国際融合科学論/先端融合科学論

LECTURE 01

Introduction to B5G and 6G mobile communication

Dr. Suyong Eum

OSAKA UNIVERSITY

Five Lectures

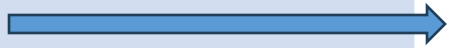
Title of each lecture	Time	Location
❑ **Introduction to B5G and 6G mobile communication** - Lecture on overview of B5G and 6G	June 26 (Thursday) : 10:30 – 12:00,	A棟1F A110: Graduate School of Information Science and Technology
❑ **Machine Learning I: conventional machine learning** - Lecture on SVM and PCA	July 3 (Thursday) : 10:30 – 12:00,	
❑ **Machine Learning II: modern style machine learning** - Lecture on Deep Neural Networks (DNNs)	July 10 (Thursday) : 10:30 – 12:00,	
❑ **Quantum Mechanics I: Introduction to Quantum mechanics** - Lecture on Quantum mechanics: introductory level	July 17 (Thursday) : 10:30 – 12:00	
❑ **Quantum Mechanics II: Quantum Machine Learning** - Lecture on Quantum Machine Learning	July 24 (Thursday) : 10:30 – 12:00	

Three group assignments

Assignments	Relevant lecture	Deadline
Assignment 1.: How do the researches in our department relate to B5G / 6G?	❑ 1st lecture: Introduction to B5G and 6G mobile communication	July 2 (Wednesday) : 09:00, July 3 (Thursday) : during class - reporting
Assignment 2.:	❑ 2nd lecture: Machine Learning I: conventional machine learning	
	❑ 3rd lecture: Machine Learning II: modern style machine learning	
Assignment 3.:	❑ 4th lecture: Quantum Mechanics I: Introduction to Quantum mechanics	
	❑ 5th lecture: Quantum Mechanics II: Quantum Machine Learning (QML)	

- ❑ All the details for each assignment will be posted in the web.
- ❑ Please, keep the deadline !!

Tentative class schedule

	Class one (6/26)	Class two (7/3)	Class three (7/10)	Class four (7/17)	Class five (7/24)
Assign. 1	▪ Assign. 1 release ▪ Interviewing the group members	▪ Introduction to your members.			
Assign. 2		▪ Assign. 2 release ▪ Discussion about the assignment	▪ Oral update on progress, e.g., each member's role, etc.	▪ Oral updates on progress, e.g., contribution of each member…	• Full presentation (10 minutes)
Assign. 3				▪ Assign. 3 release ▪ Discussion about the assignment	

Seven Groups during the class!

Group1

1) Akagi Ryusei (Nonlinear Math science)
2) Jin Yuzhou (Big data)
3) Ueno Koichiro (Network Architecture)
4) Kondo Inase (Software Engineering)

Group2

1) Banba Gen (Nonlinear Math science)
2) Xu Zichuan (Big data)
3) Ito Aoi (Network Architecture)
4) Imai Fubuki (Computer vision)

Group3

1) Kiryu Kiryu (Nonlinear Math science)
2) Anderson Kaina (Big data)
3) Tanaka Haruki (Intelligent Networking systems)
4) Araki Ryuto (Machine learning)
5) Fujii Ryota (Computer vision)

Group4

1) Nakamura Jin (Nonlinear Math science)
2) Meng Siyuan (Intelligence and Sensing)
3) Hada Ryotaro (Intelligent Networking systems)
4) Ohto Haruto (Software design)

Group5

1) Yamasaki Aoto (System Mathematics)
2) Kojima Yutaka (Big data)
3) Onda Genta (Mobile computing)
4) Alizada Nigar (Software engineering)

Group6

1) Teruya Keigo (Dependability engineering)
2) Kuraya Genryu (Big data)
3) Az Zahrah Fitriana syafira (Precision Engineering)
4) Bai JingJIng (Machine learning)

Group7

1) Oda futa (Dependability engineering)
2) Miki Takaya (Big data)
3) Yamada Tatsuya (Machine learning)
4) Nalishuwa chama Joshua (Mobile computing)
5) Wang Yizi (Intelligent and sensing)

General information for these five lectures

- Lecture materials including slides, assignments, and some other information will be available in the web
  - www.suyongeum.com/B5G6G

- Individual questions or consultations can be sent to me directly
  - suyong@ist.osaka-u.ac.jp

- Marking scheme,
  - Purely based on assignments,
  - All assignments are group assignments.

Lecture Outline

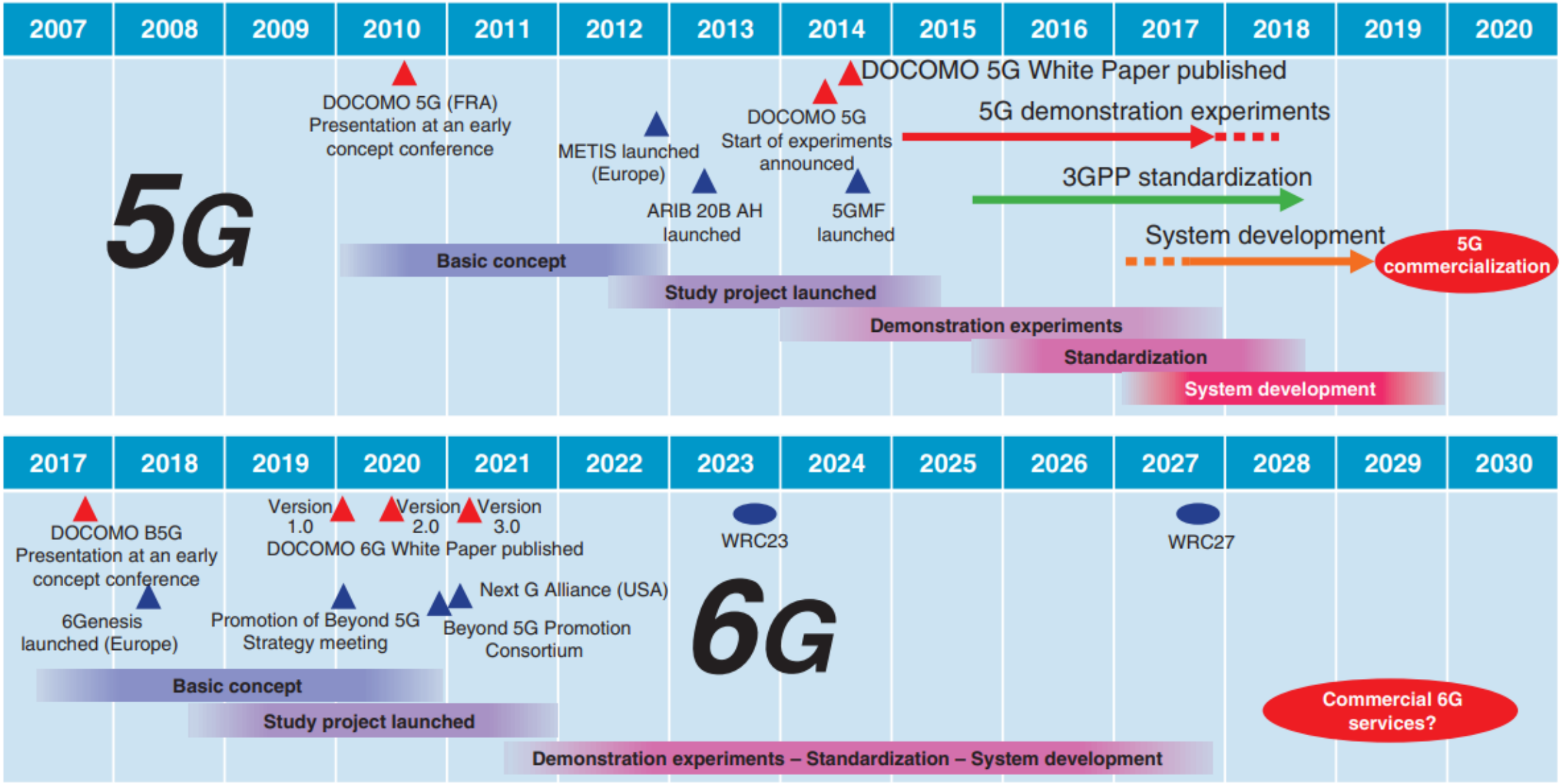
1) A brief history of mobile networks
2) The worlds that B5G/6G may bring by 2030
   - Based on five requirements for B5G/6G
3) B5G and 6G use cases
   - Digital twins
4) Two Key technologies that work with B5G/6G
   - AI/Machine learning
   - Quantum Computing

A brief history of mobile networks

A brief history of mobile networks

- 1G: 1980s, analog transmission limited to voice services,
- 2G: 1990s, introduction of digital transmission on the radio link: GSM, No compatibility,
- 3G: 2000s, enabling fast wireless internet access. iPhone: 2007! Youtube: 2006,
- 4G: 2010s, high efficiency, enhanced mobile-broadband experience.
- 5G: 2020s, no killer applications yet…

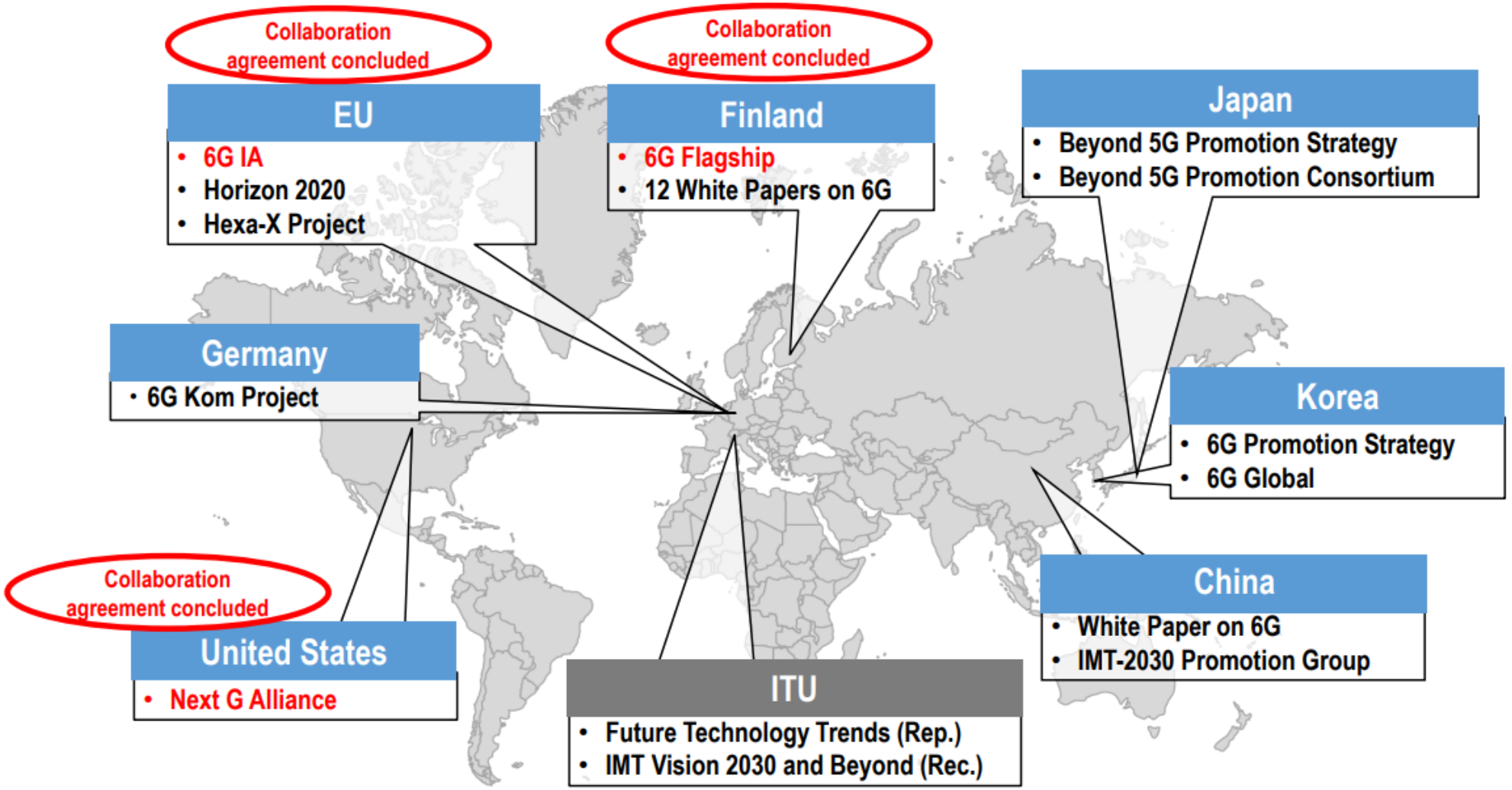
A brief history of mobile networks: B5G and 6G



Yoshihisa et al, Feature Articles: NTT DOCOMO's Initiatives on 5G evolution & 6G, 2021

A brief history of mobile networks: World efforts to realize B5G/6G

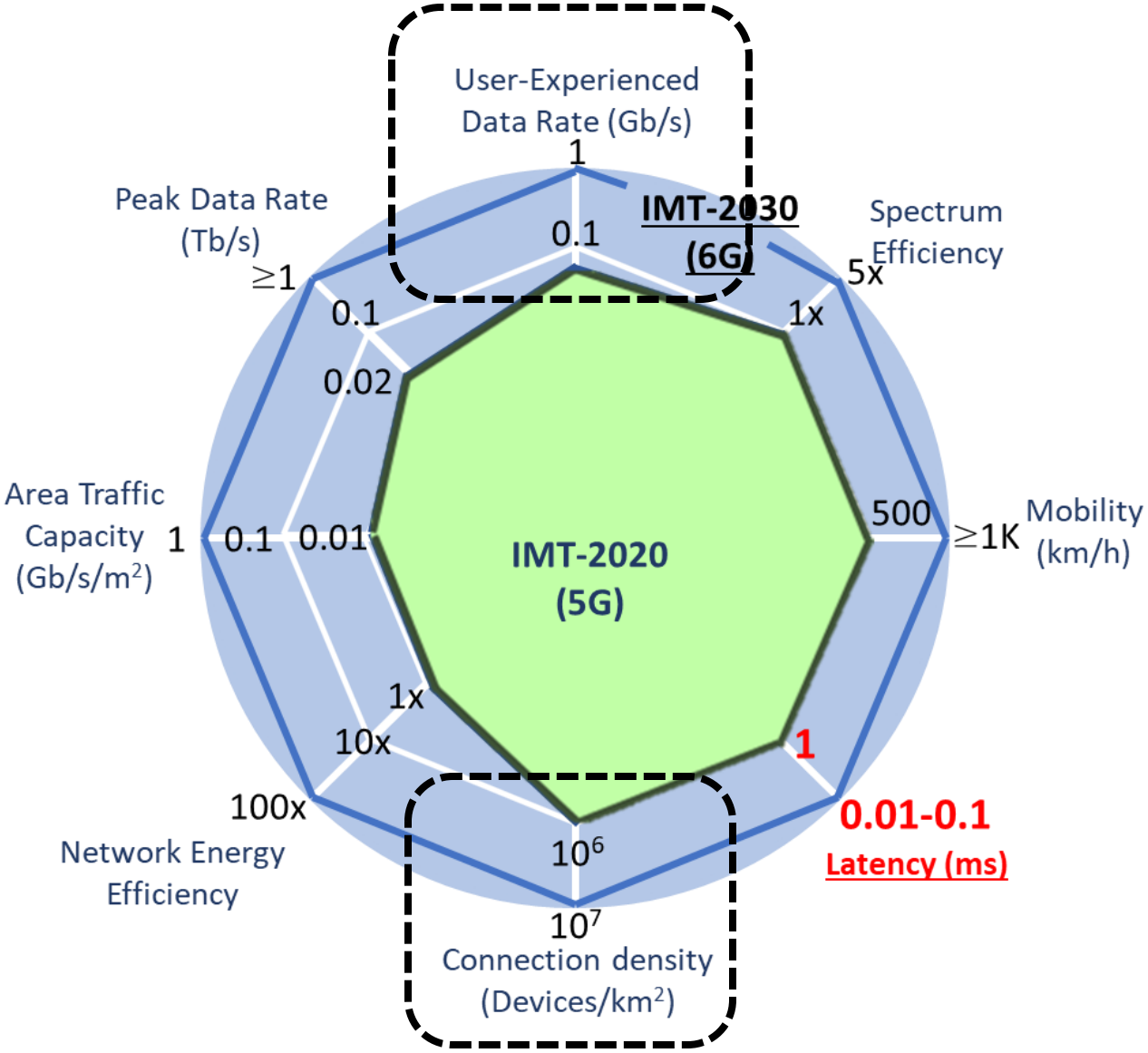
- Many countries have issued 6G white papers and have started to conduct R&D on 6G.
- ITU has started discussing standardization for IMT-2030 (Beyond 5G/6G).



https://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/presentation/pdf/Roadmap_for_the_Realization_of_Beyond_5G.pdf

A brief history of mobile networks: requirements for B5G and 6G

- ❑ Full coverage of the earth
- ❑ Extremely high-speed communication
- ❑ Extreme low latency
- ❑ High reliability
- ❑ Massive connectivity

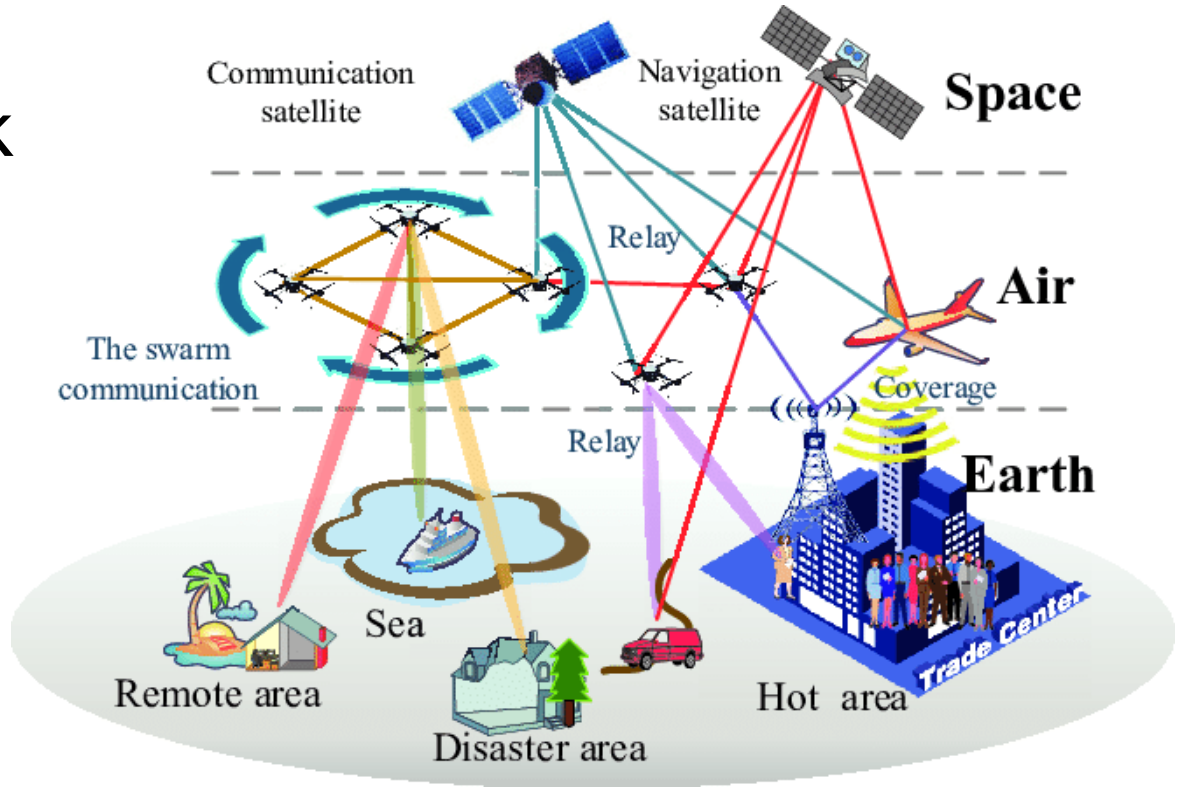


The worlds that B5G/6G may bring by 2030

Full coverage of the earth

Full coverage of the earth: what is this?

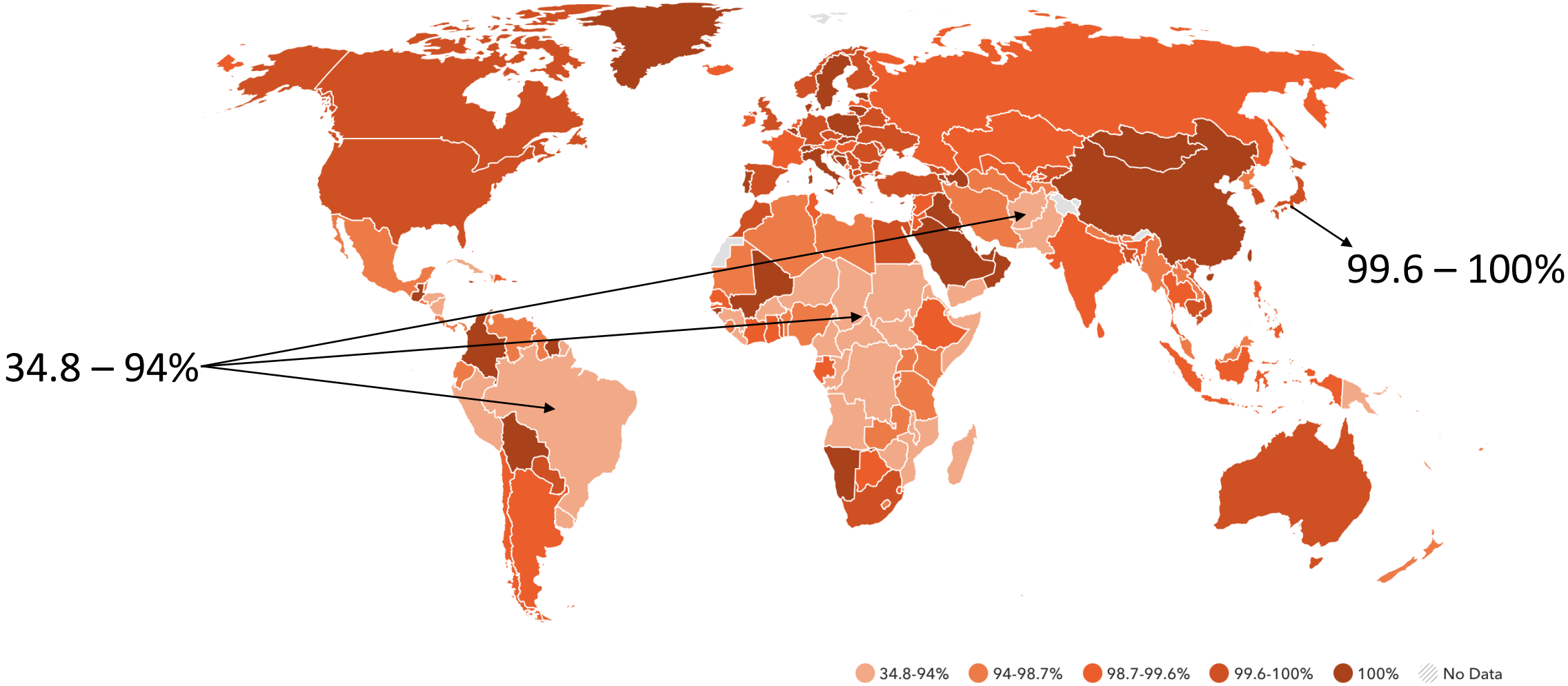
- Aims to provide full communication coverage all over the world.
- 6G will be the first mobile network that keeps people truly connected wherever we go.
- Promising applications
  - Logistics, agriculture, fisheries,
  - Flying cars, space travel, etc



J. Zhao etal, "Integrating Communications and Control for UAV Systems: Opportunities and Challenges," in *IEEE Access*, vol. 6, pp. 67519-67527, 2018

Full coverage of the earth: Regions using 2G or higher: 2024

- We are suffering from serious gaps in global connectivity.



https://datahub.itu.int/data/?i=100095&e=701

Full coverage of the earth: Connectivity of the earth in 2021?

https://www.youtube.com/watch?v=_DcjXYla9bY

Full coverage of the earth: StarLink and SpaceX

TESLA

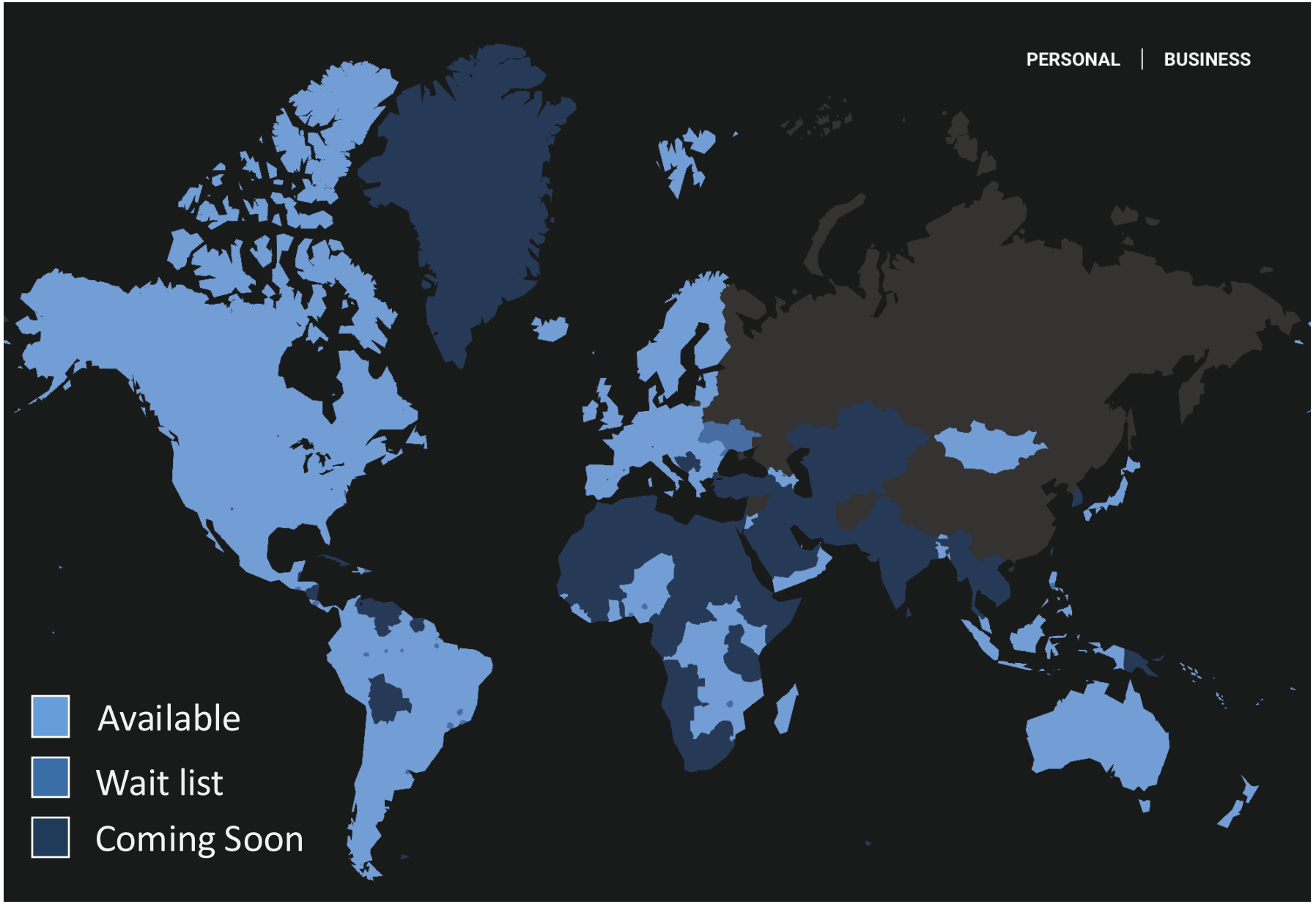
NEURALINK

XAI

STARLINK

SPACEX

Full coverage of the earth: How much it covers in 2025



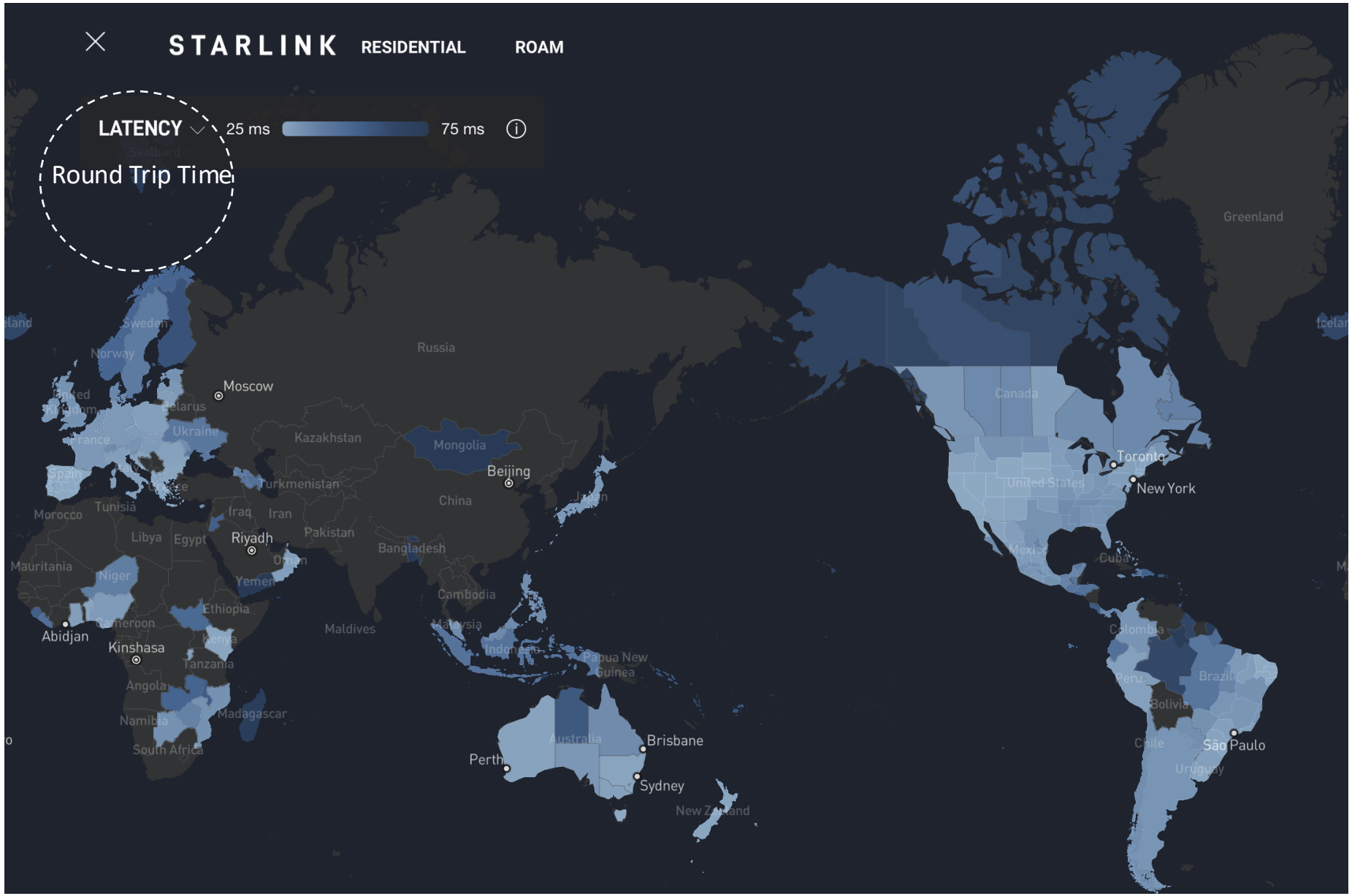
https://www.starlink.com/map

Full coverage of the earth: How much it covers in 2025

SERVICE PLAN	RESIDENTIAL LITE (FIXED)	RESIDENTIAL (FIXED)	ROAM 10GB or 50GB and PAUSE (MOBILITY)	ROAM UNLIMITED (MOBILITY)	PRIORITY
AVAILABILITY	≥99%	≥99%	≥99%	≥99%	≥99%
DOWNLOAD	45-130 Mbps	*Click For Download Speeds* 150 Mbps	45-230 Mbps	45-230 Mbps	100-280 Mbps
UPLOAD	11-26 Mbps	*Click For Upload Speeds* 25 Mbps	10-25 Mbps	10-25 Mbps	14-30 Mbps

https://www.starlink.com/legal/documents/DOC-1470-99699-90?regionCode=JP

Full coverage of the earth: How much it covers in 2025



https://www.starlink.com/legal/documents/DOC-1470-99699-90?regionCode=JP

Full coverage of the earth: How many they plan to launch?

NIKKEI Asia

July 16, 2023

Elon Musk dominates orbit with Starlink satellites

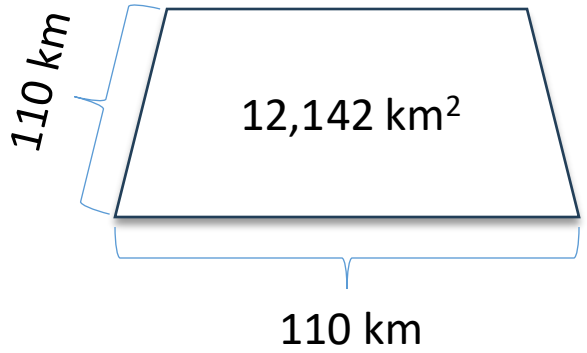
Harvard-Smithsonian Center for Astrophysics. SpaceX has sent nearly 5,000 satellites to space since 2019 and has applied for permission to operate a total of 42,000. It has few competitors; its Big Tech rival Amazon plans to launch a prototype satellite later this year.

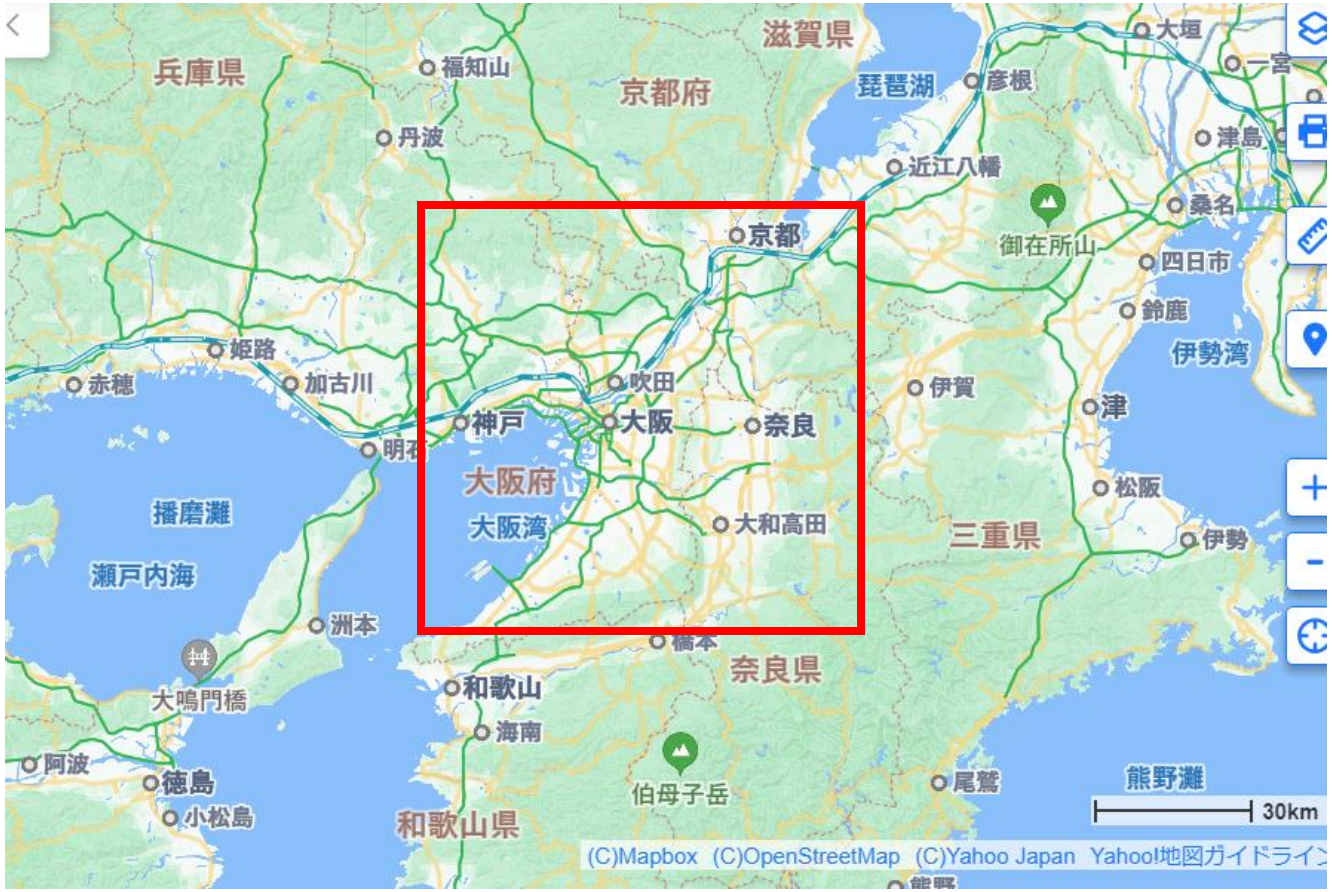
- ❑ Between Feb. 2018 and May 2024, SpaceX launched over 6,000 Starlink satellites.
- ❑ In 2024 alone, over 1300 satellites were launched.
- ❑ These satellites account for 65% of all active satellites.

https://asia.nikkei.com/Spotlight/Datawatch/Elon-Musk-dominates-orbit-with-Starlink-satellites#:~:text=SpaceX%20has%20sent%20nearly%205%2C000,operate%20a%20total%20of%2042%2C000.
https://oneworldrental.com/blog/how-many-starlink-satellites-are-in-orbit-in-2025/

Full coverage of the earth: 42,000 satellites?

- Earth
  - Radius (r): 6300 km
  - Surface area ($4\pi r^2$): 510 million km^2
- 42,000 satellites??



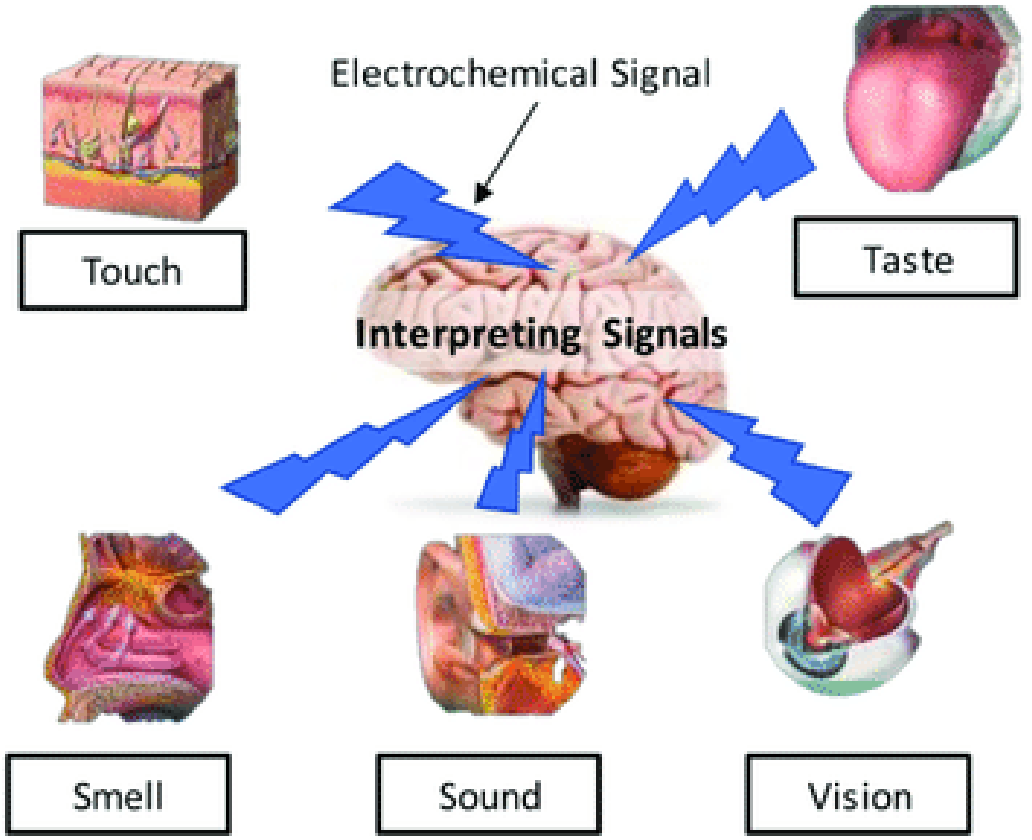


https://spacenews.com/fcc-grants-partial-approval-for-starlink-second-generation-constellation/

Extreme High-speed Communication

Extremely High-speed communication

- Aims to achieve extremely high-speed communication and ultra-large communication capacity.
- Multi-sensory communication …
  - Not only visual information but also sensory communication that engages all five senses will be possible.

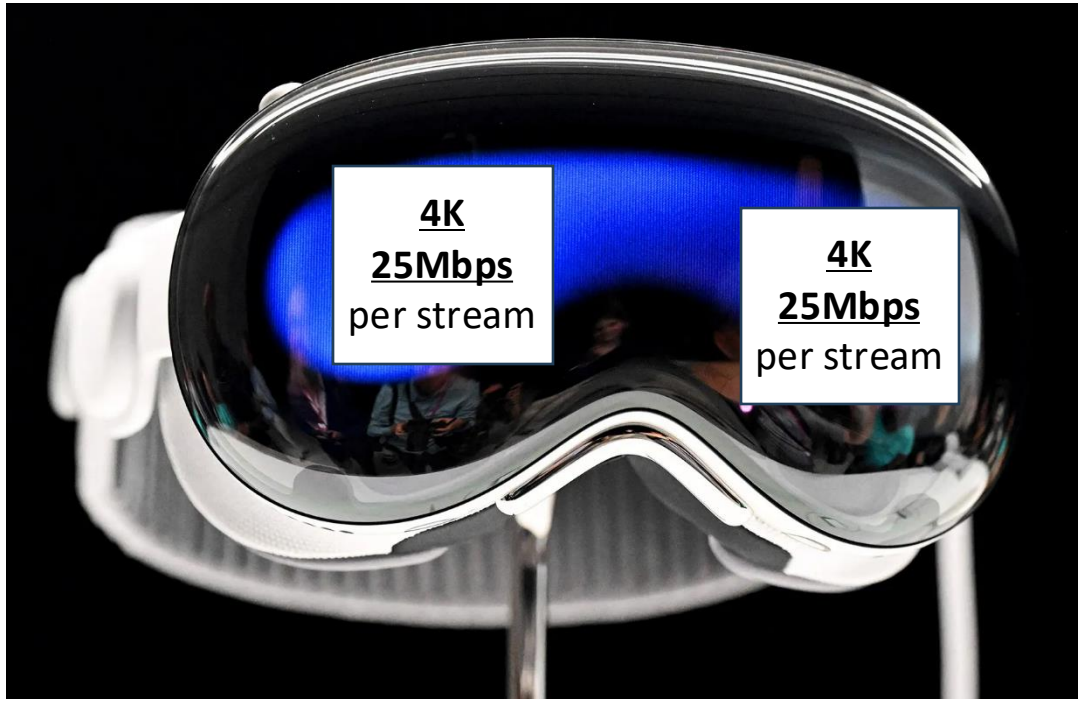


https://www.researchgate.net/publication/324594818_An_Embedded_Sensory_System_for_Worker_Safety_Prototype_Development_and_Evaluation

Extremely High-speed communication: How fast we need?

June 5. 2023

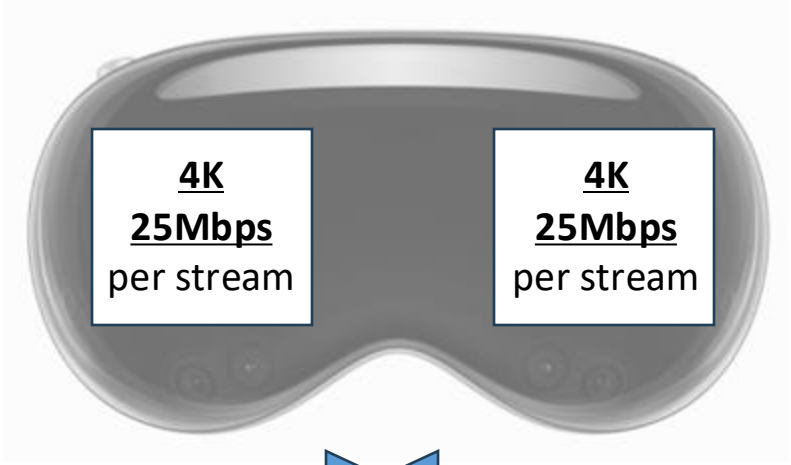
Introducing Apple Vision Pro: Apple's first spatial computer



https://www.youtube.com/watch?v=TX9qSaGXFyg

- Apple introduced a new product called "Vision Pro" for the first time in a nearly decade.
- Its specification says
  - "Vision Pro" has 23 million pixels across two panels that are each just the size of a postage stamp. That is more pixels than a 4K TV for each eye."
- 4K requires about 25Mbps/stream according to Disney+

Extremely High-speed communication: How fast we need?



https://www.anker.com/blogs/hubs-and-docks/difference-between-4k-and-8k

- Let's assume that it will be upgraded to 8K in near future.
- According to Netflix, it says that 8K streaming requires at least 100 Mbps,
- So, if Vision Pro is upgraded from 4K to 8K, and several family members use it simultaneously, we may need B5G/6G … ?

Extremely High-speed communication: VR/AR set is too heavy

	Announced	Weight	Price
Apple Vision Pro	June 2023	~ 453g to 680g	$3,499
Meta Quest Pro	October 2022	722g	Starts at $1,000
Meta Quest 2	September 2020	503g	Starts at $300
Sony PlayStation VR 2	November 2022	560g	$550
HTC VIVE XR Elite	January 2023	625g	$1,099
HTC VIVE Pro 2	May 2021	850g	$1,399
Valve Index	April 2019	810g	$999
HP Reverb G2	Refreshed in October 2021	550g	$599

https://www.androidauthority.com/apple-vision-pro-weight-3337674/

Extremely High-speed communication: NeuralLink

TESLA

NEURALINK

XAI

STARLINK

SPACEX

Extremely High-speed communication: It’s so close already

REUTERS®

May 27, 2023

Elon Musk's Neuralink wins FDA approval for human study of brain implants

https://www.reuters.com/science/elon-musks-neuralink-gets-us-fda-approval-human-clinical-study-brain-implants-2023-05-25/

The man with a mind-reading chip in his brain - thanks to Elon Musk

March 23, 2025

Share Save

Lara Lewington, Liv McMahon & Tom Gerken
BBC News

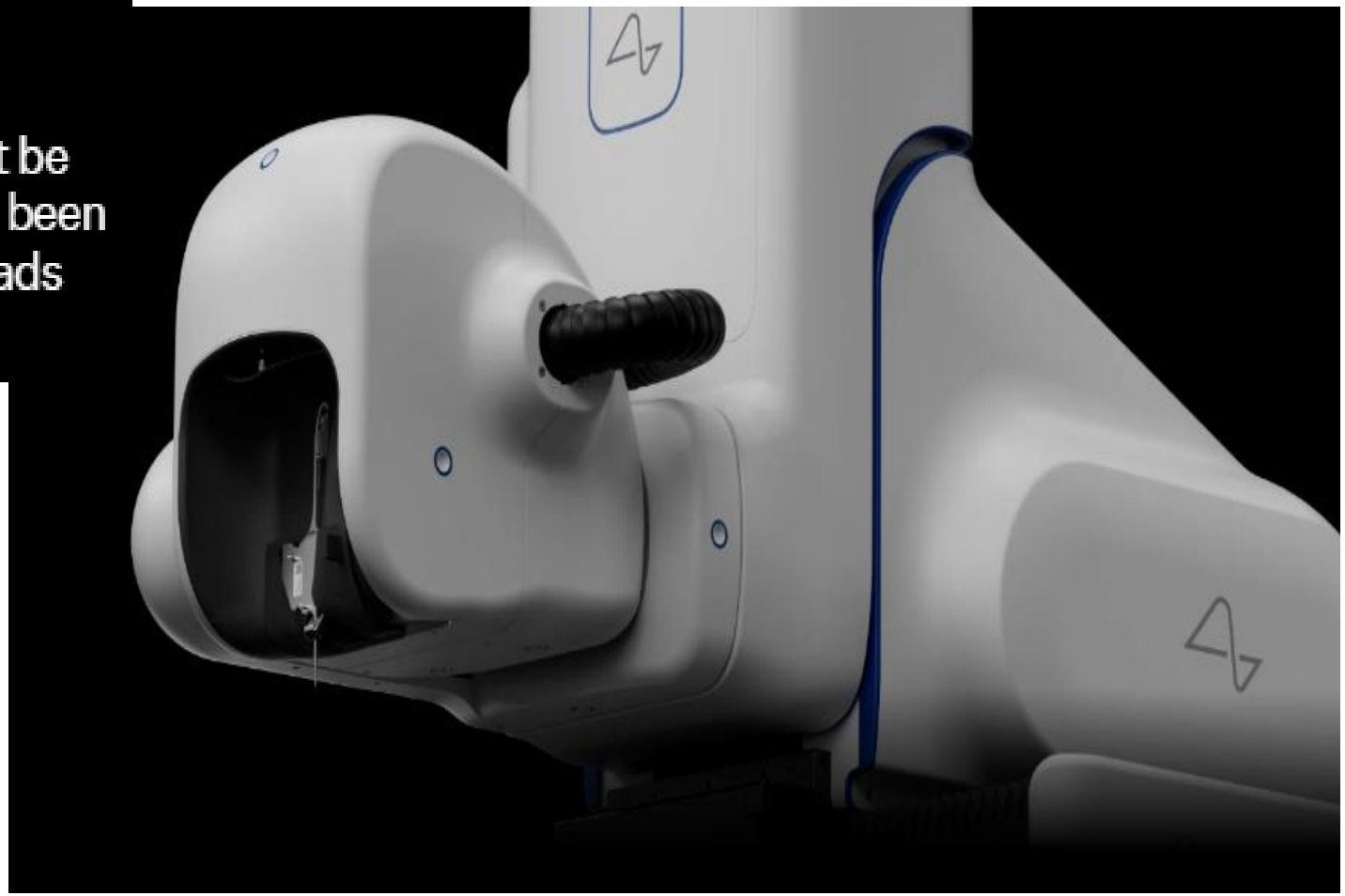
https://www.bbc.com/news/articles/cewk49j7j1po

Extremely High-speed communication: It’s so close already

Surgical Robot

The threads of our implant are so fine that they can't be inserted by the human hand. Our surgical robot has been designed to reliably and efficiently insert these threads exactly where they need to be.

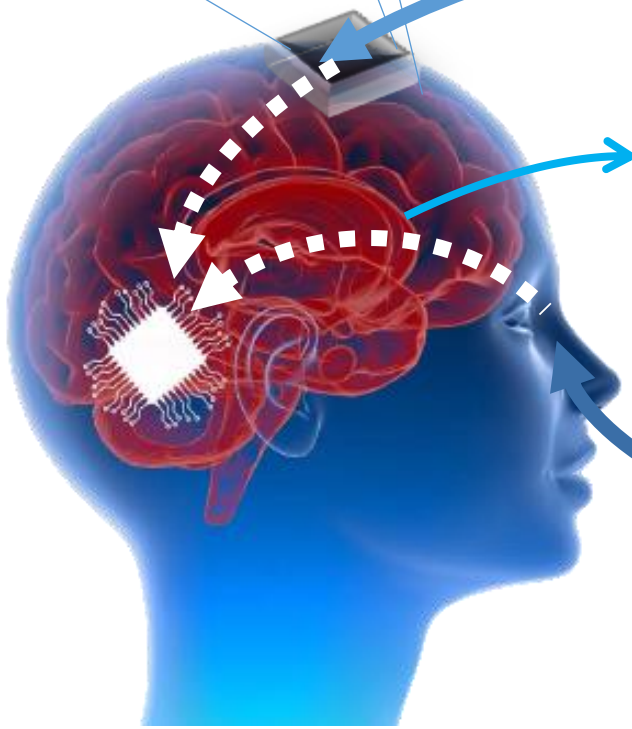
NEURALINK



https://neuralink.com/#robot

Extremely High-speed communication: A successor of smartphone

❑ Last mile bottle-neck cleared ?



Optic nerve: 8.75 Mbps

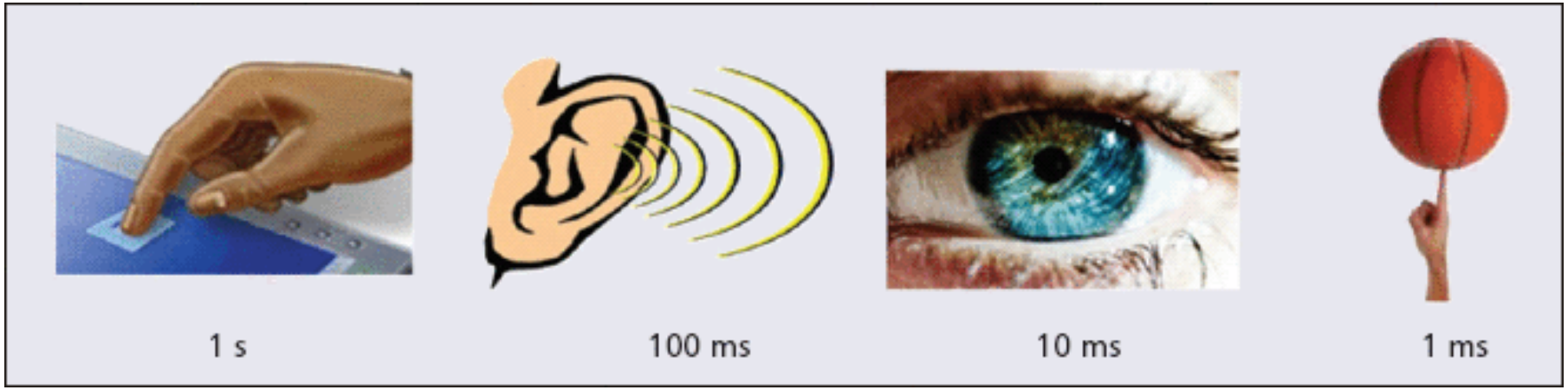
B5G/6G: 1Gbps

Extreme Low latency

Extremely Low latency

- Aims to achieve lag-free services:
  - 10 or 100 times faster than 5G
- Which applications require such a low latency?
  - Cyber sickness: in VR, the time lag between the virtual image and the movement is above 1ms, motion sickness can occur,

Delay tolerance of each application

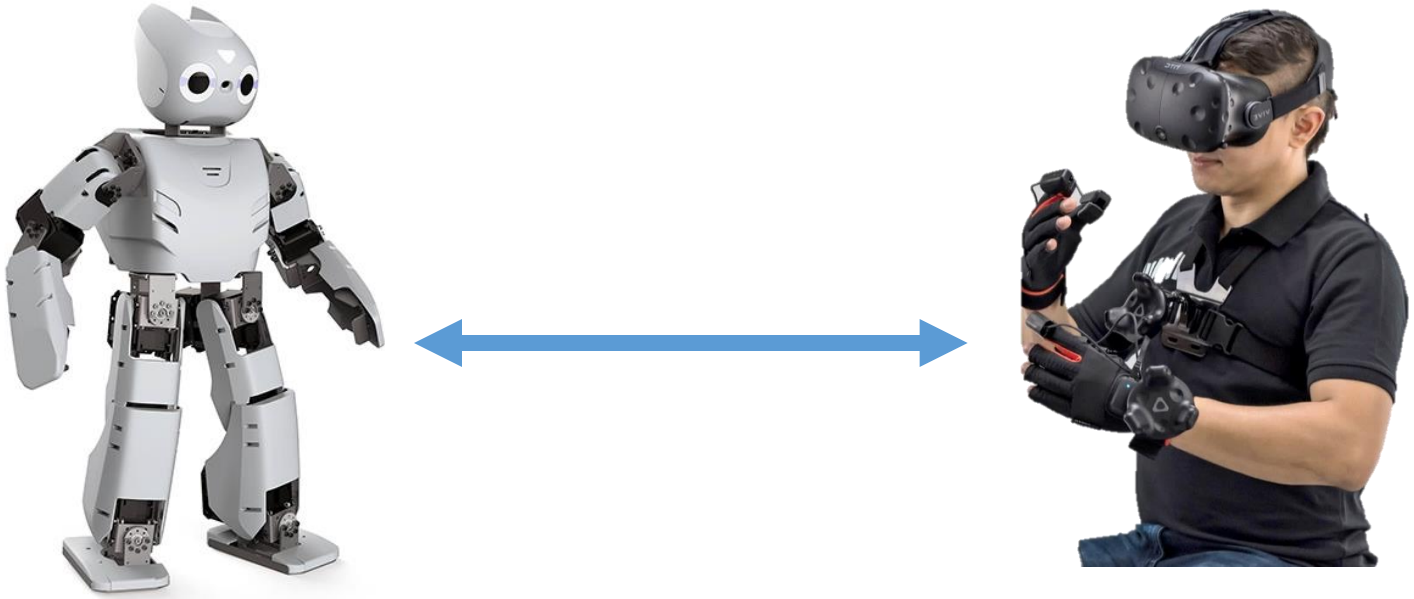


Web browsing	Delay for telephony	A minimum picture refresh rate of 100 Hz	Tactile action

5G: Personal mobile internet beyond what cellular did to telephony, IEEE Communications Magazine, February 2014.

Extremely Low latency : So …

- The delay requirement for B5G/6G is one-tenth of that for 5G, which is 0.1 ms; Light can travel approximately 30 km in 0.1 ms.
- We are approaching the physical limit of transmission latency - the speed of light.

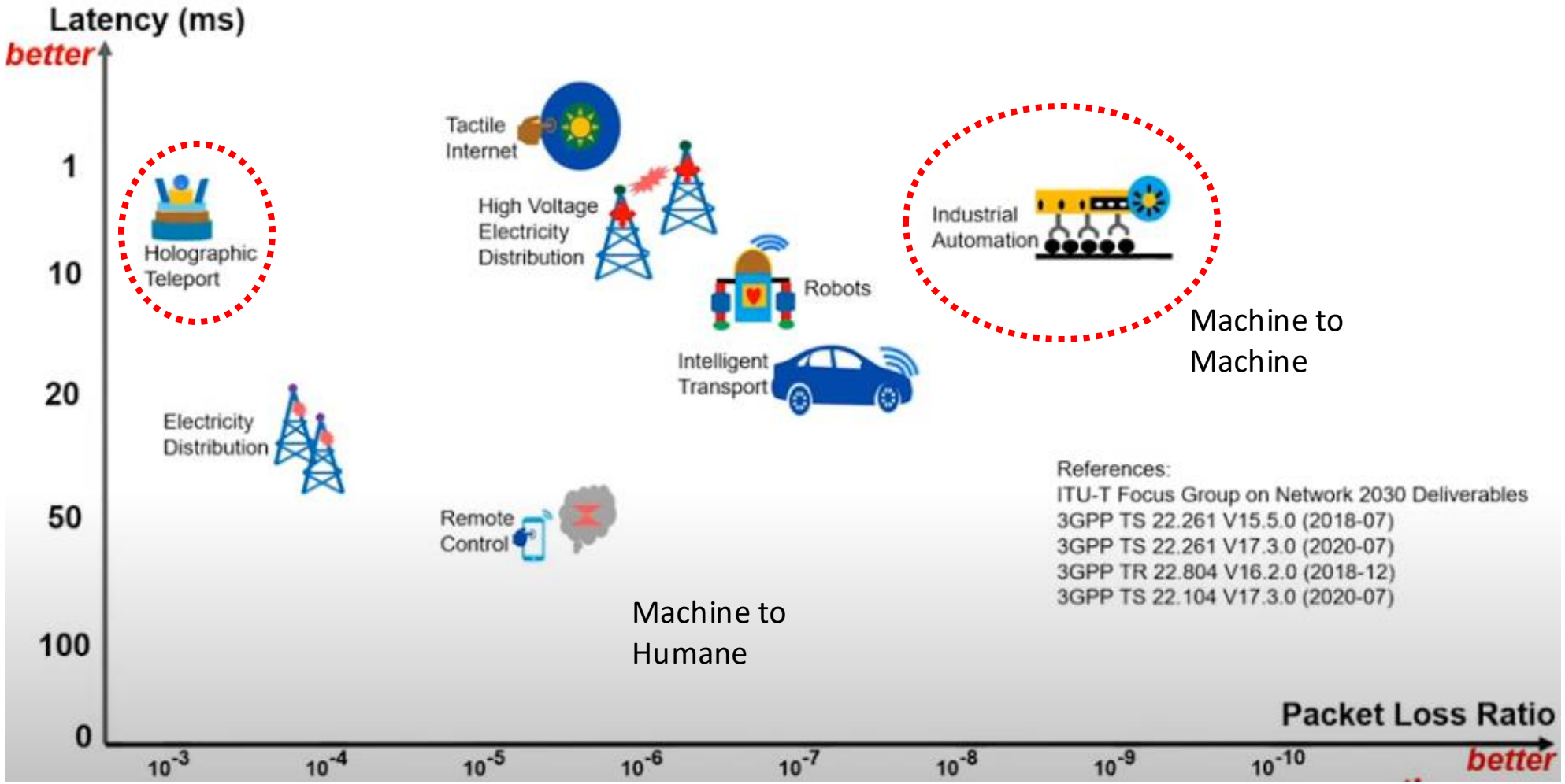


High Reliability

High Reliability

- Aims to achieve high reliability transmission, namely “six nines” (99.9999%) or “seven nines” (99.99999%) level of reliability.
- Industry and lifeline applications require high level of reliability.
- In 5G, high reliability + low latency communication is called “URLLC”: Ultra Reliable Low Latency Communication.
- In 6G, it is called “xURLLC”: eXtreme URLLC

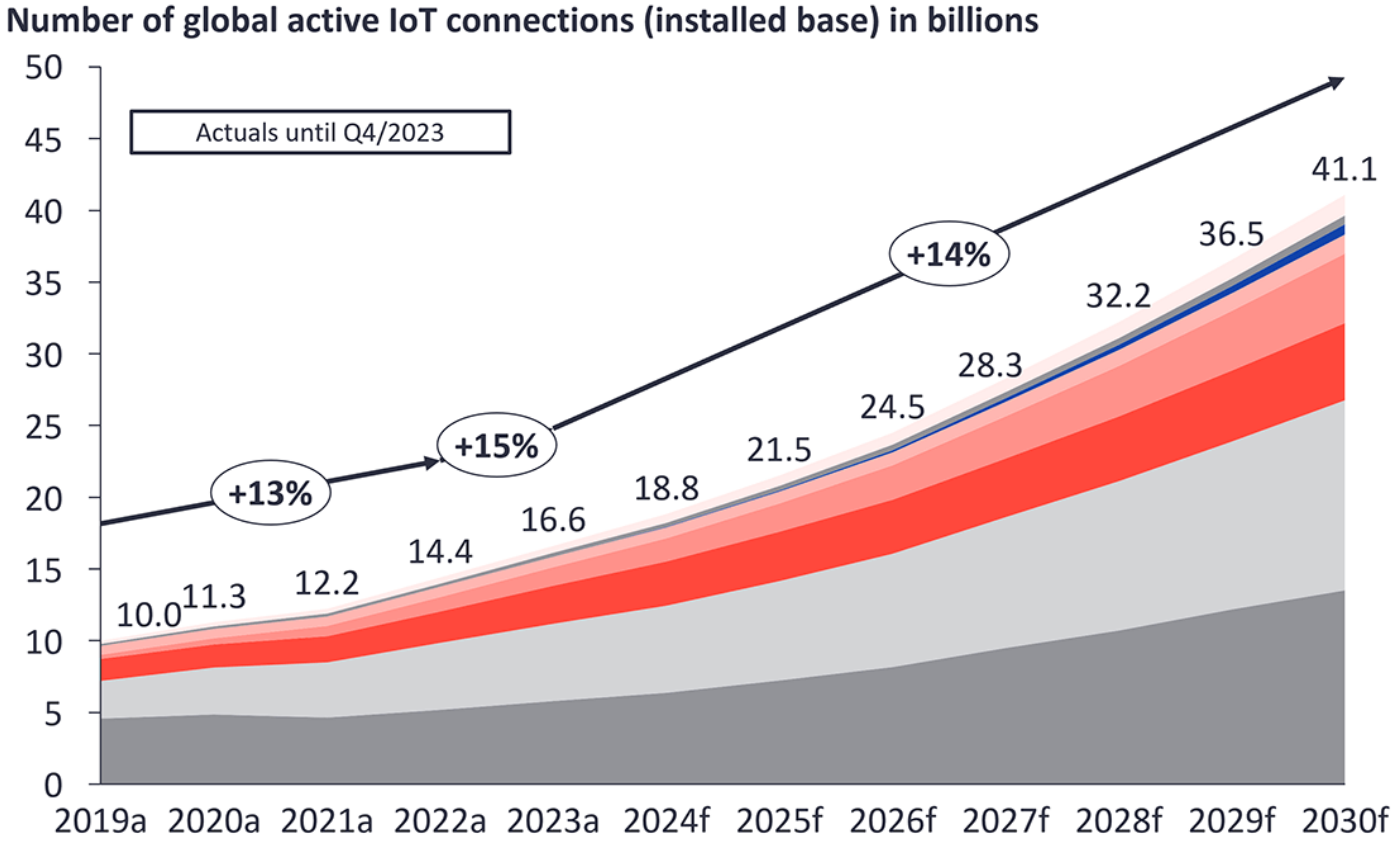
- Requirements for URLLC or xURLLC applications

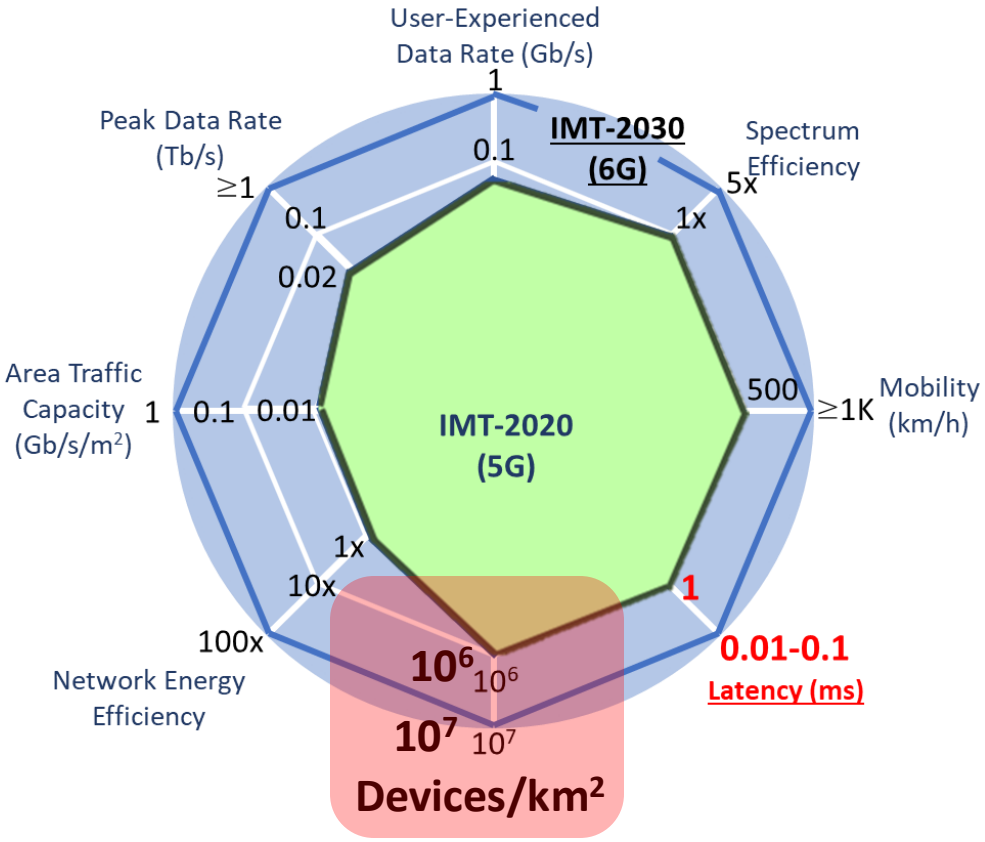


Massive connectivity

Massive connectivity

- It refers to the ability of a network to support an extremely large number of connected devices simultaneously.





https://iot-analytics.com/number-connected-iot-devices/

Massive connectivity: Tesla and XAI

TESLA

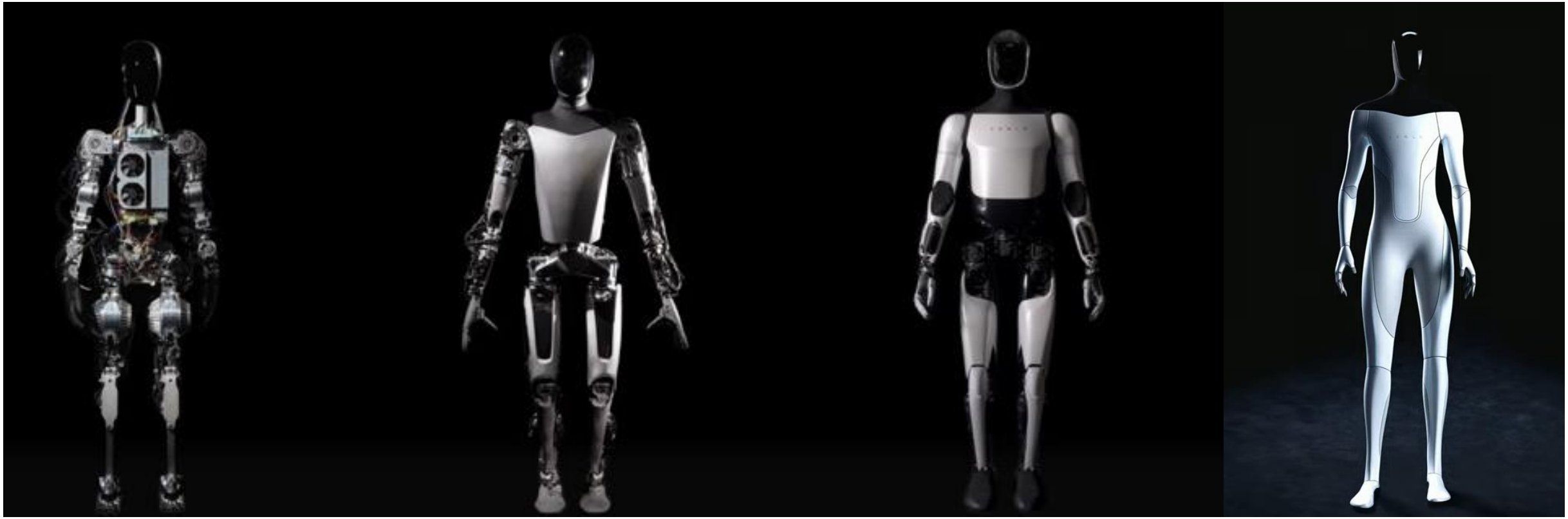
NEURALINK

XAI

STARLINK

SPACEX

Massive connectivity: Tesla and XAI



September 2022 Development Platform	March 2023 Gen I	December 2023 Gen II	Concept Model

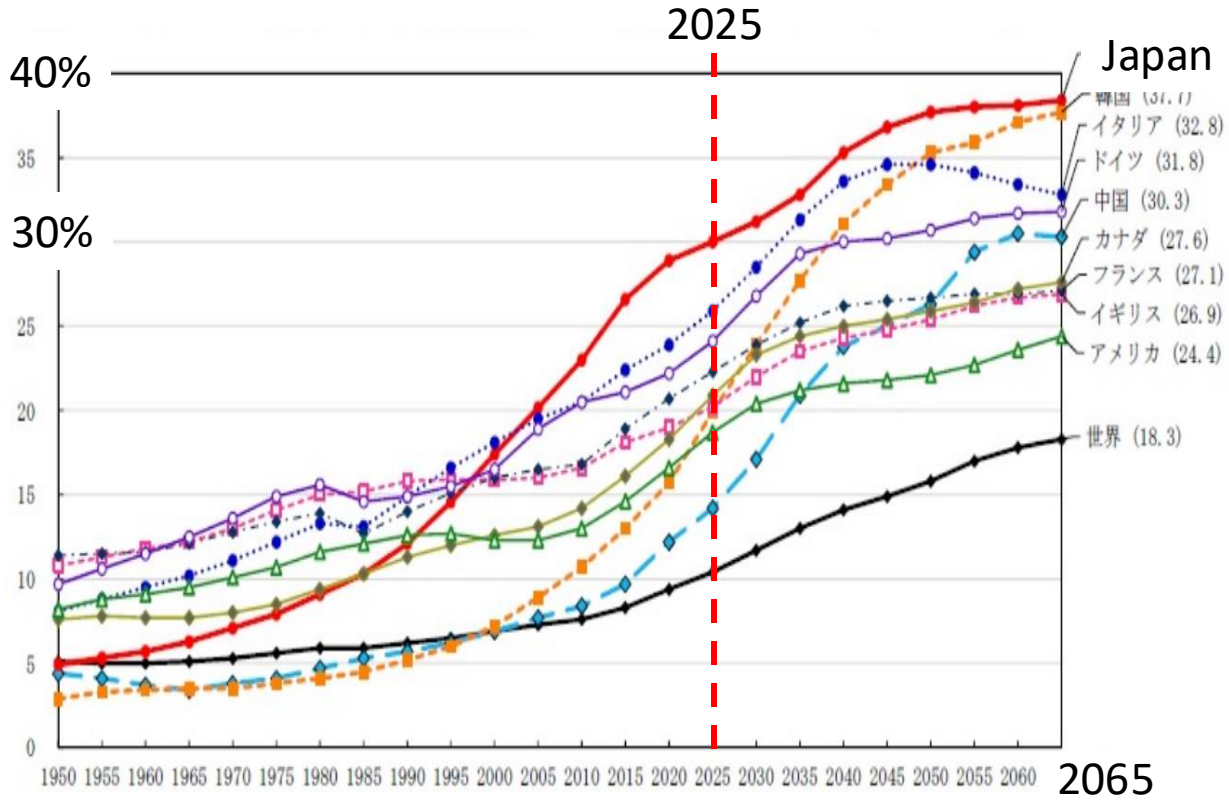
https://www.youtube.com/watch?v=ODSJsviD_SU

Massive connectivity

- Sensors and actuators in robots are main mechanical components to control the robots.

Handicap people operate their physical avatar to serve customers in Café or restaurants. Nov. 2018

https://www.sankei.com/photo/story/news/181126/sty1811260011-n1.html



The population ratio, those ages 65 and above.

https://www.stat.go.jp/data/topics/topi1135.html

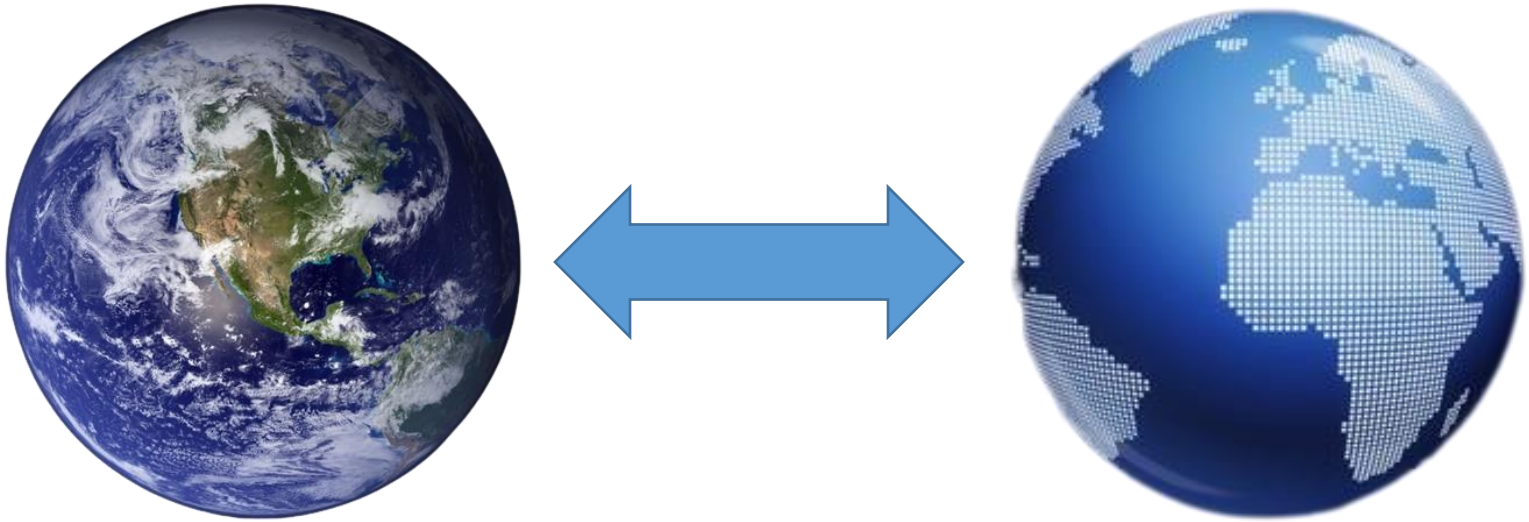
B5G and 6G Use cases: Digital Twins

B5G and 6G Use cases - Digital Twins: what it is?

https://www.youtube.com/@IEEEComSoc

B5G and 6G Use cases - Digital Twins: what it is?

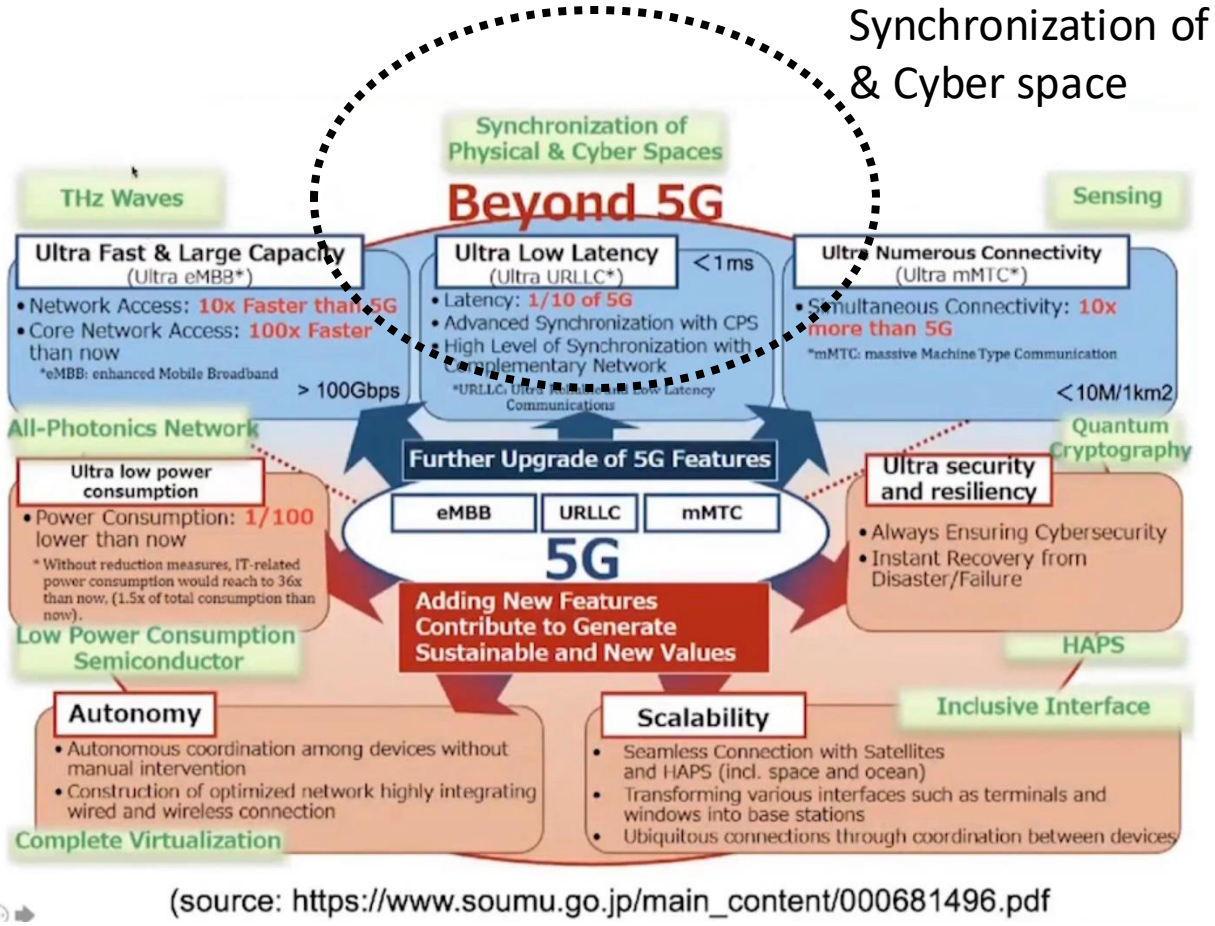
- They are virtual or digital replicas of physical objects or systems, which is another reason why we will need a massive number of sensors.
- They are connected to their real-world counterparts, enabling real-time monitoring, analysis, and simulation.
- One common 6G vision shared by many telco., manufactures, and research institutes around the world is this concept: digital twins.



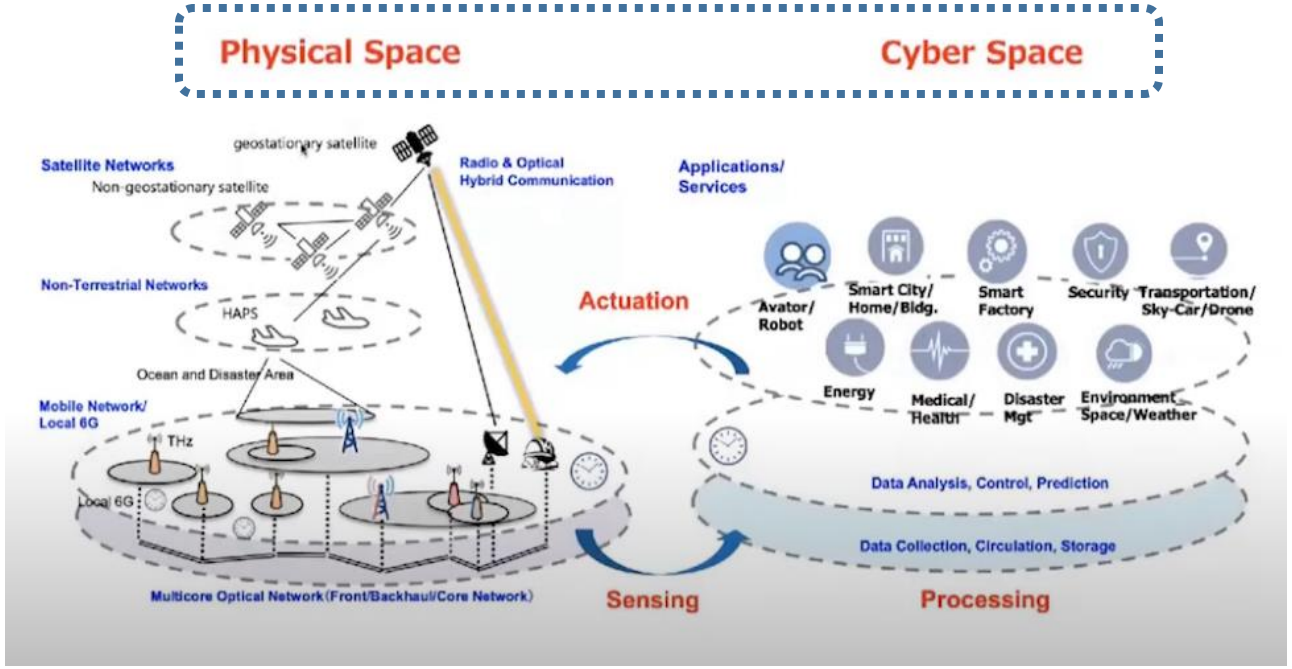
B5G and 6G Use cases - Digital Twins: NICT views on B5G/6G

❑ NICT B5G/6G opportunities and challenges

Synchronization of Physical & Cyber space



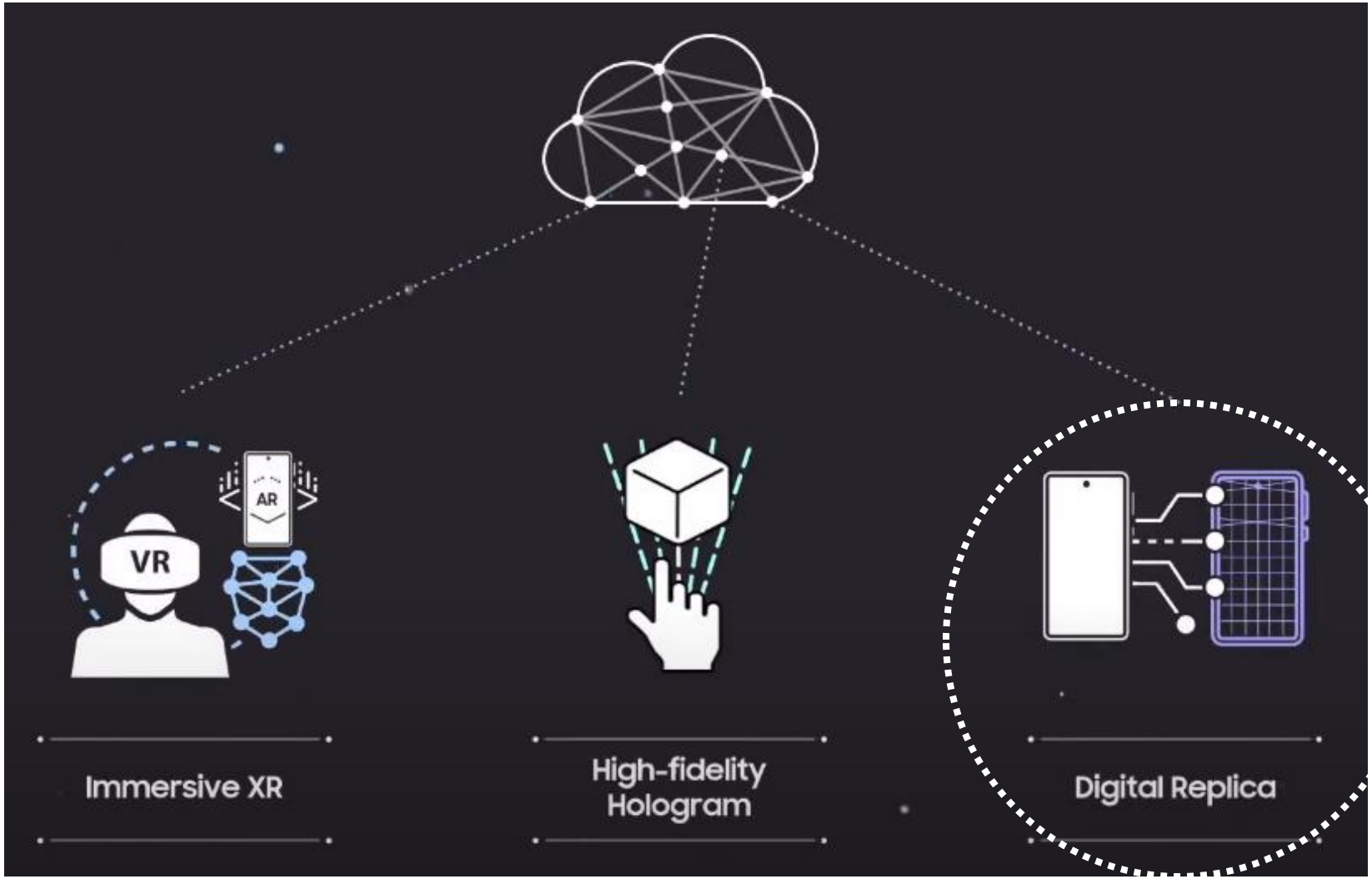
(source: https://www.soumu.go.jp/main_content/000681496.pdf



Developing B5G/6G Communication Systems: Opportunities and Challenges" by Hideyuki Tokuda (NICT)
https://www.youtube.com/watch?v=5CHFzLfB3FQ

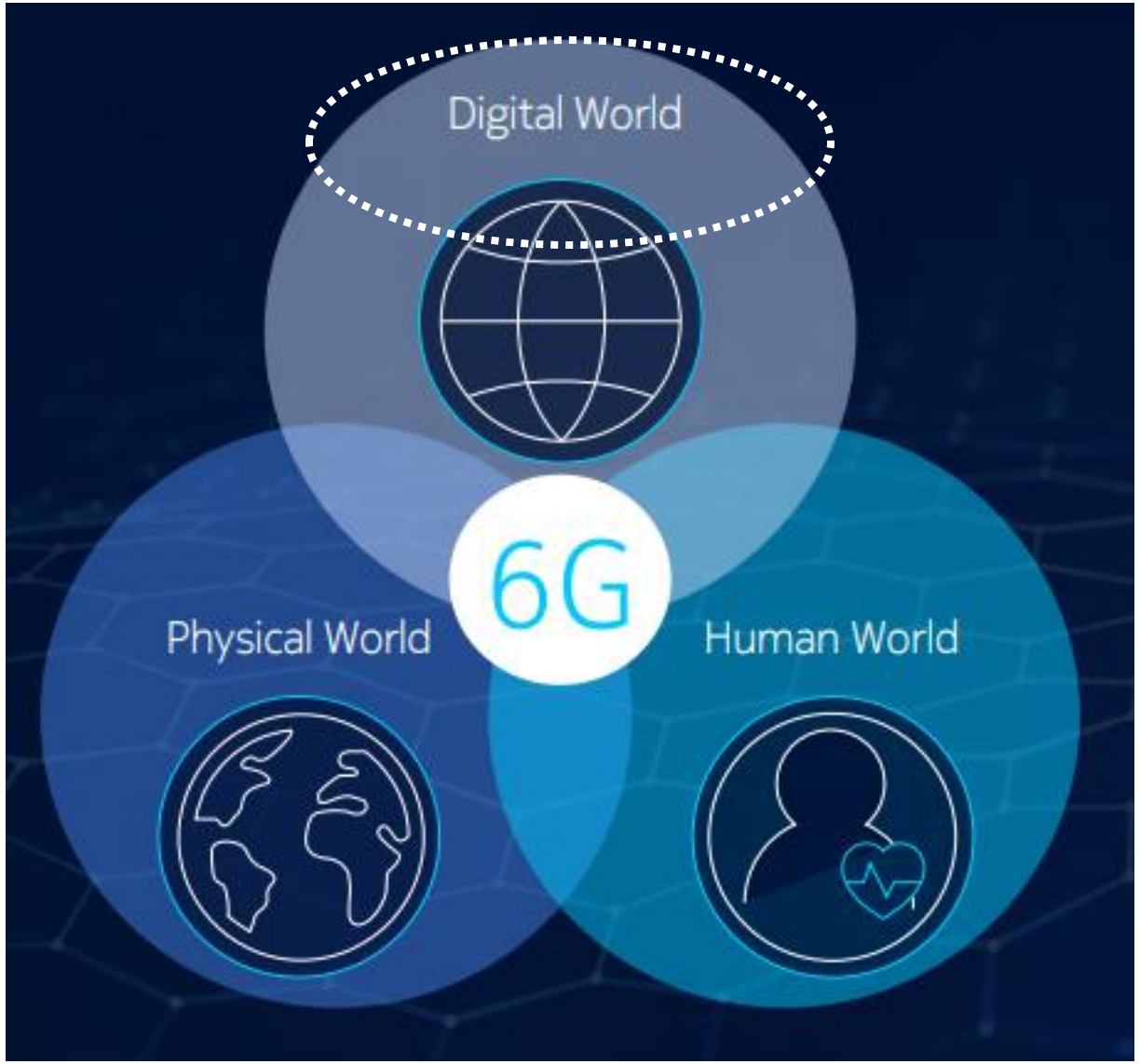
B5G and 6G Use cases - Digital Twins: Samsung views on B5G/6G

- Samsung 6G Official Preview and Future Use Cases



B5G and 6G Use cases - Digital Twins: Nokia views on B5G/6G

- Nokia 6G vision



https://b5g.jp/w/wp-content/uploads/pdf/international_doc10_nokiasolutions&networks.pdf

B5G and 6G Use cases - Digital Twins: NTT views on B5G/6G

- NTT docomo 5G Evolution and 6G

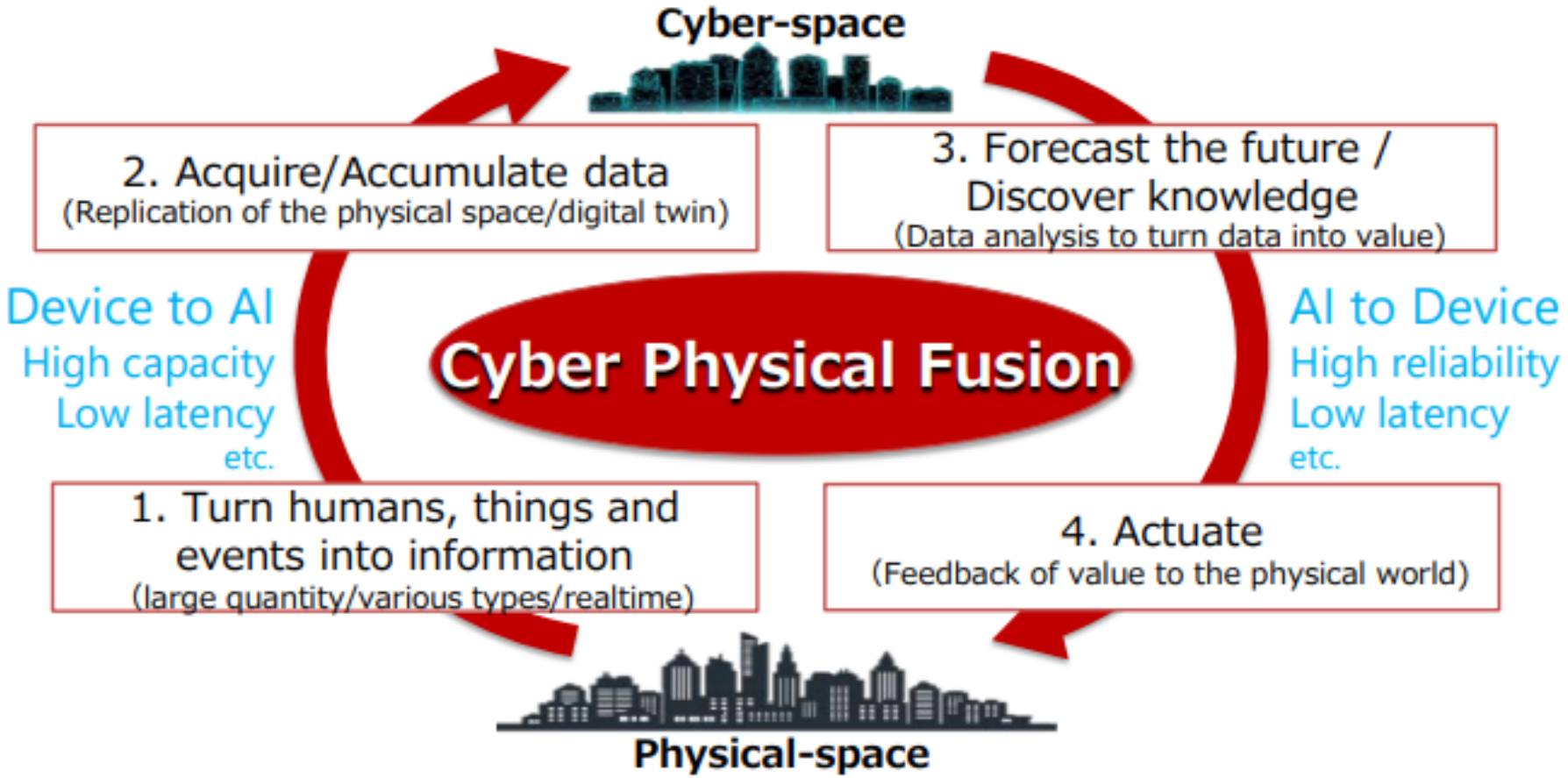


Figure 2-3. Cyber-physical fusion and wireless communications

https://www.docomo.ne.jp/english/binary/pdf/corporate/technology/whitepaper_6g/DOCOMO_6G_White_PaperEN_v4.0.pdf

B5G and 6G Use cases - Digital Twins: its history

- Digital twins was anticipated by David Gelernter's 1991 book *Mirror Worlds,*
- The concept and model of the digital twin was publicly introduced in 2002 by Michael Griesves, including
  - Real space, virtual space and spreading of data and information flow between real and virtual space,
- The term, digital twin, was used by John Vickers of NASA in a 2010 Roadmap report.

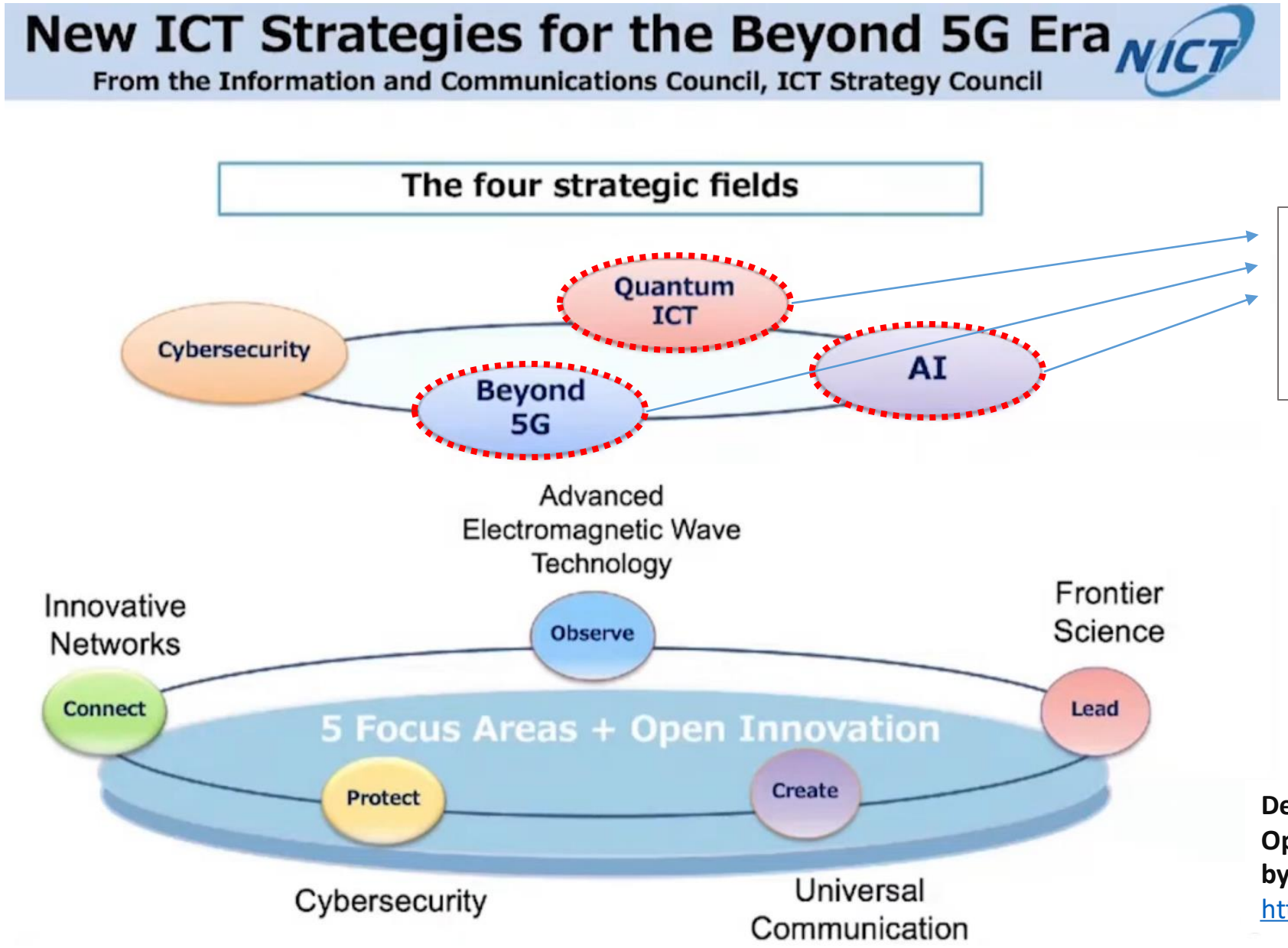
Piascik, R., et al., *Technology Area 12: Materials, Structures, Mechanical Systems, and Manufacturing Road Map*. 2010, NASA Office of Chief Technologist.

B5G and 6G Use cases - Digital Twin: what enables digital twins

- IoT infrastructure which collects data from physical entities.
- Networking technologies which connect between the digital twin and its counter part physical entity.
  - Low latency, high-speed communication, massive connectivity, ..
  - B5G and 6G can support these requirements
- AI and machine learning which analyze the data from IoT infrastructures.

Two key technologies that work with B5G/6G

Two Key technologies that work with B5G/6G



Those three are complementary to each other and would be foundation of various future technologies.

Developing B5G/6G Communication Systems: Opportunities and Challenges"
by Hideyuki Tokuda (NICT)
https://www.youtube.com/watch?v=5CHFzLfB3FQ

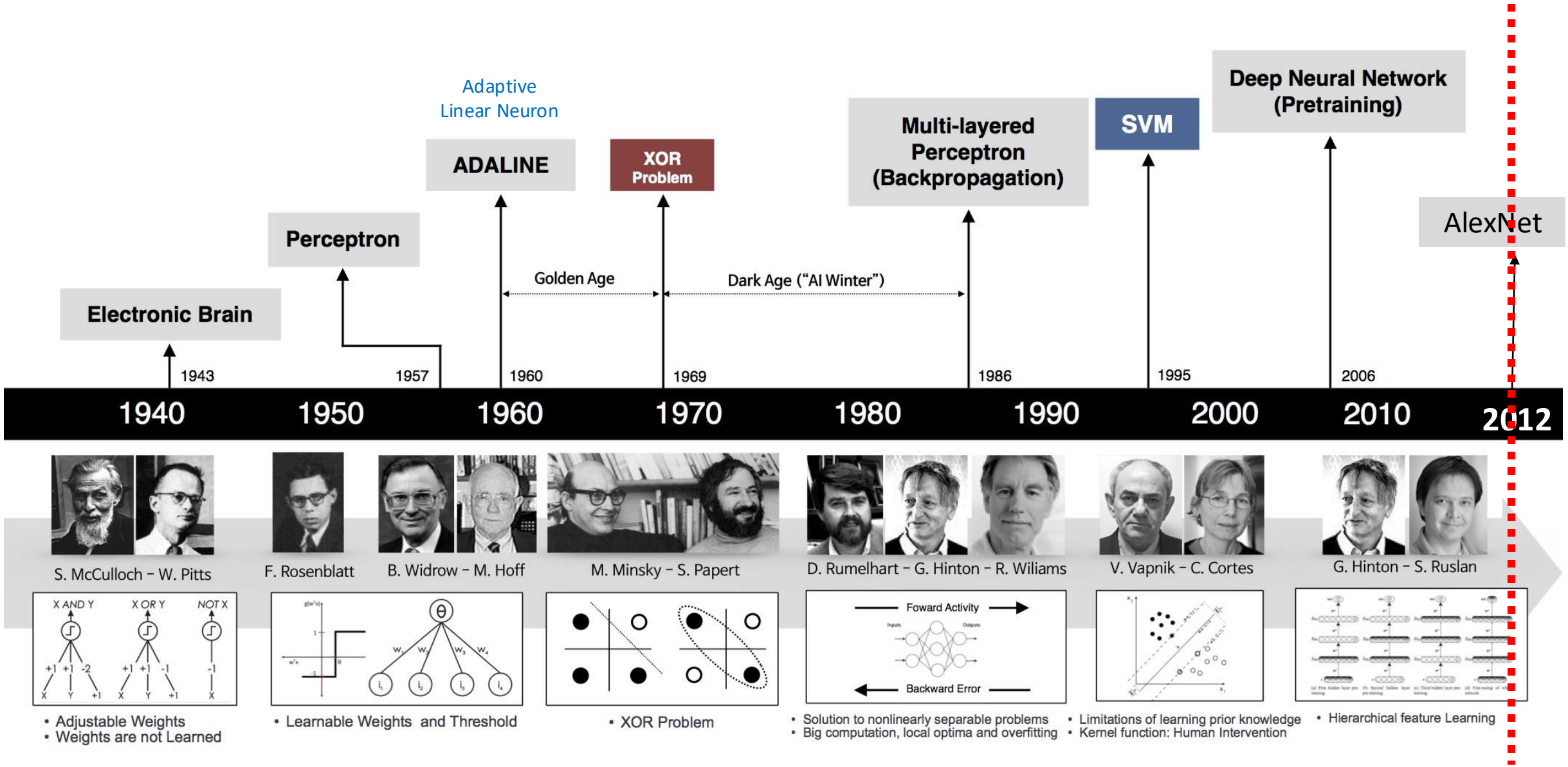
B5G/6G enabler: Machine learning

- Learning is a form of generalization that aims to understand an underlying process based on a set of observations.

CAT?

VS

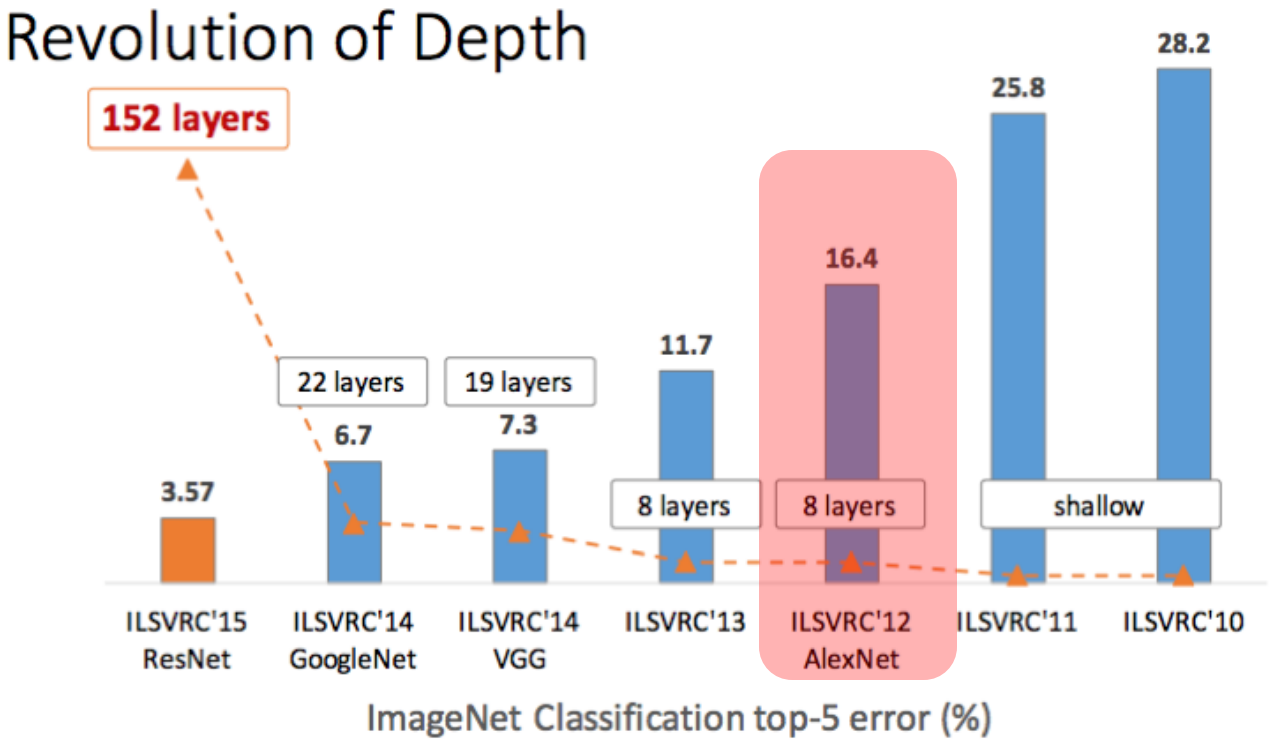
B5G/6G enabler: Machine learning: history of machine learning

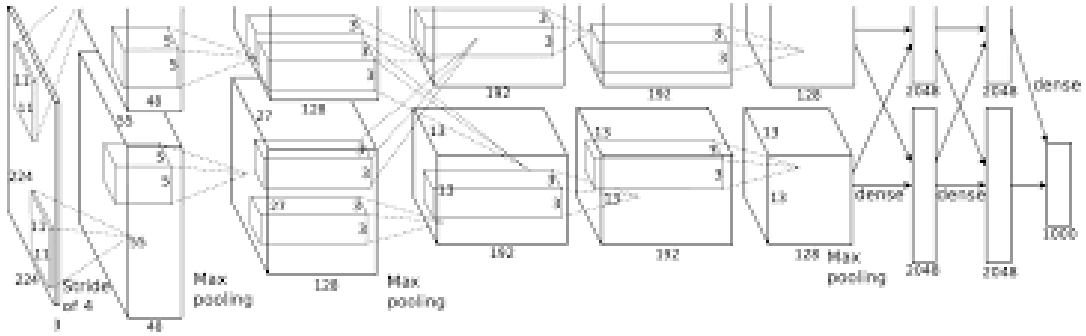


https://beamandrew.github.io/deeplearning/2017/02/23/deep_learning_101_part1.html

B5G/6G enabler: Machine learning: AlexNet 2012

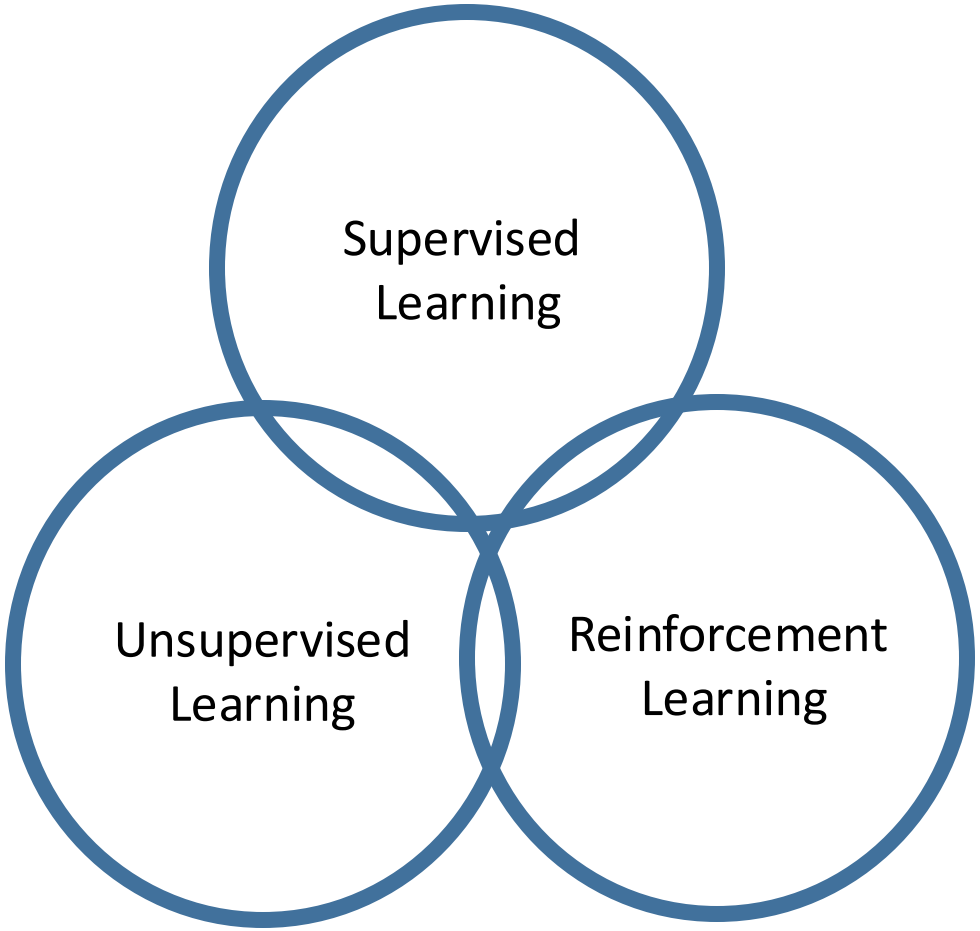
- Alex Krizhevsky et al, "*ImageNet Classification with Deep Convolutional Neural Networks*" (2012)
  - Win the imageNet competition: annual Olympics of computer vision with astounding results compared to previously existing approaches (26% to 15%).

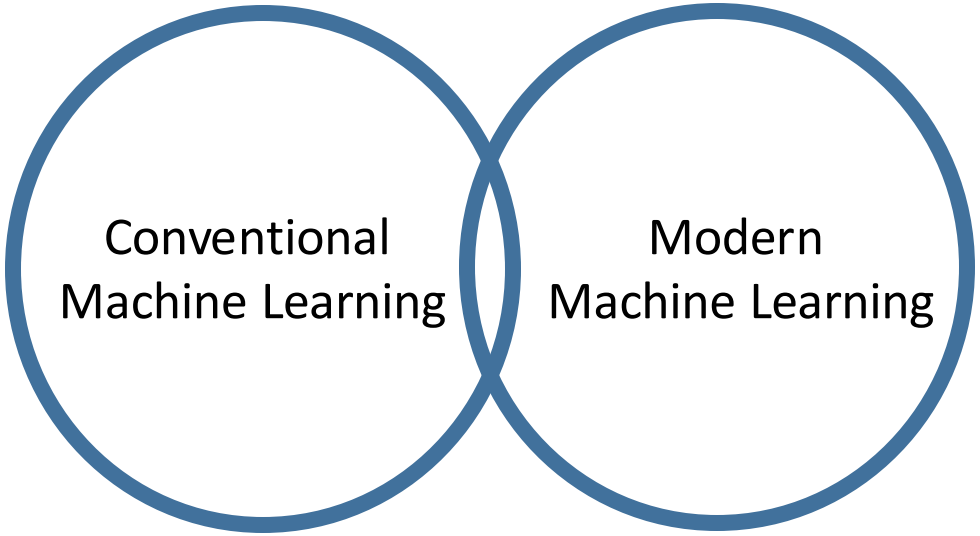




https://medium.com/@Lidinwise/the-revolution-of-depth-facf174924f5

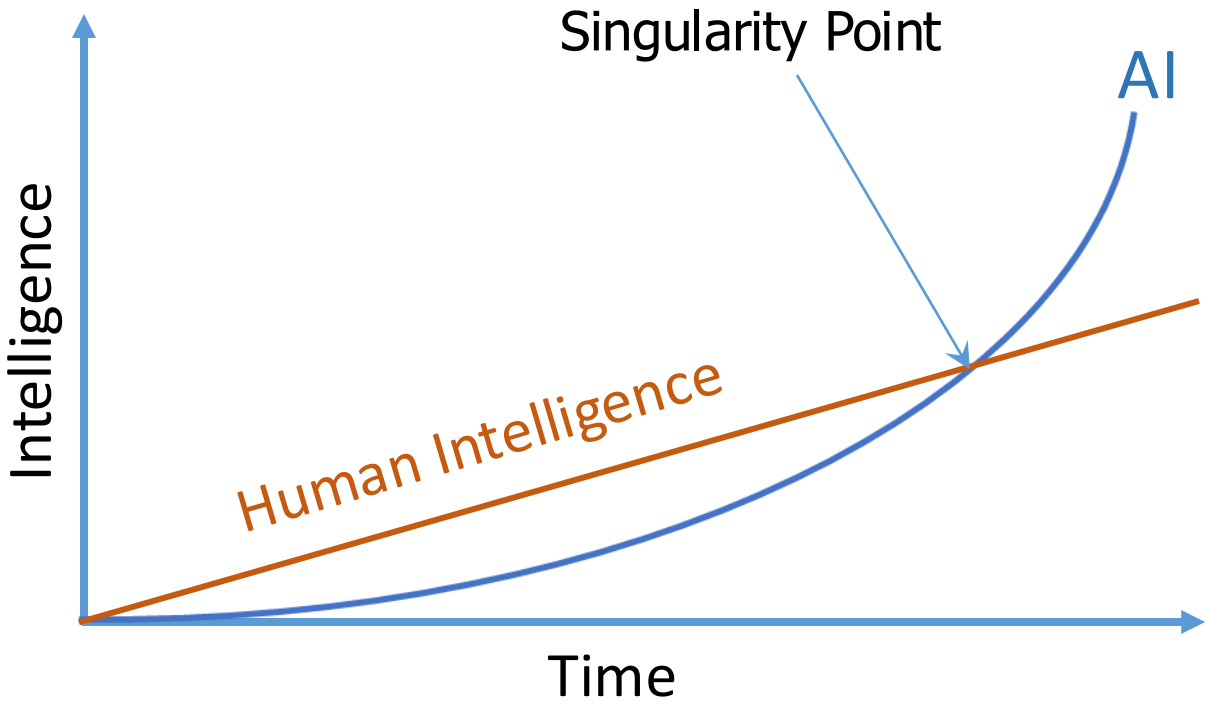
B5G/6G enabler: Machine learning: Classification of machine learning





B5G/6G enabler: Machine learning: 2030 or more

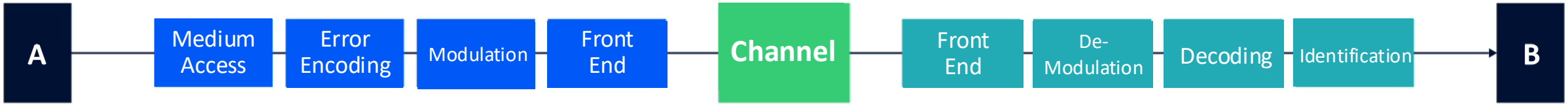
- AGI: Artificial General Intelligence
- ASI: Artificial Super Intelligence
- When are we going to see singularity point?



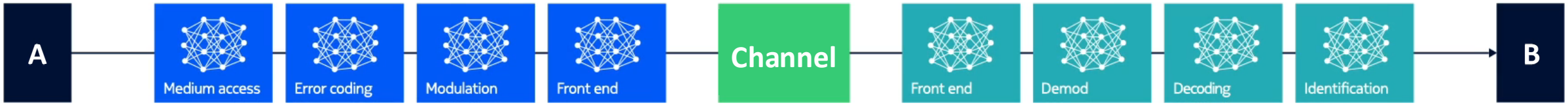
B5G/6G enabler: Machine learning: back to Now

6G native AI/ML air interface (Nokia-bell-labs):

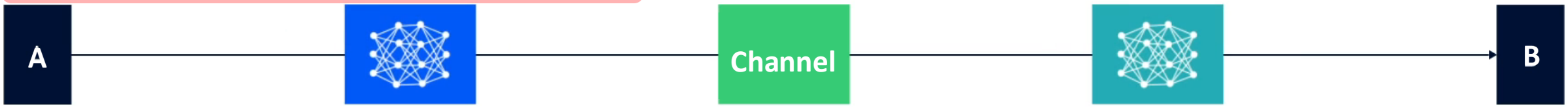
5G: the classical architecture



5G-Advanced: AI/ML will replace multiple processing blocks



6G: AI/ML will design parts of the physical layer



https://www.bell-labs.com/

B5G/6G enabler: Quantum computing

- The Nobel Prize in Physics 2022
- It's a mathematical framework or set of rules for the construction of physical theories.
  - Quantum Computation
  - Quantum Information
  - Quantum Security

The Nobel Prize in Physics 2022

Ill. Niklas Elmehed © Nobel Prize Outreach

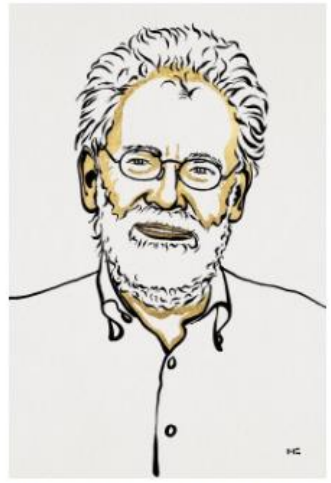
Alain Aspect

Prize share: 1/3

Ill. Niklas Elmehed © Nobel Prize Outreach

John F. Clauser

Prize share: 1/3



Ill. Niklas Elmehed © Nobel Prize Outreach

Anton Zeilinger

Prize share: 1/3

The Nobel Prize in Physics 2022 was awarded jointly to Alain Aspect, John F. Clauser and Anton Zeilinger "for experiments with entangled photons, establishing the violation of Bell inequalities and pioneering quantum information science"

B5G/6G enabler: Quantum computing … Where in B5G/6G?

- There has been some activities to combine quantum computing with ML, which is called "Quantum Machine Learning (QML)
- People have dedicated considerable effort to benefit from deep learning (DL) for intelligent wireless networks,
- However, learning rate of DL models is one of the major bottlenecks for the consideration for B5G/6G.
- Interesting ideas …
  - The entry barrier is so High…

F. Zaman, A. Farooq, M. A. Ullah, H. Jung, H. Shin and M. Z. Win, "Quantum Machine Intelligence for 6G URLLC," in *IEEE Wireless Communications*, vol. 30, no. 2, pp. 22-30, April 2023.

B5G/6G enabler: Quantum computing … where in B5G/6G, e.g.,

Kyodo News – Jun 3, 2023

Japan, U.S. universities partner with IBM, Google in quantum field

- The University of Tokyo has partnered with the University of Chicago, IBM, and Google for the next-generation quantum computing.
- IBM has announced a 10-year (2033), $100 million initiative with the University of Tokyo and the University of Chicago to develop a quantum-centric supercomputer powered by 100,000 qubits (currently 433…)
- 100,000 qubits ??? What can we do with this?

SUMMARY

- B5G and 6G is a term used to describe the technologies and standards that will come after 5G.
- They are expected to provide significantly faster speed, greater capacity, improved reliability, and support for a wide range of emerging applications.
- One of such applications, called digital twins, was introduced during this lecture
- In addition, two complementary technologies to B5G and 6G, namely AI/ML and quantum technologies, were introduced, which will be covered in detail in the following lectures.