Roadmap for future communication technology in low carbon and smart mobility: from 5G to 6G

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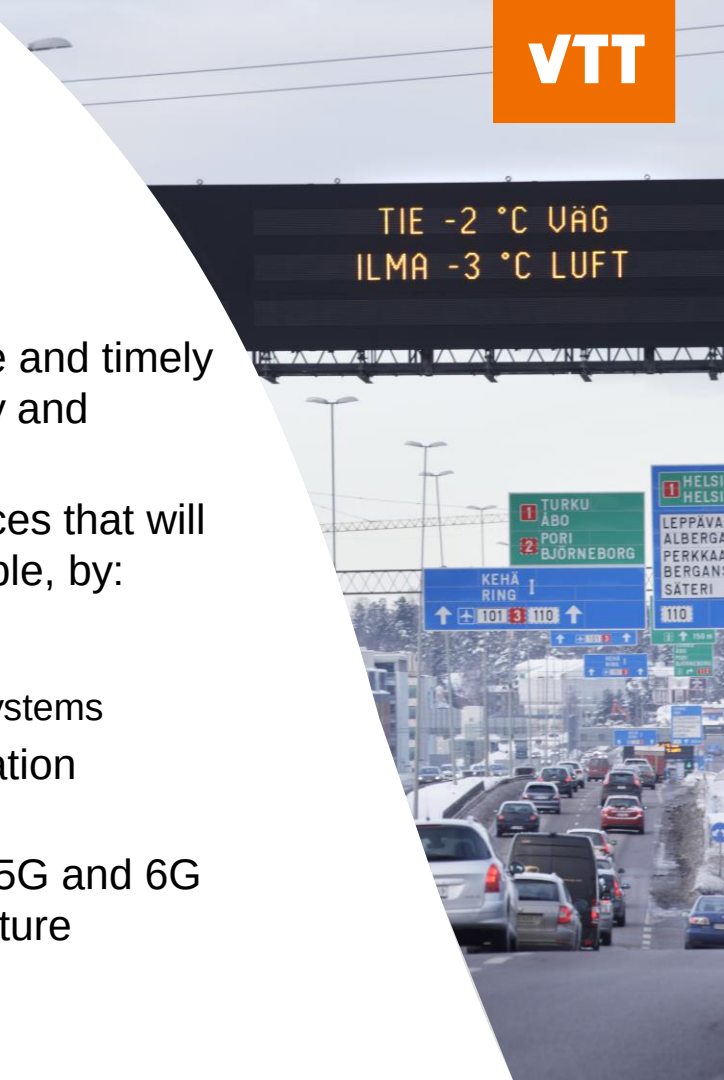
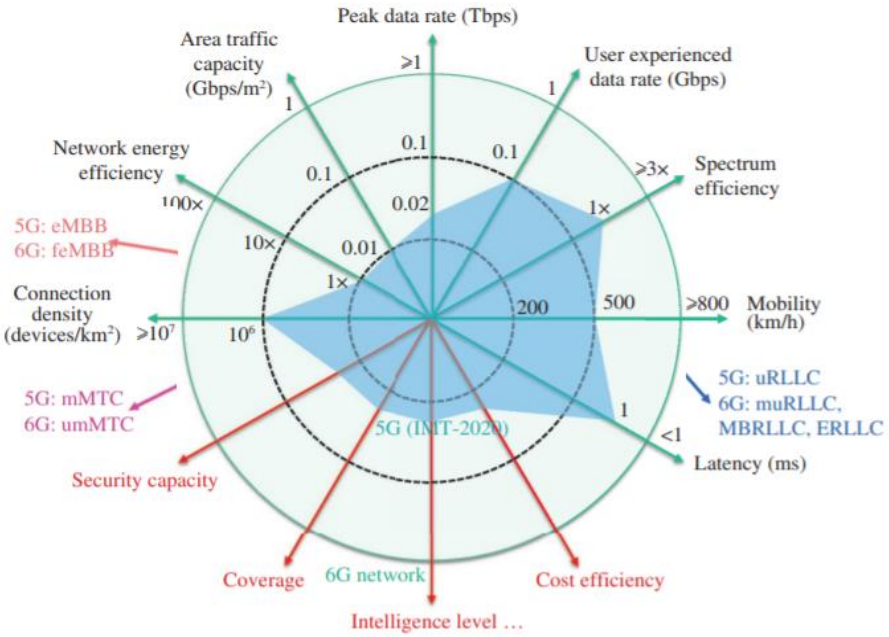
Background and motivation



- Future communication networks will enable extensive and timely data collection and processing for automated mobility and transport systems in a massive scale
- This will allow creating new automated mobility services that will bring benefits for the society and business, for example, by:
  - Improving safety
  - Achieving more efficient transport of people and goods
  - Improving the sustainability of the mobility and transport systems
- Currently, the research on future wireless communication networks is moving from 5G towards 6G
- VTT has studied what new opportunities the beyond 5G and 6G research will bring to smart mobility systems in the future

Current 6G visions and objectives

Foreseen performance metrics of 6G communication networks



Feature/metric	4G	5G	6G
Per device peak data rate	1 Gbps	10 Gbps	1 Tbps
End-to-end latency	>100 ms	>10 ms	>1 ms
Maximum spectral efficiency	15 bps/Hz	30 bps/Hz	100 bps/Hz
Mobility support [km/h]	Up to 350	Up to 500	Up to 1000
Satellite integration	No	Partial	Fully
AI	No	Partial	Fully
Haptic communication	No	Partial	Fully
THz communication	No	Very limited	Widely
Architecture	MIMO	Massive MIMO	Intelligent surface
Service level	Video	VR, AR	Tactile
Maximum frequency	6 GHz	90 GHz	10 THz

Sources:

- X. You, et al.: "Towards 6G wireless communication networks: vision, enabling technologies, and new paradigm shifts," Science China Information Sciences, 64, 110301, 2021.
- M. Chowdhury, et al.: "6G Wireless Communication Systems: Applications, Requirements, Technologies, Challenges, and Research Directions," IEEE Open Journal of the Communications Society, 1-1., 2020.

Technology enablers and areas of 6G research

TeraHerz and visible light communication (VLC) for extremely high data rates (Tbps)	Cell-free communication, multiple access (Massive MIMO, NOMA)	Reconfigurable Intelligent Surface (RIS) and metasurfaces	3D dynamic hybrid networks for global seamless ubiquitous coverage (ground, aerial, space, underwater)
Virtualization and softwarization	AI/ML and data fusion for intelligent networks/radio, cybersecurity and end-user applications	Edge computing for distributed intelligence and optimized local services	Integrated localization, sensing and communication
Cybersecurity	Tactile/haptic technologies/internet	Quantum computing and communication	Digital/cyber twins and simulations of complex 3D networks

Sustainability as a key driver for 6G

- Climate change is a threat to humanity and requires that all human activities become more sustainable
- Sustainability will be also a key part of 6G development to reduce the environmental impact of expanding communication networks
- Further savings are expected from indirect and systemic impacts of 6G-enabled use cases, if rebound effects can be avoided
- Yet, sustainability, as defined in UN SDGs and the European Green Deal, may also have conflicting goals
  - It aims to lower environmental impacts, but also to improve fairness and equality in the society

Green in ICT:
ICT becomes more sustainable through new technologies close to zero-watt loads, energy harvesting and increased use of renewable energy

Green by ICT:
Use of ICT increases sustainability and energy efficiency in other sectors by applying data-driven optimization and information exchange between previously unconnected devices

Vision of 6G-enabled smart mobility

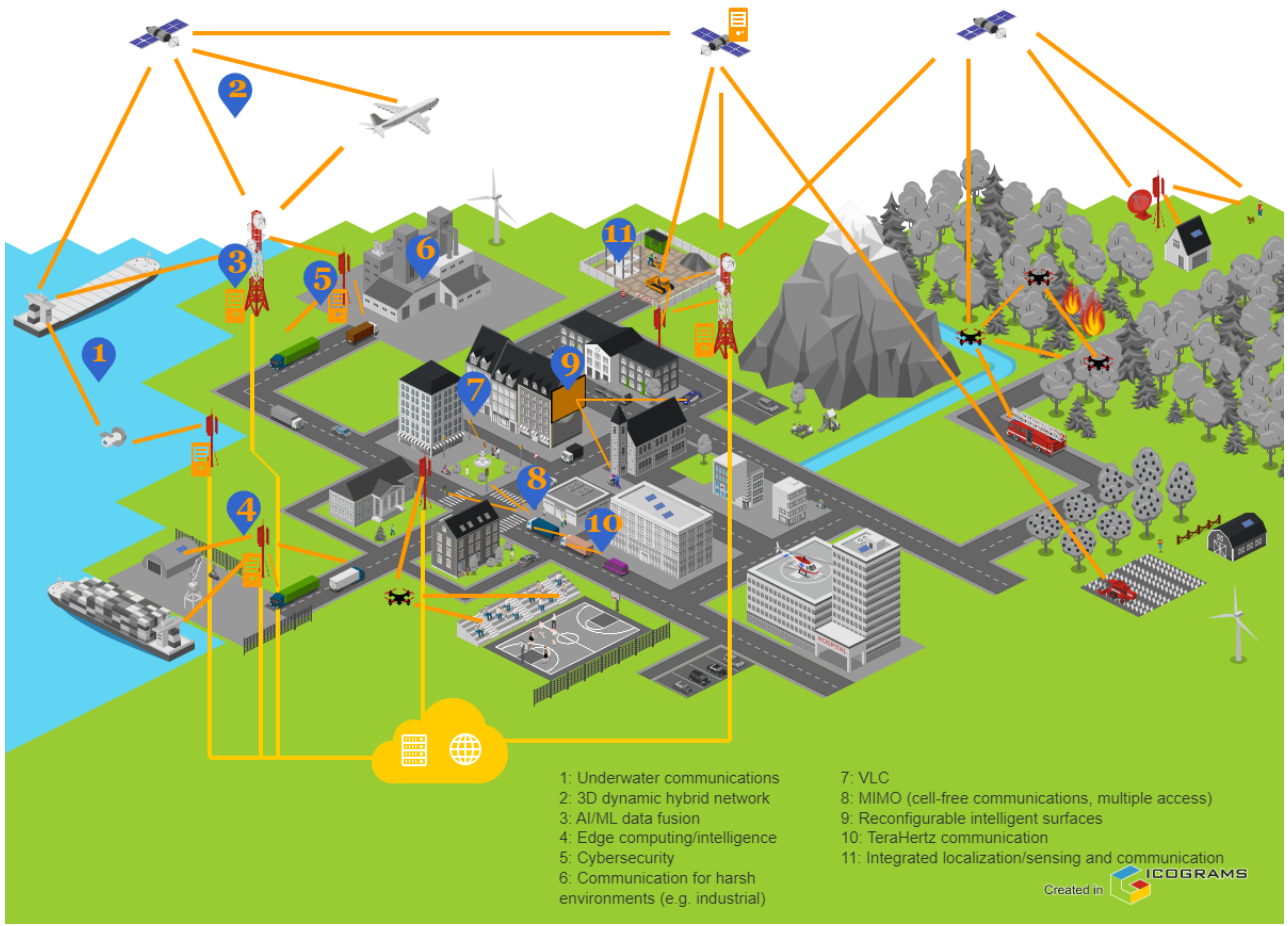


Figure created in:
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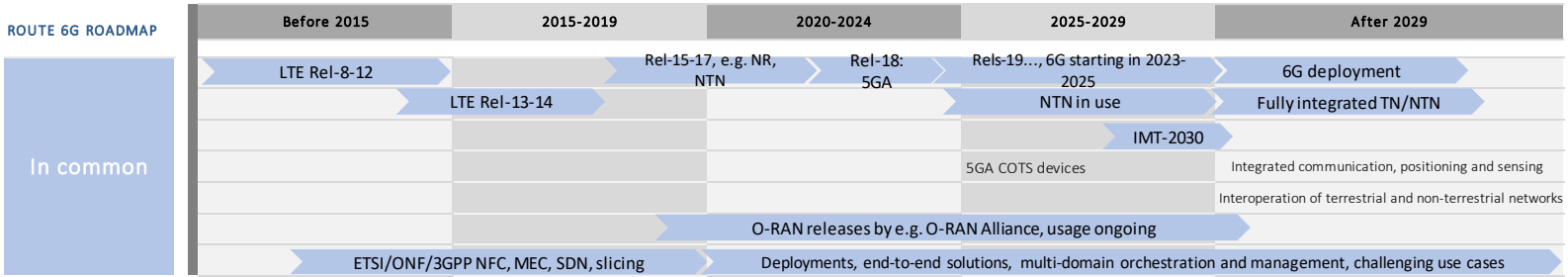
Communication technology roadmaps for smart mobility solutions towards 6G

Approach

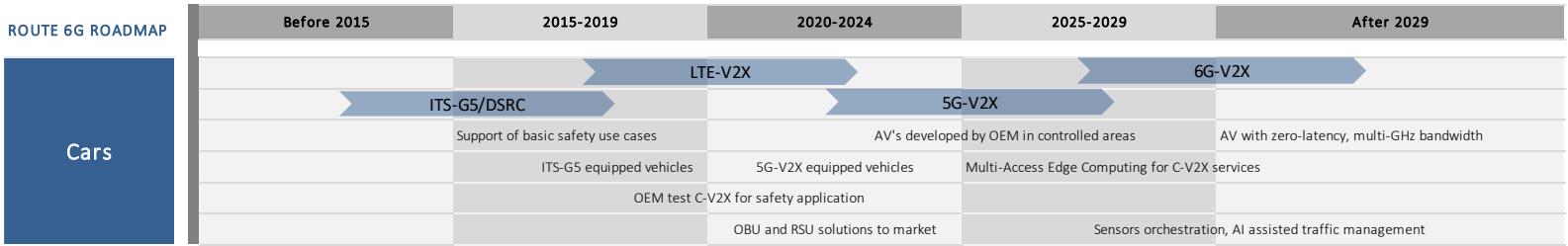
- We analyzed three areas of mobility and transport, namely **vehicles, ships, and drones**, for their state-of-the-art connectivity solutions and current visions towards 6G as well as benefits to sustainability
- As a result, we were able to draft communication technology roadmaps for the transport modes, each with specific requirements, but having also a lot of commonalities (e.g., high-capacity uplink, NTN, data-driven network optimization by ML/AI, and edge computing)



NR - New Radio, TN - Terrestrial Network, NTN - Non-Terrestrial Network, 5GA - 5G-Advanced

Cooperative, connected and automated driving (CCAM)

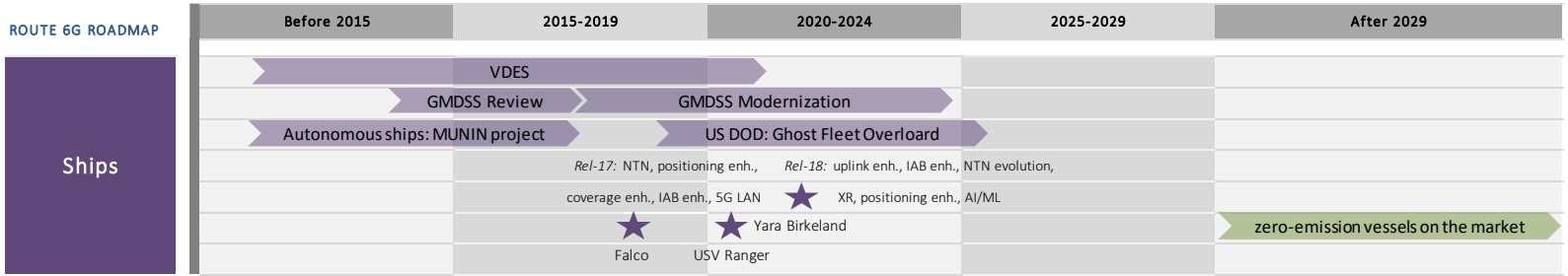
- Current networks can support a significant number of vehicles but are limited in providing enough capacity and low enough latencies for automated vehicles in high-density scenarios. Also, the support for edge computing is limited.
- The next-generation network needs to support the growing number of autonomous vehicles along with new emerging services
- Especially, more capacity, integration of distributed intelligence, energy efficiency (EE), and coverage needs to be pushed forward



AV - Autonomous Vehicles / OBU - On board unit / RSU - Road side unit

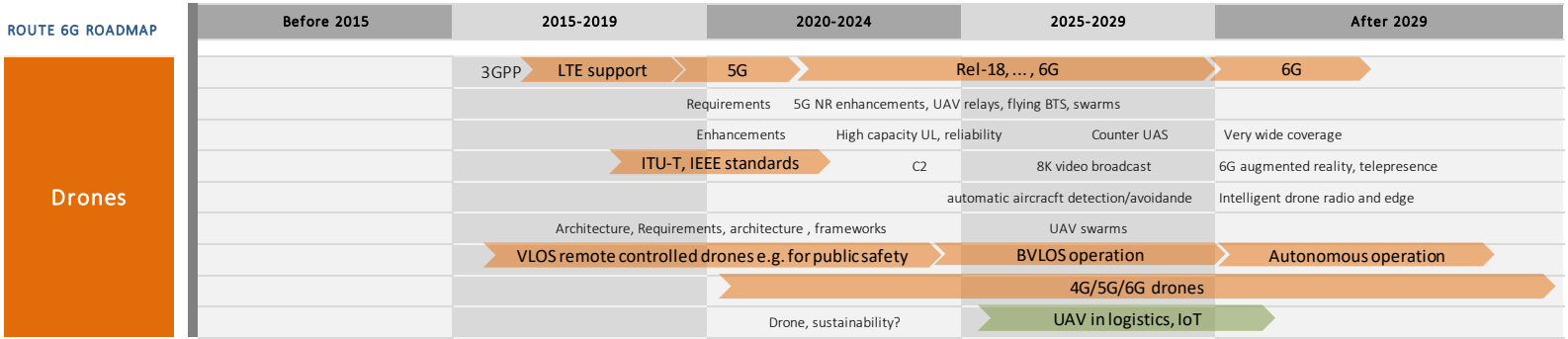
Autonomous ships

- Remote controlled and autonomous ships have direct benefit on ship design, operational costs, and safety
- Integrating shipping and inland navigation into seamless port and logistics operations is crucial to optimize the whole supply chain. Here, interoperability of maritime communication systems between countries is a challenge.
- Extending the terrestrial networks with satellite-enabled communication will be essential for the autonomous ship solutions. Also, new wireless technology is needed to reduce the amount of cabling inside ships or retrofitting older ships.



Drones and unmanned aerial vehicles (UAV)

- There is an increasing demand for aerial enabled and supported connectivity as drones/UAVs simplify the role of humans in various operations
- However, current networks are not fully optimized for flying objects:
  - Signal strength can vary or drop significantly in higher altitudes
  - Drone communication may suffer from as well as cause interference issues
- Future aerial networks' design should consider, e.g., different mobility patterns, traffic characteristics, available resources, and load balancing. It is also essential to have multiple routes for fault tolerance and reliability, as well as solutions for connecting drones/UAVs dynamically to swarms and 3D networks.



Sustainability considerations and foreseen benefits of 6G

- ICT sector is and will be a major provider of solutions to climate and environmental issues of vehicles, ships, and drones
- Also, moving objects such as drones may play a role in improving sustainability in ICT itself (e.g., efficient and green mobile radio networks via an aerial dimension)
- There are many open research questions related to ICT, its use, and sustainability that need to be addressed in the coming years
- One key issue is the measurement of the environmental impact for the whole life cycle and how to develop the corresponding metrics to assess different proposed solutions. The rebound effects can be particularly detrimental, if not acknowledged.

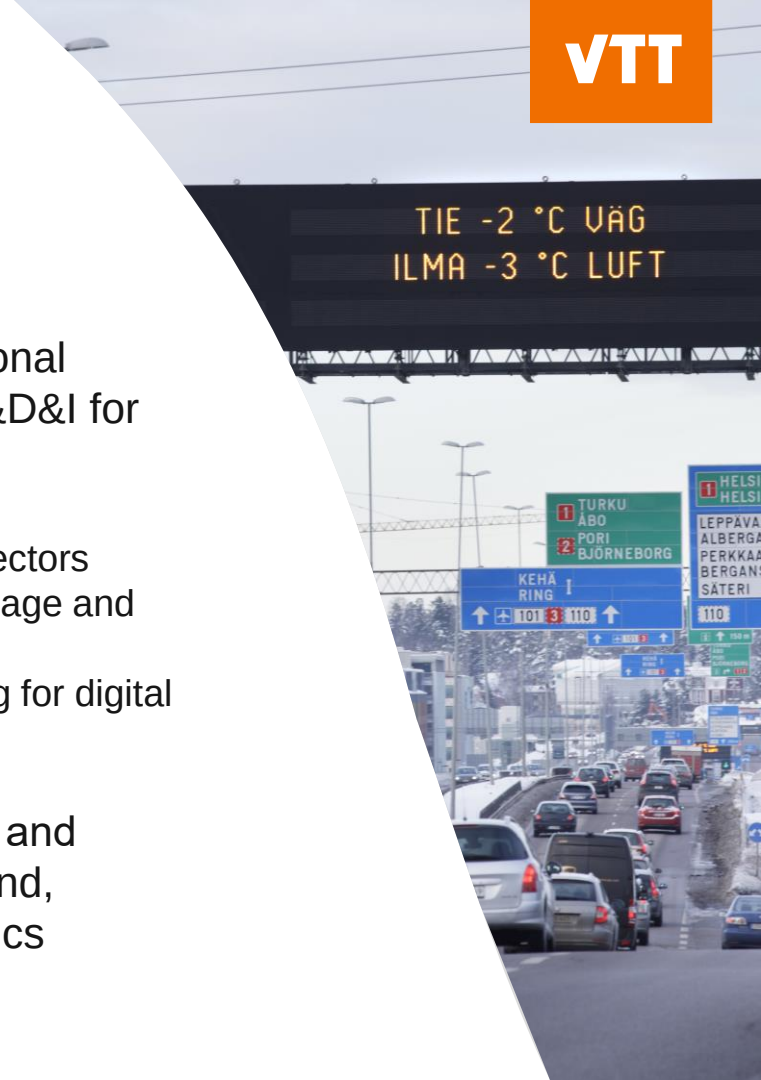
Conclusion and next steps

Conclusion

- There is a lot of R&D&I potential around the beyond 5G and 6G wireless network technologies for the mobility and transport vertical in order to address the limitations of the current technology as well as to identify and enable entirely new use cases
- Timing-wise, 6G research is currently gaining all the time a bigger momentum in key academia and industry globally. This is to be prepared for the starting of the 6G standardization around ~2025.
- VTT's extensive survey and roadmap on the future communication technologies for vehicles, ships and drones provided a good understanding on the current state-of-the-art as well as research questions to be addressed in the coming years

Next steps

- VTT would like to partner with Finnish and international organizations for beyond 5G and 6G technology R&D&I for the mobility and transport use cases
- We can offer:
  - Multidisciplinary expertise, including ICT and transport sectors
  - Studies, reviews and roadmaps regarding the visions, usage and benefits of the future communication technology
  - Wireless link, network, protocol and application modelling for digital twins and simulations
  - Research infrastructure for piloting and testing
- We’re currently looking for opportunities for funding and collaboration in EU, EUREKA, ESA, Business Finland, Academy of Finland, etc. projects around these topics



beyond
the obvious

Thank you!

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