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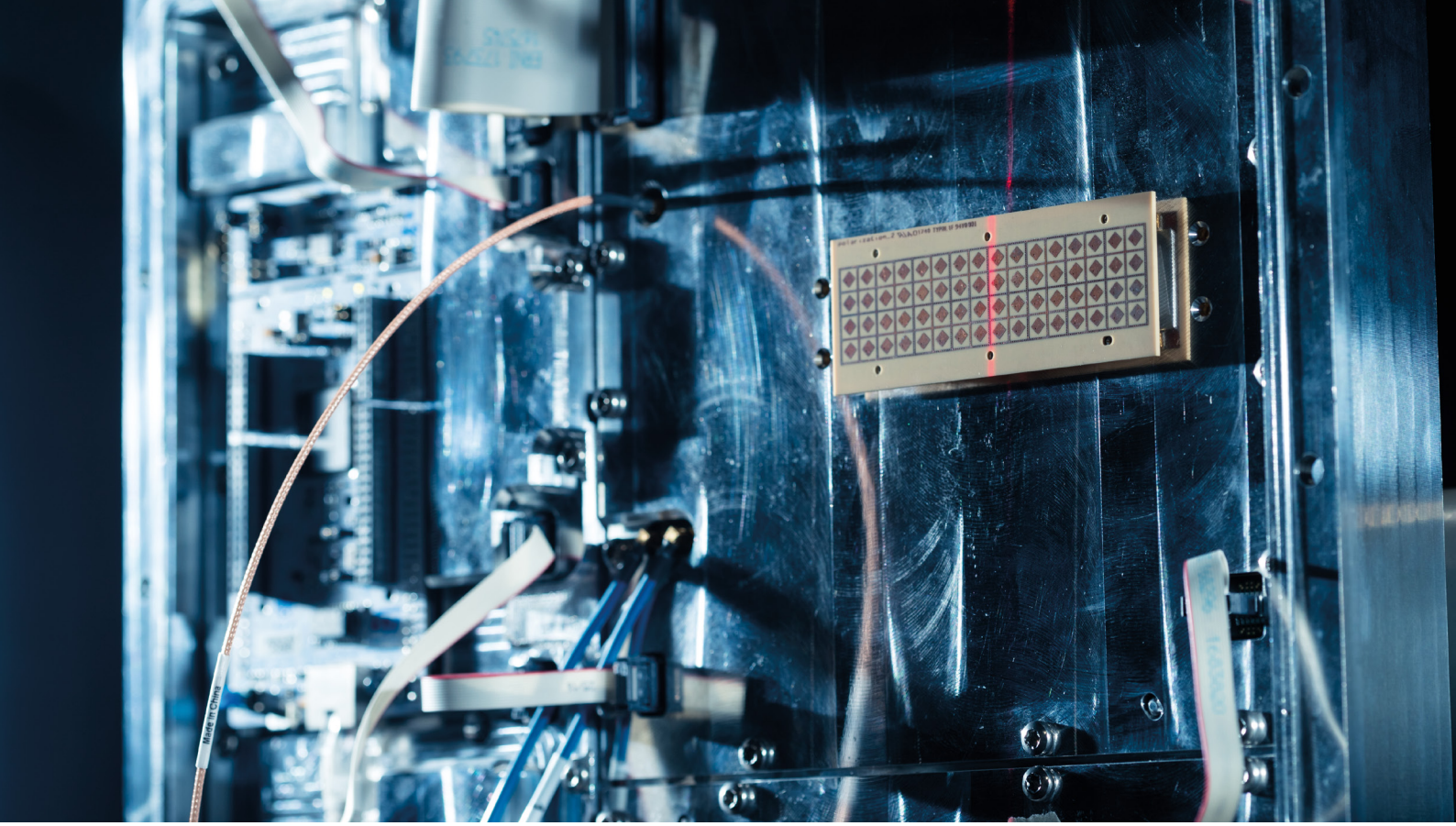
6G WAVES MAGAZINE

6G FLAGSHIP
UNIVERSITY OF OULU



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Photos: Janne-Pekka Manninen and Mikko Törmänen, among others.

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ACADEMY OF FINLAND

FLAGSHIP PROGRAMME

GREETINGS

On behalf of the Scientific Advisory Board, welcome to the first edition of the 6G Flagship magazine "6G Waves"!

The 6G Flagship is a bold attempt to shape the future of mobile communications. Framed around 2030, the Flagship is exploring technological responses to the challenges and the opportunities of evolving digital markets, a growing, ageing global population, changing societal needs, and other factors shaping our digital future. These are big concepts and the responses of 6G need to be ambitious. This magazine will help explore these issues and humanise the technologies being researched. This first edition helps frame the Flagship and covers topics including vision statements, research areas, co-creators, innovators and recent highlights.

The world's first 6G Wireless Summit was held in Levi, Finland in March 2019 bringing together experts from around the world. The 2019 event highlighted the technological advances of 5G, but also took the first steps at describing "what next". The white paper from 6G Summit described the step-change from the trajectory of 5G and the requirements of 6G.

In its second year, the Flagship continues to evolve, fostering collaboration, enabling world-leading research, and refining the vision of our future connected world. The technical papers from the 2nd 6G Wireless Summit 2020 and the 2020 white papers will take us further, covering a greater range of topics and continuing to address major research and technology challenges.

Welcome to the world of 6G!

Ian Oppermann

Chair of 6G Flagship
Scientific Advisory Board

Chief Data Scientist,
New South Wales (NSW)
Government

On the behalf of 6G Flagship Advisory Board I have great joy to introduce to you this first issue of the 6G Waves magazine which highlights the visions and latest achievements of 6G Flagship!

A lot of new technology and business models for 5G and beyond will be developed during the coming years in numerous research and development initiatives around the globe. Finland as a neutral, agile and flexible society offers an excellent innovation environment for future solutions.

In this magazine, you will find out why Oulu is an ideal spot for creating the first functional 6G test network and trialling proof of concepts leading to 6G. Over the last three decades, Oulu, the home of Nokia Radio, has been the forerunner in new ICT technologies. We are looking forward to giving our best effort again – this time for 6G.

The best results are achieved when open discussion takes place between professionals in an inspiring environment leading to new initiatives and collaboration. The second 6G Wireless Summit will be organised in Levi, Finland on 17-20 March 2020. The nature of Lapland has been the source of many unique ideas, which have made Finland what it is today. I hope that this inspiring environment will boost 6G research and steer global development efforts to a successful track!

In the next issue of the biannual magazine, you will be able read about the outcomes of the second 6G Wireless Summit and joint research efforts towards 6G. I wish you an inspiring reading experience!

Juha Ala-Mursula

Chair of 6G Flagship
Advisory Board

Director of BusinessOulu

Matti Latva-aho, Director of 6G Flagship

6G FLAGSHIP IN BRIEF

The Finnish 6G Flagship is a vigorous research and co-creation ecosystem for 5G adoption and 6G innovation led by the University of Oulu and appointed by the Academy of Finland, a governmental funding agency for high-quality scientific research. The total budget for the 8-year Flagship programme is 251M€. The programme is operated in collaboration with Aalto University, Business Oulu, Oulu University of Applied Sciences and VTT Technical Research Centre of Finland Ltd. Currently, 6G Flagship has three company co-creators: Nokia, Keysight Technologies and InterDigital.

As 5G enters its deployment phase, 6G Flagship supports global industry in the finalization of the 5G standard especially through joint projects, trials and demonstrations. At the same time, 6G Flagship experts are already working on essential technology components and solutions needed for the 2030 wireless era and seeking for major scientific breakthroughs in the interrelated domains of wireless connectivity, device and circuit technologies, distributed intelligent computing, and novel applications and services. With this approach, 6G Flagship envisions a future society, which is data-driven and enabled by near instant, unlimited wireless connectivity.

6G Flagship invites a variety of stakeholders to join the 6G Flagship ecosystem and to collaborate in ambitious research initiatives towards 6G, which aim at creating new business opportunities as well as responding to United Nations' sustainable development goals and major societal challenges.

Read more

6gflagship.com

Take a look at our vision video "6Genesis vision for 2030" in YouTube which has already been viewed 102 427 times!

LET'S SET OUR MINDS FREE!

6G research is gaining momentum all around the world now that 5G NR and its evolution path has become quite obvious. WRC'19 did not yet offer a significant spectrum regulatory booster towards 6G but that is exactly why 6G research will experience a Klondike gold rush during the next few years. No boundaries have yet been set for 6G requirements and therefore we have to set our minds free!

Of course, researchers would need some funding to grease the wheels and several governments have already started building national 6G programmes. In Finland, we started already in May 2018. We felt that one of the first things to do is to set up an international forum for the growing 6G research community where all researchers, from any part of the world, can get together to define fundamental requirements and key drivers towards 6G. In the middle of the trade war between US and China, this is utterly important. As a result, 6G Wireless Summit was born.

We in 6G Flagship have taken a very ambitious path via open white paper expert groups which aim at defining critical research questions related to some of the key areas of 6G. Moreover, we have felt that our community must take United Nations' Sustainable Development Goals (UN SDGs) seriously and we should define key performance indicators (KPIs) aiming at reaching the UN goals. Not an easy task by any means!

This work has given rise to several serious questions on how to enable global coverage in an affordable manner to those who are currently unconnected. This is a question related to several issues of economic, political, regulatory, business as well as technical challenges. Data security and privacy are also growing concerns together with ethical questions. So, 6G most definitely deals with many other issues besides wireless connectivity challenges.

Another interesting, although obvious, venue towards 6G is responding to the ever-increasing demand for broadband wireless connectivity. An evident trend towards mmWaves and even beyond will change RAN technologies quite dramatically. Very accurate beamforming and physics of radio wave propagation will transform the way networks operating at high frequencies should be designed. Super-efficient short-range connectivity solutions are needed to offer Tbps speeds mainly in indoor as well as inside vehicles. In machine-type communications, the uplink capacity needs to be boosted with more limited transmitter capabilities compared to downlink direction. Again, a great challenge to be looked at as well as many other transceiver implementation-related research topics. After all, 5G has already shown needs to improve transceiver energy efficiency dramatically.

A great promise of 5G has been a dramatic increase in different verticals. We may think of designing, optimizing and even operating future mobile systems or parts of them by better understanding different key verticals through questions such as: what is a typical radio propagation environment, what are the capacity requirements, how about reliability and latency constraints, energy and cost constraints, network operation and ownership principles, what about spectrum availability, and so worth. Thus, verticals must be driving some of the development efforts of future wireless systems. Otherwise the current "one solution fits all" approach will continue leading to rather inefficient solutions.

Our 6G Flagship Programme based in Oulu, Finland is looking at all of these challenges and many more in a vivid international research community of more than 300 researchers from more than 50 countries. We are constantly looking for new collaboration opportunities, offering visitor positions as well as recruiting new staff members to cover the most relevant and demanding areas of 6G development. We will keep you posted on our work via this biannual 6G Waves Magazine. Enjoy reading!

Matti Latva-aho,
Director of 6G Flagship

FIRST 6G WIRELESS SUMMIT

287 participants from 28 different countries spanning all inhabited continents took part in the very first 6G Wireless Summit at the top of Levi ski resort, in beautiful Lapland. The setting for such an event was very fitting, as the aim for the conference - and, indeed, 6G research - is to keep reaching ever higher.

At the Summit, the participants were asked to project themselves into the world in 2030, potentially very different from today. As professor Matti Latva-aho, director of 6G Flagship at the University of Oulu, and the driving force behind the vision of global 6G, puts it "The vision for 2030 is that our society is data-driven, enabled by near-instant, unlimited connectivity. We will be facing a growing and ageing population, demands for increased productivity and the need to connect the billions who are not currently connected. We challenged all of the conference attendants, pressing them to consider this future world beyond 5G and the most essential aspects of 6G research - a decade in advance."

Network with a Sixth Sense

Peter Vetter, Head of the Access Research at Nokia Bell Labs and a Bell Labs Fellow, says that in the future, the network needs to be thought of as a platform that creates network instances for specific environments. "I like to call 6G a network with a sixth sense. This means enhancing our ability to think with augmented intelligence, enhancing our sensing capabilities, deduce meaning, making predictions with artificial intelligence -- in short, enhancing our human existence. To connect the actions in the world beyond human capabilities, you need a nervous system, and the next-generation network will be the nervous system that connects all of these," Vetter says. And the timeline? "6G is still ten years and longer out, and I think that this is a consensus among the 6G Summit participants. However, it is time to start the research right now, because it takes 10-20 years before a new innovation sees a commercial launch," he says.

New Paradigm Calls for Fundamental Research

For wireless revolution to happen, there needs to be a revolutionary communication technology, a revolutionary application of that technology and a whole ecosystem for continued innovation, says Dr. Wen Tong, Head of Wireless Research and Head of Communications Technologies Laboratories at Huawei. "Wireless as a field has plenty of room for innovation. We need a young generation of researchers and an environment that will sustain continued innovation. The problem is not a lack of visionary imagination, it's that we don't have a concrete theoretical path to get to the realization of that vision. And for that we need fundamental research that doesn't focus just on the very near-term solutions," Tong says.

Dreams for the Future

"We need to address both the problems from the real world and the dreams for the future," says Takehiro Nakamura, SVP and General Manager of the 5G Laboratories in NTT DoCoMo. "There will be new combinations of extreme requirements for specific use cases. We need to provide extreme high reliability for a guaranteed quality of service for industry, peak data rates of over 100 Gbps, gigabyte-rate coverage everywhere, and to have everything run at extreme low energy consumption and cost," Nakamura says. As Nakamura sees it, the future will have high-quality, real-time VR and AR. Massive IoT for anything and anywhere, like satellites in space. Broadband for flying mobility, which will need high coverage and high reliability.

6G Is More than Increased Data Rate

Qi Bi, President of China Telecom Technology Innovation Center and CTO of China Telecom Research Institute says he thinks that 6G could be a turning point and a real revolution from 5G also in other terms besides technological. "So far, we have been concerned with the data rate, and while it is important, we need to pay attention to more than just the data rate. ISPs complain that incomes are staying flat and have been saturated. Well, if we turn to personalized services and build intelligent 6G networks that can think and perceive specialized needs automatically, we will find that we really are at a turning point," Bi explains.

What About AI?

Some of the hot topics in 5G and in 6G are machine learning and artificial intelligence. Magnus Frodigh, Head of Ericsson Research, is a big believer in the coming 5G evolution. "AI that is embedded in the network and can work on real-time data is going to be a key factor. Connectivity, the ability to collect more data, Edge computing, closed loop control systems--all of these will bring us to the next world. Computational needs in the device will grow, but the battery and energy consumption will be a limiting factor. There will be strong value to offloading computing from the device", Frodigh says. As networks are Ericsson's strong point, Frodigh says it will be very interesting to see what distributed AI is going to bring to the game.

Getting Ready for a New Socio-economic Reality

Bernard Barani, Deputy Head of Unit in the CONNECT Directorate of the European Commission, looks at next generation development and research as a chance to consolidate the industry. "Europe has an edge and we want to keep it. In the future, we need to take a more integrated perspective with regards to IoT, cloud and services. We will try to develop a model where we support not only research, but connectivity, services and so on, integrating everything in continuation to the 5G story," Barani says. "Even if it's not easy to foresee, this 6G puzzle, it's very important for us to get an understanding of what the industry is considering to be promising avenues in the future. The questions we ask are how do we justify investments in the technology, what are the socioeconomic implications, what shape will networks take in the future, and so on."

One of the concrete outcomes of the Summit was the 6G White Paper which describes the goals of 6G, the use-cases anticipated in 2030 and the associated technical requirements. The paper provides a focus for the major research challenges and helps in setting up the research agenda for the new decade. It is available at *6gflagship.com/6gwhitepaper*.

THE CHALLENGING TASK OF PREDICTING THE FUTURE

6G Flagship published world's first comprehensive review of 6G research topics in September under the title "Key Drivers and Research Challenges for 6G Ubiquitous Wireless Intelligence". The goal was to ignite discussion on 6G research goals in the global scale.

"We wanted to bring experts together to brainstorm 6G research directions so we organized a white paper workshop in Levi, Finland in March 2019 and the results were documented in the white paper," says professor Matti Latva-aho, co-editor of the publication. "Based on the visibility it received in e.g. technology news services, we judge that the white paper was a success and the time was right."

By the end of February 2020, the online version of the white paper has been downloaded 100 403 times.

The content of the publication was collected from 70 workshop participants but editing was done in a fairly small circle of chapter editors. A commenting round allowed the workshop participants to influence the final white paper contents.

"We tried to polish our crystal ball but did not completely succeed," says professor Kari Leppänen, co-editor of the white paper. "Seriously speaking, predicting the future ten years ahead with any level of detail is always challenging, if not impossible."

Leppänen also recognizes that the first white paper represents mainly the views of the traditional telecom sector and a more versatile group of experts might have produced more insightful predictions.

Nevertheless, the white paper presents a strong vision of ubiquitous wireless intelligence for 2030. It portrays how ubiquitous services will follow users seamlessly, everywhere, and wireless connectivity will be part of the critical infrastructure. Furthermore, intelligence will create context-aware smart services and applications for human and non-human users alike.

The paper also illustrates a major difference with previous Gs. In addition to the communication service, 6G will include many other services. "In our view, integration of new services, such as sensing, imaging and highly accurate positioning with mobility opens a myriad of new applications in 6G," Leppänen says.

Most research questions introduced in the publication are quite technical and targeted to experts in specific fields. But several questions are human-centric and carry societal importance. They are just as important for making 6G a success. These questions include the following. "What are the key societal requirements for 6G? How to assess and quantify the metrics towards UN SDG KPIs? What novel opportunities can next generation networks and devices offer to interaction between people? What are proper metrics for data privacy and security?"

By the end of February 2020, the online version of the white paper has been downloaded 100 403 times.

"We encourage experts to check the research questions," Leppänen says. "Finding answers to them will enable major steps towards future wireless systems."

Leppänen concludes his observations of the writing process with a wide smile. "We did succeed in opening the public discussion on 6G."

Read more

http://www.6gflagship.com/6gwhitepaper/

EXPERT GROUPS AS A CATALYST FOR GLOBAL 6G RESEARCH

Encouraged by the results of the first white paper and building on experiences from the earlier writing process, 12 senior experts from 6G Flagship accepted the challenge to go much deeper into novel terrain as leaders of new expert groups.

"We wanted to add more openness and invite more people to join the work," says professor Matti Latva-aho who leads the preparation of the 12 new white papers. "As a result, we had an open call in December for joining the expert groups and now have 330 people signed up."

All topics, which are introduced below with the photos of the expert group leaders, have their roots in the previous white paper. One expert group works on the linkage between 6G and the United Nations' Sustainable Development Goals (UN SDGs) and another focuses on connectivity for remote areas. Both groups reflect major societal challenges. One expert group develops business scenarios for 6G. The remaining groups are more technical and cover validation and trials, broadband connectivity, networking, machine learning, RF and spectrum, edge intelligence, security and privacy, critical and massive machine type communications, and localization and sensing.

Each of the expert groups has around 40 international participants working together through online meetings and contributing to the white paper preparation via questionnaires, among other. "The expert groups have freedom in defining their approaches and outputs, but the common goal is to depict the future research challenges to be solved and to provide a catalyst for 6G research," says Dr. Marja Matinmikko-Blue who coordinates the writing process of the white papers.

The groups are writing the white papers under a tight schedule from January to April 2020. "But this is just the starting point," she points out. "Collaborations around many of the topics will continue long after the white papers are published."

Marja Matinmikko-Blue
6G Drivers and UN SDGs

Ari Pouttu
Validation and Trials for Verticals

Samad Ali
Machine Learning in Wireless Communications

Tarik Taleb
Networking

Nandana Rajatheva
Broadband Connectivity for 6G

Aarno Pärssinen
RF & Spectrum

Harri Saarnisaari
Connectivity for Remote Areas

Seppo Yrjölä
Business of 6G

Ella Peltonen
Edge Intelligence

Mika Ylianttila
Security and Privacy

Nurul Huda Mahmood
Critical and Massive MTC towards 6G

Carlos Lima
Localization and Sensing

GLOBAL CONNECTIVITY CHALLENGE

We need to have a critical look at what still needs to be done after the success of 4G and the great potential promised by 5G. There is an ever-increasing need for capacity increase towards Tbps.

"Super-efficient short-range connectivity is one key direction for our research," says professor Matti Latva-aho, leader of the strategic research area on Wireless Connectivity. Recently, the team has developed a visible light communication (VLC) link to demonstrate capabilities of VLC for future systems. "In collaboration with our RF team we are also creating a mobile broadband communication system for 100-300 GHz frequency range," he says. "As a part of the concept, positioning at the accuracy of better than 10 cm is being developed."

Another important goal relates to remote area connectivity. Digital services must be made globally available also for remote areas and emerging economies. "Often, these do not require the latest and coolest technology, but a robust energy efficient solution for provisioning rudimentary services for daily lives," Latva-aho says. "We see the UN SDGs as the critical driver for the future. Achieving them calls for radically new business models incentivized by local societies and governments to offer fundamental digital services."

At the same time, network architectural solutions beyond MNO driven full-coverage cellular systems are needed. "We have developed a micro-operator concept for serving different vertical needs as well as remote areas' isolated service clusters," Latva-aho says. "The transformation calls for new spectrum regulatory principles as well as legislative changes e.g. related to data ownership." Latva-aho's team works actively with regulatory bodies to foster these new ideas.

A third line of research focuses on machine type of applications which require scalable solutions for URLLC that do not exist with 5G. "Recently, we started collaboration with Electronics and Telecommunications Research Institute (ETRI), South Korea, to jointly develop solutions for URLLC industrial use cases," Latva-aho says. "Although our joint effort is supporting 5GNR evolution, our team is also focusing on beyond 5G solutions: How would one optimize URLLC solutions with different design criteria for different verticals? I believe there will no longer be one solution fits all problems."

The Wireless Connectivity team has been particularly active in developing collaboration with various global players. "We need new strong players, focusing on remote areas and emerging economies, to drive the urgent need for connecting the unconnected," Latva-aho says.

FROM NEW USER DEVICES TO DEMANDING VERTICAL APPLICATIONS

The interdisciplinary Services and Applications team at 6G Flagship derives its research targets primarily from vertical-specific applications and services to create optimized technical solutions and network operating models for the 6G era. The team seeks solutions via rapid trialing using experimental 5G/6G test networks to bring research findings to real-life tests in co-operation with businesses and society at large.

The team has already successfully integrated 5G to electric locks, 4K 360° cameras, hyperspectral cameras and drones. "Integrating wireless capability to our recently acquired smart car is ongoing," says strategic research area leader, professor Ari Pouttu. "Another demonstrated futuristic area is AR/VR glasses, which allow the transmission of diverse, augmented sensor data along with 360-degree video. These allow us to interact with the real physical world in totally new ways for instance in remote medicine, factory control or distance learning to name a few." 6G Flagship's experts have also contributed to the creation of a digital twin of Oulu harbour in which measured sensor data can be displayed in an intuitive manner and in the future the real world environment can be affected from this digital twin.

"We can see for the first time that 5G will truly become an integral part of verticals now that user devices other the mobile phones are starting to appear," Pouttu says.

Another research area raising high hopes, literally, are drones. Besides the entertainment, logistics and media usage, the drones equipped with state-of-the-art wireless are gaining ground in other vertical use cases too. Surveillance and situational awareness of factories, harbours and e.g. power lines of course are obvious use cases. However, use cases such as public protection and disaster relief are gaining popularity as pop-up networks can be established where networks have become non-functional. Furthermore, drones can be equipped with almost any sensoring payload accommodating environmental IoT in the sky. Furthermore, the existing cellular networks can be augmented with base station in the sky in areas of sudden congestions.

Aiming at increased sustainability in wireless itself, the team has also recently developed a concept for a carbon-neutral 5G base station, which uses sunlight and wind for energy production based on extremely accurate energy weather predictions. "We will demonstrate the concept later this year, once the roofs of university campus buildings are free of snow," Pouttu says, smiling.

Yet, the work is only beginning. "These types of application areas are nearly endless," Pouttu says. "We are eager to scale up from medical and industry 4.0 applications in which we have already plenty of promising results."

The target verticals in the first phase of the eight-year Flagship programme include factories of the future (Industry 4.0), healthcare, automotive and transportation, and energy. Pouttu's team of experts looks constantly for new collaboration possibilities for various use cases especially in these verticals. "However, do not feel discouraged if you have an idea outside these areas – we are always willing to try new things," Pouttu says, pointing out to the truly diverse nature of the research and the open-minded approach of the team.

TOWARDS WORLD'S FIRST FUNCTIONAL 6G TEST NETWORK

6G Flagship's Devices and Circuit Technology team targets an end-to-end solution that would be world's first functional 6G Test Network operating at frequencies well above current 5G and with significantly higher bandwidth for data throughput.

The wide international experience and diverse backgrounds of the team are unique assets for the innovation of 6G transceivers, antennas and related measurement systems. The operational setup will combine the ongoing work of several 6G Flagship groups. University research is currently focused on 6G core system building blocks including integrated amplifiers, mixers, etc. for mmW/sub-THz transceivers, antennas and digital signal processing algorithms, among others.

"Research like this requires combination of theoretical understanding and practical approach," says professor Aarno Pärssinen, strategic research area leader. "Promises can be proved only by well-selected small and large-scale prototypes. Making even a single radio link for 6G network requires many different competences of a multi-disciplinary team. In addition to hard work, we must be patient to gradually move towards the big dream of the first 6G network. That will be hopefully built from the elements of our own research as well as innovations of our research partners in academia and in industry."

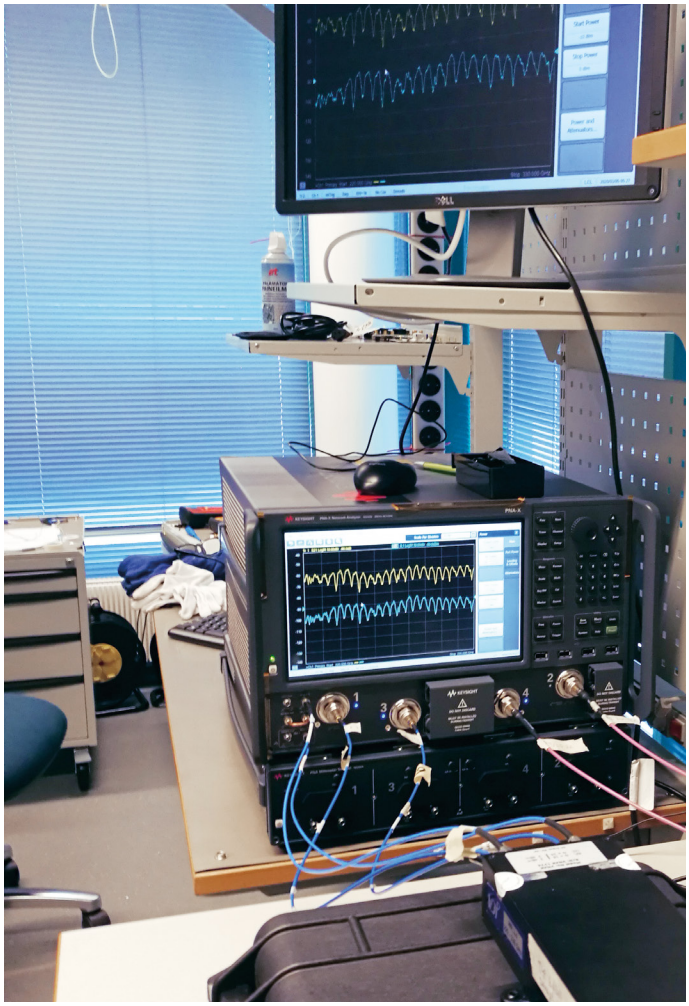
Recently the team's RF measurement capability has increased substantially with the new vector signal analyzer up to 110 GHz donated by Keysight Technologies – one of 6G Flagship's co-creators. Additionally, antenna measurement facility has been updated to 110 GHz, and conducted RF measurement capability to 330 GHz for RF ASIC and other component measurements. The 330 GHz setup can also be used for radio channel measurements and other over-the-air testing.

The work is progressing fast from theory to practical prototypes and trials. The team has already shipped selected key RF blocks for manufacturing using SiGe semiconductor process as well as done integrated antenna designs in 300 GHz range. Measured results of those prototypes are a mandatory step towards more complex radio transceiver IC's for 6G test systems. The work is extremely challenging because the team operates in technology limits of RF ASIC processes. For this precise reason, the team has great expectations for the first circuit measurements that will take place at the latest in summer.

"When you are working in the limits of technology the work is inspiring but also extremely demanding, and the border between success and failure is not easy to define," Pärssinen says. "But in research we must take risks and jump to unknown. If you always do what you have done, you will always get what you know already. That's not the right attitude to learn and find the future possibilities."

Yet, the focus also remains on the big picture as the team explores the interplay between transceiver architectures, protocols, latency and bandwidth seeking reliable communications through parallel studies from the fundamental paradigms of wireless to hardware that is often supported by software. Other crucial components are adjustable nanomaterials and 3D structures that enable characteristics for specific applications with ultra-low permittivity and adjustable structural features.

"Seeing the future is not easy and building it is even more demanding," Pärssinen concludes. "We need both the vision and a lot of hard work in research to see what are the opportunities and right technologies for radios in forthcoming 6G networks."



HARNESSING ARTIFICIAL INTELLIGENCE FOR 6G APPLICATIONS

6G Flagship's experts on Distributed Computing harness Artificial Intelligence (AI) to build intelligent applications for future wireless networks. The three key technology components developed are distributed AI, edge-native application platforms, and advanced network security.

"Our team focuses on distributed computing and Artificial Intelligence that will bring intelligence from centralized cloud services closer to end users and applications," says strategic research area leader, professor Jukka Riekki. "The true challenge is how to efficiently distribute data and the learning, data analytics and decision-making processes across network elements and locations, while fulfilling the heterogeneous service and latency requirements as well as resource limitations."

Requirements from augmented reality (AR) and virtual reality (VR) over wireless are considered in current research as these technologies are becoming major application drivers for various verticals including health and entertainment. Other important drivers are autonomous vehicles and Industry 4.0. These application domains feature large data sets and heavy computation with real-time or near real-time responsivity – a combination requiring distributed solutions and AI to achieve the targeted performance.

The team's focus is on enabling intelligent devices and machines to sense, perceive, communicate and control their environment, taking into account both the required performance and resource constraints. This fundamental research area requires multidisciplinary expertise in communication, machine learning, control theory and adjacent disciplines. "Although augmenting human decision processes has significant potential, in the long run, developing the basis for autonomous decision-making will be crucial for optimizing the network performance and marshalling the billions of devices expected to be interacting in the 6G era," Riekki says. The team's target is to provide methods for bringing together the stray pieces of information distilled in all those devices, unreachable with current centralized solutions.

In the field of distributed AI, the team explores learning, data analytics and decision-making. Research on Federated AI develops methods for learning from heterogeneous datasets. This research has generated new knowledge on theoretical and algorithmic aspects of distributed machine learning (ML) over wireless with applications on vehicular communication and UAV control, for example.

The researchers have also proposed a novel learning technique called federated distillation that outperforms Google's federated learning.

The team also studies edge-native application platforms to run the distributed AI algorithms at access points, user terminals and other devices with limited computational capabilities, while providing load balancing and robustness in case of device and link failures. "Current efforts concentrate on decentralized application architectures and on the optimal distribution of computational resources for those platforms," Riekki says. "Recent results include a microservices-based architecture for edge computing, a method for calculating optimal placement for edge servers, and a novel edge architecture for decreasing the delays of AR applications."

Security, trust, and ethical data management are of paramount importance for the critical network services of the future. The new wave of network softwarization, that is to say, edge computing, network slicing, network function virtualization and software defined networking, introduce benefits such as reduced data and control traffic, and improved programmability but also require novel security solutions. The team tackles these challenges with novel architectures with secure key management and resource allocation algorithms, their simulation and formal verification, and testbeds for real network testing and prototyping. Recent results include a secure keying scheme for network slicing, blockchain-based automated certificate revocation for IoT, and authentication scheme for gadget-free healthcare environments.

HIGHLIGHTS

World's First Open 5G Cybersecurity Hackathon Was a Success

Top hackers from all over the world gathered at the University of Oulu in early December to compete in world's first open 5G Cybersecurity Hackathon. The northern city of Oulu, known as a global 5G and 6G hotspot, showed its gravity in research and development of top-tier cybersecurity. The hackathon gathered 70 cybersecurity specialists from 15 different countries who showed their skills in challenges set by Ericsson, Nokia and 6G Flagship programme which included improving the cybersecurity in 5G infrastructure and ensuring the information security in digital services used over 5G. The main organiser of the hackathon was the National Cybersecurity Centre Finland from Finnish Transport and Communications Agency Traficom.

Read more

https://www.oulu.fi/university/news/5ghack

Autonomous Test Car Drives 5G/6G Research Efforts

Experts at the Faculty of Information Technology and Electrical Engineering (ITEE), University of Oulu recently acquired a Toyota self-driving car to be widely used in 6G Flagship programme. The car will serve multiple purposes as a research platform where 5G/6G experts can trial their own set-ups, both individually and jointly. "In fact, all twelve research units at ITEE can take advantage of the car from their own point of view," says professor **Jukka Riekki**, Dean of the Faculty of Information Technology and Electrical Engineering. "For many units, the car is a solution allowing them to test things in a real environment. It will also be important to connect the car to the 5G test network administered by the university, which can also be used to explore communication and cooperation between cars."

Read more

https://www.oulu.fi/university/news/autonomouscar

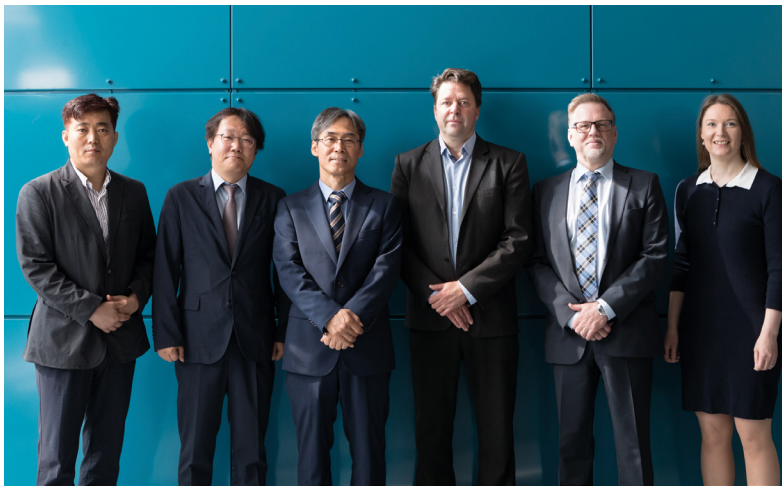
Let's Make 6G Together!

University of Oulu formalised its collaboration with the South Korean **Electronics and Telecommunications Research Institute** (**ETRI**) in June with the signing of a Memorandum of Understanding (MoU). The agreement focuses on collaboration in 5G and 6G mobile communications. The memorandum was signed by Dr. **Hyun Kim**, Vice-President of Hyper-Connected Communication Research Laboratory at ETRI and Dr. **Jouko Niinimäki**, rector of the University of Oulu.

ETRI is a leading research institute employing 2 000 researchers, funded by the South Korean government. The institute has been ranked top in the US evaluation of patents for many years. ETRI also has many world-firsts under its belt, such as the first commercialization of CDMA in 1995, and the first 4G LTE/LTE-A mobile system in 2010.

Synergies between the two organisations are strong. As laid out by academy professor Matti Latva-aho, in the 2030's we will live in a society that is data-driven, enabled by near-instant and unlimited connectivity. "We are now developing fundamental technology that will be needed 20-30 years from now," he said. "The next step will be to develop 6G enablers." ETRI's vision for mobile communications beyond 5G, on the other hand, include ultra-reliable low-latency communication, terabyte-per-second peak data rates, hyper-precision, AI-based intelligent networks which are all important and shared goals among the 6G community.

A new partnership was also launched with **Wipro** - a leading global information technology, consulting and business process services company. The two organisations signed a Memorandum of Understanding in November to collaborate in the areas of wireless communications

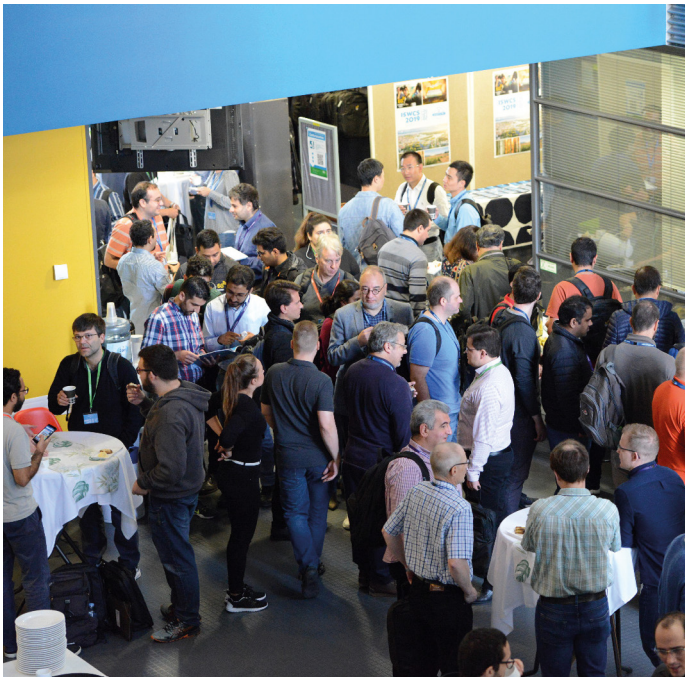


in 5G/6G at GHz, THz and light wave frequencies under the university's 6G Flagship programme. The MoU was signed at the Wipro headquarters in Bangalore, India in the presence of key delegates from the Finland's Ministry of Economic Affairs and Employment, Finnish business corporations, University of Oulu, Business Finland and Wipro executives.

Speaking about the MoU, **Timo Harakka**, Minister of Employment, Finland's Ministry of Economic Affairs and Employment, said, "The new research partnership between Wipro and University of Oulu regarding 5G and 6G will boost innovation and is an excellent start for the mutually beneficial cooperation between Finland and Wipro. This will also take the innovation corridor partnership between Finland and the State of Karnataka to the next level."

Read more

https://www.oulu.fi/itee/news/etri_mou
https://www.oulu.fi/6gflagship/wipro_mou



Great Turnout in ISWCS'19

6G Flagship organised the 16th International Symposium on Wireless Communication Systems (ISWCS'19) in August with professor Matti Latva-aho and assistant professor Hirley Alves as general chairs. The event attracted more than 250 participants and there was a strong presence of local and international telecommunications industry and industrial verticals such as automotive and satellite. The chairs were able to build a strong technical program by handpicking well-known keynote, invited and panel speakers who added value by bringing in novel and disruptive ideas leading to lively discussion. "The event helped in disseminating disruptive thinking with respect to research directions towards 6G," Alves concludes. "It was gratifying to see participants enjoying the program, and their satisfaction with such high-quality and timely content."

More information

http://iswcs2019.org/

AWARDS

ETRI Journal 2019 Best Paper Award for RF Research Team

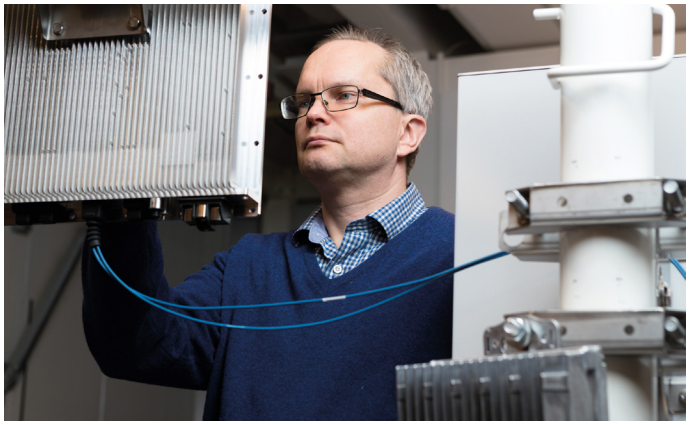
Marko E. Leinonen, **Giuseppe Destino**, **Olli Kursu**, **Marko Sonkki**, and **Aarno Pärssinen** received the ETRI Journal 2019 Best Paper Award for their article "28 GHz Wireless Backhaul Transceiver Characterization and Radio Link Budget" published in the Electronics and Telecommunications Research Institute Journal.

6G Flagship's RF researchers developed a transmitter-receiver with antenna arrays that can cope with the high-speed requirements for 5G mobile communications.

"In this work, the focus is on the design and validation of a radio frequency (RF) transceiver operating in the frequency band of 27.5 GHz–28.5 GHz," describes the ETRI Journal news story about the awarded article. "This band represents a frequency band partially endorsed in common by the European, Korean, US, and Japanese Frequency Spectrum Authorities, and it is the specification for the 5G trials at the Winter Olympics in Korea. From a design perspective, the proposed RF implementation can be considered one of the first complete solutions capable of achieving millimeter wave (mmW) urban backhaul requirements."

Read more

https://www.oulu.fi/6gflagship/etri-best-paper-award-2019



Professor Markku Juntti Elevated to IEEE Fellow

Markku Juntti, professor of Communications Engineering, has been elevated to the grade of an IEEE Fellow. He received the recognition for contributions to multiuser and multiantenna communications. He has focused especially on multiantenna and multiuser communications technology and related signal processing with applications in 3G, 4G and 5G systems. Juntti has contributed to the design of efficient receiver algorithms, architectures and implementations for multiple-input multiple-output (MIMO) systems. Significant part of his work has focused on transceiver and system optimization in multiuser MIMO systems. His current research interests include millimeter-wave and THz band communications and related signal processing in 6G Flagship programme.

Read more

https://www.oulu.fi/university/news/markku-juntti-6g

Multiple Awards to professor Heli Jantunen

Heli Jantunen, professor in Technical Physics and head of Microelectronics Research Unit at the University of Oulu, was the winner of the Finnish Science Award 2019, which is granted every second year to a Finland-based researcher or research group in recognition of significant scientific achievement. Ministry of Education and Culture grants the award based on a proposal by the Academy of Finland.

Jantunen is the first expert globally to introduce the possibility of making co-fired electroceramics in ultra-low temperatures. "Our research team is developing new kinds of materials for electronics applications," Jantunen says. "They will appear even as radical applications. Manufacturing the materials must take as little energy as possible, and they must be environmentally-friendly."

The next-generation multi-purpose electroceramics are expected to be a global breakthrough in the field of electroceramics. They will enable the use of lower production temperatures, new materials and 3D printing in the production of electroceramics and are also suitable for telecommunications technology and sensors.

Jantunen also won the Finnish Parliament´s innovation award 2019 and the Nokia Foundation Recognition Award 2018. Nokia Foundation's award announcement praised professor Jantunen's research which spans over "multitude of domains of industrial significance, ranging from high frequency applications, energy harvesters, sensors, multifunctional micro modules to modern manufacturing methods like printed electronics."

Read more
https://www.oulu.fi/university/news/finnish-science-award
https://www.oulu.fi/university/news/nokiafoundationaward2018

IEEE ComSoc RCC award to Mehdi Bennis

Associate professor **Mehdi Bennis** received the prestigious 2019 IEEE ComSoc RCC Early Achievement Award for "contribution to radio communication".

"The award bestowed by the IEEE communication society radio communication technical committee awards my contributions to the field of radio communication and more specifically in the area of self-organizing heterogeneous networks, ultra-reliable low-latency communication and distributed machine learning, which constitute three key pillars of the 6G Flagship led by the University of Oulu," Bennis says.

There are several essential research topics ongoing that Bennis is concentrating on with his colleagues as part of the 6G Flagship programme. "How to enable intelligent devices to sense, perceive, communicate and control their environment taking into account resource constraints (battery, energy, power), latency/delay, reliability, bandwidth and privacy," Bennis describes. "This is one of

the most fundamental research areas in beyond 5G/6G which requires an expertise in communication, machine learning, control theory and adjacent disciplines. My group (ICON) is one the leading groups in these topics."

Read more
https://www.oulu.fi/itee/news/awards

Other Best Paper Awards

B. Kharel, O. L. A. López, H. Alves, M. Latva-aho
EUCNC 2019 Best Student Paper Award
"Achieving Ultra-Reliable Communication via CRAN-enabled Diversity Schemes"

N. Tervo, M. E. Leinonen, B. Khan, J. P. Aikio, T. Rahkonen, and A. Pärssinen
URSI 2019 Young Scientist Award from paper and paper and presentation
"Towards Over-the-Air Characterized Transmitter Array Nonlinearity"

J. Chen, M. Berg, and A. Pärssinen
APCAP 2019 Best Paper Award
"A Differentially-Fed Dual-Band Dual-Polarized Stacked Ring Patch Antenna for 5G Millimeter-Wave Communications"

A. Regmi , M. Berg, and A. Pärssinen
APCAP 2019 Best Student Paper Award (Bronze)
"A Method For Ice Thickness Characterization Using GNSS C/N0 Data"

S. Jaeckel, N. Turay, L. Raschkowski, L. Thiele, R. Vuohtoniemi, M. Sonkki, V. Hovinen, et al.
Best Overall VTC2019-Fall Paper
"Industrial indoor measurements from 2–6 GHz for the 3GPP-NR and QuaDRiGa channel model"

5G/6G TEST NETWORK – THE NEXUS OF 6G FLAGSHIP

The nexus of 6G Flagship programme is the rapidly evolving, open 5G Test Network (5GTN), which first introduced its advanced network functions to researchers and developers in 2015. As a focal point of connectivity, it simultaneously links test beds, novel devices and applications; theory and practice; as well as research and business. Bolstering 6G Flagship's research vision, the test network combines the development of future wireless technologies with new business models and new regulatory propositions and thus enables the creation of completely new application and service concepts based on them.

The 5GTN team led by professor Ari Pouttu operates the network, which is built on major cellular network components provided by 6G Flagship's co-creator Nokia, and manages the more than 1 000 dedicated SIM cards, 2500 sensors, one of worlds largest indoor positioning systems, computation resources and state-of-the-art measurement equipment, that are available for trials, demonstrations and training – free of charge.

Unique in its diversity and structure, 5GTN provides access to multiple interfaces in advanced radio access networks (RAN), cloud-based virtualized core network controlled by SDN technology, and related service core network for applications. It offers several parallel 3GPP RAN technologies including NB-IoT, LTE-M, 4G-LTE (macros and picos), 5G NR macros as well as 5G proof of concept (PoC) on mmWaves (26-28 GHz). Recently, the architecture was complemented by 300 GHz radios supporting IEEE 802.15.3d. Also non-3GPP RANs, including WiFi, Bluetooth, and LoRa, are integrated in the platform. Open Air Interface (OAI) capable devices and core networks are also integral part of 5GTN. At the same time, in addition to normal smart phones, IoT sensors, pre-commercial non-phone centric end-user devices as well as data storage and networking devices are available as well as support for processing needs arising from vertical businesses especially related to mobile edge computing, IoT services and sensor management.

As a research platform, 5GTN is especially suitable for research on verticals, which will be driving the way future wireless networks are developing both from technical and application characteristics perspectives. "We emphasize piloting and testing in various verticals," Pouttu says. "Our current focus areas are Industry and manufacturing, port and logistics as well as hospitals and health. We are also

extending our capabilities in automotive and traffic, which are gaining increasing interest in the research community. Currently we are making our smart car 5G and beyond enabled and we plan to demonstrate connected autonomous driving with tests expected on border crossings between Finland and Sweden."

The team also integrates promising new technology components to 5G Test Network, including e.g. lidar-based asset tracking and drone based new services, to increase flexibility. The latest hardware acquisitions, on the other hand, support 5GTN's cloud-based radio architectural research, multi-mode radio interface integration and radio positioning, both indoor and outdoor as well as full 5G standalone core, which boosts 5GTN as an ideal open environment for testing end-to-end systems. "We would like to offer our research partners globally a flexible environment for international test cases covering use cases that are also global," Pouttu says.

For companies, 5GTN is an easily accessible integration framework where they can build and test technological and service-related solutions, and increase their expertise in developing, modelling and validating new concepts. The platform boosts research for challenging concepts never thought before and lowers the threshold and cost of innovation. Especially start-ups and SMEs benefit of the zero-cost option. If a user requires additional assistance or expert support to conduct experiments, compensation is considered on a case by case basis. Naturally, the platform also constitutes an excellent platform for any Horizon Europe collaboration.

5GTN offers a controlled environment for companies' service development. "We can use slicing or sandboxing to isolate experiments from each other," Pouttu says. "In addition, partners can run sensitive software also from their own computing resources that are connected to the wireless test platform over a VPN. Data from the experiments is handled confidentially if requested."

The roadmap for developing 5GTN towards 6GTN, was defined in 2018 and development has begun with full speed thanks to public infrastructure funding and collaboration with leading industry. The roadmap includes several critical steps, Pouttu confirms, starting with the introduction of 6G flavored TeraHertz proof of concept devices into the network. Full use of virtualization and cloud technology are included in the near-future targets of the upcoming 6GTN. As a result, the network becomes extra-secure and elastic with QoS and scalable resource pools for services designed to allow high-availability, high bandwidth and low latency for services. "This kind of capability is of critical importance when a test environment is built that can address the requirements stemming from different vertical needs," Pouttu says. "Slicing with dynamic resource allocation will be possible according to use, which requires intensive research and a solid infrastructure for algorithm validation to ensure network performance in all scenarios."

To address the fact that different vertical industries may have considerable differences in their working environments, it may be worthwhile to define testing environments, "golden references", which are specific to a certain industry type. So, the goal is be to create a flexible and portable testing solution. With this approach, it becomes possible to evaluate new testing ranges regarding their compliance to the reference testing system and by that the compliance to the given performance criteria can be evaluated by different neutral bodies. "Only by taking this approach the industry required certification of 6G-industrial components becomes possible," Pouttu states. "And only with such a certification will the technology be adopted inside critical environments."

Currently, THz range solutions are already being tested in the test network. Future updates will expand the research of materials, devices, waveforms, signal processing or distributed data driven network control paradigms. Improved capabilities in the next few years will furthermore support research of future radio interface, and RF assuming mmWave/THz high-capacity backhaul and fronthaul with MIMO antennas enabling adaptive beamforming. "With the addition of 6G flavoured capabilities, our test network will become an even more powerful nexus for our own innovation and co-creation especially with companies, academic partners and public sector," Pouttu says. "We can't wait to demonstrate selected vertical use cases together with our partners in the near future."

Follow the latest updates at ***6gflagship.com*** and ***@6Gflagship*** in Twitter and LinkedIn.

Ari Pouttu is a professor in Dependable Wireless Communications. He has scientific, engineering and management experience in fields such as synchronization, interference suppression, coding, modulation, and multiple access. He has been involved in cellular system designs since 3G (FP4 FRAMES). The projects under his command have resulted in system designs for positioning, defence, radar systems, and energy. Furthermore, case studies are being performed for media, sports, maritime and the future hospital. Currently, Pouttu serves as Vice Director of 6G Flagship programme. He also leads 5G Test Network research activities and the strategic research area, which develops solutions for business verticals such as industry, health, energy and automotive.

6G IS THE GLUE THAT BINDS EVERYTHING TOGETHER

5G and 6G will bring about enormous and to a large extent yet-unforeseen changes, applications and consequences in business, but they will also provide hugely exciting opportunities for researchers. And the University of Oulu is well-poised to be at the forefront of the research.

"Last year the focus was on building the networks and basic technology in a sense," says professor Markku Juntti. "I think this year we will see more reinforcements in the application arena." There are many projects running at 6G Flagship that will take advantage of 5G infrastructure. "This year they will be pushing full speed ahead," Juntti says. "I am specifically expecting to see concrete examples of applications in logistics, pilot projects in ports and so on. New applications in the new frequencies, this is what we will see this year."

Juntti says that 6G will be a pervasive element in research, technology and society. "It's the glue that binds a lot of things together. It has an impact on all the areas of ICT, naturally, but also on many other industries and businesses. 5G already will revolutionize many businesses, which will take advantage of the massive amounts of data from networked sensors, which will number in the billions. The amount of data and analytics in 5G will bring huge opportunities to all the sciences and industries, not to mention 6G."

Autonomous cars, AI, smart homes and connected appliances are standard fare when talking about 5G and beyond. What are the things Juntti expects will happen and become part of our everyday lives? "Measuring, monitoring and real-time analytics of data will change healthcare and lead to earlier reliable diagnostics," Juntti says. "Autonomous cars? Maybe in some form, but I don't think we will have so-called level-5 self-driving cars in all circumstances and on all roads. But they will observe their surroundings, transfer information to other cars or some database that is accessible to all. I'm sure there will be things like commercial local bus routes that will be operated by a driverless vehicle with a pre-defined path."

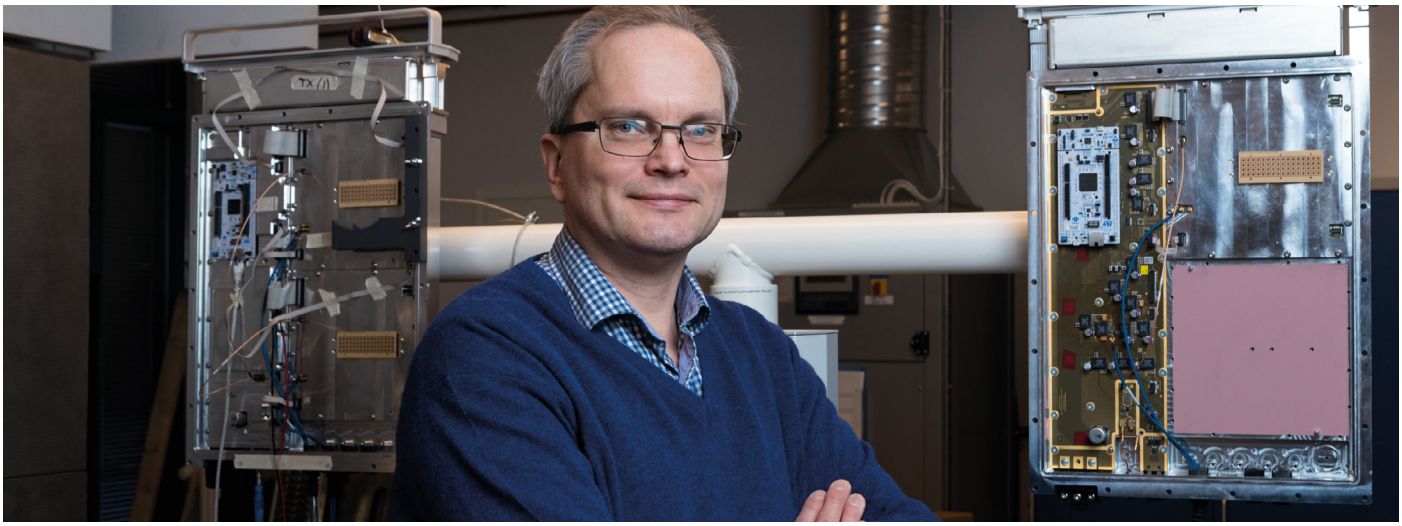
Then there is information security. All of these things require not only low latencies and massive computational capacities but networks and devices people can trust. "That's the whole thing," Juntti says. "No one will use our wonderful networks and shiny devices if they can't trust them. We've seen that any given technology that has benevolent uses is also susceptible to malevolent uses. So, information security is extremely important and that cannot be over-emphasized."

Juntti elaborates why the University of Oulu is an excellent place for exploring and studying future development of wireless networks. "One of the key factors in this is the business ecosystem that exists in Oulu," he says. "We wouldn't be able to do ground-breaking research without such close ties to industry, as all engineering sciences are applied in the end."

For Juntti, university training has personal and global significance. "I enjoy teaching and that's one of the most rewarding aspects of my job," Juntti says. "I really want to encourage young people to come and study with us. That's how change comes about, through people who study and graduate and then go out into the world. There are students from Oulu who are working in all the continents of the world – aside from Antarctica. So far."

Read more

https://www.oulu.fi/6gflagship/news/markku-juntti-6g



VR HEADSET DEVELOPER STEVEN LAVALLE CHOSE OULU

Steven LaValle, a famed roboticist and a pioneer in Virtual Reality (VR) perception technology, intends to bring many different disciplines together to work on VR and its applications in the era of next-generation networking. LaValle, whose background includes creating two patents for Oculus before Facebook acquired the VR company, has set his and his family's roots firmly in Oulu.

Now LaValle runs a research group focusing on XR broadly. He is currently looking to build a consortium of top university researchers and companies around the XR (VR/AR) ecosystem, starting first in Finland and then extending to the European Union and beyond. The team is an interdisciplinary mix of experts in virtual reality, robotics, and neuropsychology.

"We have state of the art facilities, including a robot arm, human sized 3D scanner, mobile robot, numerous VR headsets including Varjo VR 1," LaValle says. "We are also the only university in the world to have special robots (from OptoFidelity) to measure VR headset latency, which are the standard in the top global companies."

"Lately we have investigated ways to make telepresence more comfortable," LaValle continues. "We have just developed an algorithm that computes comfortable trajectories for a robot that carries a 360 camera, to which users can be interfaced via a VR headset."

"We have also recently discovered a plausibility paradox when we make VR users believe that they have been substantially reduced in size when immersed in a virtual world," he says. "They have unrealistic expectations about how the physics of the world behaves at a small scale, which must be taken into account for health care, education, maintenance training, and microscale virtual prototyping."

LaValle has a clear vision for the 2030 wireless era. "I envision a future in which people will feel co-present in spite of long distances between them, and the technology should be so seamless and accessible that people take it for granted. Next generation networks will play a key role in this. If successful, the pressure to physically travel long distances may be eased, resulting a healthier planet and improved wellbeing of its inhabitants."

LaValle's journey to Oulu has involved a few turns. As an academic working in the United States LaValle originally wrote an influential book "Planning Algorithms" on robot motion planning, control theory and artificial intelligence (AI) in 2006. The book was highly visible on the Internet largely because he was distributing it free of charge. The book eventually caught the attention of the founders of Oculus - makers of the Oculus Rift VR headset. LaValle was already in Oulu on a sabbatical from the University of Illinois at the time, and started consulting for Oculus together with his wife.

Now LaValle and his wife Anna both work at the University of Oulu and have settled in well. "I love it here. I am particularly grateful for the environment maintained by professor Timo Ojala, who directs our Ubiquitous Computing center and co-leads my research group. Due to his efforts, I have been able to focus heavily on the actual scientific work and innovative teaching. Oulu has also been a perfect environment for me and my family. There is plenty to do and I enjoy reaching it all by my bicycle, especially in winter!"

Read more and watch the video

https://www.oulu.fi/university/news/stevenlavalle
http://lavalle.pl/

In May 2019, professor Steven LaValle received the Milestone award from the IEEE International Conference on Robotics and Automation (ICRA) - the leading interdisciplinary conference on robotics. This was the first time ICRA announced the award which was granted for the most impactful conference paper (among around 3 000) published between 1997 and 2001 looking back at the actual impact a paper has had, in this case over 20 years. The paper "Randomized kinodynamic planning introduced the Rapidly exploring Random Tree (RRT) algorithm" has been widely cited in robotics, video games, computer graphics, control systems, verification, and art. RRTs were developed by Steven M. LaValle and James J. Kuffner Jr. LaValle is now a professor at the University of Oulu, Finland and Kuffner works in Toyota Research Institute, Japan.

"I was quite surprised and felt deeply honored that our community recognized this work, which I remember was pure fun at the time," LaValle says.

FIXING FLAWS OF 5G

Professor Tarik Taleb is all about networks. He has been involved with 6G Flagship from the start and has a key role in bridging the research collaboration between Aalto University and University of Oulu, splitting his time between the two universities.

Taleb's focus in research is relevant to networking, which is something that he feels very passionate about. For instance, he doesn't think 5G will deliver on all the expectations we have laid upon it - at least, not in the immediate future.

"We are expecting services which will require ultra-low latency and very high reliability," Taleb says. "5G in the next 2-3 years will not be able to support the things we need. Things like drones beyond line of sight or self-driving vehicles. These will not happen because of regulation and because the technology is not there yet."

Take self-driving cars. While we are being told that any day now, fleets of automated cars will roll out and everyone can just sit in the backseat, sipping coffee while getting to work safely and on time, Taleb says we should probably not hold our breath just yet.

"You need connectivity," he says. "Many car manufacturers say that decisions like braking or continuing to move have to be taken locally by the car. Still, you need someone with a view of the situation as a whole and you need connectivity for that. We are talking about services that are possibly life-threatening and we need to have very short latency and very high reliability for those to work safely."

And once we have self-driving cars and human drivers are made obsolete, what will the passengers in these cars do? They will obviously be consuming something, Taleb says. They will be working, they will be watching movies and TV shows, they will be playing games and so on.

"So, the car will need lots of data for situational intelligence," Taleb says. "Where are pedestrians, what's the speed limit, where's congestion, should I brake etc. At the same time, the vehicle may become a source of data, streaming videos, pictures, all kinds of data. And the passenger will be watching a movie. Therefore, the car will consume lots and lots of download data and also contribute large amounts of upload data. This is one car. Now multiply that with the millions and millions of cars around the world."

While the research is ongoing, Taleb says that he and the 6G team in Oulu are busy "making noise" about the 6G Flagship. Cutting-edge research, teleportation, science fiction becoming science fact. This all is happening at 6G Flagship with its cross-university and cross-industry approach to the next Next Generation of telecommunication.

"We are raising awareness on 6G and having brainstorming sessions in different events," Taleb says. "Things are in good swing, and now we need really great talent who can do cutting edge research."

Read more

https://www.oulu.fi/university/news/make-noise-about-6g

CARING OF SPECTRUM SHARING

Marja Matinmikko-Blue lives and breathes spectrum management. She realized very early on that wireless communications researchers must make assumptions on spectrum use but very few are aware of the reality of spectrum management. So she decided to bridge the gap between research and real life which led her to complete not only one but two doctoral theses in parallel with her contributions to spectrum regulation.

For Matinmikko-Blue, the complexity of spectrum use is visible in latest developments. "Contentious 5G spectrum debates have resulted in divergent regulation between countries in terms of who gets to deploy 5G networks," Matinmikko-Blue says. "For example, the 3.5 GHz band awards and rules differ not only globally but even from one European Union country to another."

At the same time, the process lacks transparency. "One important group of people pretty much omitted in the 5G discussions are those living in the countryside," Matinmikko-Blue says. "They will not benefit from 5G if networks are not accessible to them."

However, with the adoption of 5G, local licensing is starting to become a reality, which allows different stakeholders to deploy their own 5G networks in specific premises. "When we started to talk about local spectrum licensing and operator models five years ago, the opposition was very strong," she says. "During the last few months, local licensing has become possible in several countries which promotes innovative location-specific solutions for instance in factories and ports."

In ten years from now, Matinmikko-Blue would like to see more flexibility and less confrontation. "We should realize that in the societal level it is not sustainable to let the spectrum use continue to be inefficient," Matinmikko-Blue says. "Valuable spectrum is largely under-utilized because of the way it is allocated. Existing spectrum users should stop selfishly defending their rights, and spectrum sharing should be the new norm in 2030."

Matinmikko-Blue stresses that sustainability in all forms should be taken seriously. It is imperative to perceive spectrum as a natural resource, which must be managed and used in a sustainable manner. In line with this approach, Matinmikko-Blue initiated the development of a White Paper on the connection between 6G and United Nations' Sustainable Development Goals (UN SDGs). The outcome of the expert group will be published in spring 2020. "Efficient use of spectrum is a major design criteria in the development of any new wireless system, but efficient use of spectrum across wireless systems as a whole, is not yet a design criteria taken seriously at the societal level," she says. "The development and deployment of new wireless systems should not be postponed by incumbent technology claiming overstated protection needs."

Her strong message on spectrum management relies on 15 years of solid multidisciplinary research and wide international collaboration with industry and regulators. "I guess you can call it a passion," Matinmikko-Blue concludes. "At least it's a topic I discuss every day at home with my husband whom I brought home from an ITU meeting."

Marja Matinmikko-Blue is the Research Coordinator of 6G Flagship.

She has two doctoral degrees: in telecommunications engineering and in industrial engineering and management. The theses focus on cognitive radio techniques and stakeholder analysis for spectrum sharing.

She was first absorbed into spectrum management in 2004, in EU project WINNER.

Matinmikko-Blue worked in close collaboration with industry and regulators on mobile communications spectrum requirements for the World Radiocommunication Conference in 2007 (WRC-07) at the International Telecommunication Union (ITU).

Since then, she has worked on cognitive radio systems and chaired those studies at the ITU, led the development of Finnish Licensed Shared Access (LSA) field trials, introduced stakeholder analyses into spectrum management research, and developed local 5G licensing and alternative operator models.

Follow her on Twitter @BlueMarja

TOWARDS WIRELESSLY POWERED IOT

During these last two years, assistant professor Hirley Alves has been building the machine-type wireless communications (MTC) team working towards the 6G Flagship vision of near-instant unlimited connectivity. Under the umbrella of MTC lies two key components: critical and massive MTC.

"The near-instant aspect relates to critical MTC, where we foresee extremely reliable, ultra-low latency connectivity," Alves says. "Unlimited, on the other hand, relates to massive MTC that aims to bring connectivity to millions of devices serving a wide range of different applications."

Alves says he finds the novelty and rapid evolution of MTC both fascinating and extremely challenging. "Our research focuses primarily on the physical (PHY) layer but MTC requires a new perspective on wireless communication design in all areas from PHY layer all the way up to services and applications, business models and the whole value chain," he says.

The team seeks elegant mathematical and algorithmic solutions for several open problems in MTC. Alves gives a few examples. In the traffic monitoring case, the group focuses on random access, user identification and resource management of a massive number of users. "Since we don't know when the device will be active, its transmission might collide with transmissions of other users, which causes throughput and reliability degradation besides delay," he says. "We are tackling this problem by resorting to compressive sensing and probabilistic machine learning."

Another example relates to critical MTC and the operation of an industrial network by providing connectivity to autonomous guided vehicles. "We are addressing this issue via diversity in many levels," Alves says. "For instance, the controller and the vehicle may have several antennas – spatial diversity, there might be other controllers within the same factory floor that can coordinate their transmissions – cooperation and multi-connectivity, these controllers and vehicles might have other wireless radio interfaces (3G, 4G, 5G radios) that can be exploited as well to send redundant information – interface diversity. All these different diversity solutions build up to meet the requirements, what we seek then are mathematical and algorithmic solutions that efficiently combine all these different diversity solutions."

Thinking about sustainable IoT networks, one of the doctoral students in the team – Onel López – is going to defend his doctoral thesis shortly. López proposes a novel concept of channel state information (CSI)-free massive Wireless Energy Transfer (WET), which allows powering wirelessly a large number of battery-constrained devices. The impact of wirelessly powered devices could transform the increasingly IoT-supported smart cities, agriculture, transportation and logistics, to name a few.

"Conventional CSI-based solutions require immense overhead, which leads to wastage of resources, cumbersome coordination and scheduling," López says. "The proposed CSI-free solutions alleviate those issues, and even without considering the energy resources required for CSI acquisition the gains from CSI-based solutions decrease quickly as the number of powered devices increases. Distributed CSI-free strategies are also advantageous when we widen the energy coverage region, even when we impose high reliability on the energy transfer or increase the line-of-sight component as the network densifies."

"Our target is to demonstrate some of the novel MTC concepts in a vertical application, such as industry 4.0, using our 5G Test Network," Alves says. "We are currently looking for an environment to start making firstly channel characterization and then system design with suitable diversity methods to obtain required reliability targets. We expect to have first results out in spring 2021."

But before that, have a look at Onel López' dissertation, which is coming out in April 2020. It will be openly available in Jultika – the University of Oulu repository – at ***http://jultika.oulu.fi***.

SOLID-STATE 3-D RANGE IMAGER TECHNOLOGY IN FULL OPERATION

Professor Juha Kostamovaara's research group faces unique challenges daily as it strives for meaningful results in its research field of multi-disciplinary character. Quite seldom, deep knowledge on devices, microelectronics, photonics and laser ranging can be simultaneously found within a single research group, Kostamovaara notes.

"We want to develop a miniaturized (matchbox-size), low power and low cost solid-state sensor technology which can produce 2-D (line profiles) or 3-D range images about the environment of the sensor, depending on the needs of the particular application," Kostamovaara says.

The need for these kinds of sensors is increasing rapidly in many application fields, e.g. in vehicular applications, robotics, security and many other fields. On the other hand, in spite of very active research both in academia and industries, convincing solid-state (without mechanically moving parts) demonstrators are still largely missing. "Thus, this task has turned out to be a very challenging one," Kostamovaara says. "On the other hand, our approach seems to have great potential for a generic solution for this field."

The group aims at an end-to-end solution based on innovative building blocks. "One part of our work is the development of novel optoelectronic devices, e.g. laser diodes, capable of producing high-energy "impulse-like" optical pulses, which are essential in our range imagers," Kostamovaara says. "Another important part of the work is the development of CMOS integrated circuits, which include on the same circuit die optical detector arrays, which are capable of detecting simultaneously single photon events, and also the electronics to record their time position with respect to the emitted laser pulse. In addition, we are developing prototypes to demonstrate the developed system architectures in real-world applications, together with our research partners."

The most potential application areas for the developed technology are driver assistance systems (even driverless cars) and, especially, the control and guidance of machines (autonomous machines), e.g. in civil engineering, farming and forestry. The main performance evaluation criteria arise from the anticipated applications, e.g. measurement range, spatial resolution, measurement rate and precision. On top of these technological parameters, the cost of the technology, power consumption and size are important system parameters, especially in mass-production.

Kostamovaara refers to the recently ended six-year Center of Excellence programme on Laser Scanning Research, in which his group participated. "Within this program we proposed to develop new kind of single photon detection based 2-D and 3-D laser range imaging technologies," Kostamovaara says. "As a result of the activity, we were able to develop these technologies starting from the scratch up to the point of demonstrating fully operating 2-D and 3-D range imager prototypes."

The group's long-term work on Laser Scanning Research resulted both in technical results and publications in the leading journals of the field, including JSSC. Another important outcome of the long-term research activity was the education of several doctoral students. "They have trained themselves into the important fields of photonics and microelectronics and are spreading their knowledge into industries already now," Kostamovaara says.

One of the specific design challenges Kostamovaara's group tackles next is the development of a specific type of block-based laser illuminator technology enabling the considerable improvement of the range imaging measurement speed.

New industrial activities utilising the proposed ideas and developments are most welcome. "Our role in this research road map is to develop the basic technologies which pave the way for further R&D in industries," Kostamovaara says. "We hope that our technology finds its way to industrial R&D and eventually to applications."

RELIABLE BODY-CENTRIC COMMUNICATIONS AND SENSING

6G Flagship's Wireless Medical Communications research team (WiMeC) focuses on realizing a vision of future healthcare services, which are enabled by the use of the latest wireless technology. The team pursues essentially three lines of research: wireless body area networks (WBAN), full chain of data transfer from measurements to patient's electronic health record, and novel secure solutions for care facilities.

WBAN is a collection of small sized low-power wireless sensors with communications capability, which are employed for monitoring human body functions and vital signs, as well as the surrounding environment. WBAN communication links can be divided into off-body, on-body, and in-body (including both in-on and in-in) communications, which are all explored in the medical ICT team. "Currently, we put more and more focus on in-body communications in our research, which is an exciting task as the impact of different tissues in the body needs to be taken into account," says professor Jari Iinatti, who leads the team. "Going towards 6G, we aim to solve challenges related to serving a multitude of links simultaneously, because WBAN communications in its regular use for off-body and on-body communications can already be implemented with current technologies. However, the in-body link is largely an unexplored area and therefore highly inviting as a research area. More challenges will arise from interoperability between systems, as all the technologies should work seamlessly in a dense area populated by hundreds or even thousands of small medical and other IoT devices.

The team also explores the whole chain from body-centric information transfer to electronic health record (EHR), which requires the utilization and mastering the existing solutions, e.g., LoRa, NB-IoT and Bluetooth Low Energy, and their novel usage, taking into account the demands of healthcare data management. "We explore safe and highly reliable solutions for measuring human vital signs and delivering health data outside of hospitals and other care institutes," Iinatti says. "The ultimate goal is to provide remote healthcare services also to people who are living in rural areas, far away from health service providers. To succeed in this, we focus on diverse reliable communications technologies, which can then be utilised according to the specific needs and available services in each particular area."

One of the most promising secure solutions for hospitals, that the team is currently exploring, is the utilization of visible light communications (VLC) for certain functions. "Possible use-cases include delivery of confidential health information with high security and secrecy levels," Iinatti says. "Of course, VLC limits its use to a single room, which makes the technology resistant for eavesdropping. We are also exploring the possibilities to utilize contactless sensing approaches to detect various human vital signs, such as respiratory or heart rates using different radio or VLC-based measurement methods."

The team is now leading an EU-funded research and innovation staff exchange project "MSCA ROVER" (ID 872752), which aims at creating a novel system architecture for a complete, dependable end-to-end data transmission chain. The system architecture is a heterogeneous communications system with imaging and localization capabilities which can be used outside the hospital e.g. in homes and remote areas. Consortium members, both from academia and industry, work on four continents complementing nicely each other's expertise areas from ultra wideband (UWB), microwave imaging, localization and diagnostics to business," Iinatti states. "We plan to demonstrate the ROVER architecture during the project lifetime, by the end of 2023."

The WiMeC team has long been an active contributor to standardization starting from IEEE 802.15.6 and IEEE802.15.4 related activities. "Our current and future contribution to ETSI TC SmartBAN PHY & MAC Standards is a natural continuation," Iinatti says. "Some of the results from WBAN MAC research have been patented and have also included in the ETSI SmartBAN standard, which is a European version of the smart body area networks standard." The team continuously seeks new partnerships and development opportunities in the sector of eHealth. "We are very excited to observe how our inventions, included especially in the current and upcoming standards, such as ETSI SmartBAN, will be implemented in real system and products during the following years," Iinatti says.

SECURE LIGHT-BASED COMMUNICATIONS THROUGH BIOLOGICAL TISSUES

Visible light communications (VLC), and optical communications overall, caught professor Marcos Katz's interest when he and his team first demonstrated in 2017 a reconfigurable hybrid wireless network exploiting VLC and radio technologies. The network seamlessly switched from radio to optical, or vice versa, according to the condition of the channels, context information, local policies and others.

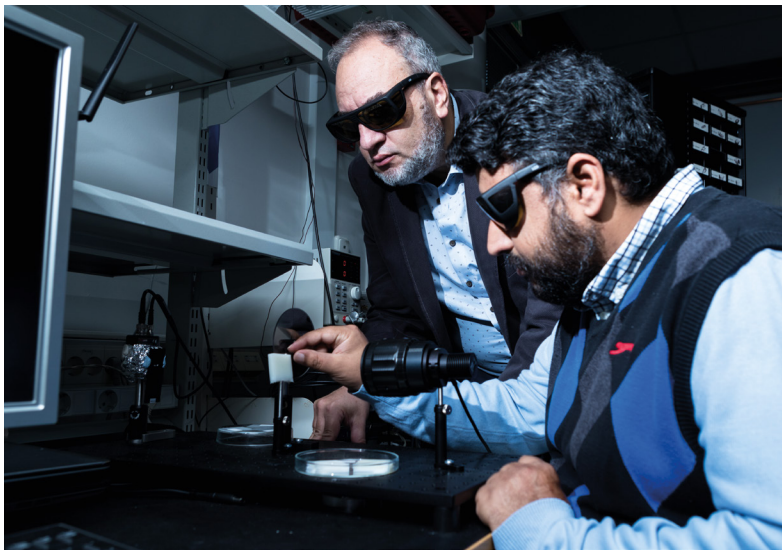
"VLC is a great complementary technology to radio," Katz says. "Its unique advantages include high security and privacy, no electromagnetic compatibility issues, support for high-data rates, all key characteristics needed for 6G." These features come in handy in his latest research challenge - communications through biological tissues.

Katz's team has recently demonstrated how light can be used to convey data to and from in-body devices such as implants. "We are using near-infrared light to transmit data across biological tissues," Katz says. "At these wavelengths, light propagation inside biotissues is more favorable, though transmitting data through biotissues is very challenging."

With the testbed, the team can utilize different types of parameters such as modulation schemes and transmit power. "We have realized all experiments with artificially manufactured optical phantoms as well as real bones and samples of fresh meat," Katz says. "The optical phantoms used in the experiments have been developed here at the University of Oulu." Currently, there are no plans for in vivo measurements, but the team complies strictly with regulations defining the maximum allowed light power per square millimeter in human tissue.

Recently, some authors have proposed the use of light for very short links, in the range of a few millimeters, for instance for communications with devices under the skin. "We have demonstrated through experiments that we can increase the range considerably to several centimeters, allowing communications with deeply implanted devices as well as between in-body devices," Katz says. He foresees that direct communication between implanted devices and out-body devices is also possible, even when these nodes are meters away from the body.

While initial results show data speeds of tens of kbps, the use of multi-source/receiver structures such as MIMO and advanced modulation schemes can increase the speed considerably. It is also possible to use pulsed communications to increase communication range in the tissue.



Light has also the major benefit that it can be employed without concerns on radio frequency exposure and privacy, Katz says. Previously, radio communications have mostly been used to transfer information to implanted devices. Third parties or malicious users can, in principle, jam communications links, eavesdrop on signals, and accede devices. Recent research also shows that commercial pacemakers and defibrillators can be hacked, which has eventually led to massive recalls of devices. Light-based communications, on the other hand, is local which practically prevents remote hacking attempts, Katz points out.

The team is continuously improving the measurement setup. Upcoming capabilities include a precise temperature control of the samples. "We plan to continue extensive measurements to be able to characterize biological tissues as a medium for wireless communications," Katz says. "Based on the results, we will be able to develop channel models and design transmitters and receivers optimized to the channel. We also plan to compare radio and optical communications in biotissues."

Katz has a clear long-term goal. "In the future, we will be able to carry out key medical ICT functions such a diagnostics, treatment, wireless communication, activation, inhibition and monitoring of cell activities and others by exploiting a unique and highly secure light-based system," Katz says. "Once we understand the biotissues as the transmission medium, we can design a full communication chain matched to it."

6G BEYOND CONNECTIVITY

Professor of practice Kari Leppänen is a pioneer in exploring complex systems. In the 1990's he pursued a career in radio astronomy and in 2000's he was in charge of Nokia's 4G research programme.

Now, Leppänen works on autonomous wireless systems in 6G Flagship. "The definition is pretty broad, but basically the idea is to look at how wireless networks enable the technologies of the future, like robotics," Leppänen says. "These include 3D mapping, positioning, sensing, low-latency connection to the cloud, possible edge computing -- all of these are needed by robots that need to work in a given environment."

Leppänen converses easily about immersive experiences, virtual, augmented, or mixed reality solutions and their applications. The expectation is that 6G will bring about unforeseen amounts of data production and consumption and with it issues like data ownership and privacy.

"Privacy concerns are absolutely among the biggest discussion points in 6G," Leppänen says. "Who controls the data, what is shared and how? On the other hand, we are creating local data marketplaces. Somebody is producing data through their radio device locally, someone else wants to access it, and so we have created supply and demand."

Real-time environmental mapping in 6G with near-instant unlimited wireless connectivity is also part of 6G Flagship's vision. "In TeraHertz frequencies, which is the 6G expectation, it is possible to construct a radio eye that 'sees' in radio frequencies," Leppänen says. "This 'eye' is a cluster of antennas, consisting of thousands of antenna elements and is still the size of a match box. This 'eye' can see things very accurately, if it functions as a radar. It can see things in 3D and map the environment. In traffic it could spot a cat running for the street from around the corner."

"Also in the TeraHertz region one can build spectrum or multispectral sensing systems, which can be used in, say, mines or other industries and monitor if there are any toxic gases or other compounds released accidentally," Leppänen says.

It is easy to see dystopian outcomes when pondering the future of telecommunications, but Leppänen points out that the key performance indicators (KPIs) in 6G are not just technological and economical as they have tended to be in previous generations.

"Now, we are talking about things like privacy, transparency and environmental impact, the United Nations' 17 sustainable development goals," Leppänen says. "It's not just about how many bits we can run per second, or how much it costs to build a square mile of coverage. People who develop communication systems are generally concerned about human repercussions and global development. Bringing these KPIs in at the start is a great way to build the future."

Read more
https://www.oulu.fi/university/news/karileppanen

TRUSTWORTHY MIRROR WORLDS

6G is about systemic disruption, which is why it is vital to look at the future of telecommunications from a variety of multidisciplinary perspectives, says Seppo Yrjölä, professor of practice. Working in mobile telecommunications from 1G all the way to 6G means that he has quite the expertise. Right now, Yrjölä holds a position as principal engineer at Nokia and a part-time professorship in techno-economics of future wireless communications services and networks at the University of Oulu.

"I've always been interested in research, going deeper into things and creating visions of the future," Yrjölä says. "As the pace of business is becoming faster and faster, it is really crucial to make time for a longer-term perspective. And this is exactly what the 6G Flagship is providing: well-founded, thorough research combined with the practicalities and realities of business."

Yrjölä describes his lot in 6G research as looking at three things: disruptions in technology, development of business models and regulation and policy. "In my career I've learned that innovation happens where different disciplines and domains overlap," he says. "You're not looking at technology as just technology, but you're considering the environment, societal change, policies, sustainability and so on."

Yrjölä spends more time on the point of privacy and security. "For the human user, it boils down to two questions. Who can I trust? What can I trust? It's about trust in human-to-human, human-to-machine and machine-to-machine interactions. What are the checks and balances? Can I opt out? These are essential questions to 6G research."

He brings up the concept of mirror world, the digital representation of the physical and biological worlds. Yrjölä thinks of mirror world as a larger concept than just creating digital twins of physical objects like the size, shape, 3D images, properties and so on.

"It is about documenting all the physical properties but also including all the contextual and other data, the function, purpose, all the defining parameters," Yrjölä says. "In a dressing room you can have a digital twin to see how a piece of clothing would look on you, but if you add things like heartbeat, blood pressure etc. you're getting closer to a proper digital twin needed to take care of your health and well-being."

Mirror world is the ability to move in the digital world, Yrjölä specifies. One can have a fully virtual image of the engine room of an ocean cargo liner or an industrial production facility. This image can be used to design, optimize and redesign complex systems before making the physical changes.

"All these digital twins are connected to create a real-time mirror world, and 6G is exactly that connectivity," Yrjölä says.

Read more
https://www.oulu.fi/university/news/seppo-yrjola

CO-CREATORS

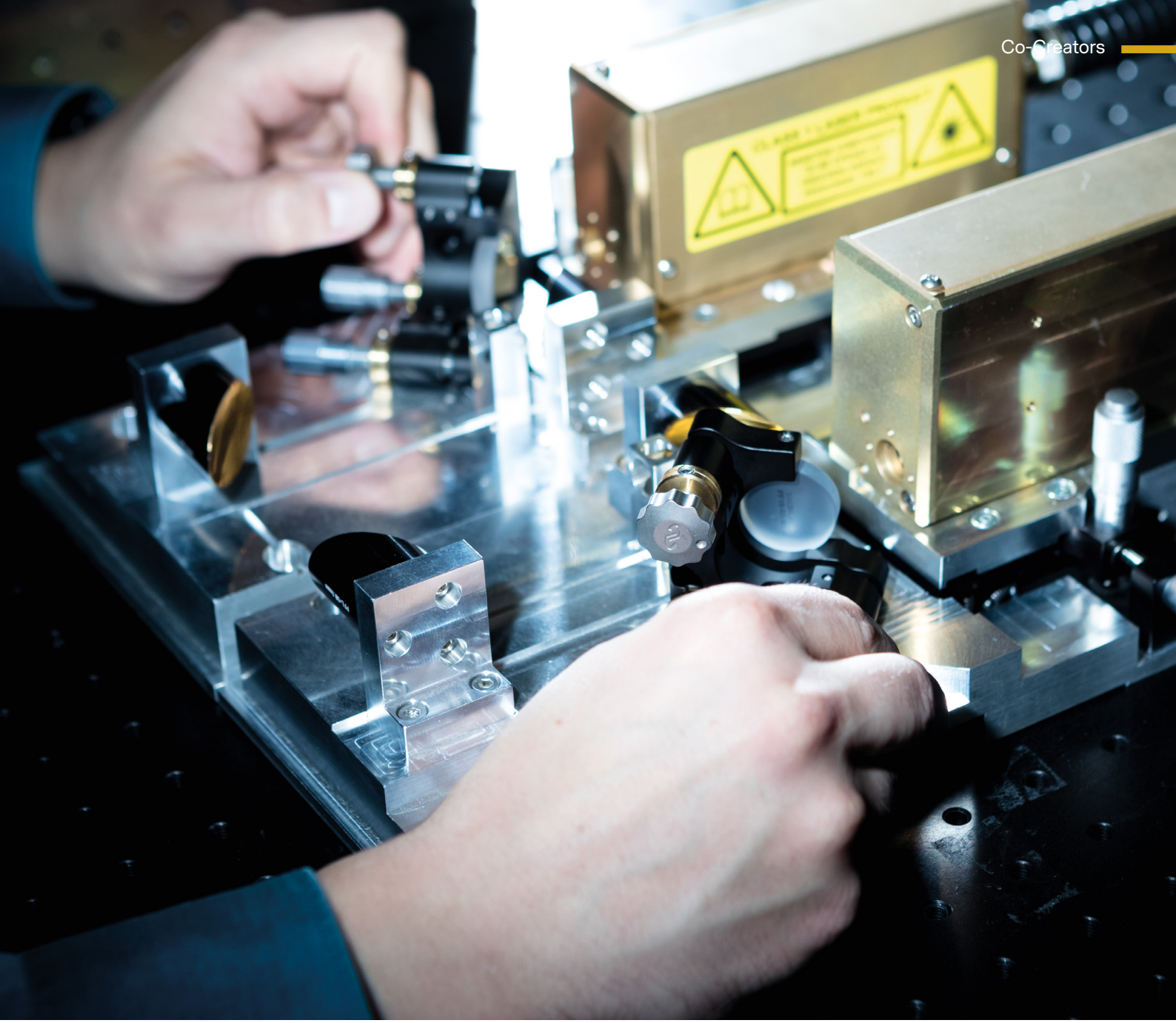
Nokia, especially its research unit Nokia Bell Labs, has a long tradition of cooperation with University of Oulu, one of the Nokia Distinguished Academic Partners. 6Gflagship program forms an umbrella for current active research topics, such as 5G radio systems concept research, including massive MIMO algorithms, interference coordination methods, and evolutionary topics like operation on high mm-wave spectrum and high accuracy positioning methods.

Reaching higher frequencies, new algorithms and pushing technology towards beyond-5G topics is only part of the cooperation. 6G Flagship has already proven to provide good opportunities also for practical experimentation of new technology, e.g. how requirements of different vertical businesses are met with new technology. Various joint actions like EU project '5Gdrones' or national 5G-VIIMA' project provide excellent opportunities for Nokia to work together with academia and other industrial partners on vertical businesses. In 5GDrones, we have integrated 5G with drones. 5G-VIIMA, in turn, has been a frame for bringing early versions of future evolution to industrial environment and analyzing not only technology but also related business potential. For this purpose, 6G Flagship is providing open 5G Test Network where technology prototypes and services can be tested in neutral environment before entering commercial networks. We have been happy with the cooperation.

Keysight Technologies – a provider of technology that enables the world's leading innovators to imagine, develop and produce products and services that make our lives richer and full of potential – joined the 6G Flagship programme in August 2019 as a co-creator to advance wireless communications research beyond 5G. With the agreement, Keysight became a strategic collaborator in the area of test and measurement of RF, mmWave and TeraHertz devices, circuits and systems. Keysight applies multi-domain industry, technology and application expertise to deliver cutting-edge solutions that shape our future.

"We're excited to join the 6G Flagship Program as one of its founding members to begin groundbreaking 6G research," said Satish Dhanasekaran, Senior Vice President of Keysight and president of Keysight's Communications Solutions Group according to Keysight's news release. "The program signals the start of a new era of wireless technology that will push the boundaries of high-speed and high-bandwidth applications. As the only test and measurement provider invited to take part of the program, Keysight is showcasing the unique role we play in solving design challenges ahead of a technology wave."

Keysight's trusted portfolio of integrated test, measurement, security and optimization solutions use common hardware and software platforms to accelerate development, manufacturing and deployment of technology critical in communications, automotive, energy, aerospace and defense. Keysight's early research capability, complemented by a wide range of software and hardware for design, simulation and validation, helps the 6G Flagship programme accomplish its overarching goals. These include supporting the industry in finalizing the adoption of 5G across verticals, developing fundamental technologies needed to enable 6G such as artificial intelligence (AI) and intelligent UX, and speeding digitalization in society.



interdigital™

InterDigital – a mobile and video technology research and development company – joined 6G Flagship as a co-creator in September 2019. InterDigital and University of Oulu are jointly exploring fundamental 6G technology especially in relation to the impact of metamaterials-based intelligent surfaces on disruptive smart radio protocols. InterDigital and University Oulu are also exploring experimental Beyond-5G research pertaining to Wireless-AI fusion on InterDigital's virtualized RAN platform.

"Our membership in the 6G Flagship program naturally builds upon our long-standing commitment to advanced research in 5G and beyond," says Dr Alain Mourad, Director of Engineering at InterDigital Europe. "InterDigital is excited to explore the opportunities, technologies, and use cases that will shape our wireless future, and do so alongside respected academic and industry leaders."

InterDigital unites two main communication technologies – wireless communication and video communication – into one of the world's largest pure research, innovation and licensing companies. With more than 300 engineers around the world, our focus is on research and development with pervasive impact: mobile technologies that underpin smartphones, networks and services via global standards, and video technologies that are the foundation for today's most popular products and services. InterDigital has licenses and strategic relationships with many of the world's leading technology companies, and our inventions help improve every product in the markets we participate in, from the most basic to the most advanced, to transform industries and improve the products and services that are part of our daily lives.

DOCTORAL THESES

We are proud to announce that since May 2018, in total 44 students have defended their thesis and graduated with a doctoral degree from research units contributing to 6G Flagship. Here are their names and doctoral thesis titles.

Uditha Wijewardhana, "Sparse recovery algorithms for streaming and multidimensional signals," Feb. 2020

Samad Ali, "Learning-based predictive resource allocation for machine type communications," Feb. 2020

Henna Ruokamo, "Time-gating technique for a single-photon detection-based solid-state time-of-flight 3D range imager," Dec. 2019

Ilkka Juuso, "A cellular automaton environment for the complex system of speech," Dec. 2019

Anna Rohunen, "Advancing information privacy concerns evaluation in personal data intensive services," Dec. 2019

Muhammad Ikram Ashraf, "Radio Resource Management in Device-to-Device and Vehicle-to-Vehicle Communication in 5G Networks and Beyond," Dec. 2019

Mohammed Elbamby, "Flexible duplexing and resource optimization in small cell networks," Dec. 2019

Kalle Lähetkangas, "Special applications and spectrum sharing with LSA," Nov. 2019

Angelos Fylakis, "Data hiding algorithms for healthcare applications," Nov. 2019

Jia Sun, "Speeding up the settling of switched-capacitor amplifier blocks in analog-to-digital converters," Nov. 2019

Florian Kühnlenz, "Analyzing Flexible Demand in Smart Grids," Nov. 2019

Matti Isohookana, "Combat durable spread spectrum data link for national military aviation," Nov. 2019

Nina Joseph, "CuMoO4 : a microwave dielectric and thermochromic ceramic with ultra-low fabrication temperature," Oct. 2019

Ilkka Hautala,"From dataflow models to energy efficient application specific processors," Oct. 2019

Suvi Tiinanen,"Methods for assessment of autonomic nervous system activity from cardiorespiratory signals," Aug. 2019

Olli Pitkänen, "On-device synthesis of customized carbon nanotube structures," Aug. 2019

Shahriar Shahabuddin, "MIMO detection and precoding architectures," June 2019

Kien-Giang Nguyen, "Energy-Efficient Transmission Strategies for Multiantenna Systems," June 2019

Aku Visuri, Wear-IT: implications of mobile & wearable technologies to human attention and interruptibility," May 2019

Kien Vu, "Integrated access-backhaul for 5G wireless networks," May 2019

Jobin Varghese, "MoO3, PZ29 and TiO2 based ultra-low fabrication temperature glass-ceramics for future microelectronic devices," Apr. 2019

Tenager Mekonnen, "Efficient Resource Management in Multimedia Internet of Things," Mar. 2019

Simon Klakegg, "Enabling awareness in nursing homes with mobile health technologies," Mar. 2019

Xin Liu, "Human motion detection and gesture recognition using computer vision methods," Mar. 2019

Mikko Hintikka, "Integrated CMOS receiver techniques for sub-ns based pulsed time-of-flight laser rangefinding," Jan. 2019

Tachaporn Sanguanpuak, "Radio resource sharing with edge caching for multi-operator in large cellular networks," Jan. 2019

Paula Alavesa, "Playful appropriations of hybrid space : combining virtual and physical environments in urban pervasive games," Dec. 2018

Jarkko Tolvanen, "Novel sensor and switch applications for flexible and stretchable electronic materials," Oct. 2018

Jiguang He, "Performance of MIMO and Non-Orthogonal Transmission in Lossy Forwarding Relay Networks," Nov. 2018

Markus Leinonen, "Distributed Compressed Data Gathering in Wireless Sensor Networks," Oct. 2018

Marja Matinmikko-Blue, "Stakeholder analysis for the development of sharing-based spectrum governance models for mobile communications," Oct. 2018

Pawani Porambage, "Lightweight Authentication and Key management of Wireless Sensor Networks for Internet of Things," Sept. 2018

Ganesh Venkatraman, "Traffic aware resource allocation for multi-antenna OFDM systems," Sept. 2018

Ayotunde Oluwaseun Laiyemo, "High speed moving networks in future wireless systems," Aug. 2018

Tuomo Hänninen, "Detection algorithms and FPGA implementations for SC-FDMA uplink receivers," July 2018

Jarkko Kaleva, "Decentralized Multiantenna Transceiver Optimization for Heterogeneous Networks," June 2018

Ijaz Ahmad, "Improving software defined cognitive and secure networking," June 2018

Juha Petäjäjärvi, "Low-power wireless communications in the Internet of Things – solutions and evaluations," June 2018

Zinelabidine Boulkenafet, "Face presentation attack detection using texture analysis," May 2018

Oskari Tervo, "Transceiver optimization for energy-efficient multiantenna cellular networks," May 2018

Pekka Kyösti, "Radio Channel Modelling for 5G Telecommunication System Evaluation and Over the Air Testing," May 2018

Teemu Nyländen, "Application specific programmable processors for reconfigurable self-powered devices," May 2018

Bidushi Barua, "Incentivizing user participation in cooperative content delivery for wireless networks," May 2018

Rashad Hajimammadov, "Plasmonic, electrical and catalytic properties of one-dimensional copper nanowires : effect of native oxides," May 2018

All theses are openly available at ***http://jultika.oulu.fi***.

6G FLAGSHIP IN NUMBERS

Staff

315
Person years in 2019

56
Nationalities

Publications (May 2018 – December 2019)

838
Peer-reviewed publications / Journal and conference articles

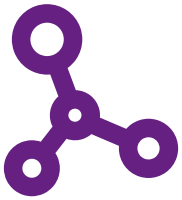
64% International joint publications

73% Joint publications with collaborators

11% Joint publications with companies

Collaboration (May 2018 – December 2019)

223
Research projects with external funding



96 **New company collaborators**

75 **Companies investing in research portfolio**

Doctoral Degrees (May 2018 – February 2020)

44
Doctoral degrees

113 852
Doctoral thesis downloads
Number of downloads in University of Oulu repository *http://jultika.oulu.fi/*

6G White Paper (September 2019-February 2020)

100 403
6G White Paper downloads

Number of downloads of publication "Key drivers and research challenges for 6G ubiquitous wireless intelligence" in University of Oulu repository *http://jultika.oulu.fi/*

6G ECOSYSTEM

Our 6G ecosystem is a versatile **collaboration platform** which gives access to next generation wireless technology development and helps in unlocking future opportunities.

"Becoming an academic, public or industrial partner in our 6G ecosystem means a deep insight to hottest differentiating technologies, solutions and opportunities e.g. in wireless, AI and IoT."

Prof. Jaakko Sauvola, 6G Ecosystem Leader

The ecosystem continuously grows with **ICT companies, public and academic partners, and applied businesses**, meaning more partnering, solution and differentiation opportunities.

Each partner is unique, thus we offer our members **tailored pathways** to get maximal benefit from the ecosystem:

- Technology and ICT companies get a front-row seat to co-develop tomorrow's solutions.
- Academic and research partners are taken to the frontiers of research with exciting use cases, technology exploration and unprecedented solutions.
- Non-technology companies can take advantage of very practical placement of new technologies in their offering through a large base of partners and interesting project opportunities.
- Public partners can enjoy deep and understandable insights on the transformation and how to benefit from it through high-impact pilots and testing of new solutions.

Why to join the Ecosystem?

- Leading 5G/6G expertise at your service
- Latest research outputs within easy reach
- Access to 5G/6G test network and joint trials
- Support for 5G adoption
- 5G/6G for verticals
- New ICT-enabled business models
- Possibility for IPR transfer

Ecosystem membership levels

Affiliate
- Information sharing

Pioneer
- Project partners

Co-Creator
- Strategic partners

Ecosystem work in practice

- Information
- Events
- Expert support
- Hosted visits
- Innovation sessions
- Project creation
- Trials and demonstrations
- Joint visibility

Jaakko Sauvola
Flagship Ecosystem Leader

Mika Rantakokko
Flagship Ecosystem Coordinator

More information
https://www.oulu.fi/6gflagship/ecosystem

Join the 6G Ecosystem
https://www.oulu.fi/6gflagship/joinecosystem

COMING UP

8-13 June 2020 | Oulu, Finland

UBISS 2020

11th International UBI Summer School 2020

13-16 September 2021 | Finlandia Hall, Helsinki, Finland

IEEE PIMRC'21

6G Driving Sustainability

IEEE 32nd Annual International Symposium on Personal, Indoor and Mobile Radio Communications

3RD 6G WIRELESS SUMMIT 2021

in conjunction with PIMRC'21

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6G Waves 1, Spring 2020
Hanna Saarela, Ville Wittenberg | 6G Flagship, University of Oulu, Finland

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