustainable society (6GESS) programme capitalises on the 6G Flagship’s technological expertise to develop the scientific framework for a data-driven, hyper-connected future society in which digital eHealth and future energy systems are intertwined. 6GESS investigates new technologies to help make healthcare and energy systems more democratic and efficient in the future. It will also help healthcare and energy providers as well as citizens become more involved in developing and using data-driven and digitised solutions.

Researchers delved through several online databases recipes to create a ‘brain phantom,’ a mimic brain with the dielectric properties of a real brain. Concoctions with dielectric properties resembling genuine tumours were also made. Both liquid and 3D brain phantoms (with tumours in them) were inserted into a real human skull.

Read more:
6gflagship.com/6gess
Radio frequency (RF) wireless energy transfer (WET) technology realizes battery charging without physical connections and favors form factor reduction and durability increase of the end devices. It will help simplify servicing and maintenance while also reducing waste.

WET solutions are attractive for wirelessly and sustainably energizing future extremely massive Internet of Things (IoT) systems. Note that future IoT deployment densities may scale up to tens of devices per square meter (devices/m²), for which network planning, maintenance and operation should be made robust as well as simple and flexible.

Supporting the powering of massive IoT deployments via WET — referred to as massive WET in the literature — constitutes a relatively novel and challenging problem. Among the main approaches to enable massive WET are the densification and appropriate deployment of dedicated energy transmitters, also called power beacons (PBs), the exploitation of massive number of transmit antennas, and the development of channel charging strategies requiring low communication overhead to limit the energy expenditure of the participating energy harvesting (EH) devices.

The PBs traditionally require channel state information (CSI) of the WET links to increase the energy transfer via energy beamforming. However, accurate CSI acquisition requires significant amounts of time and energy from the EH devices, which may erase (or even reverse) the gains from energy beamforming. Also, CSI training and corresponding energy
expenditure scale up exponentially in massive IoT deployments, thus, becoming extraordinarily costly and challenging. In addition, the (potential) gains from energy beamforming decrease quickly as the number of served devices increases. To overcome these limitations in (possibly massive) WET setups, we have been proposing efficient CSI-limited/free WET schemes in the last few years.

“In one of our recent works, we take a significant step forward by proposing a novel ‘rotary antenna beamforming’ (RAB) CSI-free scheme for massive WET. Specifically, our proposal includes a rotor into the PB’s antenna array and makes it continuously rotate while delivering wireless energy via an optimized CSI-free energy beam. As a result, robustness against no line of sight (NLOS) conditions is inherently achieved,” says Assistant Professor Onel Luis Alcaraz López from CWC-Radio Technologies.

To avoid costly rotor equipment and ease the implementation, the researcher proposes using a stepper rotor with at least $M$ equally spaced steps and shows that the resulting effective radiation pattern (after averaging over time) becomes quasi-omnidirectional. RAB performance is further optimized by employing a rotation-specific power control mechanism exploiting the devices’ positioning information. Remarkably, an average EH gain of approximately $0.85\sqrt{M}$, where $M$ is the number of PB’s antenna elements, is attainable with respect to single-antenna WET and other state-of-the-art CSI-free multi-antenna schemes.

The following figure shows the attainable performance regarding average RF power availability in a $20 \times 20$ m$^2$ area served by a PB at the area centre that uses state-of-the-art CSI-free WET schemes and our proposed RAB strategy. Interestingly, RAB allows covering up to 65% of the area with a guarantee of $-22$ dBm (−6 µW). The percentage is significantly greater than the guarantees of the competing CSI-free schemes. Indeed, RAB is shown to outstand for both loose and tight energy requirements.

Another relevant aspect of sustainability lies in controlling the RF pollution. Although, the RF transmission in microwave bands is non-ionizing and thus unable to change the structure of atoms and molecules with potentially carcinogenic effects, international regulatory bodies have set several safety limits to constrain the electromagnetic field (EMF) exposure and to avoid biological effects such as tissue heating. WET systems (as any wireless system) are subject to strict EMF regulations, e.g., in terms of specific absorption rate (SAR) and/or maximum permissible exposure (MPE). Specifically, SAR measures the absorbed power in a unit mass of human tissue by using units of Watt per kilogram [W/kg], while MPE constrains the level of EMF radiation specified [W/m$^2$] units. Our work focuses on the former, which becomes more relevant than MPE for short distances, e.g., up to a few meters. Specifically, we included SAR constraints to the proposed per-rotation power control mechanism to make RAB compliant with EMF regulations, thus, avoiding potential risks to human health.

“The outstanding features of RAB and associated performance gains are very promising. Still, much work is needed to further mature/strengthen WET technology, especially in the context of massive WET. We are constantly working towards enabling a fully wireless sustainable society,” concludes López.

Read more:
- ieeexplore.ieee.org/abstract/document/9520826
- oulu.fi/en/research/researchers-stories-and-achievements/oulu-best-choice-6g-researcher
SUPERIOT is a European Union-funded research project focusing on developing sustainable and reconfigurable IoT technologies. It brings together 11 partner organisations across Europe, including universities, research institutes, and private companies. The project is coordinated by 6G Flagship at the University of Oulu, it has a budget of €5M and is scheduled to run for three years, from Q1 2023 to Q1 2026.

SUPERIOT will develop a unique IoT approach exploiting not only radio, as in conventional IoT systems, but also light. In this dual-mode operation, radio and light will provide wireless connectivity, energise the IoT nodes and support robust and precise positioning. This will result in a highly flexible IoT system that can use resources efficiently.

The project aims to develop a genuinely sustainable IoT system by approaching sustainability holistically. In other words, SUPERIOT will develop an IoT system that is sustainable by design and implementation. The project plans to demonstrate that an IoT communication system (infrastructure and nodes) can be environmentally friendly.

One important research area is node implementation. Printed electronics technology will be used to implement IoT nodes sustainably. As the nodes will harvest their energy from radio waves and light, no battery nor maintenance will be required, decreasing the environmental footprint of the solution. Printed electronics technology allows the manufacturing of components to be sustainable and flexible. In the future, printed components could be reused, recycled, or ecologically disposed of.

In addition to working on node implementation, the SUPERIOT project will explore other ways to make IoT technologies more sustainable. This includes investigating new reconfigurable optical-radio operation methods that could reduce energy consumption and developing new communication protocols specifically designed for low-power IoT devices.

Radiowaves and light put into use side by side

Professor Marcos Katz, the coordinator of the SUPERIOT project, sits down with us to discuss the project.

“We aim to develop a new generation of sustainable and reconfigurable IoT (RIoT) technologies, which will significantly impact how we live in future. Innovative hardware and software components will be combined with radio and optical networks to create a highly flexible IoT system that works in different environments and under changing conditions. The reconfiguration capabilities will allow to flexibly combine radio and light to fulfil the requirements of different applications, even under dynamic changes of the operating scenarios.

These types of technologies will help us move toward a more sustainable society. They will help reduce our environmental footprint and make our devices and infrastructure more energy-efficient,” Katz explains and continues, “One aspect of
the SUPERIOT project we should not overlook is that it will help create new business opportunities and, therefore, also new jobs.”

**RIoT - reconfigurable optical-radio concept**
We ask Katz about RIoT in more detail. “When you say RIoT as a word, it sounds forceful,” Katz smiles. “We spell it out: ‘R-I-O-T’ to avoid confusing people thinking about any public disorder. RIoT is a reconfigurable optical-radio concept where the system automatically decides the best way to exploit radio and optical resources according to the prevailing situation. The decision depends on the availability of the networks, security issues, the application’s requirements, the user or operator decisions, etc.

**Precise goals keep the team on track**
The SUPERIOT project will showcase the technology’s potential through four proof-of-concept demonstrators. “We intend to create and demonstrate a RIoT optical-radio node, a RIoT optical-radio network, a printed limited-capability IoT node, and a large-area IoT node. These demonstrators will be built around applications. In the testbeds, the concepts of dual-mode optical-radio energy harvesting and dual-mode optical-radio positioning will also be demonstrated,” Katz outlines the project’s ambitious goals.

By the end of the project, the team aims to have developed new technologies that can be used to create genuinely sustainable IoT solutions. Compared to current offerings, the newly developed IoT concept will use more efficiently energy, spectrum, and infrastructure, and will be implemented with sustainable technologies.

**A future-proof concept**
Professor Katz thinks this project can be seen as an initial step towards developing much more impactful technology.

The 6G era will see the emergence of very low-cost, no-battery printed IoT nodes, sticker-like small surfaces than can be attached anywhere, converting virtually any possible object into a connected entity. In the long term, we will be able to integrate onto surfaces other communication technologies and other functionalities such as sensors, actuators, computational resources, and energy harvesting units, all implemented with printed electronics technology.

Katz refers to the Living Surfaces concept, where any surface, small or large, can be viewed as an opportunity to integrate functionalities sustainably, thereby creating active areas that interact with the environment and people. “In many cases, no additional physical devices are required. The walls, ceiling, floor, tables, or surfaces of smaller objects can be covered by an ‘active skin’, which contains key capabilities like displays, access points, microphones, screens, touch-sensitive areas, lighting panels, computing units, IoT nodes, environmental sensors, energy harvesting and storing blocks,” Katz lists. These functions could be designed to be massively repeated across the surfaces, ensuring that they are always present and close to the user. “This vision won’t come true in the 6G world, however, but rather in the double-digit G world,” Katz predicts.
The development of future technologies, like 6G, is largely contingent on business model innovation. Understanding emerging new business opportunities and novel business models and their consequences calls for a multidisciplinary approach where technology, regulation, and business come together. Data-based content, location or service-specific context, and platform-based commerce business models are expected to complement 6G connectivity-related business models.

The local and private 6G networks are an excellent example of where any combination of these four is expected to occur. Private local networks are suitable for future factories and campuses like hospitals, universities, or shopping malls where humans and machines use 6G for different purposes. “Algorithms, novel devices as components, open interfaces that connect different systems, and data owned by various stakeholders are the new sources of business opportunities and value creation in 6G,” underlines Professor Petri Ahokangas at the Martti Ahtisaari Institute. He refers to this method as the ‘acid test’ approach to creating new value. “With emerging novel opportunities,” he continues, “businesses cannot be successful until new regulations and societal challenges are solved.”

What will 6G business become?
No one knows precisely what 6G will become. Multidisciplinary technology and business foresight can provide insights. “Our recent research has focused on using alternative scenarios and the business model approach to define and describe what 6G could become and how it could be used,”
Ahokangas states, “6G development is also an excellent context for deepening our knowledge on how companies’ innovation landscape will be disrupted in the future,” he continues. This kind of new knowledge will help companies to develop more competitive businesses. “We envision 6G as a multisided, multi-platform business ecosystem where no single firm can create and capture value alone; where collaboration becomes inevitable.”

The team Marja Matinmikko-Blue, Petri Ahokangas, and Seppo Yrjölä have contributed to 6G vision work with a framework that helps to define and describe what 6G could be. They have also explored how companies could profit from innovation with 5G and 6G with novel business models. The results of this research are available in leading business and engineering journals. The team actively researches what human-centricty and triple bottom line of sustainability – combined economic, environmental, and societal sustainability – will mean for 6G business. With the increased importance of mobile connectivity as the backbone for all digitalisation in modern society, questions such as how the requirements for empowerment, inclusivity, and creating trusted and resilient networks will be tackled represent examples of relevant future research questions for the team.

Impacting future regulation and policies
Multidisciplinary business research has already advised the development of future regulation and policies. The group’s research has focused on mapping the regulatory landscape of the emerging future 5G and 6G businesses and proposed how to develop future regulation, for example, in the local mobile communication networks via local spectrum licensing. The team has also contributed to global 6G vision-building at ITU-R.

Another recent research outcome was to propose a framework action plan for benefiting from 6G innovation at the European level. Ahokangas concludes that for 6G, Europe should “build a competitive innovation policy, develop European values-based regulation, consider full triple bottom line sustainability, pay attention to the trustworthiness of 6G, and ensure sovereignty in 6G.”

As a part of the 6G Flagship, the team has built a unique expertise for analysing and developing the business of 6G with a global impact. “It took our team a decade to build the expertise needed to make sense of mobile business in 6G,” Ahokangas concludes.

Read more: 6gflagship.com/white-paper-on-business-of-6g

With emerging novel opportunities, businesses cannot be successful until new regulations and societal challenges are solved.
Zaheer Khan, the newly appointed professor in System on Chip Technologies (SoC) at the University of Oulu wants to make the most of the connection between academia and industry.

The professorship has two goals, as he sees it. “The first is you make people in research more familiar with SoC architectures and intellectual property core designs used in SoCs. The second is that we train people in research in a way that fits the needs of industry,” he says.

Khan is looking to nurture a group of experts at the University who have a strong connection to electronics, computing, computer science and wireless technology. Algorithms are only a part of the equation, says Khan, and he wants to emphasise the importance of platforms now and in the future.

In the 4G era, Khan’s main research interest was making networks more adaptive. He received two PhD offers, one from Paris and the other from Oulu.

“I had lived in Sweden for three years when I got my Master’s degree there in electrical engineering, so I knew about life in a Nordic country. In the end, we decided to come to Oulu,” Khan says.

Game theory, a concept from economics, was a hot topic, which meant looking at networks as strategic entities that can make adjustments to their environment intelligently. This was the topic of his doctoral thesis, which he completed in 2008 in Oulu.

After his PhD, he got funding from the Finnish Academy and collaborated with Professor Matti Latva-aho. By this time, 4G research was going forward to the next generation, 5G.

“During this period, I changed my research focus because I saw a lot more potential in how we use different computing platforms for wireless algorithms. Theoretically, we can hypothesise about wireless algorithms, but how could we design and prototype them for real systems? So, I started working on embedded systems because when you go to a real algorithm designed and implemented on a chip, there are real constraints such as area and energy in addition to performance.”

Khan started playing around with FPGAs, or Field Programmable Gate Arrays. These are semiconductor devices which can be reprogrammed to the desired application or functionality and can be used to simulate how wireless algorithms perform. Eventually, the project he was working on ended, and he took a leave of absence from the University of Oulu to join a Tenure Track Position at the University of Liverpool, England. During his work in Britain, he moved from working with Wireless Access Research Platforms (WARP) to more advanced Zynq-based wireless platforms for his work.
Towards 6G
During his time in Britain, Brexit happened, and Khan and his Finnish wife started figuring out their next step and eventually decided to move back to Oulu. He applied for a position at Nokia and started working as a Technical Lead in Nokia’s SoC Architecture and Specification Group.

He, academia, and industry are shifting their gaze to 6G, the next generation of telecommunications technology. Khan is keen to stress the computing platform and its significance.

_For every new ‘G’, two things have happened. You can have more antennas, and you can have more bandwidth._

“For 6G, my question is how we can make algorithms more efficient given that computing platforms are changing very fast. This is extremely important. To keep the pace with platform development, we must design algorithms from the platform’s perspective and improve the computing platform for wireless algorithms.”

For every new ‘G’, two things have happened, says Khan. You can have more antennas, and you can have more bandwidth. Both of these things mean you have to be able to handle much more data than before.

“But from an SoC perspective, you don’t have more margin in terms of energy in 6G,” Khan explains. “In the past, when we transitioned toward 7 nanometer (nm) process technology, we saw expected gains in terms of area and energy. However, 5 nm chips do not seem to perform in terms of area and energy efficiency as well as they should. As chip makers are trying to transition from 5nm to 3nm technology, transistors are reaching a tipping point, and the gains in energy efficiency tend to decrease. The same can be said about different generations of memory.”

As the easy gains seem to have been reaped already, 6G presents new challenges, Khan muses.

“We need to come up with very clever strategies to process more and more data efficiently in 6G SoCs. Because we can’t expect a smaller area of the chip to carry more and more transistors efficiently.”

_The new professorship will be established with the support of Nokia, Nordic Semiconductor, MediaTek and the City of Oulu._

Collaboration
In late summer and early autumn 2022, the University of Oulu and its 6G Flagship made significant advances in cooperation with Japanese research institutions and companies. A large delegation from the University of Oulu, led by Rector Jouko Niinimäki, Vice Rector Arto Maaninen and Dean Jukka Riekki from the Faculty of Information Technology and Electrical Engineering, met with Shimizu Corporation and NICT. Kazuhiro Fujimura, the Japanese Ambassador to Finland, visited 6G Flagship. And young researchers from Oulu visited the Japanese Science and Technology Agency (JST).

The 6G Flagship Twitter audience appropriately reacted to the many good tidings from Japan as an excellent example of a handshake on how national programs can lead to global initiatives that benefit all.

The visit to Japan was important for several reasons. Firstly, it deepened the existing cooperation between the University of Oulu and 6G Flagship and Japan. Secondly, it helped to create new relationships and networks between Japanese and Finnish researchers. Thirdly, it showcased the excellent research being conducted at the University of Oulu in the field of 6G technology.

Dean Jukka Riekki and 6G Flagship’s directorate were impressed by the level of research conducted at NICT and the potential for further cooperation between the two institutions. Rector Niinimäki was similarly impressed by the work at the University of Tokyo and saw great potential for future collaboration. Vice rectors Tapio Koivu and Arto Maaninen were very pleased with the meeting with Shimizu Corporation and believe there is excellent potential for further cooperation between the two organisations.

6G Flagship welcomed Ambassador Fujimura and his delegation Kazuhiro Fujimura, the Japanese Ambassador to Finland, paid a visit to the University of Oulu in early September. The Ambassador wishes to see collaboration and cooperation in
wireless communication technology and other cutting-edge ICT technologies between industry, academia, and government, as well as local initiatives that lay the groundwork for such collaboration. By request, the visit included a lot of high technology. “We are interested in how the University of Oulu, Oulu University of Applied Sciences, companies, the City of Oulu (BusinessOulu), and related facilities work together as organisations,” the Ambassador said.

Marja Matinmikko-Blue, the Director of Sustainability and Regulation at 6G Flagship, hosted Ambassador Fujimura at the 6G Flagship. They discussed 6G Flagship research, the global R&D situation for 6G, and the current status of Finnish-Japanese collaboration on 6G.

“In 2016, a joint statement on the strategic partnership between Finland and Japan was signed by then Prime Minister Abe and President Niinistö. In May of this year, Prime Minister Sanna Marin visited Japan, and at a summit meeting with Prime Minister Kishida, cooperation between the two countries in the field of science and technology was emphasised. Today, the world is in upheaval due to various issues such as security environment and global warming. In this context, I think it is very important that Japan and Finland, which share the same aspirations, cooperate with each other by leveraging each other’s strengths in the latest science and technology,” Ambassador Fujimura stated.

Shimizu Corporation teams up with the University of Oulu to develop new 5G technology
On August 31, 2022, the University of Oulu and the Shimizu Corporation signed a Memorandum of Understanding (MoU) in Tokyo. They agreed to partner and jointly explore new possibilities emerging through the evolution of information and communication technologies, including 5G/6G. Both parties agreed to start with a co-funded Idea Contest to explore new possibilities using 5G/6G technologies to make society more resilient, inclusive, and sustainable.

Wireless communication and disruptive technologies beyond 5G/6G are expected to enter the market around 2030, disrupting various industries, including the A/E/C industry. Numerous researchers and practitioners are investigating new possibilities in 5G/6G-related technologies and the application of such evolutionary technologies in advance. Through this collaboration, the brightest minds will be encouraged to envision a better world and develop critical, world-changing ideas that can contribute to a brighter future for all. Participants will also be required to co-create future-applicable product and service prototypes. This industry-university collaboration is anticipated to benefit education, energy, logistics, and personal health.

The Idea Contest will be held in conjunction with a radical innovation course designed by the University of Oulu. Entries to the contest will be judged by both parties and Professor Akihiro Nakao of the University of Tokyo’s Graduate School of Engineering. With the assistance of Shimizu Corporation’s Business Innovation Unit (BIU) and potential partners in Japan and beyond, the contest winner(s) will be invited to Japan in July 2023 to share and exhibit their creative ideas and prototypes.

The University of Oulu is known for its expertise in information and communication technologies, while Shimizu Corporation is a leading Architectural/Engineering/Construction company with a long history of innovation. This partnership will allow both parties to explore new possibilities and advance the field of information and communication technologies.

Future-oriented research beyond 5G and 6G
Back in September of 2021, the Japanese Science and Technology Agency (JST) hosted a web-based workshop on the Future IoT. In August 2022, JST extended an invitation to all those who had attended the virtual workshop to foster further collaboration and connections between young postdocs and assistant professors in Finland and Japan. The visit focused on future-oriented research beyond 5G and 6G, the Internet of Things (IoT), and international cooperation.

6G Flagship representatives included Professor Tarik Taleb, Assistant Professors Onel Alcaraz López, Erkki Harju, and Research Director Susanna Pirttikangas. The 6G Flagship delegation was headed by Dean Jukka Riekki of the University of Oulu’s Faculty of Information Technology and Electrical Engineering.

Discussions at the roundtables and lab visits at the National Institute of Information and Communications (NICT) included various cutting-edge issues, including quantum cryptography, beyond 5G-related technology, multilingual translation technology, and cybersecurity.

Professor Hide Tokuda, president of the NICT, launched the in-person conference on future IoT collaboration by discussing NICT’s involvement in standardisation initiatives beyond 5G/6G. He updated NICT’s contributions in the ITU-R SGS’s work on the future 6G vision in June of 2023. Although representatives from both countries were immersed in fruitful discussions on wireless technology and hardware, security, data management, analysis, and 6G and future IoT applications, time was also reserved for having some しゃぶしゃぶ (Shabu-shabu).
Four days of telecommunications research talks, dazzling keynotes, special sessions, workshops, tutorials, and panel discussions were a tremendous success. From the 7th to the 11th of June, the who’s who of Europe’s telecommunications industry gathered in sunny Grenoble at the heart of France’s Silicon Valley for the 31st EuCNC & 6G Summit.

This was the first large-scale European wireless community event after two years of Covid restrictions. Although the days were long and the topics were complex and serious, the exuberant joy of reunion among speakers and participants was tangible.

The European Union has taken extraordinary steps to mitigate the humanitarian crisis in collaboration with key stakeholders.

First Covid, and now Russia’s war on Ukraine, has underlined the importance of connectivity, and the importance of network resilience has gained appreciation.

Although telecommunications conferences naturally give much credence to the various technical aspects, many speakers clearly emphasized the importance of the user, that they be the focus of everything we do, as well as the significance of going beyond the traditional mobile network operators. Understanding the increased need to address the entire supply chain, including microelectronics, also received particular attention due to Covid and the Ukraine war.

In the coming years, 6G systems are expected to provide a new leap forward in performance from Gigabit to Terabit capacities.
and sub-millisecond response times. New smart network technologies and architectures will need to dramatically improve connectivity infrastructures’ energy efficiency to manage significant traffic growth while keeping electromagnetic fields within strict safety limits. Technologies will also need to serve as the foundation for a user-centric Next-Generation Internet and address SDGs such as technology accessibility and affordability.

“We are back in business organizing conferences like this. 522 conference guests on-site and 16 sponsors mainly from industry clearly show that both researchers and industries want to attend and support conferences. CEA-Leti did a marvellous job in practical arrangements which made us all enjoy these four days,” says 6G Flagship Director, Professor Matti Latva-aho in reflecting on the conference.

This year is an important milestone toward 6G communications systems in European RDI. The European Partnership on Smart Networks and Services (SNS) collaboration should enable European players to develop technological capabilities for 6G systems as the foundation for future digital services by 2030. The scope goes beyond networking, encompassing the entire value chain, from components and devices to the Cloud, AI, and cybersecurity. Events like EuCNC & 6GSummit help bring together the many players who must ensure the trust, security, and competitiveness of future technologies beyond 5G and 6G.

522 conference guests on-site and 16 sponsors mainly from industry clearly show that both researchers and industries want to attend and support conferences.

Read more:
eucnc.eu/2022/www.eucnc.eu

Watch selected interviews:
youtu.be/xIMDdqCWmGY

View recordings:
eucnc2022.com

Professor Aarno Pärssinen leads a panel of experts on the topic of “Developments and Challenges Enabling 6G THz Radio HW.”
This year's SPAWC was a hybrid event, allowing people to meet both in person and virtually. The event’s 23rd edition drew in 180 signal-processing professionals in total.

Signal Processing Advances in Wireless Communications (SPAWC) is an annual signal processing conference hosted by the IEEE Signal Processing Society. This year’s conference was held in Oulu for the first time and for the second time in Finland. SPAWC began at the end of the 1990s. Since then, it has held an annual event to provide a forum for academics and professionals to present their most recent signal-processing research and findings.

The event is a small single-track conference where papers are presented as a poster. Contrary to larger conferences, this helps people occupy the same space together and creates a splendid environment for having fruitful discussions and making new connections over exciting topics. All oral presentations, as is customary at SPAWC, are done by invitation only.

Many researchers are interested in the sixth generation of mobile communications. This year’s conference drew well-known researchers, such as TU Dresden’s Professor Gerhard P. Fettweis, who spoke in his keynote about the importance of reducing energy consumption and the bottlenecks in developing transceivers. He urged developers to reconsider their 6G objectives, stating that we must correct what went wrong in 5G. Fettweis believes that data connections should be made more affordable, use less energy, and be more secure.
Recognising that people from other research institutions share similar perspectives on developments gives the confidence to continue research with new insightful ideas. Assistant Professor Nir Shlezinger, for example, provided support by demonstrating with a few examples how we should not turn a machine learning neural network into a big black box but rather use the structure as much as possible and direct it to solve complex partial problems.

The exoticism of Finland shone through in every way. The participants experienced the Finnish smoke sauna, a traditional style of sauna that has been added to the UNESCO list of Intangible Cultural Heritage, on one white night. Conversation among colleagues became more casual, as it does in a Finnish sauna, and bonds became stronger.

These types of events bring together the best in the field. They are critical for young doctoral researchers because they allow them to network with others in the field. They are also important for long-term signal processing professionals as they network and absorb new ideas. The post-presentation discussions were lively, and many new connections were made. One-on-one workshops are excellent for gaining a thorough understanding of all papers and having time to discuss and get to know colleagues, network, and generate new research ideas.

We want to thank all participants for your active participation and a fantastic event. Next year SPAWC is arranged in Shanghai, China. See you there!

**Read more:** spawc2022.org

Among the keynote speakers were also Ali. H. Sayed, Lee Swindlehurst, Andreas Molisch, and Wen Tong. The use of artificial intelligence in mobile networks, propagation channels for sixth-generation wireless systems and what they mean for signal processing, and native AI-enabled 6G networks - challenges and design aspects were among the topics addressed in the keynotes.

This year’s International Workshop on Signal Processing Advances in Wireless Communication hosted altogether 180 signal processing professionals.
WHAT EXTERNAL FORCE WILL PUSH 6G BEYOND AN IMPROVED VERSION OF 5G?

Professor Henning Schulzrinne will be conferred as an Honorary Doctor at the University of Oulu at a ceremony this weekend. He has called it “one of the memorable occasions that define an academic life” and is very honored to have it bestowed upon him by Oulu, a place he has strong ties to.

Professor Henning Schulzrinne has a long-running relationship with the northern University and was a member of the original 6G Flagship Scientific Board. Having made fundamental and pioneering contributions to key protocols used in Internet multimedia applications in a career that spans several decades, the Internet Hall-Of-Famer is well poised to outline what he sees as the future for research in next generation communications.

Schulzrinne has a background in electrical engineering and he got his PhD in the subject at the University of Massachusetts in 1992. He worked on signal processing and participated in research and development that was concerned with how to better carry voice and video across the Internet. Developing communications is a throughline in Schulzrinne’s work to this day, as he has been working with public safety systems, evaluating how public health measures such as lockdowns impact Internet usage and performance, and
how very large, real-time Internet of Things systems work with millions of devices online.

**6G: Two perspectives**

Schulzrinne has also been an integral part of 6G research at the University of Oulu. In 2019, the 6G Flagship stated its vision for the next generation of telecommunications as such: “The vision for 2030 is that our society is data-driven, enabled by near-instant, unlimited connectivity.” How does Schulzrinne feel about this statement in 2022?

“I think there is still no grand convergence in terms of what 6G is going to be. Instead, there are two broad and different perspectives on what it might be”, Schulzrinne says.

“The first perspective maintains that 6G is going to be an architecture with behaviour very similar to 5G. It will be a relatively modest transformation with some additions, maybe a set of releases that will at some point be called 6G. You will see large, typically nationwide carriers operating networks that are maybe supplemented with some local enterprise solutions, much like what has happened with 5G. In other words, if you were to time travel, things would look pretty much the same—only a little faster.”

The second perspective is one that changes the current models and ecosystems, says Schulzrinne.

“This extends the concept of semi-private, semi-public IoT systems where people put up base stations not just for personal use or for corporate use but also available to third parties. These are systems that can be designed by any device that happens to be in a certain area. I wonder if the 6G model will try to be more cognizant of the fact that there are at least three ecosystems, from large network providers to the enterprise, home, and public-private models and whether they can be better integrated architecturally”, Schulzrinne muses.

The easiest path forward is more of the same: current businesses are not invested in disrupting themselves. Usually for major change to occur, there has to be some external force setting it in motion. Schulzrinne brings up GSM as one such example: there was a strong political desire for a trans-European standard in mobile telephony, even though network carriers and vendors didn’t mind having national cellular markets as it provided some protection as well. And 4G happened because the Internet became a must-have service and telephones had become pocket computers.

“So, what is going to be the equivalent disruptive element for 6G to make it more than gradual improvement of 5G technology?” Schulzrinne asks. “Is it virtual reality? Is it this expectation that people will want to do things that require a hundred per cent of their attention all the time? VR gaming and entertainment are great immersive experiences people can do for a couple of hours a day maybe, but most people don’t have the luxury of spending all day every day in the metaverse and are unlikely to do this while walking or driving,” Schulzrinne says. And considering the way things are in the world today, do we need more escapism?

**Connectivity alone will not be the solution**

To take 6G to another level means embracing a variety of business and technology models which will allow for more flexibility. As Schulzrinne sees it, there will be combinations of operator and private enterprise models as well as hybrid models. Also there might be less emphasis on connectivity, moving forward. For sure, there are many areas where adding connectivity can bring more value, such as energy management, traffic safety or wildlife monitoring. But many of our concerns today and in the future are not about enabling just connectivity in and of itself, Schulzrinne argues.

“For many of the issues that we grapple with today, such as infectious diseases, global warming and degradations of political systems, what will more connectivity mean? The technology that helped us during the pandemic was pretty basic. It was Zoom, emails, data management. It wasn’t super fancy connectivity,” Schulzrinne says, his video image and voice carried over the Internet from the U.S. to Finland for our interview in a scene that would have been deemed science fiction only 30 years ago, instead of just another day at the office, as it is today.

Even if technology helps us communicate across borders smoothly, research is becoming more regional, says Schulzrinne. For a place like Finland, this can be a major opportunity.

“I think 4G research was the peak of ‘internationality’ in the sense that we had a global standard that everybody used and everybody developed. The next generation alliances seem to be more regional, aligned geopolitically. Another factor is that the number of organisations in communications research is relatively small, which is a real incentive to reach across borders internationally. There are major opportunities for collaboration and small countries like Finland can have a large impact. The U.S. Europe and Finland are well aligned, they share similar values, they have similar ideas on things like privacy, who should run things and so on,” Schulzrinne says.

**Listen podcast episode:**

[open.spotify.com/episode/3DYcbatSEJit2yFazAhwft](open.spotify.com/episode/3DYcbatSEJit2yFazAhwft)
University of Oulu’s 6G professors again among the top researchers in the world

Researchers Mehdi Bennis and Tarik Taleb from the University of Oulu are nominated as Highly Cited Researchers. This means that they are in the top one percent in their field in the number of citations of research publications.

Of the researchers working in Finland, 18 researchers made it to the list this year. Two of them are located at the University of Oulu’s Wireless Communications Research Center (CWC) and the 6G Flagship coordinated by the Academy of Finland. Bennis and Taleb were on the list last year as well.

The highly anticipated annual list identifies researchers who demonstrated significant influence in their chosen field or fields by publishing multiple highly cited papers during the last decade. Determining the “who’s who” of influential researchers draws on the data and analysis performed by bibliometric experts and data scientists at the Clarivate Institute for Scientific Information. It also uses the tallies to identify the countries and research institutions where these citation elite are based.

Read more:

2022 IEEE Antennas and Propagation Society Fellowship to Dr Tung D. Phan

Dr Tung D. Phan, a postdoctoral researcher at the Centre for Wireless Communications and 6G Flagship, has been awarded a 2022 IEEE Antennas and Propagation Society (AP-S) Fellowship. The Committee chose the applications that scored the highest based on reviewer scores and other pre-set metrics. Dr Phan will continue his research as planned and will be awarded a fellowship of 5,000 USD as well as an award certificate to commend his efforts.

Read more:
RF SAMPO project strengthens Finland’s competitiveness in radio technologies

The RF SAMPO project is designed to enhance Finland’s competitiveness in radio technologies. The project’s primary goals are to improve the efficiency of developing new RF and antenna technologies and increase the commercial viability of these advancements. Finland has a strong tradition in radio technologies, and this project will investigate new RF solutions for 5G and 6G. The RF Sampo project will create new jobs and business opportunities through technological development.

The project includes the development of radio subsystems, components, and algorithms. The coordinator is professor Aarno Pärssinen from the University of Oulu.

Partners of this industrial co-creation project funded by Business Finland include at the moment nine companies and three research organizations: Nokia, Flex, Bittium, Optenni, Keysight Technologies, SAAB, Senfit, Okmetic, ExcellAnt, University of Oulu, Aalto University and VTT. Overall budget is 14 million euros.

Read more:
6gflagship.com/collaboration/rf-sampo-project-strengthens-finlands-competitiveness-in-radio-technologies

Finnish Foundation for Technology Promotion prize to Onel Luis Alcaraz López

Onel Luis Alcaraz López received the Finnish Foundation for Technology Promotion prize. His research focuses on energy-efficient solutions, algorithms, and protocols that can reduce the energy consumed by charging and transferring energy. This year, the quality of Young Researchers of the Year applications the Finnish Foundation for Technology Promotion received was so high that TES decided to grant two prizes of €10,000 each for the first time.

Read more:
Happiest Country in the World
Finland has been ranked the world’s happiest country for five years in a row. It is a land where world-class research and innovation thrive; where life is safe and easy. The crime rate is low, the social safety net is strong, the air is clean and pollution-free, and the water is safe to drink straight from the tap.

Finland has excellent public services and a strong economy. Children attend school free, and municipal childcare and universal healthcare are available to all residents. 6G Flagship employees receive occupational healthcare. And the University of Oulu has a special Spouse Programme, which helps the whole family to adjust to the Finnish society.

High Tech Up North
The city of Oulu is the home of 6G Flagship. The city is located in northern Finland, which is widely regarded as one of the world’s safest and most stable regions. With only 250,000 residents, Oulu is quite compact, but it is also very smart! A whopping one third of the residents has a university degree.

Oulu is a major high-tech hub, with 50 years of experience in ICT and related operations – technologies used by almost 3 billion people every day. The university of Oulu has a long history with telecommunications technology, and particularly wireless telecommunications research. It has been a strength of the university since the 1st G in the 1980s.
The big pro of Oulu is an optimal life-work balance, I think it’s one of the best - better than Stockholm, better than Helsinki. Why? Life is so easy and simple. You don’t have to commute. My gym, my supermarket, my house, my office are within half an hour’s walk. I don’t have to drive, I just bike to work. To me this is unbeatable.

Professor Mehdi Bennis

Compact City – World-class Research
The university is home to the world’s first 6G research programme, 6G Flagship, where top innovators and leading experts work passionately to build a data-driven, sustainable future society.

Professor Mehdi Bennis, one of the world’s most highly cited researchers and and a Professor at 6G Flagship, summed Oulu’s appeal to world-class researchers perfectly: “The big pro of Oulu is an optimal life-work balance, I think it’s one of the best - better than Stockholm, better than Helsinki. Why? Life is so easy and simple. You don’t have to commute. My gym, my supermarket, my house, my office are within half an hour’s walk. I don’t have to drive, I just bike to work. To me this is unbeatable.”

Join the crew of trailblazers in 6G
6G Flagship is continually looking for new talents. We offer positions for doctoral and post-doctoral researchers in four research areas:
- Wireless Connectivity
- Devices and Circuit Technology
- Distributed Intelligence
- Human-centric Wireless Services

Are you the trailblazer we are looking for? Apply to one of our four research areas and help us shape the future of wireless communication!

Read more and apply: 6gflagship.com/careers
6G Flagship in Numbers

2018 - Nov 2022

Staff

483 experts in 2022

49 Nationalities

56% International

Publications

2,324 Peer-reviewed publications / Journal and conference articles

73% Joint publications with collaborators

66% Joint international publications

12% Joint publications with companies

6G White Papers

White Paper 2019 155,349 downloads*

White Papers 2020 875,246 downloads*

1,030,595 Total White Paper downloads*
### Doctoral Degrees

- 81 Doctoral degrees
- 281,834 Doctoral thesis downloads*

### Investments & Funding

- 354 Research projects (external funding)
- 120 Companies investing in research portfolio

### Company Collaboration

- 432 Company collaborators
  - 49% International

### 6G Waves

- 315,648 Total downloads

* Number of downloads of 6G White Papers in University of Oulu repository [jultika.oulu.fi](http://jultika.oulu.fi)