



6G

FLAGSHIP
UNIVERSITY
OF OULU



ACADEMY
OF FINLAND



FLAGSHIP PROGRAMME

6G Future Directions— According to the 6G White Papers published by 6G Flagship

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Why and what is 6G?



- Mobile communications have driven major societal changes in 20-year cycles



1G - 2G

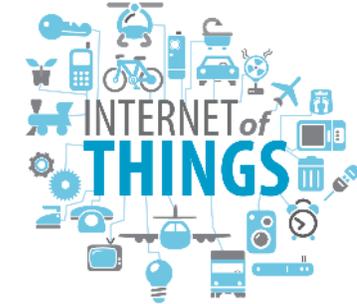
1980s – 2000s

Millions of voice users



3G - 4G

– 2020s Billions of Mobile
Broadband users



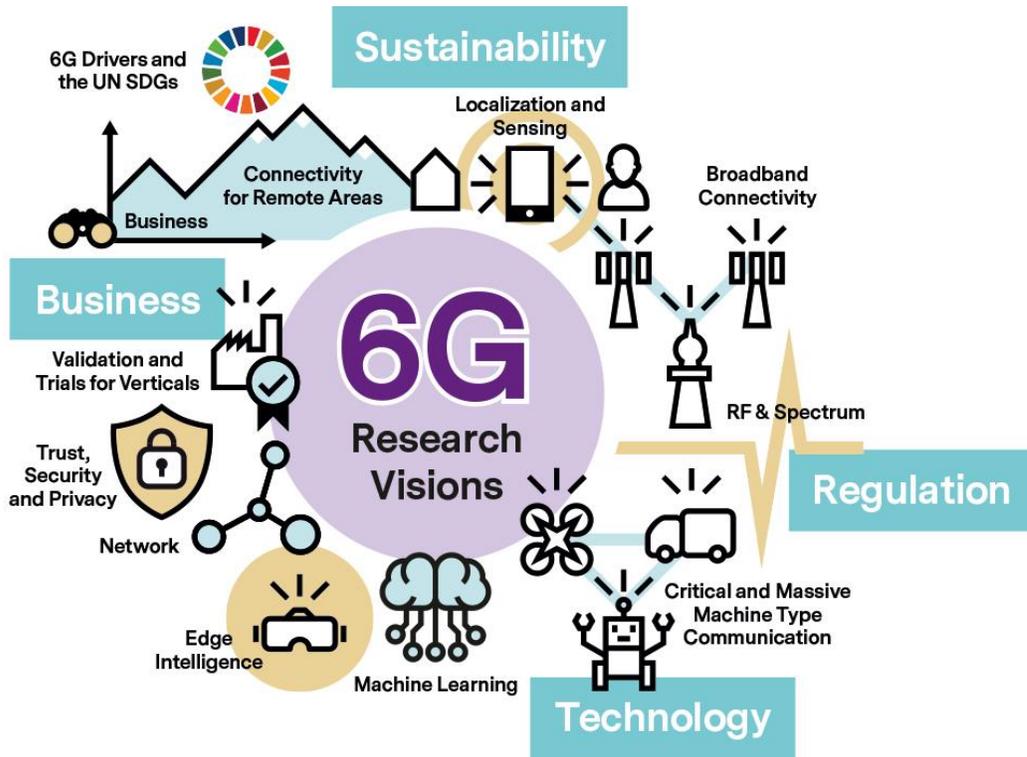
5G – 6G

– 2040s Trillions of
connected objects & intelligence

- **Massive automation of society** needs more than 5G can offer.
- 6G will **merge physical, digital and biological worlds** fulfilling UN SDGs of digital societies.
- 6G requires more radical transformations:
 - capabilities of **wireless transmission must be pushed to the limits**
 - **massive utilization of artificial intelligence** in networks and applications
 - radical **innovations needed for future wireless business ecosystems**

6G

We have defined global 6G research agenda



- Finnish Flagship for **2018-2026**
- Volume **251 M€**
- Operated by **University of Oulu**
- Collaboration with **Nokia, VTT, Aalto University, BusinessOulu, OUAS, Keysight, Interdigital**
- **300 Project Partners**

1.

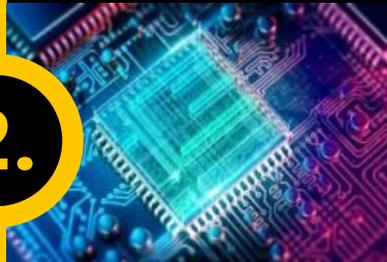


Wireless Connectivity

Ultra-reliable low-latency communications vs. 1 Tbps

Enabling **Unmanned Processes**

2.



Devices & Circuits

THz communications materials & circuits

Enabling **Unlimited Connectivity**

3.



Distributed Computing

Mobile edge intelligence

Enabling **Time Critical & Trusted Apps**

4.



Services & Applications

Multidisciplinary research across verticals

Enabling **Disruptive Value Networks**

KPIs Approach to Use Cases



100 μ s

- Hysteresis free remote control with haptics
- Active protection circuitry
- 2000 Hz control loops

1 Tbps

- Holography
- 16K/240 Hz eXR
- InChip Radio
- InDevice Radio
- Data center connectivity
- Data kiosks
- Huge datasets (DNA, Astronomy)

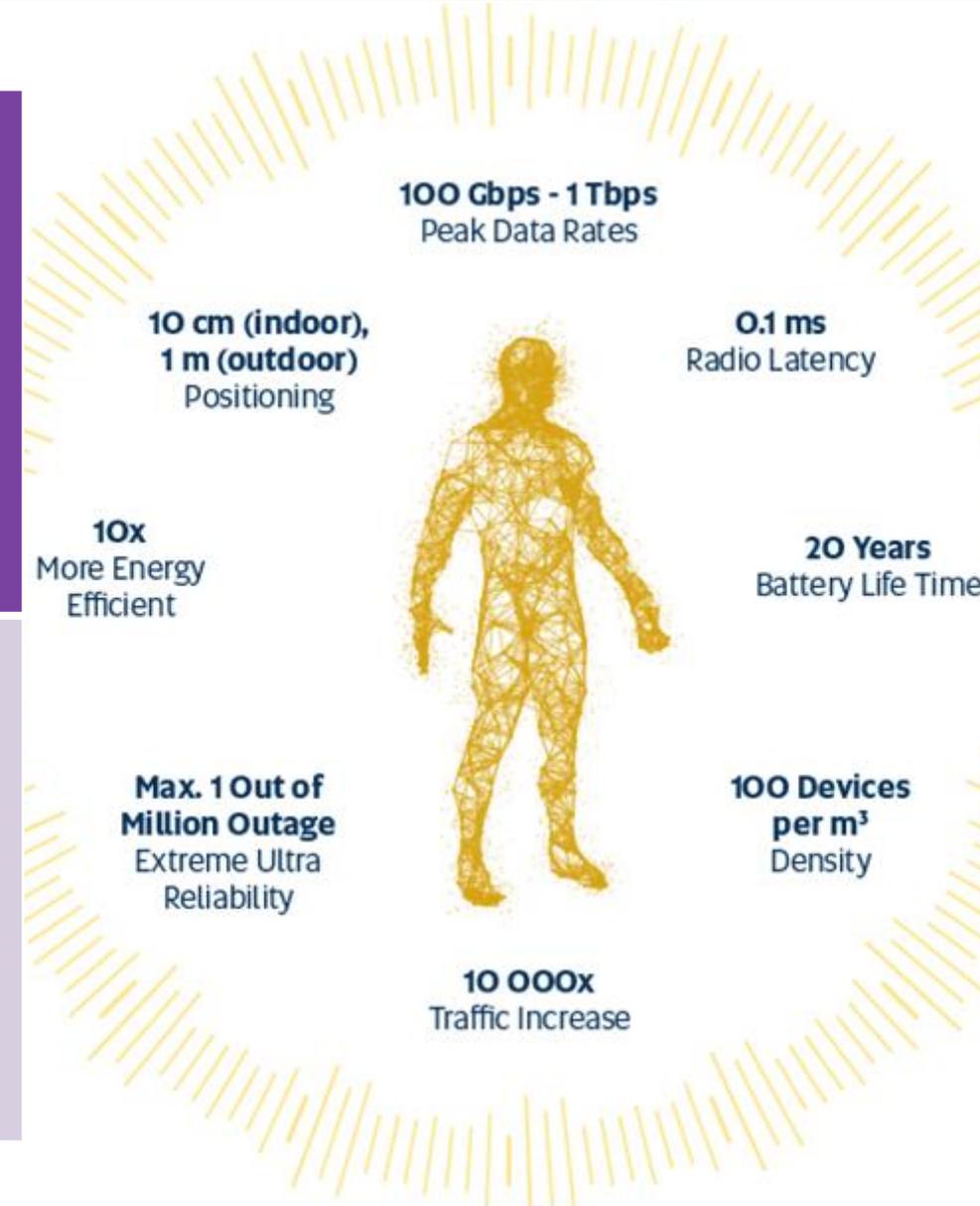
Seeing the future:
Augmented human

- Holography (multi-stream synchronisation)
- Industrial ethernet

- Real-Time Digital Twins and virtual remote control
- Holography
- Extreme Swarms
- Material identification

10 ns

1-3 mm



Micro use cases (or drivers)/parallel technologies

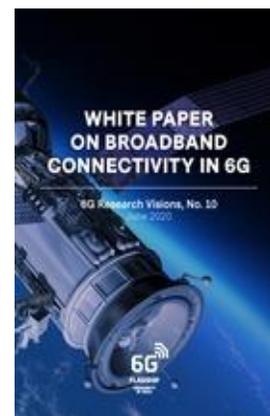
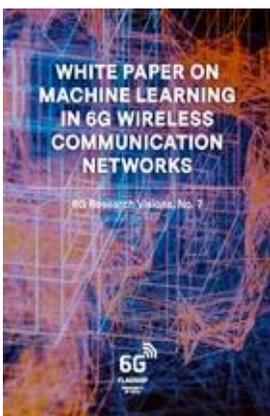
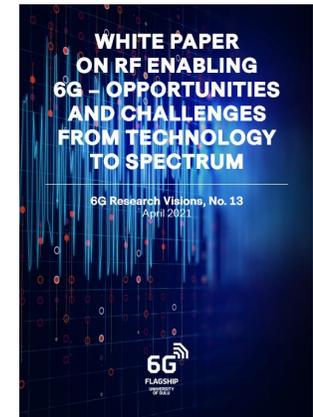
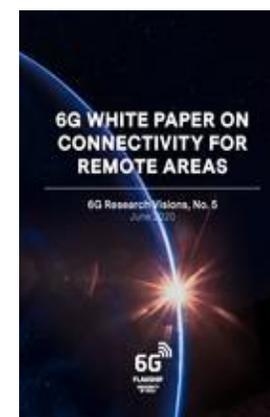
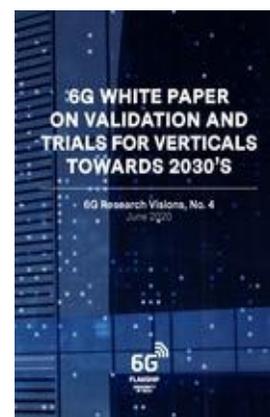
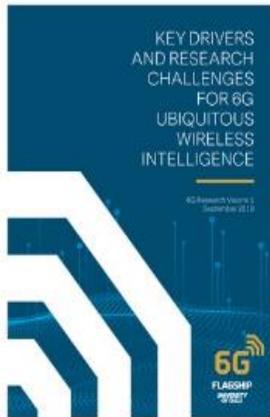


- Full NTN+TN integration → Remote/Unserved
- $1-10^{-9}$ reliability vs. low latency → Industry eURLLC
- Transmit only, receive only devices → Smart cities, homes etc.
- Real-time AI on small data at the edge → Dynamic processes with age of information
- Best effort → QoE dependability
- Uplink heavy future
- Simultaneous communications and sensing
- Radio complemented by VLC → Fast hetnet handovers

6G Research Visions



- University of Oulu has established "6G Research Visions" publication series to make 6G Flagship findings openly available to a wider community. Publications can be found from: <http://jultika.oulu.fi/> or <https://www.6gchannel.com/6g-white-papers/>

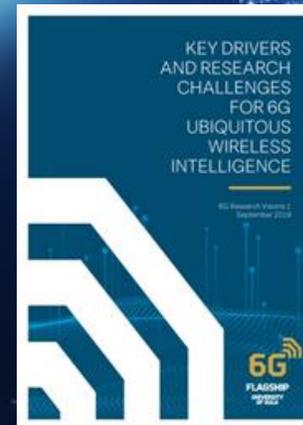


World's first 6G White Paper

- **World's first 6G Wireless Summit gathered major telecom players to vision 6G in Finland in March 2019.**
- **The Summit launched 6G White Paper development with 70 experts from around the world.**
- **Consensus that 6G is driven by United Nations' Sustainable Development Goals (UN SDGs).**

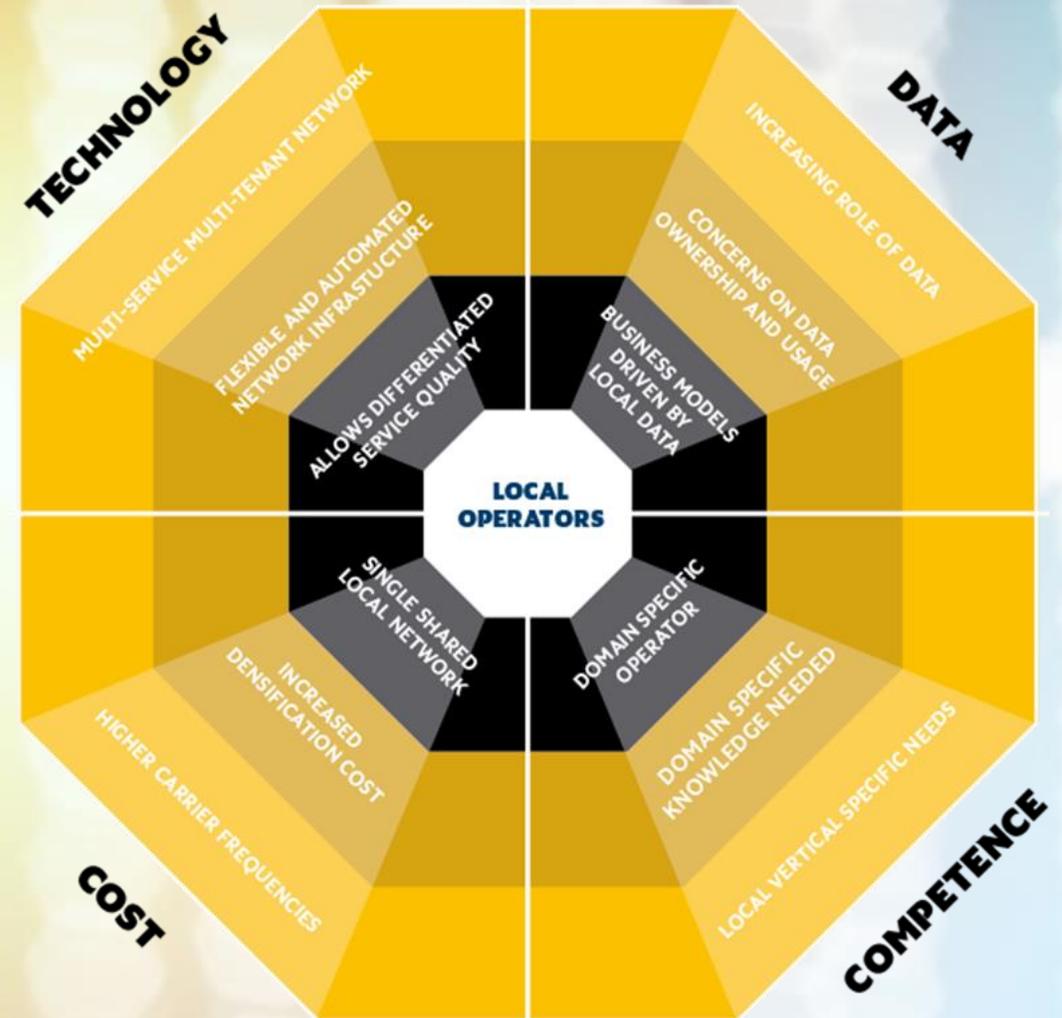
Published in September 2019:

<http://6gflagship.com/6gwhitepaper/>



Towards Local Operator Paradigm

Transition to higher frequencies and increasing role of indoor networks will boost network sharing in cities and indoor spaces, and drive the “local operator” paradigm.

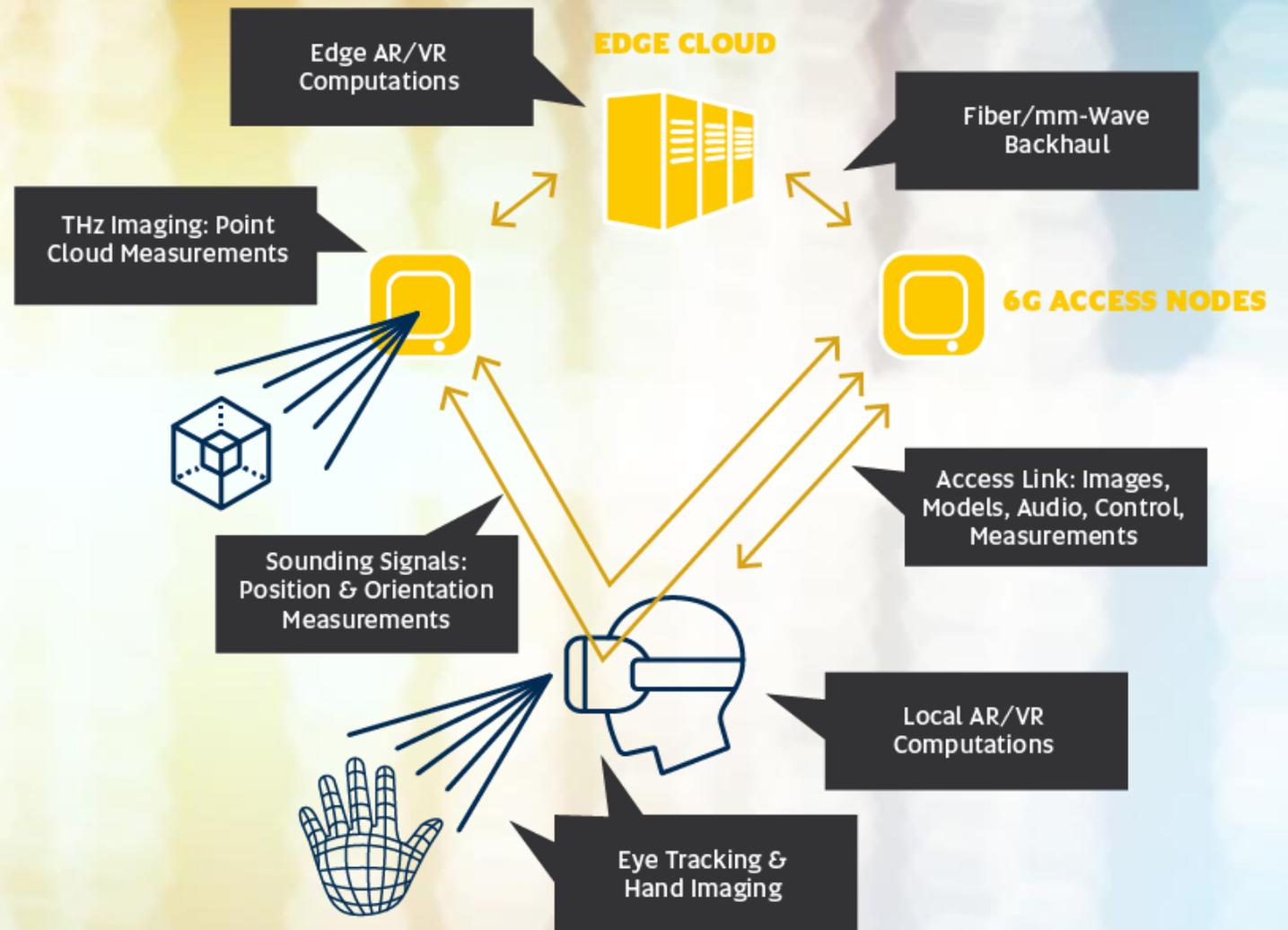


Published in September 2019:

<http://6gflagship.com/6gwhitepaper/>

6G Merges Communications with New Applications 6G

Integration of sensing, imaging and highly accurate positioning capabilities with mobility opens a myriad of new applications in 6G.

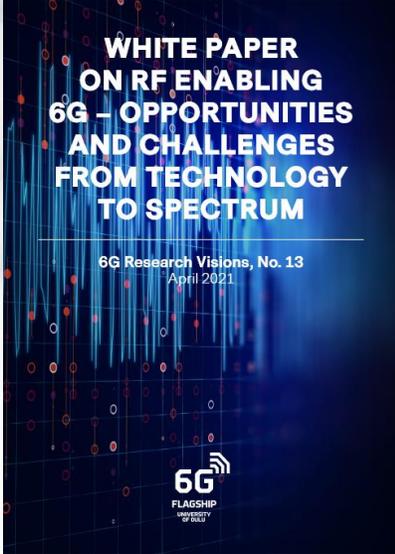
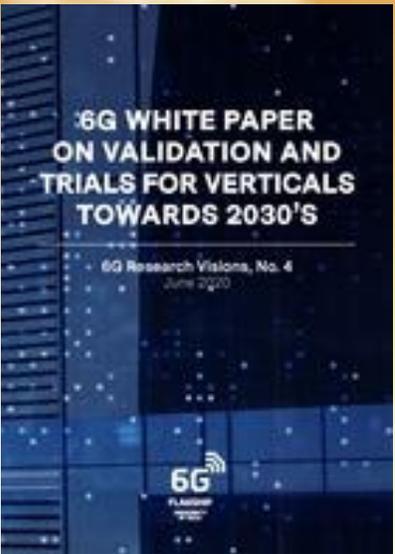
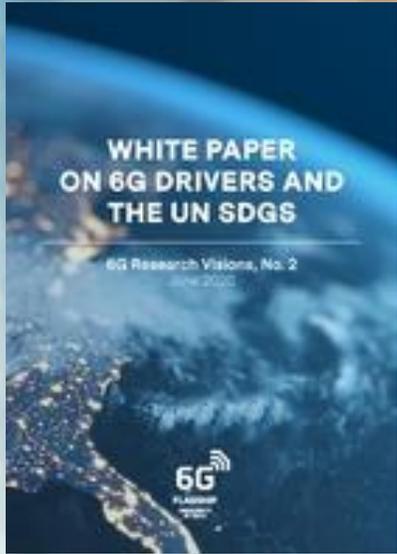


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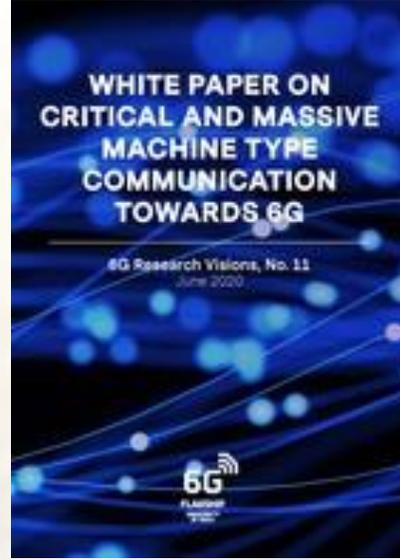
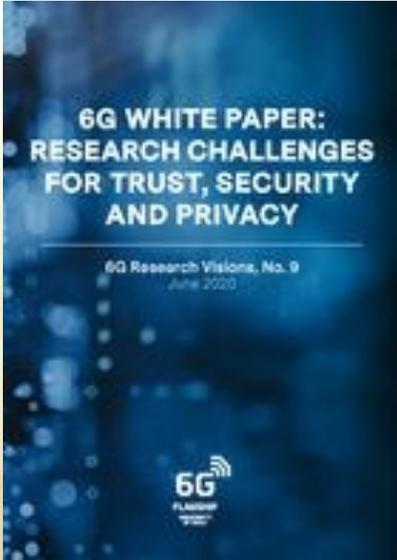
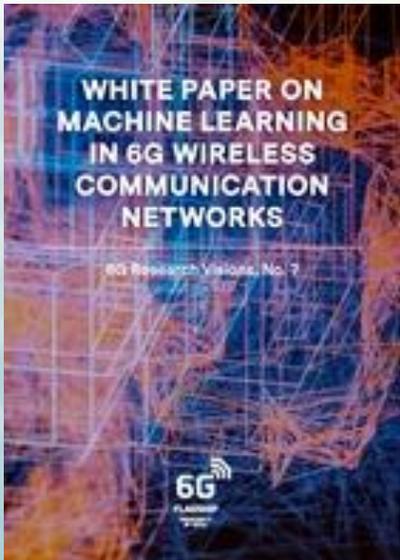
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12 thematic 6G White Papers published

- Experts groups with more than 250 participants from more than 100 organizations and 30 countries started to work on 12 new white papers in conjunction with the 2nd 6G Wireless Summit held virtually in March 2020. <https://www.6gsummit.com/>
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- 12 new 6G White Papers were published as draft versions in April 2020 and final versions in June 2020, and one will appear later at: <https://www.6gchannel.com/6g-white-papers/>



<https://www.6gchannel.com/6g-white-papers/>



White Paper on 6G Drivers and the UN SDGs

HIGHLIGHTS:

- We identify megatrends influencing the sustainable development of 6G.
- We develop a novel linkage between 6G and the UN SDGs that are both targeted for 2030.
- We envisage three-fold role of 6G as:
 - 1) a provider of services to help support activities towards reaching the UN SDGs,
 - 2) a measuring tool for reporting of indicators;
 - 3) a reinforcer of developing 6G in line with the UN SDG.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-6g-drivers-un-sdgs/>



White Paper on 6G Drivers and the UN SDGs



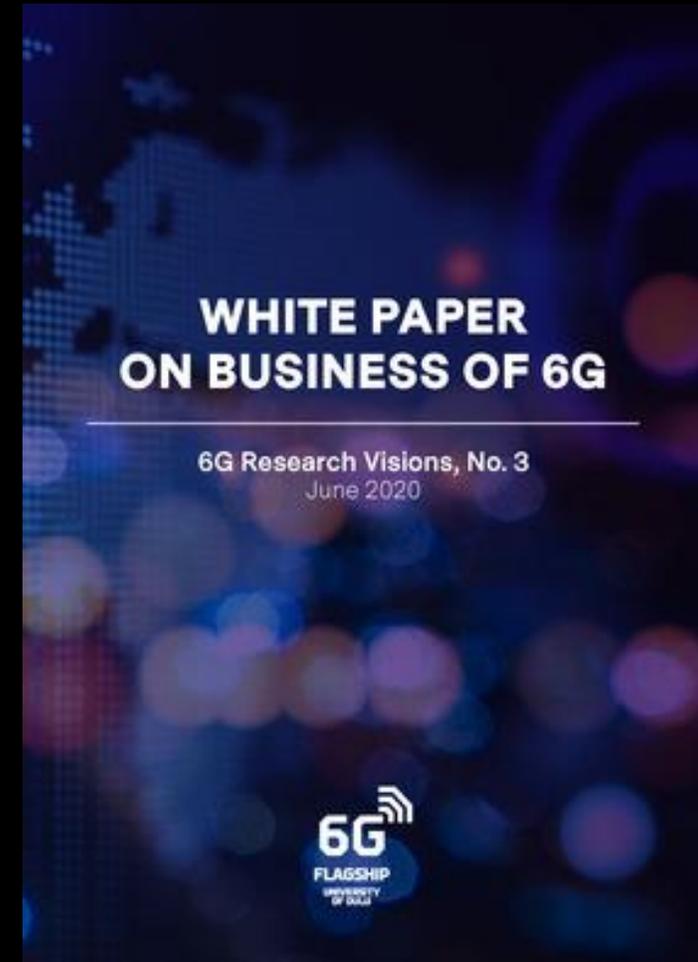
UN Targets	UN Indicators	6G can
<p>9.c Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020</p>	<p>9.c.1 Proportion of population covered by a mobile network, by technology</p>	<p>Help telecommunication operators achieve greater mobile network coverage enabling access also to the most remote areas.</p> <p>Increase the percentage of inhabitants living within the range of mobile-broadband network.</p> <p>Improve market competition by enabling smaller operators to participate in vertical markets.</p>

White Paper on Business of 6G

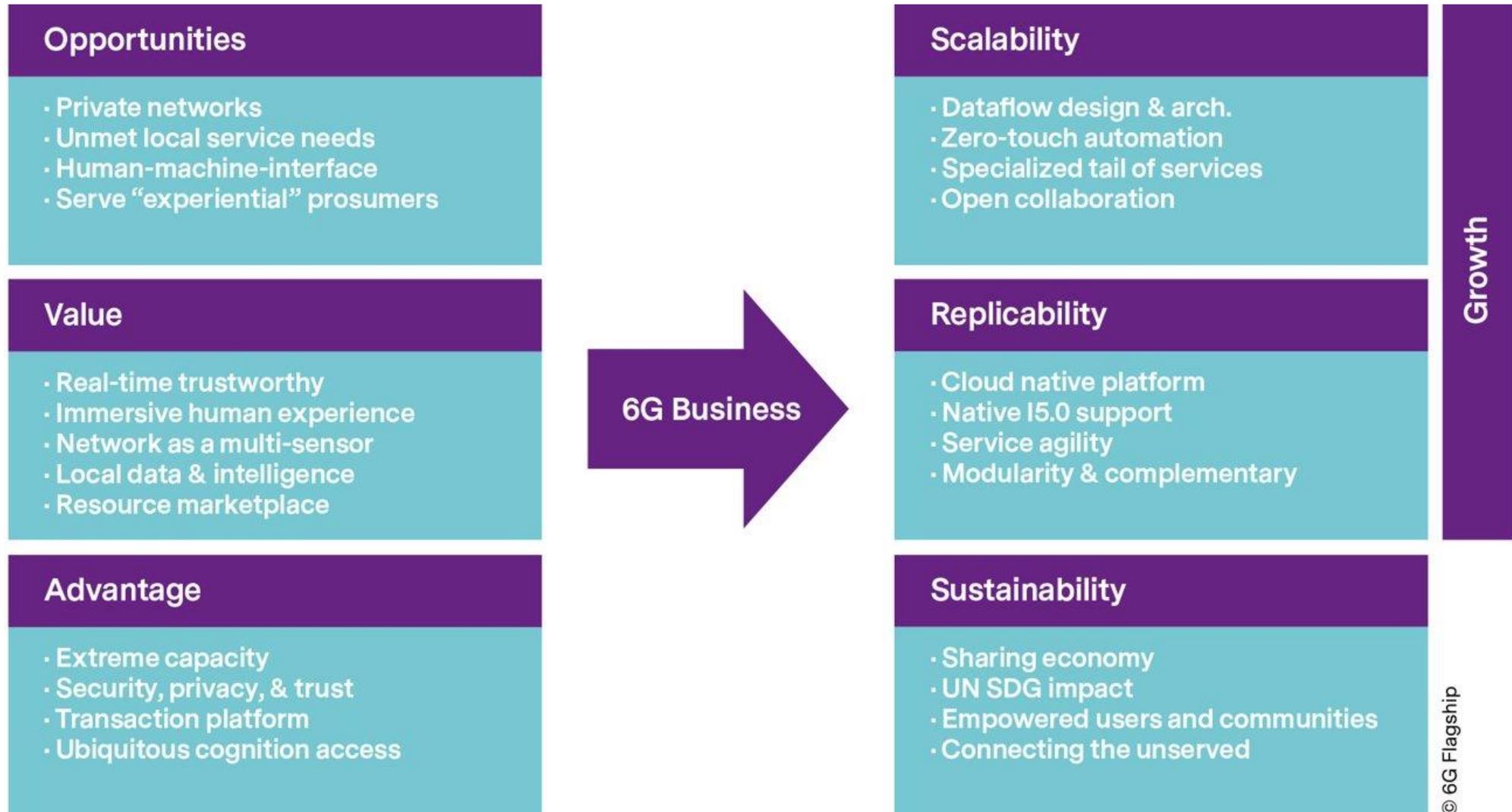
HIGHLIGHTS:

- Value-capture in 6G era requires understanding dynamics of platforms and ecosystems. Access to data and data ownership are major factors and limiting is a means of control.
- Modularity and complementarity of technology solutions raise difficult openness and transparency as well as collaboration vs. competition issues.
- 6G business ecosystem for solving sustainability problems needs open value configuration and decentralized power configuration focusing on specialized user requirements that cross a variety of industries.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-business-of-6g/>



White Paper on Business of 6G

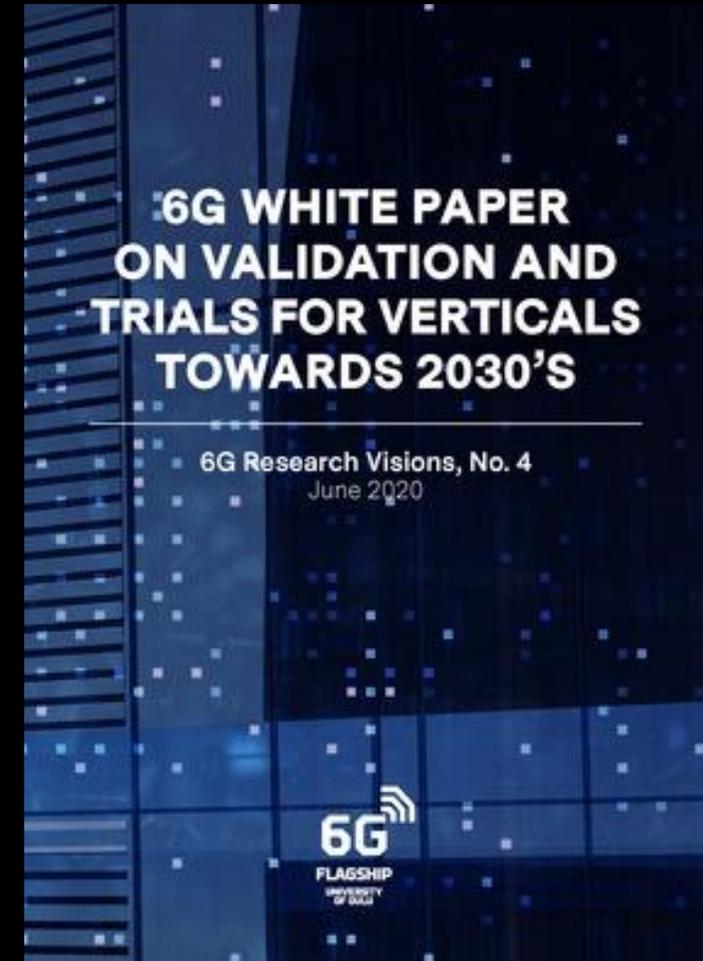


White Paper on Validation and Trials for Verticals towards 2030's

HIGHLIGHTS:

- We take a close look on 6G drivers within selected verticals and propose a set of key performance and value indicators.
- We propose golden references for trialing within different verticals for commonly measurable results.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-validation-trials/>



White Paper on Validation and Trials for Verticals towards 2030's



Examples of KPIs for verticals

Vertical	Link DataRate	Latency	LinkBudget	Jitter	Density	EnergyEfficiency	Reliability	Capacity	Mobility
Industry mMTC	< 1 Mbps	< 100ms	+ 10 dB	100 μ s	100/m ³	High	1-10 ⁻⁶	< 10 Gbps	240 km/h
Industry eURLLC	< 5 Mbps	< 100 μ s	+ 20 dB	< 1 μ s	10/m ³	Nominal	1-10 ⁻⁹	< 100 Mbps	240 km/h
Mobility	<10 Gbps	< 100 μ s	+ 20 dB	100 μ s	100/m ³	Nominal	1-10 ⁻⁷	1 Tbps	1200 km/h
eHealth	< 1 Gbps	< 1 ms	+ 10 dB	100 μ s	1/m ³	High	1-10 ⁻⁹	< 10 Gbps	240 km/h
Energy	<1 Mbps	< 500 μ s	+ 40 dB	< 1 μ s	10/m ³	Nominal	1-10 ⁻⁶	< 100 Mbps	N/A
Finance	< 1 Gbps	< 10 ms	varies	N/A	1/m ³	High	1-10 ⁻⁹	< 10 Gbps	Low
Public Safety	<1 Gbps	< 1 ms	+ 20 dB	100 μ s	1/m ³	Nominal	1-10 ⁻⁷	< 10 Gbps	240 km/h
Agri-business	100 Mbps	< 10 ms	+ 40 dB	100 μ s	100/km ²	Nominal	1-10 ⁻⁷	1 Gbps	240 km/h



Smart cities



Media



Auto motive



Energy



Emergency response



Telecom



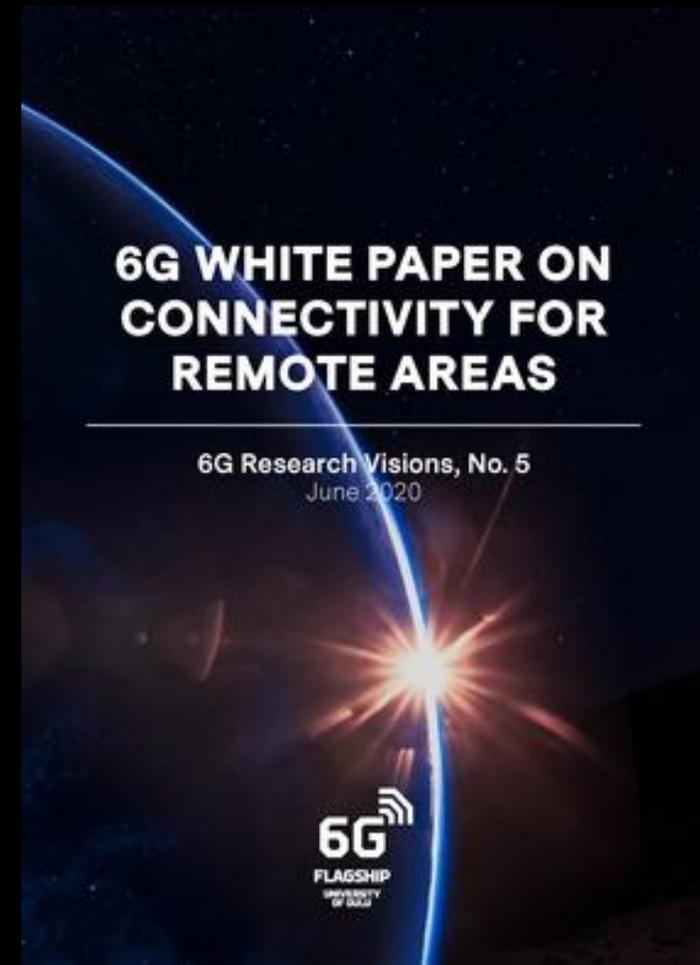
Industry 4.0

6G White Paper on Connectivity for Remote Areas

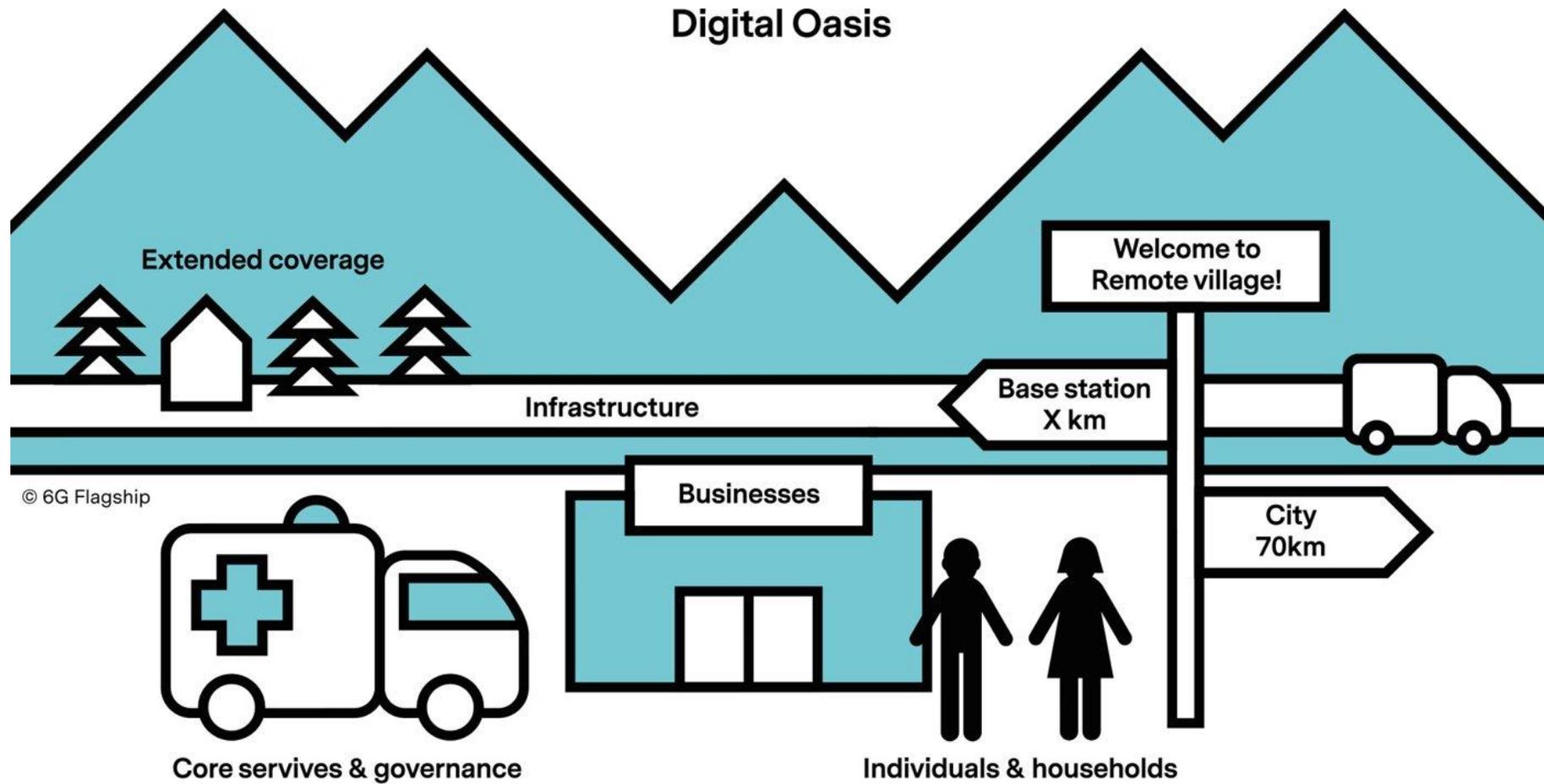
HIGHLIGHTS:

- We emphasize that solutions to bridge digital divide in rural and remote areas must be easy to use, affordable and provide sufficient data rate and availability.
- 6G could be the first mobile generation to close the digital divide. 6G needs to concentrate on challenges of rural and remote areas from the beginning of the design cycle.
- Technical solutions can use mobile cellular solutions where people live and work (digital oases) and various backhaul solutions including large cells, relays and satellites.
- Novel regulation and cooperation between various stakeholders is also needed.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-connectivity-remote-areas/>



6G White Paper on Connectivity for Remote Areas **6G**

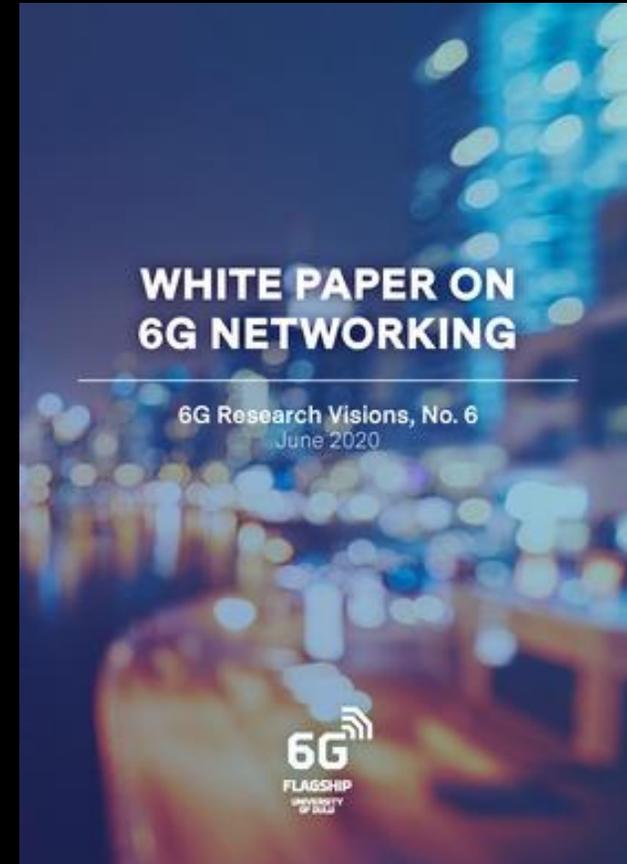


White Paper on 6G Networking

HIGHLIGHTS:

- We present network advancements and implications introduced by the evolution of softwarization and service-based architecture.
- We present key technologies that constitute the pillars for the evolution towards 6G networking, considering the evolution toward a cloud native mobile communication system and the adoption of a new IP architecture that supports high precision services.
- We explore the different analytics that can be gained from the different segments involved in the delivery of a particular communication service.

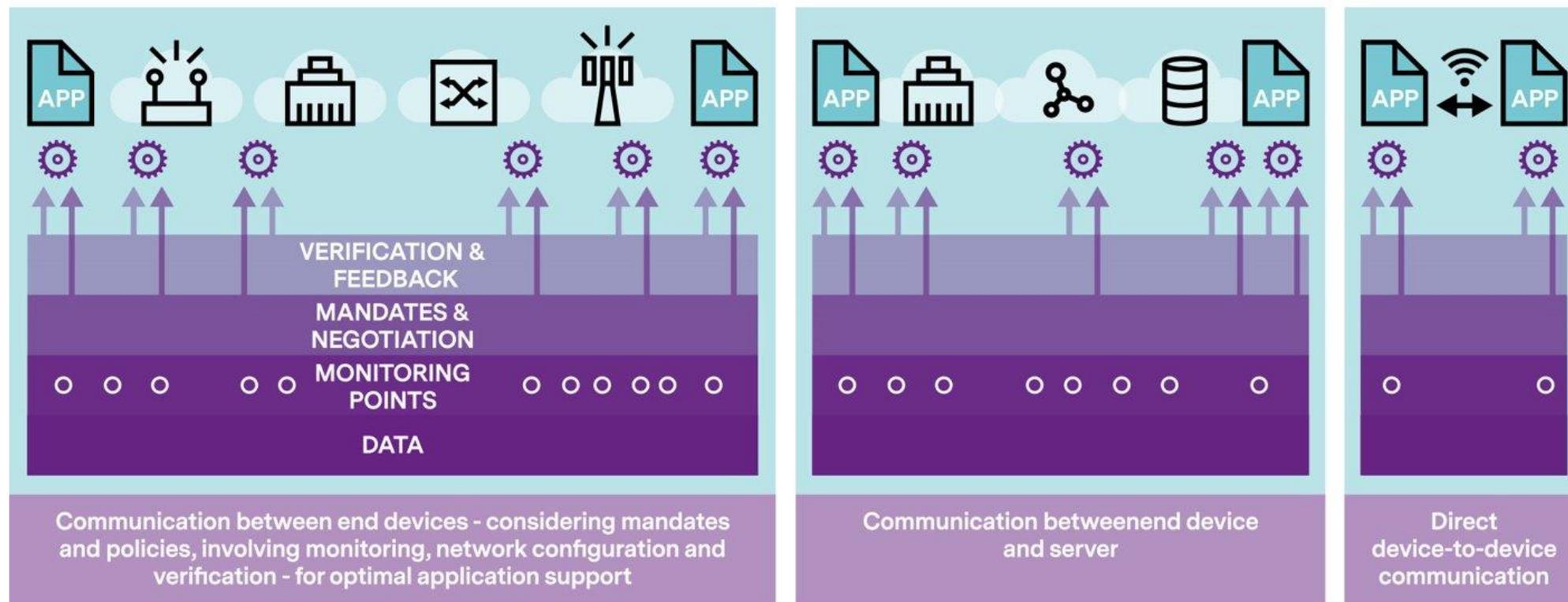
<https://www.6gchannel.com/portfolio-posts/6g-white-paper-networking/>



White Paper on 6G Networking



Connectivity view

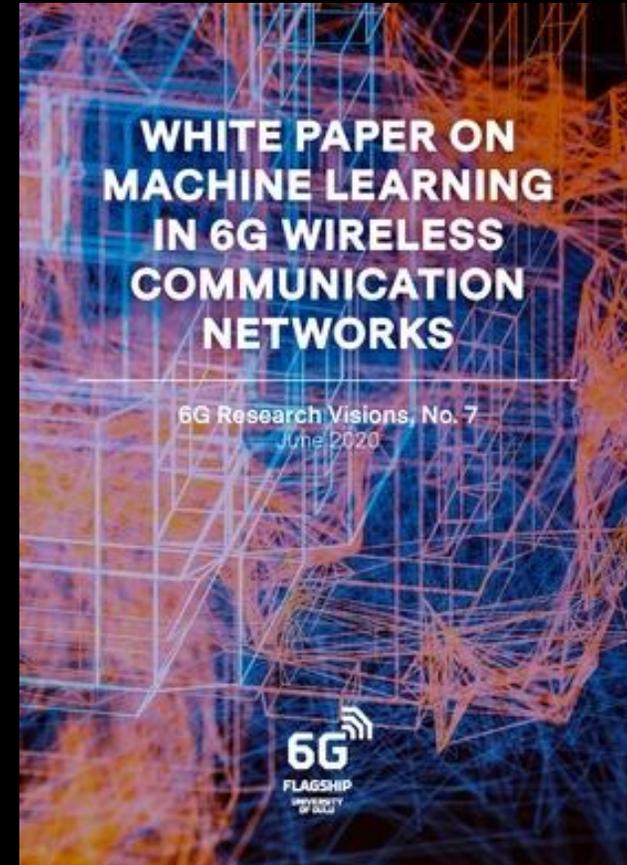


White Paper on Machine Learning in 6G Wireless Communication Networks

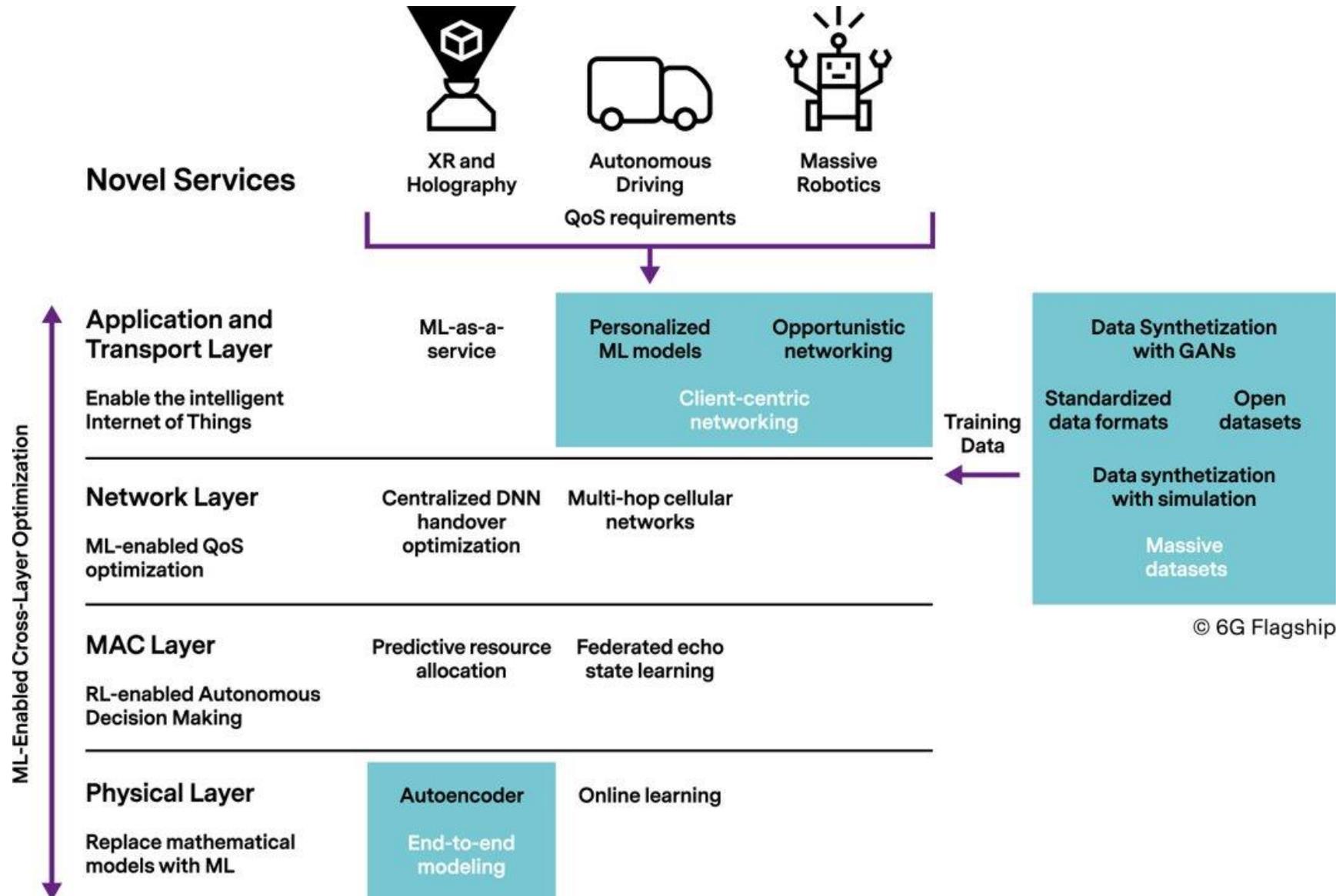
HIGHLIGHTS:

- We provide an overview of the role of machine learning in 6G networks. By looking at various problems in different layers of the communications protocol stack, we propose a machine learning tool for each problem.
- Applications that will be able to utilize machine learning within the broader scope of wireless communications such as UAV communications and networking are also studied and novel ideas and future directions for them are provided.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-machine-learning/>



White Paper on Machine Learning in 6G Wireless Communication Networks

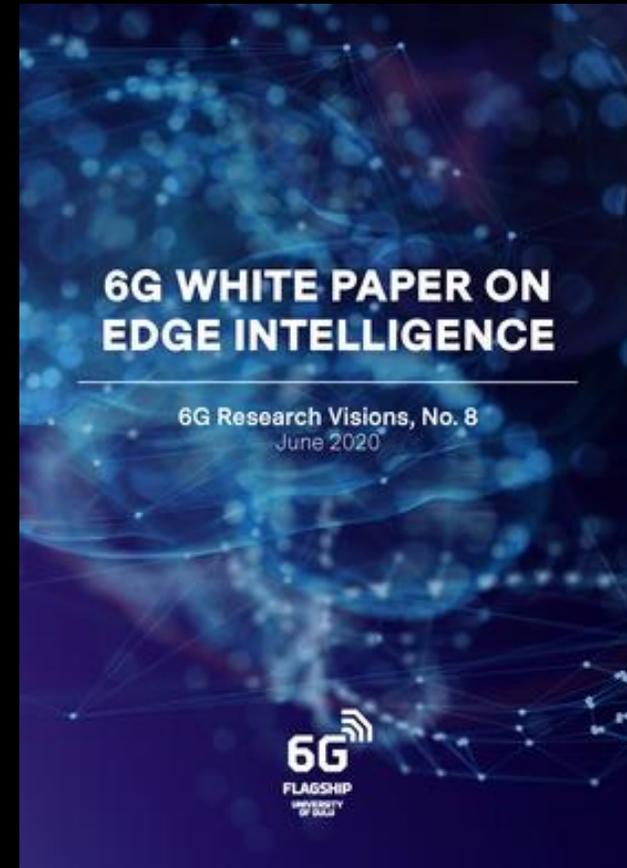


6G White Paper on Edge Intelligence

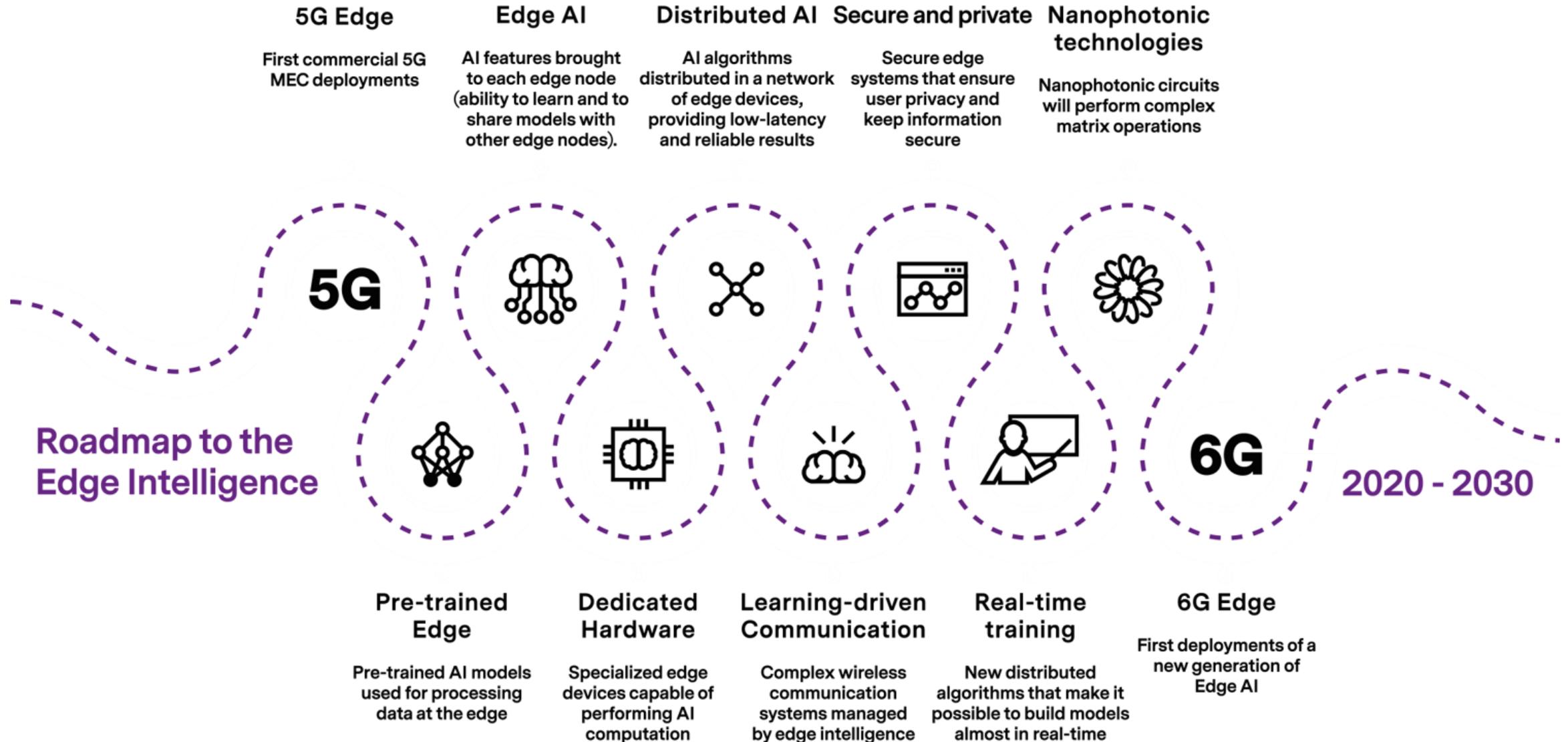
HIGHLIGHTS:

- We identify the need for an “Intelligent Internet of Intelligent Things” to make Internet more reliable, efficient, resilient, and secure, where 6G with edge-driven AI can play a fundamental role.
- We claim that performance, cost, security, efficiency, and reliability are key features and measurable indicators of any edge intelligence solutions.
- The evolution of a new generation of edge intelligence systems, applications and services will take place during the next ten years, with the completion of different technological steps that will provide new devices, technology, and applications.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-edge-intelligence/>



6G White Paper on Edge Intelligence

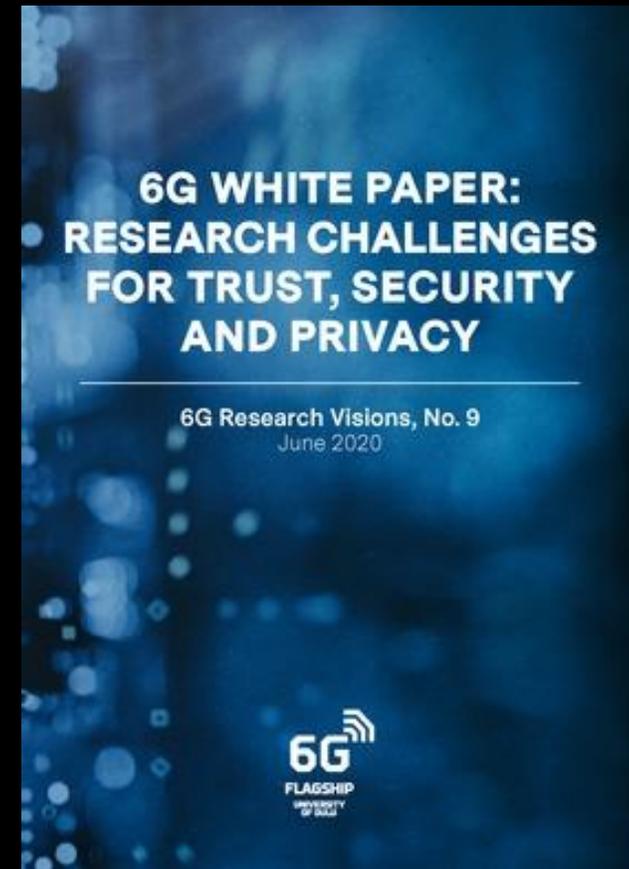


6G White Paper: Research Challenges for Trust, Security and Privacy

HIGHLIGHTS:

- We address fundamental research challenges of 6G in three key areas – trust, security and privacy.
- The roles of trust, security and privacy are somewhat interconnected, but different facets of next generation networks.
- The challenges in creating a trustworthy 6G are multidisciplinary, spanning technology, regulation, techno-economics, politics and ethics.

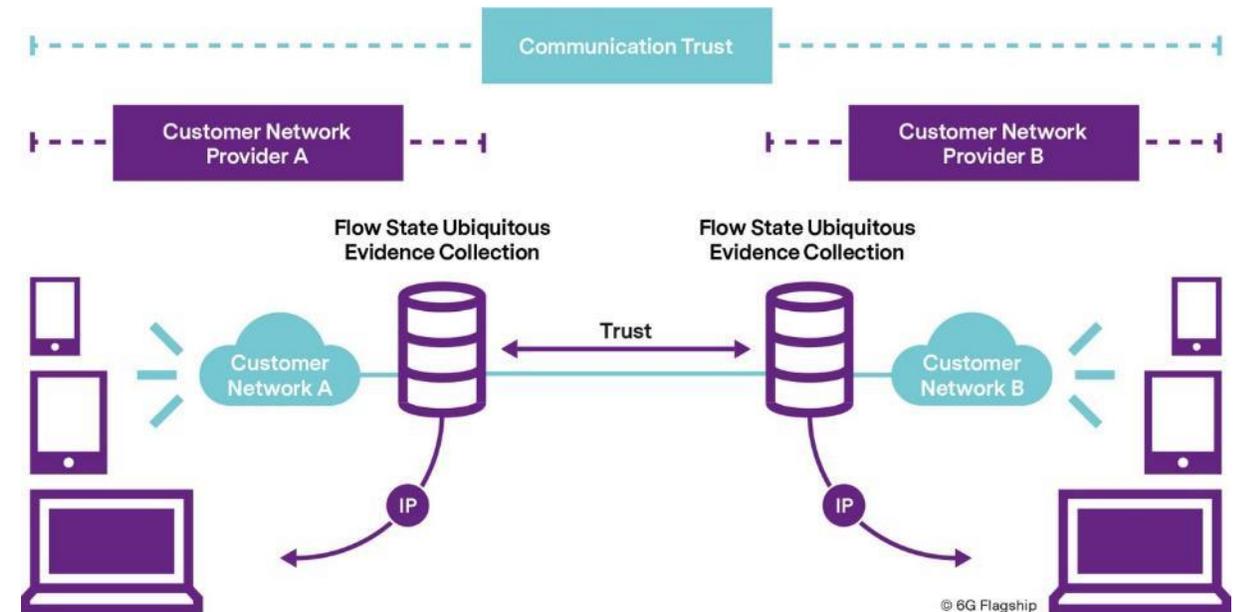
<https://www.6gchannel.com/portfolio-posts/6g-white-paper-trust-security-privacy/>



6G White Paper: Research Challenges for Trust, Security and Privacy



- **Trust:** 6G network must support embedded trust for increased level of information security. Trust modeling, trust policies and trust mechanisms need to be defined.
- **Security:** The role of IT and networks in security keeps rising. We need holistic 6G network security architecture planning. Machine learning can be used to make safer systems but enables dangerous attacks. Physical layer security techniques can represent efficient solutions.
- **Privacy:** There is currently no means to determine when linked, deidentified datasets cross the threshold of becoming personally identifiable. Courts are making decisions about whether privacy is being infringed without formal measures of the level of personal information, while companies seek new ways to exploit private data.

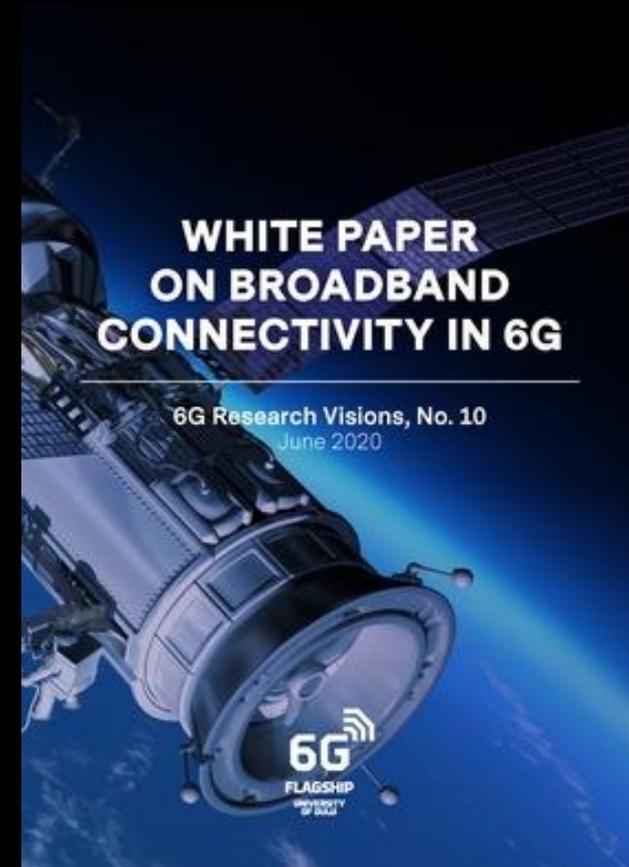


White Paper on Broadband Connectivity in 6G

HIGHLIGHTS:

- We expect ultra massive MIMO to be realized with fully digital arrays and holographic radio to enable ultra-high density and ultra-high resolution spatial multiplexing.
- We expect user-centric and scalable cell-free networking to enable the densification of network infrastructure with access points in 6G.
- We expect THz communications to provide high capacity point-to-point links complementing the wide area coverage at lower frequencies.
- We believe that intelligent reflecting surfaces (IRS) will be integrated to wireless systems to create a smart, programmable, and controllable wireless propagation environment.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-broadband-connectivity-6g/>



White Paper on Broadband Connectivity in 6G



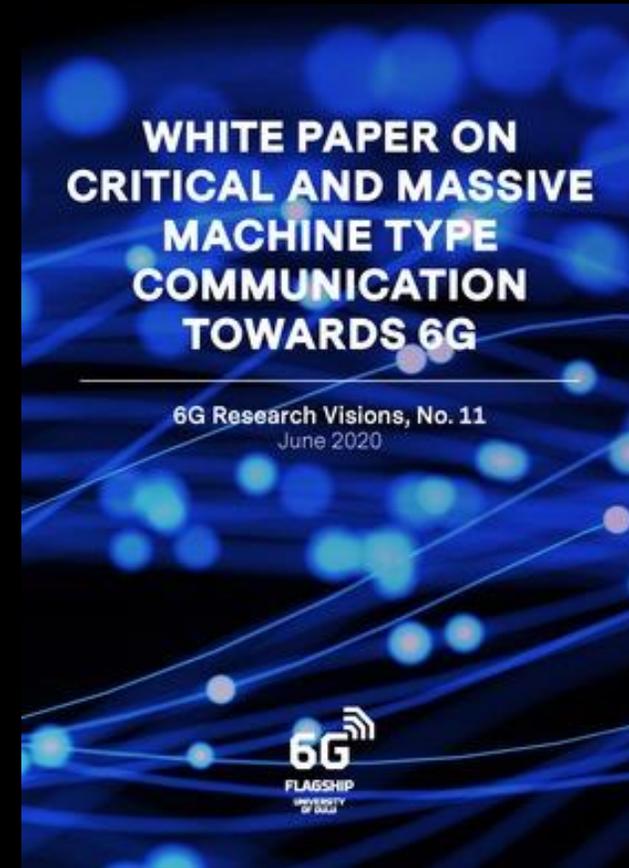
Summary of key open problems		
Challenges	Potential 6G solutions	Open research topics
Stable service quality in coverage area	User-centric cell-free massive MIMO	Scalable synchronization, control, and resource allocation
Coverage improvements	Integration of a spaceborne layer, ultra-massive MIMO from tall towers, intelligent reflecting surfaces	Joint control of space and ground-based APs, real-time control of IRS
Extremely wide bandwidths	Sub-THz, VLC	Hardware development and mitigation of impairments
Reduced latency	Faster forward error correcting schemes, wider bandwidths	Efficient encoding and decoding algorithms
Efficient spectrum utilization	Ultra-massive MIMO, waveform adaptation, interference cancellation	Holographic radio, use-case-based waveforms, full-duplex, rate-splitting
Efficient backhaul infrastructure	Integrated access and backhauling	Dynamic resource allocation framework using space and frequency domains
Smart radio environment	Intelligent reflecting surfaces	Channel estimation, hardware development, remote control
Energy efficiency	Cell-free massive MIMO, suitable modulation techniques	Novel modulation methods with limited hardware complexity
Modeling or algorithmic deficiencies in complex and dynamic scenarios	ML-/AI-based model-free, data-driven learning and optimization techniques	End-to-end learning/joint optimization, unsupervised learning for radio resource management

White Paper on Critical and Massive Machine Type Communication towards 6G

HIGHLIGHTS:

- We present the main drivers, potential use cases, key requirements and new service classes pertinent to machine type communication (MTC) in 6G networks.
- We provide a bird's eye view of a holistic end-to-end MTC network architecture.
- We discuss the challenges and potential 6G enablers of ultra-low power, massive and critical MTC.
- We touch upon privacy, security and trust concerns in an MTC optimized 6G network.

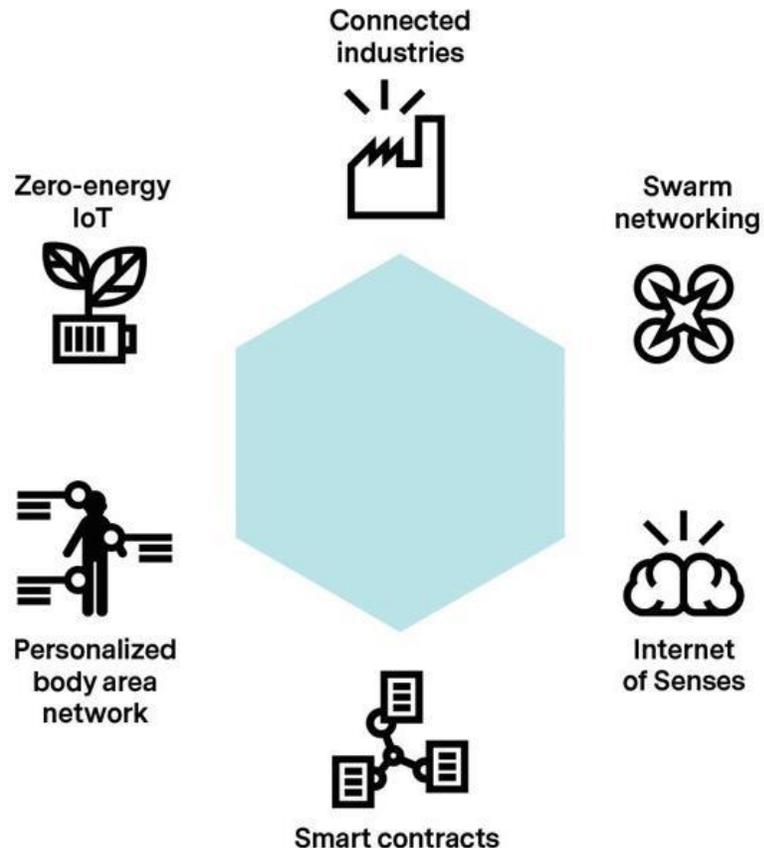
<https://www.6gchannel.com/portfolio-posts/6g-white-paper-critical-massive-type-communication/>



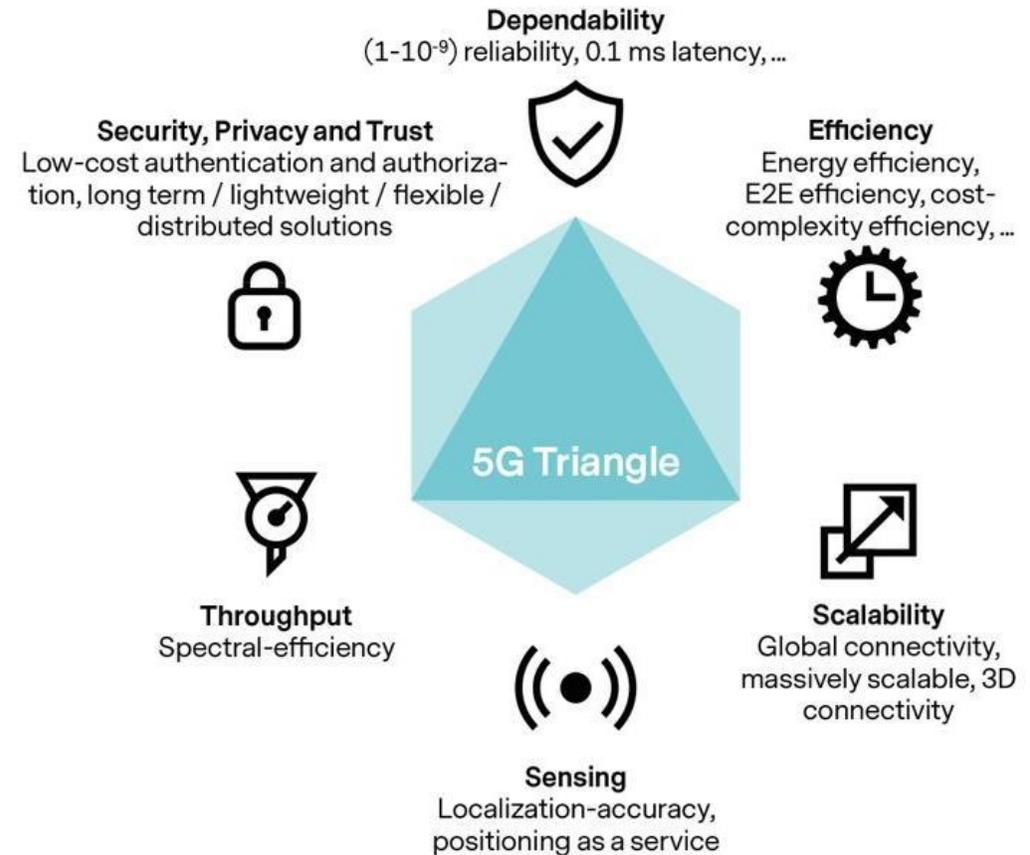
White Paper on Critical and Massive Machine Type Communication towards 6G



Selected Use Cases



Requirements

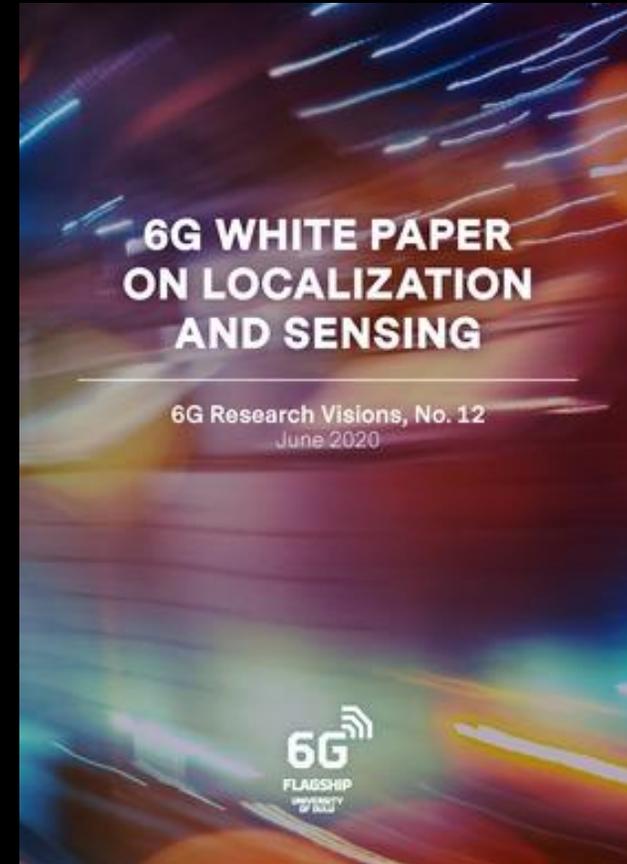


6G White Paper on Localization and Sensing

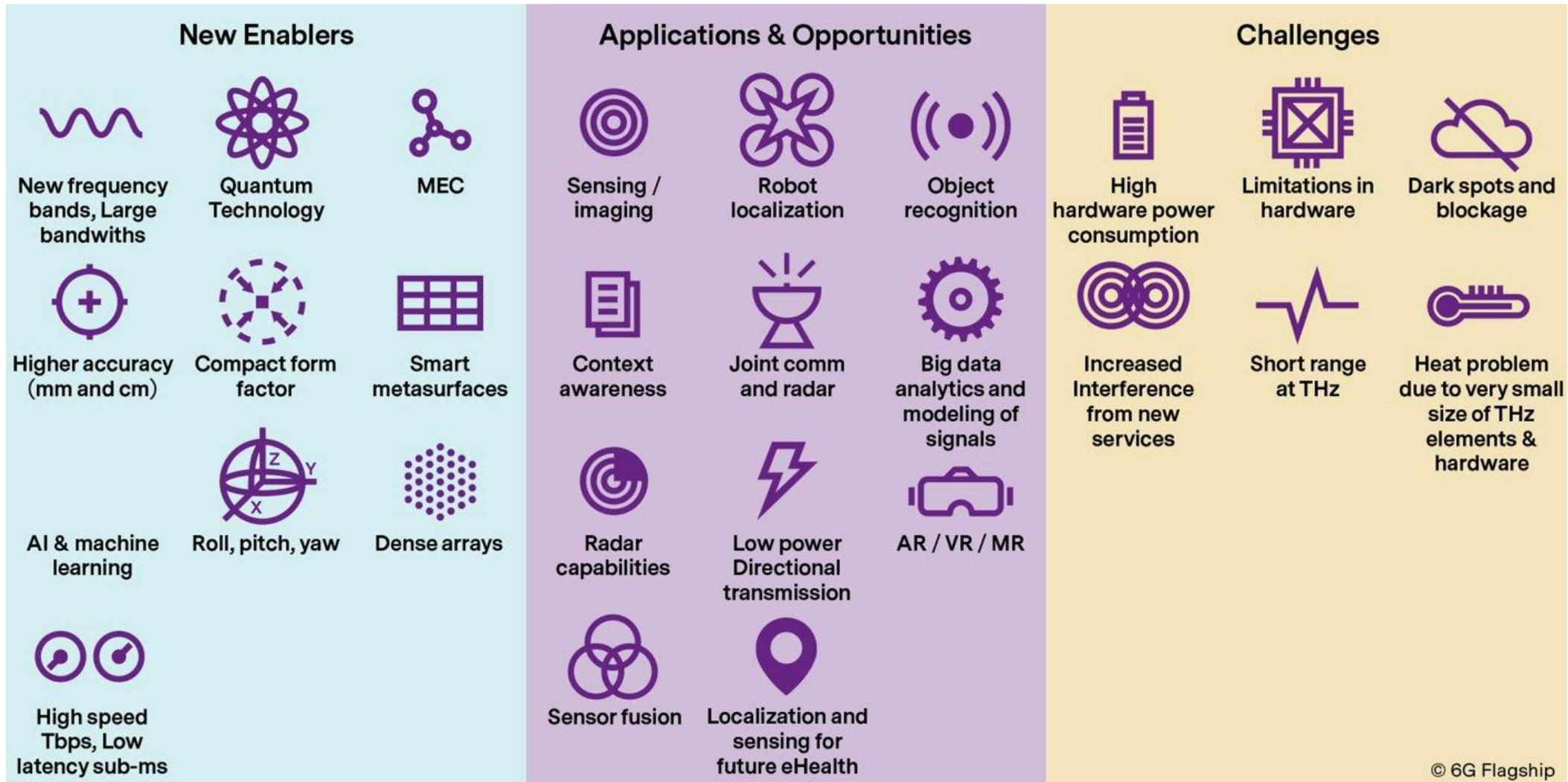
HIGHLIGHTS:

- We identify potential enabling technologies and main features for localization and sensing, assess new opportunities of the environment-aware applications, recommend latest trends on and pose key research questions.
- We expect 6G systems to be intelligent context-aware networks exploiting built-in localization and sensing features to enhance communication with no or limited human intervention.
- We expect 6G systems to achieve high-accuracy positioning and high-resolution sensing/imaging enabling autonomous navigation and advanced XR applications with rich and accurate virtual imagery of the environment.

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-localization-sensing/>



6G White Paper on Localization and Sensing



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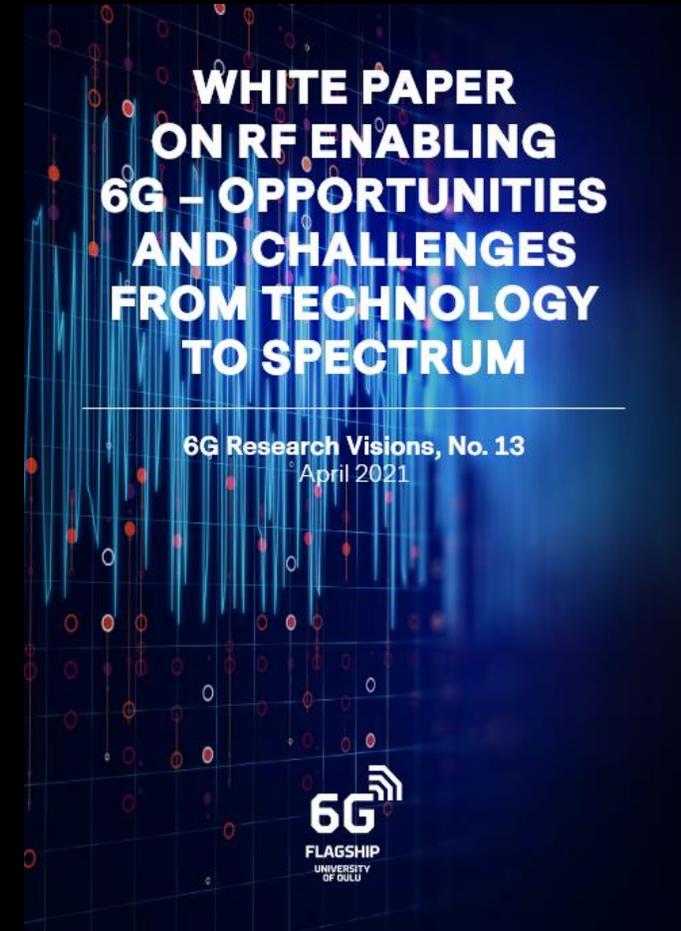
<https://www.6gchannel.com/portfolio-posts/6g-white-paper-localization-sensing/>

6G White Paper on Localization and Sensing

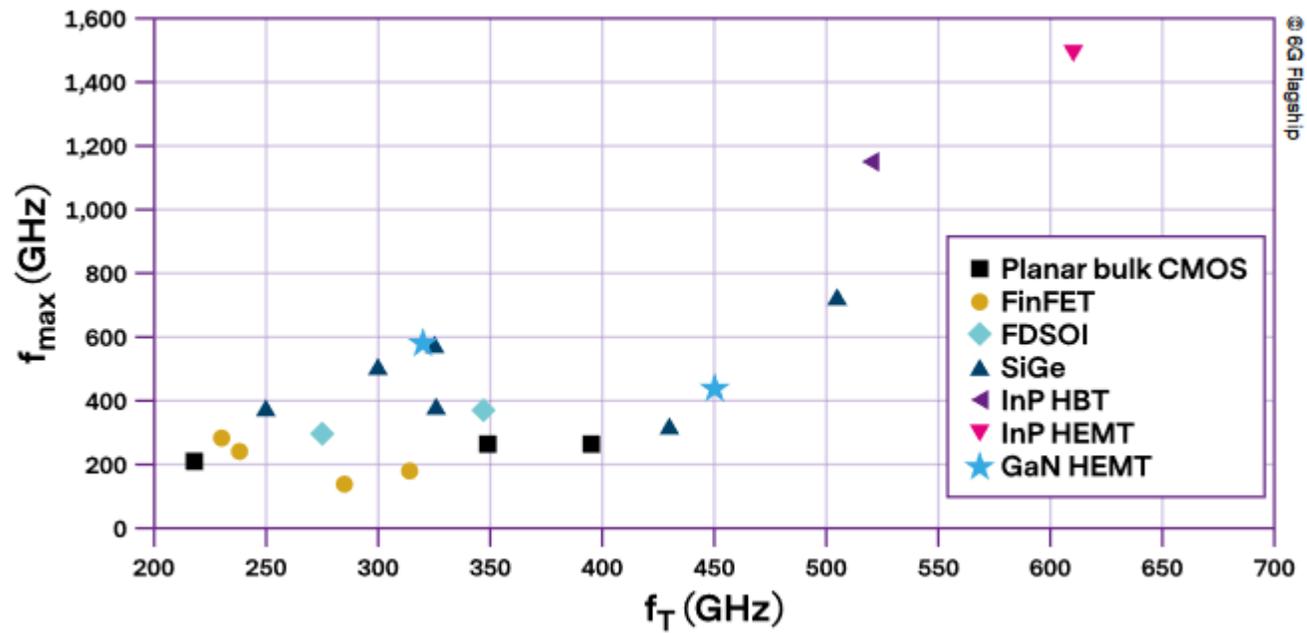
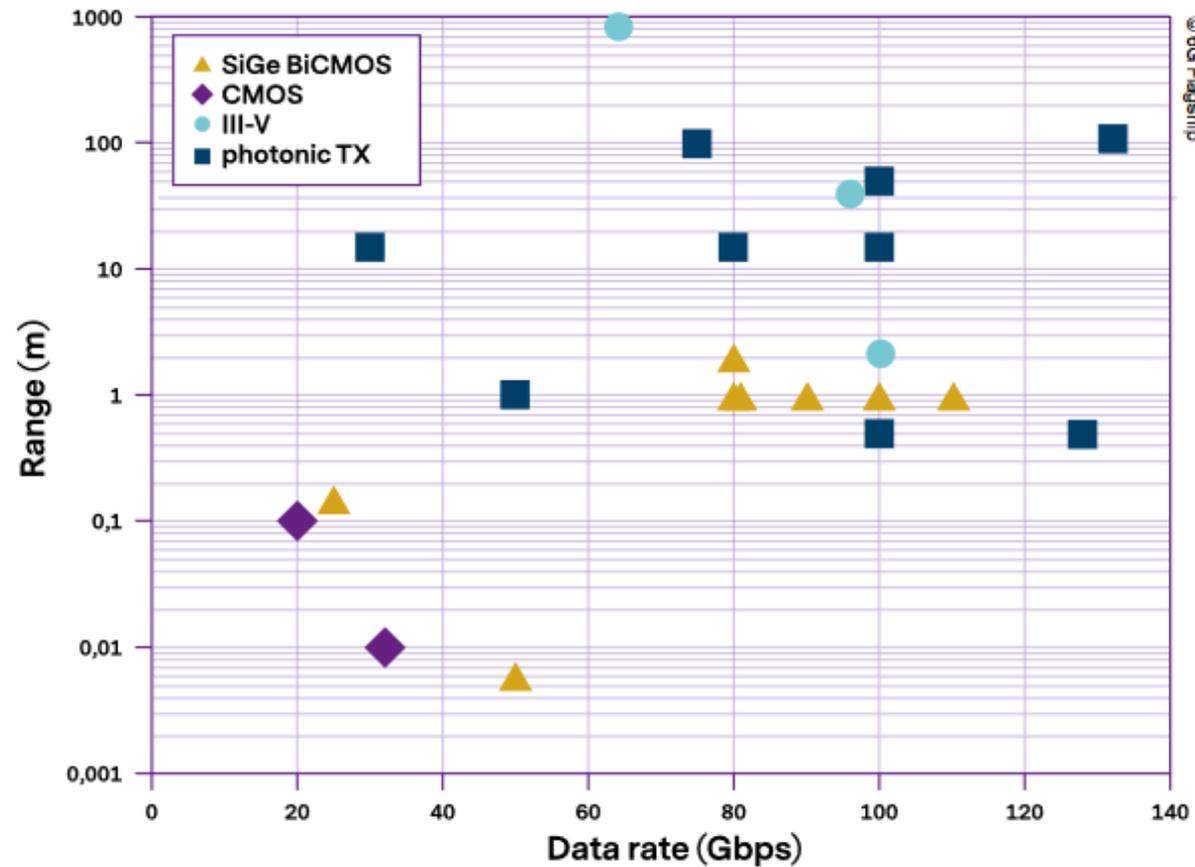
HIGHLIGHTS:

- Capability to generate power with current semiconductor materials is getting worse at high frequencies → New semiconductor materials
- New physical phenomena → new circuit designs
- New materials and circuits → new manufacturing processes

<https://www.6gchannel.com/portfolio-posts/6g-white-paper-localization-sensing/>



6G White Paper 6G Enabling RF



Thank you!



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