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6G Flagship, University of Oulu, Finland  
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6G Flagship is part of the Finnish Flagship Programme  
funded by the Academy of Finland.
We are thrilled to welcome you to explore this second edition of our 6G Waves magazine!

When we published the first magazine in early March, none of us at the Faculty of Information Technology and Electrical Engineering (ITEE) at the University of Oulu fully grasped what lies ahead for us as individuals and experts, and as members of communities and the society. COVID-19 has since then made remote work a default at our university, limiting international contacts and face-to-face collaboration because of tight restrictions for gathering and travel, which are still in place.

Yet, our 6G Flagship research program has managed to be highly productive both in scientific work and in creating impact on multiple levels, as our results show. In just two and a half years, our experts have published more than 1,100 peer-reviewed scientific articles. This magazine highlights our latest results, collaborations, and the expertise of innovators who are taking 6G research to where no one has gone before. You can also discover how we contribute to 5G adoption and beyond 5G development with our collaborators.

We are proud of the new set of 6G white papers that we published in June. They illustrate the complementary views and visions of 250 global experts who answered our open call and joined the thematic expert groups. The white papers introduced in this magazine show the wide-scale importance of coupling research and technology development with sustainability and business, with key verticals as pathways to future sustainable systems and services. The white papers also discuss how optimal 6G solutions will rely on various stakeholder groups’ early engagement to create a real societal impact towards 2030.

We have adopted new means of collaboration during this unusual year while we have also strengthened our expertise in maneuvering virtual platforms and tools. Next year, these competencies will help us organize two major international events – 2021 Joint EuCNC & 6G Summit in June and IEEE PIMRC 2021 in September. We will utilize our research results and recent practical learnings to create intriguing 6G-focused program for both events.

Our global 6G research effort necessitates highly skilled experts. We are continuously looking for new innovative individuals to join us in fulfilling our ambitious goals, which we introduce in further detail in this magazine. Industry is also getting ready towards 6G era. The first EU Horizon 6G projects led by industry are starting early next year. Next G Alliance founded by American industry and operators, aiming to steer development of 6G, was founded in the US in October. Thus, now would be a perfect time for companies to join our expanding 6G ecosystem to tackle the challenges of future systems together.

With this 6G Waves magazine, we wish you a safe and productive end of the year 2020!

Jukka Riekki
Professor, Dean of Faculty of ITEE, University of Oulu
6G Flagship, Strategic Research Area Leader, Distributed Computing
The Finnish 6G Flagship is the world’s first 6G research and co-creation program led by the University of Oulu and appointed for 2018-2026 by the Academy of Finland, a governmental funding agency for high-quality scientific research. 6G Flagship envisions a future society towards 2030, which is data-driven and enabled by near instant, unlimited wireless connectivity. The 6G experts in Finland seek major scientific breakthroughs in four interrelated strategic research areas: wireless connectivity, device and circuit technologies, distributed intelligent computing, and novel vertical applications and services. During the first two and a half years, the experts have shared key results and initial solutions in more than 1,100 peer-reviewed articles demonstrating the scientific impact of the 300-person research effort.

6G Flagship’s experts foresee the main future uses of 6G in specific verticals, including health, industry 4.0, automotive and energy, which are already present in the ongoing 5G rollout. Together with stakeholders in industry, academia, governmental organizations, and regulatory bodies, 6G Flagship responds to major societal challenges such as connecting the unconnected. Local entities in increasing numbers are able to establish and operate their own 5G networks, thanks to 6G Flagship researchers’ long-term endeavors. The program creates wide societal and economic impact with stakeholders through targeted actions which include e.g. collaborative research project development, cross-sectoral researcher mobility, open research and development environments, expert services and expert groups for white paper writing. In addition to major international conferences, including world’s first 6G event “6G Wireless Summit”, 6G Flagship organizes research to business events, co-creation workshops, open innovation events and hackathons, among others, which aim at boosting digitalization and creating innovations especially in verticals through 5G and 6G enabled applications and services.

Already, 6G Flagship has produced very promising outcomes towards its three main goals: 1) to support industry in finalization of the 5G standard; 2) to develop the essential technology
components needed for 6G; and 3) to speed up the digitalization of society via targeted application areas.

Under the first goal, the 6G Flagship initiative has supported 5G-enabled economic growth in industry through co-creation with more than 300 companies in projects, through shared human resources, joint standardization and regulation efforts, and the commercialization of research results has given the companies a competitive edge by opening new business and digitalization opportunities. The open 5G Test Network (5GTN), upgraded with 5G new radio and sensors, has attracted more than 150 companies to test 5G prototype devices, and to explore higher frequency bands, cognitive management functionalities, and system testing tools for new solutions. 5GTN has also boosted trials in numerous externally funded projects. In addition, major international conferences and workshops organized by the 6G Flagship have speeded up 5G-enabled digitalization in industry through shared research and validation results.

Under the second goal, 6G Flagship has embraced its global leadership role in launching large-scale 6G research, built a vigorous 6G ecosystem and constructed novel discussion forums to critically analyze the limitations of 5G evolution and to explore most promising enablers for 6G with its global network of more than 1,000 collaborators. 6G vision-building has greatly benefitted from the new open forums created by the 6G Flagship initiative: the annual IEEE 6G Wireless Summit (2019 – 300 participants, 2020 – 600 participants) and 6G White Paper expert groups (2019 – one generic white paper, 2020 – 12 thematic 6G white papers). At the University of Oulu, the Flagship has defined an ambitious 6G research architecture to organize the research efforts within the four strategic research areas. Testing capabilities towards 6G were greatly improved with upgrades in 5GTN including THz radios and virtualized network. Most recently, the radio-frequency integrated circuit (RFIC) probe station measurement capability and the antenna near-field measurement system have been upgraded to support 330 GHz measurements with frequency extenders. Additionally, the RF research team has developed a 3-dimensional (3D) over-the-air (OTA) measurement system to measure physical objects such as lens antennas supporting measurements up to 330 GHz. As a next step, a channel measurement system is under development with a 330 GHz frequency support.

Under the third goal, the 6G Flagship initiative has successfully applied 5G in selected verticals; gained regulatory acceptance for disruptive local 5G operator models; promoted 6G for European and global research agendas; and strengthened global support for using UN SDGs as a basis for 6G development. 6G Flagship has refined its full-stack model which links connectivity, services, content, end-user community and devices and developed novel solutions atop 5GTN for example in automotive, health, transport and energy applications through collaboration between industry, academic and public sectors. The program has supported regulation and legislation based on the requirements rising from research especially in the areas of ownership and use of radio spectrum, communications infrastructure, and data. Already now, the Flagship program’s results are visible in decision making at national, European and international levels. Furthermore, researchers have adopted a strong expert role in steering society towards the 6G era through active communication, high-quality content for various audiences, open discussion in media and targeted events.

6G definition work continues with a focus on the most promising enabling technologies, the identification of key performance and value indicators, as well as the investigation of new business opportunities and related regulatory challenges. For latest news and collaboration opportunities, please visit 6gflagship.com and 6gchannel.com, and follow @6gflagship in Twitter and LinkedIn.
As the World Health Organisation (WHO) declared COVID-19 a pandemic and the world began to go into lockdown, the organisers of the 2nd 6G Wireless Summit 2020 decided to transform the leading global 6G event to a virtual one – in less than five days.

The virtual event was launched in the morning of 17 March 2020, as originally planned for the physical event. “It was made possible by a seven-member team including students, technical staff and myself as technical programme committee chair,” said Nandana Rajatheva. “We worked nearly around the clock in a highly time-constrained scenario as we also wanted to ensure a high-quality outcome.”

By March, very few major events organised with technical support by IEEE - world’s largest technical professional organisation - had taken place online. “We have received positive feedback from different parts of the world stating that this was truly a landmark achievement leading the world towards other similar events realised virtually,” Rajatheva said.

The turnout left no questions about the timeliness of the discussed topics as 610 experts from 42 countries explored the online material. An absolute highlight at the event were the live Q&As by all seven keynote speakers in the discussion forum which defied the restrictions of time zones. The live Q&A sessions attracted a lot of attention and provided the virtual summit attendees an opportunity to directly interact with the leading experts. The website tool and browsers caused some challenges, for sure, but the statistics demonstrate a strong participation.

Academy professor Matti Latva-aho, general chair of the 2nd 6G Wireless Summit 2020 and director of 6G Flagship programme, concluded that the virtual event was a success and it showed how much progress has been made around the globe. “Industry actors have clearly formed their own 6G visions which was a major advancement from last year,” Latva-aho said. “In the Summit, industry representatives expressed their views on the timing of 6G development in relation to upcoming World Radiocommunication Conferences (WRC). In the course of next years, 6G community will focus on the research of enabling technologies and 6G requirement specifications as an integral part of the International Telecommunication Union (ITU) process.”

Patrons of the 2nd 6G Wireless Summit were Ericsson, Huawei, ZTE, Keysight Technologies, Nokia Bell Labs, Rohde&Soharz, Virginia Diodes, InterDigital and Wipro. All patrons were very active in different programme roles, contributing to keynotes, invited talks as well as Q&A sessions. The patrons also extended their thanks to organising the event successfully. However, one disadvantage with the virtual event realisation were the live exhibitions, which unfortunately had to be cancelled. “Exhibition materials in high quantities already arrived in Levi, but we sadly had to return them all back to their origins,” said Tuomo Hänninen who was in charge of organising the exhibitions.

The technical programme of 6G Wireless Summit was both versatile and thought provoking. The organisers were pleased to see that experts were starting to speak out about possible 6G indicators and responding to societal challenges with a more optimistic and daring tone which was a major leap from their more cautious approach in the first 6G Wireless Summit held in Levi, Finland in March 2019.

The suggested indicators not only measure the performance of future 6G systems, but assess novel societal and value-re-
lated aspects such as trust, open collaboration, flexibility and underserved areas while a strong emphasis was also put on value creation through new business models and private networks, among others.

The role of imaging and sensing, as integrated functions in 6G networks, was also highlighted in numerous presentations. Experts shared somewhat aligned visions of integrated communication, imaging and sensing in 6G systems towards 2030 where the Internet of Senses will reshape human-machine interaction and where interconnected digital twins for both physical beings and environments will be a norm.

Major investments for 6G research and development were also discussed. The European Commission has taken initiative proposing carbon neutrality by 2050. “It’s huge task and we will be expected, when we develop our 6G technology, whatever domain is, 6G or other any type of domain, to contribute to this carbon neutrality objective,” said Bernard Barani, Deputy Head of Future Connectivity Systems Unit at the European Commission, in his invited talk. He also stressed that there is a very strong political momentum behind 6G developments in Europe. Under the next Horizon Europe programme for 2021-2027, the Commission has proposed more than 2.5 billion € of EU investment matched with at least 7.5 billion € of private investments to prepare for 6G.

Clarifying both 6G research visions and a wide array of views on most intriguing 6G development challenges and paths, the event achieved its goal. Although the virtual space at 6gsummit.com/virtual-event could hardly compete with the winter wonderland in Levi, Lapland, it came with other benefits. Participation was flexible and attendees could focus more intensively on their specific topics of interest. The pre-recorded video presentations provided more insights than mere slides and papers in Proceedings ever could. Last, but not least, the online forum gave even the more silent attendees a voice by providing equal opportunities for in-depth conversation while also producing more elaborated exchange of ideas than speedy Q&As in regular conference sessions.

Read more: www.eucnc.eu www.6gsummit.com/story-of-virtual-6g-summit

Virtual Event Statistics until 18 March 2020

| 610 | Users |
| 42 | Countries |
| **TOP 10 Countries by sessions** |
| 177 | Finland |
| 58 | China |
| 57 | United States |
| 35 | United Kingdom |
| 24 | Canada |
| 21 | France |
| 20 | Germany |
| 19 | India |
| 17 | Japan |

| 7 | Keynotes |
| 37 | Invited presentations |
| 117 | Papers and posters |
| 414 | Posts on Discussion Forum |
| **TOP 3 Keynotes by browsing sessions** |
| Communications in the 6G Era | Harish Viswanathan, Nokia Bell Labs |
| Wireless Communication and Applications Above 100GHz | Ted Rappaport, NYU WIRELESS, USA |
| 6G: The Next Horizon | Pelying Zhu, Huawei |

| 686 | Browsing sessions |
| 13 663 | Page views |
| 715 | Opening Video views |

EUCNC 6G Summit
Porto, Portugal, 8-11 June 2021

- 6G Summit will be co-organized with European Conference on Networks and Communications (EuCNC) in Porto, Portugal, on 8-11 June 2021.
- The event celebrates the inauguration year for Horizon Europe research programme with a target volume of € 100 billion for 2021 – 2027.
- 6G standard will be largely developed during the programme time frame, and thus, bringing 6G Summit and EuCNC together is a natural move to join forces. Flagship Director, Professor Latva-aho is Steering Committee Vice-Chair for the event.
The set of 6G white papers prepared by 250 global experts presents a comprehensive analysis of technological advancements and societal challenges that we see today as key enablers and drivers for 6G ten years from now. The use of new higher frequency bands requires giant technological leaps but the laws of physics will not change. Ten years is a short time in fundamental technology development.

Overall, it was an intensive spring for the experts who stepped onboard the white paper writing process in January and cheered the publication of the final versions of 11 white papers in June, with one still in production. “When we saw the high number of experts registered to the twelve groups through our open call, we realized that the wider community was ready for this type of activity and highly motivated to deepen the 6G vision in the selected themes,” says Dr. Marja Matinmikko-Blue who coordinated the writing process of the white papers. “The groups worked very actively and the effective white paper content creation was done in around three months, partially under COVID-19 lock-down. Some expert groups took a more scientific approach in the white paper process through action research and scenario planning, while other groups focused on the compiling of new technology inputs collected from telecom experts.”

Technology, sustainability and business are recurring themes in the white papers. Many topics fall under all three - yet the emphasis is different. “The telecommunication community is usually good at technology development, but the inclusion of sustainability at the level discussed in the white papers is something totally new and goes beyond the approach in the prior generations of networks,” Matinmikko-Blue notes.

The business environment will undergo a drastic change when digitalization is gradually introduced to all aspects of society. “Looking at different continuums, for instance humans-machines, the needs of the different types of users must be addressed, with the goal of sustainability at all levels,” Matinmikko-Blue says. “Technology-centric versus business focused continuum, on the other hand, is a good reminder for us telecom experts. The potential we see for wireless in verticals is only realized when the vertical businesses can harness the benefits.”

The key enablers and research challenges envisaged for 6G in the white papers are based on the knowledge we have today. “The young people of today will be the developers and users of the new 6G systems in the next decade and we must invest in offering them a solid knowledge base with tools to achieve the best possible outcomes that transform societies.”

The white papers offer a comprehensive set of research challenges covering technology, sustainability and business themes and serve as a good starting point for future innovations while guiding the research on 6G. “It was also a great learning experience to facilitate these stakeholder interactions,” Matinmikko-Blue concludes and thanks each of the 250 experts from numerous fields of science and business who contributed to the creation of the white papers!
MEET THE EXPERT GROUP LEADERS

Marja Matinmikko-Blue
Dr. Marja Matinmikko-Blue wishes to transform spectrum management for mobile communications via multidisciplinary research from business, regulation and technology views - with two doctoral degrees.

Ari Pouttu
Prof. Ari Pouttu looks for optimal solutions for dependable wireless systems applied in various business verticals including health, connected mobility, industry 4.0, critical infrastructures and energy.

Tarik Taleb
Prof. Tarik Taleb develops architectural enhancements to mobile networks with a focus on network softwarization, network function virtualization, and software-defined networking.

Ella Peltonen
Dr. Ella Peltonen focuses on sensing data analytics and edge computing to build intelligent solutions for the future of the pervasive computing.

Nandana Rajatheva
Prof. Nandana Rajatheva focuses on physical and MAC layer enhancements in wireless together with related developments in applications such as autonomous driving via ML / AI.

Carlos Lima
Dr. Carlos Lima focuses on intelligent environment-aware solutions exploiting localization and sensing information to optimize the deployment and operation of future wireless communication networks.

Seppo Yrjölä
Dr. Seppo Yrjölä is passionate about digitalizing the 70% of the GDP that has not yet been digitalized in order to drive massive productivity growth and new business.

Harri Saarnisaari
Adj. Prof. Harri Saarnisaari paves the way for solutions to provide affordable and sufficient connectivity for the unconnected, including technical, regulatory and collaboration aspects.

Samad Ali
Dr. Samad Ali investigates the role of machine learning in design and zero-touch optimization of the future wireless communication systems.

Mika Ylianttila
Prof. Mika Ylianttila leads NSOFT (Network security and softwarization) research group which studies and develops secure, scalable and resource-efficient techniques for 5G and beyond 5G and IoT systems.

Nurul Huda Mahmood
Dr. Nurul Huda Mahmood is passionate about designing effective and efficient yet simple algorithms for wireless communications, with current focus on enablers for critical machine type communications.

Aarno Pärssinen
Prof. Aarno Pärssinen explores opportunities in RF and HW design at mmW frequencies up to 300GHz and looks for hardware-aware communications concepts towards 6G with physical boundaries in mind.
WHITE PAPER ON 6G DRIVERS AND THE UN SDGS

The White Paper on 6G Drivers and the UN SDGs builds on the current relation between mobile communications and the UN Sustainable Development Goals (SDGs) and creates a strong linking between the upcoming 6G systems and the UN SDGs – both targeting year 2030. The multidisciplinary expert group led by Dr. Marja Matinmikko-Blue defines a three-fold role for 6G as 1) provider of services to help reaching the UN SDGs, 2) enabler of measuring tools for data collection to help with the reporting of indicators, and 3) reinforcer of a new ecosystem to be developed in line with the UN SDGs.

The group identified global megatrends, which will drive 6G research and shape the world in the coming decades. The group also discovered that future 6G systems can offer a massive array of services which will change our perception of time and space in drastically new ways, empower the people and contribute to the achievement of all UN SDGs. Existing indicators in the UN SDG framework served as a point of departure in the development of the novel view on the future communication system, where various stakeholders have an active role. “For example, reducing inequality and securing a better quality of life to those in the most vulnerable position in a sustainable way by extending the network infrastructure is critical and requires actions from governments and operators,” Matinmikko-Blue says.

The group started from the vision of 6G systems created in the first 6G White Paper in 2019, where 6G merges the communication service with locationing, sensing, and imaging services, and took this vision one step further. In the new white paper, the expert group proposes that 6G systems could gather a variety of data to report on the achievement of the UN SDGs on a highly local granularity level which today is a challenge that nations face. “Examples of data include the use of networks and services for the achievement of the SDGs,” Matinmikko-Blue notes. “However, counter effects are also expected and therefore it is crucial to look into what data actually should be collected and reported and how.”

The new ecosystem, on the other hand, will be built around a number of new stakeholders and principles. Pure business-driven operations will be complemented with new societal models including community-driven networks which will emerge depending on the regulatory environment. Another big transformation will come from the vertical industries and their public sector counterparts to whom the achievement of the UN SDGs will place significant economic constraints and they will need to take everything the future technologies can offer to improve systems and processes. This requires an early engagement in the process of 6G development instead of waiting for the telecommunication industry to define what 6G can bring for them.

The power of group work became visible in the preparation of the white paper. The multidisciplinary multi-actor expert group, with representatives from engineering and social sciences, adopted a collaborative process to identify new, not yet found linkages between 6G and the UN SDGs. “When the 32 experts continued to participate in the regular telcos month after month, and several said they had missed the initial call for experts and came on board later, I realized that the need for this activity was high,” Matinmikko-Blue says. “The outcome is more than the sum of individual inputs.”

Read more: www.6gchannel.com/wp-6g-drivers-un-sdgs
6G unlocks unprecedented opportunities of enabling and empowering multiple new stakeholders to actively participate in 6G ecosystem. Current network-for-connectivity business models will be transformed towards novel “network of services” open ecosystemic business models enabling agile service innovations. Developing products and services for the future digitized 6G society requires a transdisciplinary approach and a redefinition of how we create, deliver, share and consume network resources, data and applications.

“We will move from owning to access - 6G sharing economy,” says Dr. Seppo Yrjölä, who led the preparation of the White Paper on Business of 6G. “To achieve an actionable 6G future in the 2030s, several types of multi-level ecosystemic interaction needs to be reconsidered. We must focus on collaborative standards development, modularity, and the complementarity of technological solutions.” In addition to platform owners, platform developers, integrators, managers, public, corporate and individual users also need to be able to reach scale and scope to obtain 6G benefits.

The potential is massive as 6G services through digital automation are estimated to grow 3 to 10 times larger than the current wireless operator business. On top of that, 6G is expected to improve work productivity by up to 40% by 2035 when combined with platform economy and artificial intelligence. “No single mobile operator will own all of the resources in the future and more localized networks will be set up leveraging virtualized shared resources from marketplace,” Yrjölä says.

The scenarios that the expert group explored reflect increasing tensions between competitive, protective, networked and empowered worldviews. “High volatility, uncertainty, complexity and ambiguity (VUCA) was visible in all scenario themes as a “meta trend” highlighting the global concern to ensure resiliency and stability from every stratum of society,” Yrjölä says.

From the economic perspective, the explored scenarios showed that local-demand-supply-consumption models will become prominent in an already globalized world, with a marked emphasis on localized spatial circular economies. In parallel, new societal models for future service provisioning will emerge building on community-driven networks and public-private partnerships. “The decoupling of technology platforms will lower the market entry barrier, allowing multiple entities to contribute to the innovations envisaged with 6G while decentralized platform cooperatives will become counterforces to winner-takes-all platform monopolies,” Yrjölä says.

Platform ecosystems will not only offer search, social media, and ecommerce, but will provide an infrastructure in which innovation and transaction platforms are built. At the same time, fine-grained modularity and open source will allow highly specialized solutions and services from smaller players to be widely deployed. “6G enables the emergence of new digital exchange tools, the creation of new value, new business models and new ecosystemic roles as it connects data streams in real time to data lakes at the intelligent edge cloud, close to the user, people, the machine or us together,” Yrjölä says. This raises difficulties in openness and transparency as well as collaboration vs. competition issues especially in the use of data and algorithms. Access to data and data ownership are increasingly the major factors in value creation, and limiting such access is a means of control and restricting empowerment.

The exploration on societal perspective, on the other hand, evidenced that power configuration may be transforming from a multi-polarized world to a poly-nodal world in which power will be determined in economic, technological, and cultural networks and interaction. Hybrid military, economic, technological, and cultural powers have become overlapping, exercising threats and hybrid influence. As a result, privacy regulation will be strongly linked to the rising trends of the platform data economy, sharing economy, intelligent assistants, digital twins’ reality, connected living in smart cities and transhumanism at length. “In this context, empowering experiential citizens as knowledge producers and users will contribute to a process of human-centered democratizing innovation stemming from pluralism and diversity,” Yrjölä points out.

The environmental perspective led the group to identify 6G as provider of services that helps to steer communities and
countries towards reaching the United Nations sustainable development goals (UN SDGs). “6G solutions play an important role in achieving UN SDGs by connecting unconnected people, providing things and services more quickly and securely and by creating a more equitable, safer and healthier society,” Yrjölä says. “6G will offer opportunities for monitoring and steering the circular economy and understanding the big picture of the sustainable data economy.”

Aiming to fulfill UN SDGs, companies will shift focus, developing products and technologies that innovate to zero, including zero-waste and zero-emission technologies bringing social innovation to the forefront. In utilizing sharing and circular economy trends, co-creation will employ existing resources and processes to promote the sustainable interaction of mechanisms.

“Our findings indicate that business ecosystems that aim to bring together stakeholders to solve systemic sustainability problems will require open ecosystem-focused value configuration and decentralized poly-nodal power configuration, focusing on the long tail of specialized user requirements that crosses a variety of industries,” Yrjölä says.

Technical dependencies are difficult to avoid when separate companies commercialize different 6G technologies and solutions. At the same time, consumer and production complementarities are required to efficiently regulate, standardize, and balance the supply and demand of 6G services. “We need technological complementarities to ensure that the various technological innovations created complement each other in commercialization,” Yrjölä says. “This is particularly important if we wish 6G to become a pervasive general-purpose rather than merely an enabling technology with complex technical dependencies.”

Read more: www.6gchannel.com/wp-business
The research community is increasingly absorbed in exploring and developing technology enablers for 6G including radio components as well as network architectures of the future. It has become clear that one solution fits all is no longer feasible as innovation for new business models, introduction of novel use cases and vertical specific key performance indicators (KPIs) diversify the future wireless. Therefore, an analysis of real life systems is needed to offer concise views on most probable use cases, KPIs, regulatory aspects, and legislative changes as well as methodologies to implement them. At the same time, the UN SDGs and how to measure the effect towards the SDGs with a given system design are still very much open challenges.

Based on 6G drivers, megatrends as well as assessment of the most opportunity-rich verticals with revenue expansion potential, the 16-person expert group that wrote the White Paper on Validation and Trials for Verticals towards 2030’s selected seven vertical businesses and future software-based testing areas for discussion: industry 4.0, future mobility, eHealth, energy, finance and banking, public safety, and agribusiness. Early on in the writing process, the team of experts recognized that the different verticals require a very different set of capabilities from the wireless communication system stemming from the expected use cases within the verticals. “As our KPI table indicates, the selected verticals require a quite diverse set of KPIs,” says Prof. Ari Pouttu, who led the white paper work. “They may lead to market adoption with vertical specific service providers who have thorough understanding of the needs, dynamics and the business of a vertical thus having a position of being able to provide optimized solutions for its customers.”
This is also evident from the NTT DoCoMo white paper, which suggests that starting with 5G but fully flourishing with 6G, we shall have new vertical-specific markets appearing. Whereas a new cellular generation emerges every ten years and traditional value markets emerge every twenty years, the speed in the transformation of verticals is changing through digitalization. The potential technical KPIs under 6G umbrella are currently under discussion, mainly in the scientific community, with respect to the envisaged usage of future systems, cost implications, business cases, and technical feasibility. So, for the time being, no KPIs are agreed. ITU-R WP5D has initiated the development of a report on the future technology trends towards 2030 and beyond, which will later lead to agreed technical KPIs at the global level.

The white paper also introduces a roadmap which was conceived in conjunction with the idea of gradually transforming the 5G test network (5GTN) at the University of Oulu to 6G test network (6GTN) as we move towards 2030’s. “The roadmap presents both expected technology developments needed and the most opportunity rich verticals,” Pouttu says. “It also points out the regulatory and legislative changes required as we move towards the expected new business model innovations.”

In the 6G era, it is expected that the peak data rates required will begin to approach the Tbit/s regime indoors, which will require huge available bandwidths. Examples of such applications could be 16K video resolution in 360° with a refresh rate of 240 Hz for a “true immersion” experience or holographic displays. This will necessitate a spectrum use beyond millimeterwave (mmW), giving rise to (sub-) terahertz (THz) communications. However, a large portion of the verticals’ data traffic will be measurement-based or actuation-related small data, which in many cases, requires extreme low latency, because many processes aspire to 1,000–2,000 Hz control loops, necessitating over-the-air latencies in the 100 μs domain to allow time for computation and decision making as well.

At the same time, the reliability requirement (which is the opposite of low latency) in many industrial, automotive, or health applications is expected to be of the order of 1–10⁻⁹. Even more challengingly, industrial devices and processes, future haptic applications, and future multi-stream holographic applications require timing synchronization to set requirements for transmission jitter of less than a microsecond. Many verticals will also need a multitude of extremely inexpensive sensors or actuators that are transmit-only or receive-only devices, hence requiring the granting of free access, because either the uplink or downlink is missing to reduce the cost.

To address the fact that different vertical industries may also differ considerably in their working environments, it may be worthwhile to define testing environments, which are individual to a certain industry type. “Thus, the goal should be to create a flexible and portable testing solution,” Pouttu says. “With this, it will become possible to evaluate new testing ranges regarding their compliance with the reference testing system, and the compliance with given performance criteria (KPIs) can thus be evaluated by various neutral bodies.” Only by taking this approach, will the industry-required certification of 6G industrial components become possible. And, only with such a certification, will the technology be adopted inside critical environments.

Read more:
www.6gchannel.com/wp-validation-trials

<table>
<thead>
<tr>
<th>Vertical</th>
<th>Link Data Rate</th>
<th>Latency</th>
<th>Link Budget</th>
<th>Jitter</th>
<th>Density</th>
<th>Energy Efficiency</th>
<th>Reliability</th>
<th>Capacity</th>
<th>Mobility</th>
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<tbody>
<tr>
<td>Industry mMTC</td>
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<td>&lt; 100 ms</td>
<td>+10 dB</td>
<td>100 μs</td>
<td>100/m³</td>
<td>High</td>
<td>1-10⁻⁶</td>
<td>&lt; 10 Gbps</td>
<td>240 km/h</td>
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<tr>
<td>Industry eURLLC</td>
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<td>10/m³</td>
<td>Nominal</td>
<td>1-10⁻⁹</td>
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<tr>
<td>Mobility</td>
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<td>+20 dB</td>
<td>100 μs</td>
<td>100/m³</td>
<td>Nominal</td>
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<td>1 Tbps</td>
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<tr>
<td>eHealth</td>
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<td>&lt; 1 ms</td>
<td>+10 dB</td>
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<td>1/m³</td>
<td>High</td>
<td>1-10⁻⁶</td>
<td>&lt; 10 Gbps</td>
<td>240 km/h</td>
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<tr>
<td>Energy</td>
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<td>&lt; 500 μs</td>
<td>+40 dB</td>
<td>&lt; 1 μs</td>
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<tr>
<td>Finance</td>
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<td>1-10⁻⁷</td>
<td>1 Gbps</td>
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</tbody>
</table>
Connecting the unconnected is a massive challenge as half of the world’s population remains without any or sufficient internet connectivity. The reasons include low level of income, low population density in the living area or lack of infrastructure such as roads or power grids. These characteristics, among others, reduce network, infrastructure and service providers’ interest to invest in these areas since expected revenues would be small. “6G will be a part of the solution needed to solve the constantly increasing problem of the digital divide which is at the core of our 6G white paper,” says Dr. Harri Saarnisaari, who led the white paper team consisting of 34 experts.

Requirements for connecting the unconnected must be included into discussions and development processes since the beginning, not after a new broadband 6G has been defined, Saarnisaari urges. “We have to define globally what we mean, in the 6G era, by affordable and sufficient services that should be available for everyone,” he says. “We believe that 6G could be the first data-driven standard where the unconnected are taken into account since the beginning. And, this consideration must be extended to remote and rural areas as well.”

Spectrum, when it is allocated nationwide, is not necessarily used in an efficient manner on the local level, and rural and remote areas suffer precisely of this mismatch. “Novel, innovative spectrum regulation should open new, feasible ways to improve connectivity in these areas,” Saarnisaari says.
“Furthermore, if big operators are not interested to provide local remote connectivity, then maybe local micro operators are.”

Connectivity solutions for digital oases, as the remote and rural spots are called in the white paper, require new approaches. “It seems that a separate rural/remote mode is needed so that sufficient services can be provided while keeping the solutions economically feasible,” Saarnisaari says. “Furthermore, in many places low energy consumption in local relay and base stations is needed to support solar-panel powered operations. Mostly autonomous installation and maintenance functions are also an important factor.”

The white paper covers wireless technical solutions including terrestrial, air, space, power grid, optical and so on. They must be enhanced by sea cables and terrestrial fibre networks. “It is important to realize that we need both local connectivity and backhaul solutions,” Saarnisaari points out. “And we should not forget air and sea routes that also need connectivity in remote locations.”

To tackle the multifaceted connectivity problem, collaboration between stakeholders is required. Political decision makers are needed to adjust and guide regulations and rules as well as to provide the necessary financial support. Regulators, on the other hand, play a key role in guaranteeing sensible spectrum usage, whereas connectivity providers can offer the necessary infrastructure and services. Local inhabitants must be tightly integrated to express their connectivity needs but also to learn and adopt new technology. Furthermore, local governance, healthcare and appropriate education must be involved to provide the much-needed digital services in future systems thus increasing the value of improved connectivity.

It is also important to understand local culture and to ensure that the community is involved and trusts those who offer connectivity services in the future society. This is particularly true in the developing world. Along with the technology key performance indicators (KPIs) such as bandwidth, latency, jitter, security, and resilience, new KPIs reflecting the increase in economic growth, education, health, gender equality, digital literacy, happiness index, and others in unserved/underserved remote and rural regions should therefore be considered in 6G network design.

“In 6G, connectivity and quality of service is truly measured by the degree in which it reaches individuals - whether in cities or in the furthest corners of the world,” Saarnisaari says. “No-one should be left out.”

Read more:
www.6gchannel.com/wp-remote-areas
In 6G networking, we are looking for a unified end-to-end network solution, which can meet the very strict and challenging requirements of 6G services. In 6G, the networking problem shall not be regarded per one individual segment in the communication chain, but rather as an end-to-end problem. Therefore, there is need for solutions that would support tight and efficient integration between the different segments from radio access network (RAN) to backhaul and core network passing by transport networks.

Covering most relevant topics and converging multiple views caused some challenges for the white paper expert group that wrote the White Paper on 6G Networking. “However, with the help, understanding and contributions of all 31 experts, we could get to the version of the white paper we submitted,” says Prof. Tarik Taleb who led the expert group.

The white paper introduces an end-to-end service-based architecture, which is truly cloud native, supported by analytics from all different segments involved in the end-to-end communications. 6G services, such as emerging immersive services (Virtual Reality – VR, Augmented Reality – AR, and holography), are expected to have much stricter requirements in terms of latency and bandwidth. In parallel, there is a general agreement that the current IP network architecture has many limitations that would hinder the wide deployment of such 6G services. With 6G networking, we do expect a new IP network architecture, or a drastically modified one, that shall support high precision networking services.

Effectively, the current IP transport network falls short when it comes to the support of extremely interactive, extremely bandwidth-intensive, extremely latency-sensitive services,
such as immersive services. In this vein, the new IP architecture is an alternative solution to the current IP network. Its main features could be summed into the adoption of new quality of service (QoS), the support of qualitative communications, and the contract-based delivery of packets.

Moving towards 6G service and infrastructure, we can expect true cloud nativeness of the end-to-end communication system and tight integration between the mobile network and the underlying transport network to ensure extremely strict end-to-end latency. At the same time, the expert group perceives an extensive application of artificial intelligence (AI) to achieve the vision of zero-touch network and service management. “The 6G service based architecture envisaged can also be optimized for energy efficiency by optimizing the embedding of services and their interconnections in a way that makes best use of the remaining processing capabilities in nodes and at the same time makes use of locality in communication links,” Taleb says. “Perhaps softwarizing the entire ecosystem is also one line of development, ultimately leading us to speak of network software versioning instead of network generations (6G, 7G, etc)!”

Full support of immersive services with great perceived quality of experience is certainly something to look forward to. “With the ongoing COVID-19 threat being an ongoing concern, it is time to invest in novel technologies that will make communications more immersive and at the same time less demanding, putting less strain in the existing infrastructure and hence, less concerns that the solutions will not work when “Black Swan” events occur,” Taleb says. “Such technologies must enable immersive communication applications, such as VR, AR, or holography, to become largely available, reliable, and commercially sustainable.”

Read more: www.6gchannel.com/wp-networking
The immense complexity of 6G wireless networks affects the performance of future systems due to the abundance of elements. The research community is currently rethinking the design of blocks of wireless communication systems, which are traditionally designed and optimized separately. The White Paper on Machine Learning in 6G Wireless Communication Networks explores how to replace these blocks with trained machine learning models - an approach promising major improvements especially in terms of energy consumption and implementation complexity. The recent surge of interest in the design of communication systems using machine learning methods is a result of advancements in machine learning research, which has led to the development of advanced neural network architectures. Such solutions are becoming possible due to the availability of large datasets and existence of high computational power to train large neural networks that are capable of modeling such complex systems.

Training neural networks for communications engineering problems necessitates raw material. Most of the data used for deep learning for communications is synthetic and generated using sophisticated simulators thus offering an easy and cheap access to a massive amount of data. “The existence of such high-quality datasets in large quantities will ensure that the deep learning models are trained with sufficient accuracy, which again will result in design of robust and reliable communication systems,” says Dr. Samad Ali, who led the 28-person expert group that wrote the white paper.

One promising approach is the use of autoencoders, which are expected to greatly simplify practical implementation of wireless systems in 6G. In this approach, an autoencoder is comprised of two neural networks – one in the transmitter and another in the receiver. The transmitter and the receiver are trained as an autoencoder, which receives the signal as the input and produces an output that can be decoded by another neural network after going through the channel. The first neural network receives the input signal and produces an output by encoding the data, which usually has smaller dimensions in comparison with the input data. The output is then given to the second neural network after which the output of the second neural network is compared with the input of the first neural network. “The entire system goes through a single training process as we provide the same input and output for the network,” Ali says. “The modelling of the whole transmitter-receiver block as an end-to-end communication system creates simple power-efficient implementation that can be upgraded easily.”

On the other hand, cellular communication networks can also be perceived as multi-agent systems that have heavily coupled elements due to the interference between cells. “Solving problems such as power control and beam-management in an optimal manner benefits from advanced multi-agent system...
modeling tools," Ali says. "Moreover, communication systems can learn and adapt to new conditions and scenarios in an online manner which makes reinforcement learning a natural fit for optimization of wireless systems."

Deep reinforcement learning is expected to play an important role in modeling complex systems since it uses neural networks as a function approximator for mapping between the states and actions of the reinforcement-learning problem. "Multi-agent deep reinforcement learning will enable zero-touch optimization of the communication networks in a sophisticated and simple manner," Ali concludes. "This optimization approach will revolutionize 6G wireless communication networks while providing connectivity for the most demanding applications of future digital societies."

Read more:
www.6gchannel.com/wp-machine-learning
Edge intelligence aims to bring distributed artificial intelligence (AI) and machine learning (ML) methods into the edge computing environment to harness all the available computing and communication capabilities efficiently. The development has two sides: truly distributed and intelligent applications, so-called edge-native artificial intelligence, can be performed in the edge of the network only if dynamic edge platform orchestration is in place, which is only possible with AI and ML.

The expert group that wrote the 6G White Paper on Edge Intelligence created a roadmap with 10 key components. The path begins with the current edge network technologies, such as mobile edge computing (MEC) and software-defined networks (SDN), which play an important role in the 5G development: “These deployments aim for dynamic orchestration of the network, but with the edge intelligence, we can take one step further,” says Dr. Ella Peltonen, who led the expert group. “In addition to deciding the links and loads of the networking links and nodes, we can distribute and transfer from node to node the computation, data analysis, AI/ML model building, and many other factors of the whole application or service.”

The edge intelligence makes it possible to dynamically decide if a task requires cloud computing capabilities, some pre-learned models, or if it can be performed locally. Such decisions are application specific – they need understanding of the task in the specific context. However, with context-awareness, the same technologies and solutions can cover multiple application verticals.

The main question to be asked is “what to compute, where, and when”. The answers can vary over time and place. “Network load and latency are important tradeoffs, but we can also consider many other context-related factors, such as energy consumption, priority of running applications, availability of different resources, and optimal state of the whole network,” Peltonen says. “To become truly dynamic in real time and to be aware of its own context, network behavior needs to be defined intelligently. And when you have intelligent operations to manage the computing environment, you can also utilize the same capacity for novel application areas.”

Current AI technologies usually require massive amount of computational power to learn from large-scale data. Whenever large-scale databases are needed, e.g. for learning natural languages, image processing, and other data-heavy tasks, there is and will be need for cloud computing resources. The role of the edge is different: not all AI tasks are heavy in terms of computing, but may require very local and real-time data, especially when considering small-scale physical environments such as traffic, driving, or manufacturing robotics.

In 6G, many real-time applications become available with higher computational capacity and more intelligent solutions. They can be directly related to the everyday life of end users, such as driving assistance systems which react to different changes in the road conditions, or privacy-preserving real-time monitoring of home patients in the healthcare. Some applications, such as those related to industry, manufacturing, or network orchestration, may not be straightforward for general users to see, but will open possibilities for novel products and services we can only imagine.

“We are now drafting the first steps towards pervasive intelligent systems that can benefit different heterogeneous computing resources, from clouds through network infrastructure all the way to home appliances,” Peltonen says. “It is important to hear perspectives of different specialists, not only computer scientists or engineers but also those specialized in social sciences, psychology, medicine, and other human-related studies. At the end of the day, we are developing these solutions for people to use and benefit, not for the sake of the technology itself.”

Read more:
www.6gchannel.com/wp-edge-intelligence/
Roadmap to the Edge Intelligence

5G
- First commercial 5G MEC deployments

Edge AI
- AI features brought to each edge node (ability to learn and to share models with other edge nodes)

Distributed AI
- AI algorithms distributed in a network of edge devices, providing low-latency and reliable results

Secure and private
- Secure edge systems that ensure user privacy and keep information secure

Nanophotonic technologies
- Nanophotonic circuits will perform complex matrix operations

Pre-trained Edge
- Pre-trained AI models used for processing data at the edge

Dedicated Hardware
- Specialized edge devices capable of performing AI computation

Learning-driven Communication
- Complex wireless communication systems managed by edge intelligence

Real-time training
- New distributed algorithms that make it possible to build models almost in real-time

6G Edg e
- First deployments of a new generation of Edge AI

2020 - 2030
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In 6G, physical safety will increasingly depend on information technology and the specific networks we use for communication. The 6G White Paper: Research Challenges For Trust, Security and Privacy discusses widely various technology solution alternatives, including trust networking for 6G, network security architecture and cryptographic technologies reaching for post-quantum era, physical layer solutions and technologies, and privacy protection in 6G. Trustworthy 6G is therefore a multidisciplinary challenge, which relies on complementary areas of technology, regulation, techno-economics, politics and ethics.

From the technology perspective, there are many alternatives for building trust in the 6G network. “Currently, trusted third party (TTP) or certificate authorities (CA) are commonly used in the Internet, but this approach has several vulnerabilities,” says associate professor Mika Ylianttila, editor in chief of the white paper written by an international expert group. Thereafter, trust networking with virtual networks, Software Defined Networking (SDN), and Customer Edge Switching (CES) have been proposed. A new trend is to consider smart contracts and distributed ledger technologies, such as blockchain, which may have many alternative consensus mechanisms to support trust between all the parties in a system. Also, trust modeling is needed to describe what evidence is used, how this data is collected, processed, stored and distributed among the stakeholders and how trust decisions are made.

The expert group perceives that novel features of 5G, such as network slicing and virtualization, serve as starting points, and the development towards cloud and edge native infrastructures is expected to continue in 6G networks. Security should be part of the systems design, not an add-on. “We need to further explore the vulnerabilities in the communications protocols, software and the system architecture, as well as the role of post-quantum cryptography (PQC), as powerful quantum computers are expected to appear in the vicinity of the 6G era,” Ylianttila notes. “Naturally, the regulatory aspects and the role of Internet Service Providers (ISPs) will continue to be essential too.”

For example, while the more advanced use of network slicing techniques in 6G has many interesting use cases, it may also open new vulnerabilities to the network. Also, the use of AI/ML in security automation opens also new questions - machine learning can be used to make safer systems, but also more dangerous attacks, depending on how it is used and for which purposes. “We need to consider how to enable security-by-design in 6G, while enforcing rigorous security monitoring, software testing and hardening practices,” Ylianttila emphasizes.

Physical layer security techniques are important for securing the most critical physical links, such as wireless links to a medical ICT monitoring, body-area networks and bio-cyber interfaces. “The network density will increase in 6G, so there will be a lot of personal and sensitive information in the physical layer links, which can be eavesdropped or jammed,” Ylianttila notes. “Protecting that will be the first line of defense.”

Safety risks are also high in application areas such as traffic safety (smart cars, drones and traffic), energy (control-systems), and due to increased use of social media where people...
share more personal and sensitive information. System security is only as strong as the weakest link. “If someone can eavesdrop, tamper or create malicious attacks towards these systems, the impacts in the future can be more drastic than ever,” Ylianttila points out. “However, we are confident that the aspects of systems security will continue to improve as we move towards the future systems. It is our task and duty to make sure of that.”

Divergence in the approaches for trust, security and privacy taken by regulators in different continents and countries is of major importance for 6G development. One notable example of divergence considers network neutrality, which has also wide impacts on trust, security and privacy in the communications networks. “Essentially it means that ISPs should treat all data in the Internet equally,” Ylianttila explains. “Europe leads the effort for open and neutral Internet. In the USA, FCC first endorsed net neutrality but later repealed it (and it remains a debated topic), and China does not currently have it. However, the Internet is a global network, and we need to find common denominators for trust and security, as it is up to the technological community to create standards and technologies that pave the way towards a trustworthy 6G.”

At the same time, we need an active development community – an involvement from various sectors of society and increased awareness of the end users. “Cybersecurity involves all aspects of modern communications. Therefore, we need also active discussion and open debate about the future directions”, Ylianttila challenges. One means to promote wide discussion and open development is to organize webinars and hackathons, as the 6G Flagship program is doing. Welcome to join the webinar session “Fundamental Research Challenges for Trust, Security and Privacy: Where Are We Now and What Needs to be Done to Have Trustworthy 6G” taking place on 28 October 2020!

Read more:
www.6gchannel.com/wp-trust-security-privacy
The recent White Paper on Broadband Connectivity in 6G, published in June, explores enablers of the future intelligent wireless environment. “Our approach is multipronged and the enablers depart from the current network-centric massive multiple-input and multiple-output (MIMO) regime,” says Prof. Nandana Rajatheva who led the expert group, which wrote the white paper. “The intelligent wireless environment we suggest would establish connection easily and at high rate realizing it eventually at 1 Tbps rate. In addition, it would enable improved localized services and highly accurate positioning with low cost solutions such as radio stripes. By contrast, a network-centric solution would need much more resources for optimal connectivity which makes it costly and unwieldy.”

The white paper examines the user-centric paradigm in three specific levels. At the infrastructure level, the group focuses on ultra-massive MIMO technology and the possibly of implementing it with the support of novel solutions including holographic radio, intelligent reflecting surfaces or reconfigurable intelligent surfaces (RISs), user-centric cell-free networking, integrated access and backhaul, and integrated space (satellite and platforms) and terrestrial networks (ISTN).

“Holographic radio is a new method to create a spatially continuous electromagnetic aperture to enable holographic imaging-level, ultra-high density spatial multiplexing with pixelated ultra-high resolution,” Rajatheva says. “RISs, on the other hand, enable user-centric nature by bringing users, who are further away from access point, into coverage.”

At the spectrum level, the group perceives that the network must seamlessly utilize sub-6 GHz bands for coverage and spatial multiplexing of many devices. Higher bands, on the other hand, will be used for pushing the peak rates of point-to-point links. This will lead to (sub-)Terahertz communications together with visible light communications which will facilitate dense networks with short-range connections, especially.

At the protocol/algorithmic level, the suggested enablers include improved coding, modulation, and waveforms to achieve lower latency, higher reliability, and reduced complexity in comparison to 5G. The resource management is realized via combinations of full-duplex radios, interference management based on rate-splitting, machine-learning based optimization, coded caching, and broadcasting. “All these are novel approaches in the sense that these are not realized in a global manner in 5G and thus intensive research is still needed,” Rajatheva says. “For instance, 5G does not highlight the role of satellites, except for remote areas, creating a demand to be fulfilled by 6G,” Rajatheva says. “The enablers we chose are expected to provide full-coverage broadband connectivity, across the globe, and this means not just being confined to urban areas.”

As a large scale solution, combining all levels, the white paper proposes integrated space and terrestrial networks (ISTN) which will facilitate full-coverage broadband connectivity thus ensuring global coverage at any time and from anywhere, such as on the sea, over the air and space, and in rural and remote areas. The architecture of a typical ISTN would consist of three layers – the spaceborne network layer, the airborne network layer, and the conventional ground-based network layer connected through microwave/free space optical links in space and fiber links on ground. The spaceborne network relies on various orbiting satellites such as the geostationary-Earth orbit (GEO) satellites, medium-Earth orbit (MEO) and LEO satellites, and mini satellites known as CubeSats. The airborne network, on the other hand, consists of various aerial platforms including stratospheric balloons, airships and aircrafts, unmanned aerial vehicles (UAVs), and high altitude platforms (HAPs). The traditional ground-based networks include wireless cellular networks, satellite ground BSs, mobile satellite terminals, and more.

“The integrated space and terrestrial network we suggest can make full use of the signal propagation characteristics of large space coverage and low loss line of sight (LoS) transmission to achieve seamless high-speed communications with global coverage,” Rajatheva says. “With these capabilities it will take us closer to an intelligent user-centric network by 2030, or even sooner.”

Read more: www.6gchannel.com/wp-broadband-connectivity
Machine Type Communication (MTC) is a broad topic, which brought challenges to the international expert group tackling it with Dr. Nurul Huda Mahmood in the wheel. How to define the scope when the expert group comprised of 31 experts from 15 organizations with very diverse backgrounds? “To resolve this, we formed a nine-member editorial team represented by both academy and industry,” Mahmood says. “Internal discussions helped us to converge to the scope that we now have, and also address other challenges that came up along the way.”

MTC and Internet of Things (IoT) are at times used interchangeably, which is not fully accurate. “Technically speaking, MTC is the paradigm of machines communicating with each other, whereas a network of connected machines is at the core of IoT,” Mahmood says. “So, MTC is an enabler for IoT.”

MTC is by no means a new invention. It has been around for more than 30 years now, or even more if you consider some niche applications, e.g., in industrial communications networks. However, it is experiencing exponential growth since the last few years. Most recently, 5G has introduced two new service classes targeting MTC – massive MTC (mMTC) and ultra reliable low latency communications (URLLC) – which somewhat represent the two ends of MTC. In other words, 5G is natively designed to support MTC through mMTC and URLLC service classes.

With 25 billion IoT devices expected by 2030, MTC will undoubtedly be the dominant traffic source in 6G networks, Mahmood projects. “The demands on MTC are expected to significantly evolve and diversify by 2030, requiring services with a combination of existing and novel requirements and hence posing new design challenges,” he says. “In the white paper, we have tried to identify and characterize promising new use cases by introducing five new MTC service classes as the first step towards designing MTC-specific 6G solutions.”
Energy efficiency will be a key design goal in future 6G systems driven by the growing interest in sustainability and the need for cost-efficiency. “We believe that energy efficiency in future MTC networks will primarily be enabled by three capabilities: energy harvesting from natural, as well as, transmitted sources; improved communication schemes that can operate with very low power, e.g., backscatter communication; and ultra-low power hardware design to reduce the energy consumption of devices,” Mahmood says.

Zero energy MTC will be an important aspect of MTC overall. This is mostly relevant for MTC devices without stringent requirements. Like many other sectors, the communication industry is also strongly committed to reducing its carbon footprint. Furthermore, many of these devices might be installed in hard and/or dangerous-to-reach locations where it would not be possible to replace or charge their batteries. The ultimate goal is to keep such MTC devices operating until the device itself becomes obsolete and reaches the end of its shelf life.

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Design complexity and trade-offs for MTC are evident e.g. for self-driving cars, which is one of the most prominent application areas along with other use cases depicted in the illustration. A fully autonomous vehicle has a vast number of sensors performing different tasks at different criticality levels. For example, sensors that control the speed of the vehicle need to constantly monitor the road and its surroundings and therefore require scalable and extreme URLLC services. Other sensors, that monitor and control the vehicle temperature, sound volume and fuel level, require scalable mMTC to support a large concentration of device connectivity with a much lower level of criticality. The downloading of maps, traffic information and infotainment material from road-side units only require broadband MTC due to a rather large traffic volume. “This demonstrates the need to have optimal solutions addressing different criticality levels smoothly integrated into a single system, as envisioned for 6G,” Mahmood says.

The white paper team rose to the challenge of addressing a variety of solutions and squeezed MTC’s key drivers, potential use cases, evolving requirements and emerging service classes into a solid package. “We hope that our white paper will trigger further discussions and research on this highly important and interesting 6G research topic to accommodate billions of IoT devices,” Mahmood says.

Read more:
www.6gchannel.com/wp-machine-type-communication
Until now, wireless networks have been designed targeting solely their communication features. In contrast to 5G and earlier generations, 6G localization and sensing will be built-in from the outset to both deal with specific applications and use cases, while supporting flexible and seamless connectivity. In 6G systems, intelligent context-aware networks should be designed so that they can exploit localization and sensing information to optimize deployment, operation, and energy usage with no or limited human intervention.

The expert group that wrote the 6G White Paper on Localization and Sensing assesses the specificities of the 6G convergent communication, localization and sensing systems, as well as its overall structure through three main aspects. It identifies the most promising technologies, which will most likely pave the way towards the next generation of wireless communication systems. Based on the desired features of the upcoming 6G networks and the opportunities created by the technologies, the group discusses interesting new applications. Furthermore, it introduces challenges and identifies future directions to realize smart 6G wireless systems that will not only provide ubiquitous communication but also empower high accuracy localization and high-resolution sensing services.

Currently, the 5G new radio (NR) access interface offers large bandwidth, very high carrier frequency, densification and massive antenna array, which in their turn provide great opportunities for accurate localization and sensing systems. Yet, the inherent localization and sensing potential has been repeatedly overlooked. “The full potential of environment-aware applications such as wireless cognition, high-accuracy positioning, high-resolution sensing and imaging can only be realized throughout the 6G enabling technologies,” says Dr. Carlos de Lima who led the expert group.

6G will continue to develop towards even higher frequency ranges, wider bandwidths, and massive antenna arrays. This will enable sensing solutions with very fine range, Doppler and angular resolutions, as well as localization to cm-level degree of accuracy. Moreover, new materials, device types, and reconfigurable surfaces will allow network operators to reshape and control the electromagnetic response of the environment. In fact, such intelligent reflective surfaces allow network operators to programmatically shape and control the electromagnetic response of the environment objects by dynamically adapting parameters such as the phase, amplitude, frequency, and polarization without requiring either complex decoding, encoding or radio frequency operations. At the same time, machine learning and artificial intelligence will leverage the unprecedented availability of data and computing resources to tackle the biggest and hardest problems in wireless communication systems.
The white paper foresees that 6G systems will become the catalyst of a major transformation and the relevance of specific applications depends on the target use cases. For example, THz imaging and spectroscopy have the potential to provide continuous, real-time physiological information via dynamic, non-invasive, contactless measurements for future digital health technologies. 6G Simultaneous Localization and Mapping methods, on the other hand, will not only enable advanced XR applications but will also enhance the navigation of autonomous objects such as vehicles and drones. In addition, convergent 6G radar and communication systems will benefit of both passive and active radars which will simultaneously use and share information to provide a rich and accurate virtual image of the environment.

“The unprecedented technological revolution evidenced by these examples demonstrates how our digital and physical worlds are merging and, by doing so, changing the way we make business, interact with others, and experience our very own lives,” de Lima notes. “6G localization and sensing, as built-in system components, help in unleashing this extraordinary potential while still taking ethical, privacy and security aspects into account.”

Read more:
www.6gchannel.com/wp-localization-sensing

Enabling technologies, new application opportunities and technological challenges of 6G.
The role of radio engineering and technologies is fundamental in the development of a new generation of cellular networks. White Paper on RF Enabling 6G – Opportunities and Challenges from Technology to Spectrum covers key topic areas of RF including radio transceiver implementation, radio signal propagation, antennas, packaging, optical communications, regulation and standardization, and RF testing. The expert group leader Prof. Aarno Pärssinen took an active role in defining the contents and invited leading experts on radio engineering to contribute to the white paper. The international expert group with 32 participants represented various complementary dimensions of expertise. “The group’s expertise ensured a holistic end-to-end view over the radio topics, which need to be carefully explored before the 6G networks are in operation in the 2030 timeframe,” Pärssinen says.

The radio spectrum is the foundation for wireless communications and the 6G system is targeted for the current and upcoming mobile communication spectrum bands, as well as with a whole new range of higher mmW and THz spectrums. The access to the spectrum is governed by the regulation bodies and the availability of new frequency bands is restricted by existing usage. The envisioned 1 Tbps extreme data rates require a significant amount of spectrum to operate, and such frequencies are available at upper millimeter-wave (mmW) frequencies from 100 GHz to 300 GHz or terahertz (THz) above 300 GHz frequencies. Higher frequencies offer improved data rates for short-range connectivity, enabling a high frequency reuse factor in the 6G network, thus significantly improving network densification and throughput compared to the current 5G networks. On the other hand, lower frequencies currently used for the 4G networks offer a great benefit of larger cell sizes with wide-area coverage. Those systems can offer data rates for the vast majority of the applications we are currently using with our mobile devices.

The spectrum availability through dynamic spectrum sharing is an opportunity, which needs to be carefully studied for 6G
systems. The sharing can be performed between different radio systems or operators themselves, leading to interference management being a key research challenge. Even if the 6G system is technically feasible for the upper mmW and THz band operation, the protection of the existing systems may restrict the use of these bands.

In current 4G and 5G mobile terminals, radio transceiver solutions are mainly implemented with complementary metal oxide semiconductor (CMOS) integrated circuit (IC) technology due to favorable cost, modularity, and high level of integration. The expert group foresees that future 6G frequencies at 100 GHz and above will also face major challenges due to the available transistor speeds from the IC manufacturing processes especially in silicon-based technologies such as CMOS and silicon germanium (SiGe) heterojunction bipolar technology (HBT), since approaching the technology boundary leads to exponential degradation in gain and output power as well as increased noise. "This aspect is often omitted at the early phase of conceiving of new standards," Pärssinen notes. "This is somewhat visible already when mmW is adopted in 5G but will become a serious issue if we will not take the hardware-aware approach into account as the basis when defining 6G."

All parts of the radio spectrum do not support communications equally well due to different characteristics and implementation boundaries. The white paper discusses how atmospheric attenuation is composed of free space path loss, molecular absorption, and specific attenuation due to rain. Doubling the frequency quadruples the free space path loss per antenna element due to physical size issues. Molecular absorption has a moderate peak at 60 GHz by oxygen molecules and severe peaks above 380 GHz due to water vapor. Fortunately, there are wide spaces between the absorption peaks with only moderate attenuation. Heavy rain and temporal rain rate variation substantially affect the signal strength of the long links. High gain antennas can be used to compensate for high propagation losses enabling the range of up to 1 km with the fixed links at frequencies up to 300 GHz.

Fundamentally, the antenna's gain can be improved by increasing its aperture, which means either electrically large aperture antennas, such as integrated dielectric lens antennas, or arrays of hundreds or thousands of antenna elements. Traditionally, an antenna is designed separately and connected to the RF system with a connector interface. "A separate dedicated antenna 6G radiator will not be feasible at upper mmW or THz frequencies due to significant transmission line losses and high integration level of RF circuits and antennas," Pärssinen notes. "The antenna performance can be improved by integrating the 6G antennas with the RF circuits or into RF component packages. The phased arrays are used with 5G systems, and will be further studied for 6G systems. Currently, new materials are explored for 6G lens antennas in conjunction with integrated antennas. "The biggest challenge is to reduce size of phased arrays to avoid solutions that require thousands or tens of thousands antennas with parallelism in RF electronics and, on the other hand, provide electrical steerability with reasonable complexity," Pärssinen says.

Electromagnetic (EM) simulations, circuit-level simulations, and system-level simulations are critical to reduce complex

6G hardware prototyping and the needed radio performance testing. As absolute physical dimensions diminish, the tolerances in the physical dimensions of electrical components, mechanical parts, and assembly accuracy will introduce significant variation to the radio performance when the operational frequencies increase. The envisioned 1 Tb/s data rate requires a wide information signal bandwidth, e.g., 30 GHz, and the generation of such will be a challenge. Another challenge is to shift the modulated signal to the operational frequency > 100 GHz. The highest frequency for the traditional coaxial test cables and connectors is 110 GHz, and testing of higher frequencies requires the usage of rigid waveguides. The conducted RFIC measurements can be done with measurement probes connected with waveguides to frequency extenders. The system-level measurements of 6G radios will be performed in over-the-air (OTA) manner as with current 5G mmW systems. However, the setup is much more complex. Some of the technologies are still in early phase of the research/development and, due to small physical distances when approaching THz, any setup is very sensitive to tolerances.

The white paper lists a set of research questions that the radio engineering community should tackle in order to achieve affordable 6G communication at THz frequencies with extreme data rates. The many major research questions include, e.g.

* What are feasible 6G frequency bands >100 GHz, and which are usage policies of those?
* How to create a unified 6G channel model from GHz to THz?
* How to define spectrally efficient and radio hardware-aware 6G waveforms for Tb/s data rates for affordable hardware implementation?
* What are the roles of electrical and photonic technologies and new materials in 6G and what is the achievable silicon-based technology performance in THz/Tb/s systems?
* How to implement steerable antenna arrays >100GHz, and what is machine learning's role in controlling the tunable antennas and RF solutions?

“Although the hype towards 6G is rising rapidly, we must acknowledge that without major efforts and investments in technology research and development, 6G as we envision it now, will not happen by 2030,” Pärssinen concludes. “Patience and resilience are needed. It also took more than 15 years from the start of serious research in lower mmW range to achieve commercialization in 5G.”

Read more:
www.6gchannel.com/wp-rf-spectrum
Digitalisation is developing fast and becoming more widespread. Seeing the business opportunities it offers requires foresight – or the help of researchers.

Experts at the University of Oulu analyse opportunities for digitalisation and help companies to develop new business models. Partners include the Port of Oulu, which is now building a 5G local network with digital services. “Digital business is any business that digitalisation is changing,” says Dr. Petri Ahokangas from Oulu Business School at the University of Oulu. “The key question is how digitalisation can make the business more profitable, more efficient, easier…”

This is where Ahokangas and Dr. Marja Matinmikko-Blue from the Centre for Wireless Communications (CWC) research unit at the University of Oulu, come into the picture. “When a new wireless technology emerges, we start to look at what kind of business opportunities it opens up and how the company should apply the new technology,” Ahokangas describes. “We start to discover this by bringing together different stakeholders: companies, researchers, and the public sector. We use foresighting methods such as future scenarios and action research, and combine strategy and technology research with it. We help companies map out opportunities and constraints and find solutions. We do not prepare a ready-made business model for only a single company but keep the research at a general level so that others can also take advantage of it.”

Solutions are sought from a triangle with sides for regulation, business, and technology. The task is often complicated because these are new, largely undiscovered possibilities of technology, as well as the fact that the operating environment in question is rarely simple. Usually the target is a complex multi-stakeholder environment – similar to the Port of Oulu. “It is a closed area where companies traditionally have their own information and communication systems that don’t interact. In addition, there is official information, customs clearance, etc.,” Ahokangas says. “When these are combined with digitalisation, all stakeholders at the port can benefit from the added value. They can utilise each other’s knowledge, which creates an environment for competition and cooperation. We have not been able to fully exploit these opportunities until 5G.”

The Port of Oulu is one of the test environments in the Business Finland funded 5G VIIMA project coordinated by the University of Oulu. A key element is the locally operated network, having roots in the local micro operator concept introduced by the University of Oulu researchers several years ago, which makes it possible for a company to have its own 5G network. These private networks are one of the most important innovations that will define digital business of the future. New business opportunities associated with these include different platforms with services that can be integrated into local networks.

In the case of the Port of Oulu, data from various sources is collected in the platform and content services are built for stakeholders in the area. “For example, we offer a real-time snapshot of traffic within the port, which makes it possible to optimise driving routes and improve safety,” says Mira Juola, who is leading the digitalisation project at the Port of Oulu. “For the most critical port communication needs, it is a closed data network. We are selling its capacity to operators in the region.” The system is not yet complete but is already ready to use. “Our 5G network is in the pilot phase. The technology needed today is affordable, which enables data to be collected in cloud services and shared with the end users. In 5G, network capacity is no longer a problem, for example, when streaming video or using a large number of sensors that produce data.”

Regulation also poses a challenge. “As industry boundaries disappear, regulations for mobile networks and the verticals can collide,” Ahokangas predicts. Regulation is already hampering digital business, especially in Europe. “In a recent listing in Wired magazine, no company that had reached a turnover of over one billion in the first five years of their operation was European. Here, the business environment is so highly regulated that new start-ups are basically prohibited.” Utilising and commercialising data, such as reselling it, is one of the key opportunities for digital business. The regulation on this also varies. In America, data is owned by the corporation that...
collected it, but in many Asian countries the state owns the data and in Europe it is owned by the consumer, Ahokangas points out.

The regulation also applies to new radio frequencies on which 5G is based. “Governments decide on spectrum awards and often hold auctions and, at the same time, shape the frameworks for future digital business,” Matinmikko-Blue says. The deployment conditions in the different frequency bands differ drastically. Also the approaches for awarding spectrum access rights differ. Some countries offer fewer frequency licenses and make money out of them through auctions, while in other countries, large operators can more easily obtain a license. Countries are also moving from country-wide spectrum auctions to other models, such as offering local licenses. “Making affordable spectrum available for private networks in frequency range with favorable propagation conditions will be the major differentiator between countries,” Matinmikko-Blue concludes. “Countries that miss this window will lag in the quest of new business opportunities.”

Read the original story by Jarno Mällinen: www.oulu.fi/6gflagship/news/digitalisation-boosts-business

5G VIIMA project: 5gtnf.fi/projects/5g-viima
INTELLIGENT REFLECTING SURFACES
CHANGING THE WIRELESS SYSTEM DESIGN PARADIGM

The randomness and non-controllable nature of transmitted electromagnetic (EM) waves that propagate from transmitters to the receivers calls for overturning. 6G Flagship’s wireless system designers, together with wireless experts at InterDigital, are seeking to change the system design paradigm with the introduction of Intelligent Reflecting Surface (IRS) arrays into the wireless environment. In the ARIADNE project under the EU programme Horizon 2020, the IRS is seen as one of the enabling technologies for the implementation of wireless systems above 100 GHz frequencies.

The researchers now focus on the use of the IRS as a controllable reflecting surface especially when implemented with metasurfaces. “We are looking into how the EM propagation environment can be altered by controlling the reflection, refraction and absorption properties of an IRS,” says Prof. Markku Juntti who leads the signal processing team at 6G Flagship. “Beamforming, in particular, is of interest as we consider the curvature of the EM waves, along with other real physical phenomena, near the IRS.” The practical and cost-efficient realization of the surfaces will be a major challenge for the antenna technology and material researchers of 6G Flagship to begin with.

At best, the IRS can provide hassle-free solutions as they can be introduced into a wireless system without a need to change the system concept (standard) or hardware. Additional signal processing in transceivers is not necessarily needed either. Unleashing the full potential of the IRS will nevertheless require changes to all of these. Just how much alteration is needed or is worth of, remains an open research question, which drives the team forward. One of the key problems is how to estimate the radio channel in IRS assisted systems and how to use the estimated channel information to control the IRS. “Our results so far show that the channel estimation is a major challenge, but we recently devised an atomic norm minimization based super-resolution algorithm capable of accomplishing it,” Juntti says.

The researchers are also modeling IRS as a component of ray tracing based channel modeling. In order to quantify the potential benefit of IRS usage, the team uses the same channel models as in other scenarios without IRS, whenever appropriate.

What is certain, the IRS based approach should not be considered as a direct competitor of the conventional MIMO technology. Instead, the IRS can be used in MIMO systems to improve the performance. In conventional MIMO systems, the antenna arrays are connected to a transceiver. In IRS applications, on the other hand, the emphasis is on the cases where arrays are not connected to transceivers, i.e., they do not receive or transmit signals but redirect and focus them into the desired directions.

Sustainability of IRS solutions further increases their appeal. “The introduction of IRS can potentially reduce the number of transmitters in a wireless system allowing us to achieve the same performance with lower power consumption and less hardware than in systems without IRS,” Juntti says. “In addition, the manufacturing of an IRS is likely to consume less resources such as rare earth metals, than the electronics used in transceivers.”

Dr. Alain Mourad, Director Engineer R&D at InterDigital, sees great potential in IRS solutions. “The incorporation of IRS surfaces capable of steering radio waves in a controlled manner, i.e. enabling control of channel characteristics, promises to progressively impact the evolution of wireless technologies and protocols beyond 5G,” he says.

From an industrial R&D perspective, the IRS roadmap sees nearer term opportunities in the areas of coverage, directivity,
and range extension in support of massive MIMO and new band applications up to 50 GHz. In the medium term around the year 2025, InterDigital envisions that the IRS roadmap expands the applications to include support of multi-Gbps links and high-resolution localization in outdoor and indoor deployments. This is added to the IRS support in bands up to 100GHz. Longer term towards 2030 timeframe, IRS promises enablement of ambitious technologies and applications such as support of data rates of more than 100 Gbps at 300 GHz frequencies, holographic MIMO with 1000’s of elements, wireless power transfer and new physical layer security methods.

“The IRS trend is a key enabler for smart radio environments and is perhaps the final frontier of network softwarization turning the channel into a software programmable entity too,” Mourad says. “This will push the B5G/6G roadmap far and is poised to challenge the network architecture in time.”

The impact of IRS goes beyond wireless and will embrace other fields including artificial intelligence (AI)/machine learning (ML) opening up new applications that will support challenging coverage, positioning, energy and capacity KPIs forecast in B5G/6G. These prospects make IRS a great research topic for new passionate researchers that the 6G Flagship program is constantly seeking, especially within its collaborative research projects.

Read more: www.interdigital.com
FEASIBILITY TESTS FOR FUTURE AIR MOBILITY

Ambitious project plans with tight schedules have faced drastic delays due to the pandemic, which has put a halt on mobility and has limited access to research premises and equipment. One of the multi-partner projects forced to redraft its research steps is the EU-funded ICT project 5G!Drones. Committed to trial selected use cases for the most prominent unmanned aerial vehicle (UAV) applications, the project relies on the complementary expertise from 20 organisations around Europe, both universities and companies. After a four-months’ wait, 5G!Drones project partners were finally able to realise feasibility tests in Oulu together with colleagues from Tallinn, Estonia and Helsinki, Finland once travel between “green” countries, based on the traffic light system, was approved in Finland in August.

“The feasibility tests provided us with much insight on which portions of the trials can be safely executed remotely and what kinds of experts are required on-site,” says Dr. Jussi Haapola from the University of Oulu who co-ordinates the project. “It was also relieving to note that with appropriate planning both on-site and off-site collaboration can be managed, even though the pandemic situation brings forth uncertainty.”

The goals of the feasibility tests included integration, legislative, network coverage and service level, and exact trial site identification aspects. With regards to integration, the drone operator had its mission software installed at a 5G Test Network (5GTN) edge server in Oulu and operated the mission remotely from Estonia. The 5G quality-of-service and 3D mapping missions were uploaded to the drone and managed real-time using 5G cellular connectivity. A drone carried a 5G cellular handset for the 5G quality-of-service measurements and delivered the information to the drone operator in real time.

Legislative aspects, on the other hand, included obtaining permits to fly the drones equipped with cellular devices, mission planning and all relevant documentation for safe execution of the feasibility tests.

Furthermore, network coverage, service level and exact trial site identification aspects included testing of the components required for missions as well as mapping the areas around 5GTN, at various elevations, for identification of 5G signal quality and performance.

“The upcoming trials themselves will involve the validation of both 5G and UAV key performance indicators (KPIs) - 5G being able to fulfil its generic KPIs and UAV specific ones, and UAV vertical sector being able to fulfil its use cases KPIs by exploiting 5G features,” Haapola says.

5G and beyond 5G cellular communications solutions take drones one step further towards autonomy by providing reliable beyond visual line-of-sight (BVLoS) connectivity for extended drone operations. Reliable remote operations and management are key requirements in enabling urban air mobility in smart cities.

“The use of drone services at the network edge to operate and manage missions is a significant milestone paving the way to next breakthroughs in service migration based on drone mobility,” Haapola says. “Edge deployments minimise the command and control delay between drones and their operators and provide crucial data offloading capabilities for a number of real-time, high-bandwidth consuming solutions like high-quality video streaming, lidar, 3D-mapping, and so forth.”

The integration of drones in smart cities involves addressing many of the challenges required for U-space advanced or full services. “The UAVs need to be able to communicate not only with one another, but with the unmanned aerial systems traffic management (UTM), the drone operator, the city urban air mobility infrastructure, the service provider, and the customer,” Haapola says. “The drone missions need to secure a certain service level from mobile operators throughout the mission requiring an intricate interplay with communications, service virtualisation and migration, advanced data processing, and automated flow of information between multiple actors.”

The autonomy of drones, on the other hand, is a long-term goal, closely aligned with U-space development targeting 2035. Currently, especially professionally operated drones...
support many automated operations, including completely automated missions. However, there always exists a drone operator supervising the missions and an on-site safety pilot who can take over in situations the drone is not capable of handling. Other automated features include, for example, obstacle and collision avoidance, and return-to-home features.

Drone swarms, which are gaining a lot of interest, are very useful in search and rescue operations where they can reliably cover large distances in a short amount of time. Control of drone swarms require wireless mesh connectivity between drones, collaborative localisation schemes, swarming management, as well as interfacing of swarms with other actors, including U-space. Other use cases include large area 3D or lidar-mapping for agricultural purposes, forest mapping, or even cave system mapping. For example, 3GPP is currently working on enhanced cellular V2X standardisation that could be a good starting point for all-cellular swarm management. This kind of required feature set probably co-aligns with U-space, U3 - advanced services targeting 2027.

In the meanwhile, researchers tackle challenges in carrying out validation activities, from day to day. Yet, COVID-19 has brought attention to the capabilities of UAVs in somewhat unexpected ways. “The pandemic situation has also shown the potential of UAV applications in remote parcel delivery and remote safety surveillance, among other things,” Haapola says.

Read more: 5gdrones.eu
Sustainability is a recurring element in almost all of our recently published 6G White Papers, which offer food for thought to a number of stakeholders. It appears in the developed scenarios for the business of 6G and it is a key driving force for remote area connectivity. White Paper on 6G Drivers and the UN SDGs examines different facets of sustainable 6G and introduces a preliminary action plan for engaging different stakeholders along with prioritized focus areas within the mobile communication sector technology and industry evolution to best support the achievement of the UN SDGs.

“The role of ICT in meeting the sustainable development goals is critical,” says Dr. Marja Matinmikko-Blue, research coordinator of 6G Flagship. “It is not enough to treat 6G development and UN SDGs separately. The UN SDG framework will also need to evolve – with the technology development.”

The role of ICT should be seen broadly, not only through ICT related indicators in the UN SDG framework, which are currently very few. “ICT’s role in helping to achieve all 17 SDGs is significant through new collaborative business models that build around the common target of achieving the SDGs,” Matinmikko-Blue says. “The group suggested freemium models and free access to the Internet for basic content which would help accelerate the subscriber base among the digitally disadvantaged. While considering the increasing machine-centric communications, human-centered 6G development should ultimately have the goal to improve the quality of life.”

The research community has taken the leading role in facilitating stakeholder interactions in the writing of the white papers that define 6G vision. But, more is required and a broad stakeholder group is needed in developing sustainable 6G. The use of new wireless techniques broadly in society brings along new stakeholders without knowledge of how ICT could help them in the achievement of the SDGs. Novel ideas and out-of-the box thinking on various aspects of 6G need to flourish, driving experts and end-users alike to discussions on the most promising and even surprising combinations of technology components needed to make 6G a reality.

The action plan identifies specific roles for stakeholder groups in the joint development and evaluation effort. “Governments play a key role in contributing to coverage and low cost of service for everyone through the creation of the regulatory framework and incentives to invest and operate the systems,” Matinmikko-Blue says. “More flexibility is needed to allow low-cost solutions in challenging areas that are not of business interest to operators.”

Both 6G and UN SDGs can increase openness, not only through new key performance and value indicators, but also through early participation and strong commitment. Verticals and their public sector counterparts will face significant economic constraints as national and international level agreements are adopted for inherent changes to meet the UN SDGs in areas such as automotive, healthcare and energy. To adapt their operations, the verticals will need to take everything the future technologies can offer and engage early on in the process of 6G development instead of waiting for the telecommunications industry to define what 6G can bring for them. For the mobile communication sector, 6G is not only about developing yet another generation, but a true opportunity to contribute to sustainability at large.
IMMERSIVE MEDICAL DEMO AWARDED

6G Flagship’s researchers received an innovation award from 5G Momentum, an ecosystem coordinated by the Finnish Transport and Communications Agency Trafcom, earlier this year for their Remote Medical Expertise and Education demonstration. The award was granted for an organisation, which has contributed to making 5G visible nationally and/or internationally and has demonstrated considerable creativity in 5G development. Possible use cases, on top of the rewarded eHealth case, include all kinds of remote consultancy and guidance situations e.g. in industry maintenance, repair and installations, as well as all kinds of hands-on instructions. All this can now be remote.

The idea for the demo, which is illustrated below, came from researchers’ realization that there are no complete commercial solutions available that would combine the use of AR-glasses, VR-glasses, 360-camera, and 5G in both uplink and downlink. Initial version now already shows the power of mobile technology, but the demo team has already new enhancement ideas for improving end-user experience, introducing new eHealth devices and the usage of edge processing.

The idea of “remote medical consultancy or operation with a patient” is fully scalable and can be utilized for different types of consultancy or educational purposes. Digital data is collected via 360 and close-view cameras and connected biosensors. Critical data is shown through AR-glasses locally and remotely with video via VR glasses and/or handheld devices. The limitations of current state-of-the-art technology cause a few-second delay mainly due to video format conversions and scaling to target device type – a challenge, which can be overcome once devices get up-to-speed with network capabilities. The demo experience can be real-time or shown via recordings.

The current medical use case offers alternative views supported by wearable and video equipment. An ordinary visit by a nurse to a patient’s home gets holistic content as observation of critical symptoms can be shared with a distant specialist with modern means. In a more challenging use case, inside a hospital the surgeon gets vital sensor information to own AR glasses during a medical procedure and can thus observe the data effortlessly with a glance – without having to turn the head. In the demonstration, sensor readings of the patient - body temperature, accelerometer and skin conductancy – are visible in the glasses.

In parallel, colleagues or groups of medical students can observe the activities anywhere - next door to the operation room or on the other side of the globe. Viewers can see either the exact nurse’s or doctor’s view with the vital sensor information, or the overall view of the space allowing them to focus attention to any desired detail.

Watch the video
yout.be/b4j9Tz3SOoQ

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With the introduction of latest innovations in mobile technologies, the ICT sector can create wide positive impact on the reduction of CO2 emissions. For each CO2 ton caused by broadband radio networks, ten tons can be reduced elsewhere by e.g. increased remote working, avoidance of traveling and effective use of digitalized services. This makes wireless connectivity a major contributor towards a zero-carbon society. Researchers and developers in Finland, and around the globe, are seeking innovative combinations of technical solutions, which build on renewable energy and novel features of mobile networks.

6G Flagship’s “Smart Energy Grids” team seeks to connect the electricity grid with communication networks and automation and to define novel mechanisms for energy market systems and structures. The team is now exploring a 5G/6G solution, which is powered by Renewable Energy Sources (RES), and provides the backbone for communications as well as computing for the information exchange required for maintaining such grids. “The ultimate goal is to integrate and intertwine the solutions on flexibility management, grid control, energy trading, network management and distributed wireless communications into an environment that can demonstrate renewable generation penetration approaching 100%,” says professor Ari Pouttu who leads the team.

Recently, there has been a rapid growth in RES such as photovoltaics (PV) and wind generation. Furthermore, storage systems, electric vehicles, micro-generation and flexible loads at the premises of end users add flexibility to the system. “To address the volatile nature of RES, we aim at developing fully distributed novel paradigm empowering peer-to-peer (P2P) flexibility approaches that are able to optimize the usage of demand-response (DR) as well as RES,” Pouttu says.

The researchers are now modeling a virtual power plant where a large number of small micro-generation units are aggregated into one larger entity, which can then enter the energy market. The research focus at this stage is on the design and implementation of the sustainable microgrid scenario. “We are investigating the most suitable wireless communication strategies in order to distribute information more efficiently,” Pouttu says. “The use of key cloud functionalities, such as time-based approach and event-based approach, edge computing and edge devices coupled with accurate energy weather forecast for 48 hours ahead, can aid the demand response management, diagnose wasted energy and thus improve our sustainable microgrid model. In addition, real-time data of the university’s 800 kW solar production unit is connected to and is available from the 5G live Test Network and with accurate local weather estimates the day ahead, give us tools for handling the balancing market.”

The team also develops advanced P2P multi-agent or machine learning based DR-based frequency and voltage control methodologies. They allow local trading of energy and inclusion of accurate weather and power consumption data. As a result, flexibility of usage between prosumers increases inside a microgrid, consisting for example of sustainable communities in remote or developing areas as well as of microgrid operators and distribution system operator / transmission system operator for grid-connected microgrids in developed areas.

“The solution itself can be built in a hierarchical manner from household level to microgrid, to distribution grid, and all the way to transmission grid making the solution scalable and more importantly resilient,” Pouttu says. “On the other hand, large investments to our current mostly centralized power grid makes the penetration of these technologies rather slow, but it does offer an avenue to integrate gradually large amount of microgeneration into our future carbon positive power system.”
Nokia Energy Efficient Mobile Networks

Minimizing energy consumption is one of the key design criteria for new base transceiver station (BTS) products at Nokia. The most straightforward way is to improve power efficiency with the help of new technology that allows increased processing capacity per unit of energy consumed. Another important area is algorithmic evolution where things get done in a smarter way, thus reducing overall power consumption. Good examples of this are the various means to improve the power amplifier efficiency through signal processing.

In practice, the resource utilization of a cellular network is not constant; it typically varies greatly over time and based on geographical location. “Data consumption typically peaks in the evenings, while other times it can be just a fraction of the peak,” says Jukka Peltola from Nokia BTS product management. “For an energy-efficient BTS, it is important that it can dynamically adjust power consumption according to processing needs. This can include powering off unused processing resources and shutting down unnecessary cells or frequency layers.”

Nokia’s products undergo continuous evolution, where improvements happen both via advanced software (SW) features and introduction of new products based on new technology, such as next-generation systems on a chip (SoCs). “They have quite different development cycles and offer different levels of improvement,” Peltola says. “SW features often have less relative impact, but on the other hand, they are often applicable to the entire installed base, whereas new products offer much higher relative improvement, but will impact only those sites that have new products installed.”

In June, Nokia released news that its commercial liquid cooling 5G AirScale Base Station solution has been deployed for the first time anywhere in the world in base stations of the Finnish mobile operator Elisa. During operation, a BTS transforms most of the electricity consumed into heat. With liquid cooling, this heat can be captured and easily removed from site and either dissipated, or reused to heat premises or to warm household water, among other uses. “Much focus is put into making products energy efficient, and quite rightly so,” Peltola says. “However, often the power consumption of an entire site is neglected even if site cooling can account for up to 66% of the site total. In addition, site locations can be thermally challenging, meaning that it is very difficult and expensive to keep the site cool. “By modernizing the hardware of an existing BTS, its energy consumption can be reduced by up to 46%. With the latest BTS SW energy-saving features, consumption can be further reduced by 30% during periods of low traffic.”

This is where liquid cooling excels, as it not only reduces the cost of cooling due to significantly better energy efficiency, but also enables further energy savings. It is estimated that with reuse, site CO2 emissions can be reduced by up to 90%. “In addition to the energy-related benefits, liquid cooling offers operators a way to use site resources more efficiently by being able to pack more BTSs into the same floor space,” Peltola says. “This is relevant for network architectures where baseband processing of tens or hundreds of radio sites is centralized in a single location.”

Another benefit is that a liquid-cooled BTS is completely silent. “This allows operators to install BTSs in locations that are otherwise impossible due to the fan noise inevitable with air-cooled BTSs,” Peltola notes. “Because of this, operators have a bigger choice of potential sites. This will further help in reducing site acquisition and rental costs, and offers easier access for maintenance.”

Ideas depicted in the concept image (above) of an optimized carbon-neutral system indicate that BTS power consumption optimization and control will better enable completely off-grid operations by relying on batteries/solar panels/windmills for energy production and storage. Energy efficiency is a key enabler for such solutions. This, in turn, will enable operators to further expand the terrestrial network coverage to areas that would otherwise be difficult or impossible to reach. In parallel, the only means to achieve a zero-carbon radio network is to use carbon-neutral or renewable energy. Finland is the first country in the world where all national 5G networks are operated carbon-neutrally, and it is leading the way.

Read more:
https://www.nokia.com/about-us/sustainability/
Academy Professor Matti Latva-aho is now known as the head of 6G Flagship, and is the international face of 6G research that stems from Oulu and Finland. Not shying away from ‘impossible’ things, Latva-aho has always taken on challenges more formidable than the one before throughout his career. “I have never tried to take the easy way out, that’s just who I am,” Latva-aho says.

Latva-aho has been deeply immersed in the world of radio technology and mobile telecommunications for decades now, and is a veteran of all the “G’s”, leading up to 6G. As a researcher, he says he was always driven by the desire to solve practical problems as opposed to pure theoretical research. “For me, theory is another tool in the toolbox,” Latva-aho says. “I have always wanted to solve problems that are relevant to everyday or practical life. This has been my guiding principle from the very early days of my career.”

The early 1990’s was the time of great economical recession in Finland and internships were very few and far between. Latva-aho was lucky to get one, and this led to a stint in Nokia Mobile Phones, which was the cell phone arm of the company at that time. Latva-aho originally planned a career in industry, but fate would have it otherwise.

He was offered a part in a research project at the University. “The idea was to do this one project at the University and then go back to Nokia. Well, here we are,” Latva-aho says with a laugh.

An ambitious researcher, he says one of his most significant personal achievements was when he finished his doctoral thesis, in 1998. He says it was a long time coming and he doubted many times if he would be able to finish the thesis and get his doctorate. In the end, his work paid off, and he was awarded the best doctoral thesis prize of technical sciences in Finland.

Before 6G Flagship, Latva-aho had been considering his options in terms of his work. He had purposefully been taking a back seat and was thinking about how to make the most of his Academy Professorship. Then he received the news that would join the entire University.

“We felt euphoric,” Latva-aho reminisces. “We couldn’t believe that we had been selected. That this amount of funding was secured. The first few months were a blur to us all, it was very unreal. It was very joyful, of course, but a huge change at the same time.”

Everybody sprang into action. “We rolled up our sleeves and went to work,” Latva-aho says. “We wanted to get everything up and running first and foremost and build up our international reach and scope during the second year of operation. Then, the U.S. President tweeted about 6G in February 2019 and there we were, thrust in the spotlight. Things accelerated from there.”

The exceptional circumstances that have defined this year have impacted 6G Flagship like the entire world. Everybody has been working remotely and the second 6G Summit was held virtually, a change in plans that happened in a matter of weeks, if not days. Travel days dropped to zero for Latva-aho, which is something he welcomes. This means more chances to re-energize in nature, which is very important for him. He has been an avid fisherman since childhood, and he often wakes up early in the morning to check the nets before getting to work. In the winter he likes to ski cross-country, and he says he has worked out many work-related problems while in the woods, listening to nature, observing the animals.

A well-balanced life leads to an ability to focus clearly. Latva-aho is as ambitious as ever and still not one to take the easy way out. There are new and exciting things happening at the Flagship and the momentum is not only maintained but gained. But, all the while he is keeping an eye on the future.

Read more:
www.oulu.fi/6gflagship/news/6g-matti-latva-aho
NEW MATERIALS ENABLE FUTURE ELECTRONICS

Professor Heli Jantunen is the first person in the world to introduce the possibility of making electroceramics in ultra low temperatures. The next-generation multi-purpose electroceramics are a global breakthrough in the field of electroceramics. They enable the use of lower production temperatures, new materials and 3D printing in the production of electroceramics and also allow production to be small-scale, local and energy-efficient.

One of the areas where printed intelligence and new solutions based on novel synthetic materials will be needed is in telecommunications, in 5G and 6G networks and devices. Moving up to the ultra-high frequencies, as is expected to happen in 6G networks of the future, means that researchers will encounter things they are not even aware of at the moment, starting with physics.

"I think this is such an exciting time and we will come across some extremely intriguing issues. The physical properties of conductors will change, or reveal their limits when we are in the 100-150 GHz range or higher. For instance, there is a hint that at very high frequencies carbon nanotubes have better conductive properties than silver, which is the best known conductive material at the moment. Right now, no one knows why this is," professor Heli Jantunen says.

She is the Leader of the Microelectronics Research Unit in University of Oulu, focusing on novel ICT electronics, high frequency applications, energy harvesters, sensors, multifunctional micromodules and printed electronics devices. Her research group has also invented electro ceramic materials with ultra-low sintering temperature including even fabrication at room temperature in 2014.

Professor Heli Jantunen, who specializes in electronic materials, holds 76 patents and has published over 250 journal papers, many of them in the fields of ultra-low temperature co-firing ceramics.

The results of her research have been broadly utilized in the telecommunication industry where the high technology materials enable advanced high efficient radio systems. Professor Jantunen leads a team of researchers at the University of Oulu that has a pivotal role in the innovation ecosystem of companies of diversified profiles. The close collaboration between public and private actors demonstrates its best achievements in Oulu through leadership, knowledge, and systematic, resilient hard work.

"Because of my background in industry, I have always seen the research as a development process. We have a good team and solving problems collectively is our strength. The multidisciplinary approach produces high-quality scientific results and the research challenges are often based on the needs of our industrial partners. Our group is also a part of the 6G research ecosystem. We research and create new materials, and develop devices using the most feasible manufacturing technologies. The research method is both theoretical and practical", says professor Jantunen.

Yet another award

Professor Heli Jantunen, the receiver of 2019 Finnish Science Award and many more, was recently awarded Yushan Scholar by the Ministry of Education (MOE), ROC Taiwan. As known and mentioned her works on ultra-low temperature co-firing ceramics in particular have received world-renowned recognition.

"This is a relevant award. I have had a long research relationship with Taiwanese universities for almost 20 years. We have focused on strengthening joint research in both countries. This award shows that collaboration with top researchers has been rewarding and important to all of us. The award will enable several visits in the future as well", Heli Jantunen greets.

Read the story New electronics through new materials: www.oulu.fi/university/news/hrf
Enthusiastic and expressive, Mehdi Bennis has a way of pulling a listener into his field of excitement without resistance. The Centre for Wireless Communication associate professor has been wrapping his head around the 6G vision and while he thinks the real revolution is yet to come, he has a pretty good idea where it will come from.

“Google’s federated learning is a low-hanging fruit,” says Bennis, but there is more to come with federated knowledge distillation.

While 6G is still years in the future, we can count on a few things as certainties, when it does come. First, the amount of data generated, transmitted and analyzed is going to grow exponentially. Second, we will have super-high transmission rates to whisk that data around in the ether. Then the two big buzzwords of the moment—artificial intelligence and machine learning—are usually thrown in the mix as all-purpose solutions. But how do we get to the promise of the future, to a digital mirror world where we can simulate our complex systems before building them for real, to having the ability to reason and plan instead of mere pattern matching and curve fitting as done today.

Machine learning and its marriage with communication are what keep Bennis busy at the University of Oulu. Coming from a background in communications engineering, Bennis earned his PhD in Oulu in December 2009 and stayed as a post-doc researcher at CWC. He now runs ICON, a research group of 12 talented researchers whose focus is on the intersection of machine learning, communication and control, focusing on how to enable intelligent communication based on limited data and extracted knowledge. Bennis says that he is incorporating many disciplines in his work, drawing from such fields as game theory, control theory, financial theory and neuroscience, among others.

“During my visit in Princeton in 2017, I began looking at tail distributions,” Bennis says, gesturing with his hands, creating a Bell curve in the air, and then focusing on a tiny sliver of its end. “The things that happen very rarely, but when they do, a lot of stuff goes wrong.”

“So, it’s things like earthquakes and hurricanes and the like, rare, or hard-to-predict events that cause massive repercussions. I was not convinced by the focus back then on running time-consuming simulations without gaining any basic understanding of URLLC. So I decided to bring in the concept of tail distribution thinking into wireless, especially as it relates to the reliability of communication networks. And so my focus became how to bring in this awareness of tail distribution to wireless, machine learning, and, basically, how to manage risk. Now the entire industry talks about tails,” Bennis adds.

“ICON is the first group to investigate federated learning in the context of wireless communication in the context of 6G, an area that is rapidly evolving. But we need much more,” Bennis says.

Because even in this approach we are still trying to do pattern matching and correlation. As Bennis sees it, the important thing is to extrapolate, not interpolate. This is why we need to look into neuroscience, physics, and other areas.

Read more: www.oulu.fi/university/news/mehdi-bennis-6G
Dr. Samad Ali graduated with a doctoral degree early this year. In his thesis, he examined two-step design of predictive resource allocation for Machine Type Communications (MTC). “First step, which is known as source traffic prediction, is the process of predicting the set of active devices that want to transmit data,” Ali defines. “The second step is the optimal selection of the devices without prior knowledge about their quality of service (QoS) requirements.”

The concept of the so-called fast uplink grant is at the core of his research. It refers to the process by which the users are scheduled for transmission of data packets. “The users are selected by the two-step process that I develop in the thesis,” Ali says. “Fast uplink grant is crucial because it eliminates the extra signaling that the IoT devices must perform before the transmission of their data packets.”

Often, radio channels that are used for such a signaling, are overloaded due to the large number of devices that share the same resources. “Fast uplink grant saves radio resources, eliminates collision and congestion, and reduces the latency by skipping the scheduling request process of the IoT devices,” Ali clarifies. “By saving such scares radio resources, wireless networks can provide connectivity for massive number of devices.”

His research derives inspiration from carefully selected machine learning tools. “Causal inference enables the source traffic prediction in event-driven MTC that have a burst of transmission from many devices in a short period of time,” Ali says. “This, if implemented correctly in combination with anomaly detection tools, can solve a big problem that the wireless networks face when a large number of IoT devices start a burst of transmission while facing an unexpected even.”

Multi-armed bandit algorithms, on the other hand, are a set of classic tools that are used to balance the exploration and exploitation dilemma. “This dilemma shows up in many problems in real life as well as in engineering,” Ali says. “In predictive resource allocation, they are used to select the best IoT devices for transmission without a prior knowledge about their QoS requirements.”

For more complicated problems, where the set of observations is large, Ali relies on deep learning, which is used as a function approximator to make the optimal selection. “All these tools can solve complex problems in a simple and elegant way without complicated calculations,” he concludes.

Overall, 6G Flagship and the University of Oulu have offered the recently fresh doctor of technology a great launch pad for his career in research. “As a pioneer in the research field, 6G Flagship constantly pushes the boundaries of science and technology,” Ali says. “It is a great opportunity, and privilege to be a part of a forward-looking team that provides an environment to work on novel ideas and encourages out-of-the-box thinking. This helps creative people to come up with innovative technology solutions that can transform the societies and help the humanity in finding solutions to some of the most challenging problems in the world. Therefore, I would highly encourage talented students and researchers to consider joining 6G Flagship to follow their passion in science and technology. Keep an eye on our study programs and open positions!”
Onel Alcaraz López defended his doctoral thesis “Resource allocation for machine-type communication: from massive connectivity to ultra-reliable low-latency” in April. We asked him a few questions before his thesis defense. These are his thoughts on his research outcomes and their significance.

What is the link between Machine-type Communications, wireless energy transfer and IoT in your thesis? What triggered your interest in the topic?

The Internet of Things (IoT), composed at the core by machine-type devices, is a revolutionary paradigm that promises wireless connectivity to anything, and paves the way to a sustainable data-driven society.

Wireless Energy Transfer (WET) technology has emerged as an efficient and sustainable solution for powering low-complexity IoT devices. WET eliminates the need of the traditional wired and/or battery-based charging, and thus allows simplifying the servicing and maintenance, reducing the form factor of the IoT devices, improving their durability and reliability thanks to contact-free designs, and facilitating waste-free (ecological-friendly) deployments. Realizing WET in practical scenarios seemed challenging and futuristic at the time when I started my research, which sowed my passion for this research area.

What is lacking from current solutions?

The main open problems are related to how to further boost the end-to-end WET efficiency, support low-speed mobility, and seamlessly integrate wireless communication and WET. In addition, providing wide coverage with quality-of-service (QoS) guarantees is critical since the number of low-power IoT devices with challenging requirements will dramatically increase in the coming years.

In your solution, how are battery-constrained devices powered wirelessly?

The deployment of power transmitters, named power beacons (PBs), may be mandatory for supporting QoS. PBs equipped with antenna arrays have traditionally used Channel State Information (CSI)-based energy beamforming to increase the energy availability at the devices’ side. However, CSI is difficult to acquire in WET systems, because it demands costly procedures in terms of energy expenditure from the IoT devices. We propose CSI-free/limited schemes that allow the PB to efficiently power massive deployments of low-power IoT devices.

What is the essence of the suggested distributed architecture?

In a distributed architecture, multiple PBs are deployed and no strict coordination between them exist. The proposed CSI-free/limited solutions are local, hence, easily adapted to multi-PB setups. However, complementary solutions exploiting certain low-coordination mechanisms from the PBs are also attractive and worth to deeply investigate.

What would the proposed solution, once implemented, mean for IoT sustainability?

Industry and academy are foreseeing hundreds-thousands of IoT devices in a 10 meter-radius circular coverage area. Our solutions aim to sustainably power and provide connectivity to such massive number of devices, and constitute an initial spark towards realizing “always-alive” devices with ubiquitous QoS guarantees and zero battery wastage.

What inspiration are you hoping this thesis brings to developers?

Researchers on wireless communications will benefit most of the analysis in this thesis. We delved into concepts that are relevant moving forward to the 6G era: data aggregation, scheduling mechanisms, non-orthogonal access, distributed radio resource management, and the novel schemes for massive WET, of course.

How will your work on this topic continue?

We will investigate the most appropriate antenna array architectures at the PB and evaluate collaborative schemes. We plan to use machine-learning/artificial intelligence to allow the proposed schemes update and optimize themselves on the fly based on devices’ clustering information and their energy demands.

Read more:
www.oulu.fi/6gflagship/zoom-into-massive-iot-wet
## 6G Flagship in Numbers

### Staff

- **305** experts in 2020
- **58** Nationalities

### Publications (May 2018 – September 2020)

- **1,151** Peer-reviewed publications / Journal and conference articles
- **65%** International joint publications
- **75%** Joint publications with collaborators
- **11%** Joint publications with companies

### Collaboration (May 2018 – September 2020)

- **259** Research projects with external funding
- **136** New company collaborators
- **85** Companies investing in research portfolio
### Doctoral Degrees (May 2018 – September 2020)

- **46** Doctoral degrees
- **178,861** Doctoral thesis downloads

Number of downloads in University of Oulu repository [http://jultika.oulu.fi/](http://jultika.oulu.fi/)

### 6G White Paper (September 2019 – September 2020)

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ASSISTANT OR ASSOCIATE PROFESSOR IN MACHINE LEARNING FOR WIRELESS SYSTEMS

We are looking for highly talented individuals who hold a doctoral degree and have excellent potential for a successful scientific career in Machine Learning for Wireless Systems.

The position, starting as tenure track from 1 June 2021, or later according to mutual agreement, is directed to investigate design of fundamental theory and algorithms of machine learning applied in wireless communications and networks, its applications in sensing, and massive distributed networked applications.

The position of an Assistant or an Associate Professor is initially a fixed-term position for five years. Career advancement in the tenure track system is based on assessments of the candidate’s performance and merits as described in the University of Oulu Tenure Track guidelines.

The position is placed Faculty of Information Technology and Electrical Engineering in one of the following research units:

• Center for Machine Vision and Signal Analysis (CMVS) (www.oulu.fi/cmvs)
• Centre for Wireless Communications (CWC) – Radio Technologies (RT) (www.oulu.fi/cwc)
• Centre for Wireless Communications – Networks and Systems (NS) (www.oulu.fi/cwc)

Responsibilities include conducting outstanding world-class scientific research, publishing in leading journals and conferences, acquiring external research funding, supervising doctoral students, active participation in the international scientific community, creating and teaching related BSc and MSc level courses, and exhibiting academic leadership and innovativeness.

Application deadline: 15 January 2021

More information: www.oulu.fi/6gflagship/career_opportunities
ASSOCIATE OR FULL PROFESSOR IN WIRELESS NETWORK TECHNOLOGIES

We are looking for highly talented individuals who hold a doctoral degree and have excellent potential for a successful scientific career in Wireless Network Technologies.

The position, starting as tenure track from 1 June 2021, or later according to mutual agreement, is directed to investigate, apply, and design the fundamental theory and new solutions for wireless networking.

The position of an associate professor or full professor is initially a fixed-term position for five years, but a continuation period may be granted, or the position may be made permanent. Career advancement in the tenure track system is based on assessments of the candidate's performance and merits as described in the University of Oulu Tenure Track guidelines.

The position is placed at the Faculty of Information Technology and Electrical Engineering, Centre for Wireless Communications – Networks and Systems (NS) research unit.

A successful applicant is expected to master and to have a substantial research track record in queuing theory, network information theory, network coding, and network protocols.

Responsibilities include conducting outstanding world-class scientific research, publishing in leading journals and conferences, acquiring external research funding, supervising doctoral students, to be an active member of the international scientific community, and creating and teaching related BSc and MSc level courses, and exhibiting academic leadership and innovativeness.

Application deadline: 15 January 2021

More information: www.oulu.fi/6gflagship/career_opportunities
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<td>16 Sept. 2020</td>
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