Horizons 6G:

Emergent leaderships,

Key-characteristics, and

Development pathways

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All along the technological watch-tower:

1) Long and punctuated evolution

2) What is to be done of 6G

3) 6G dinamics

Evolution

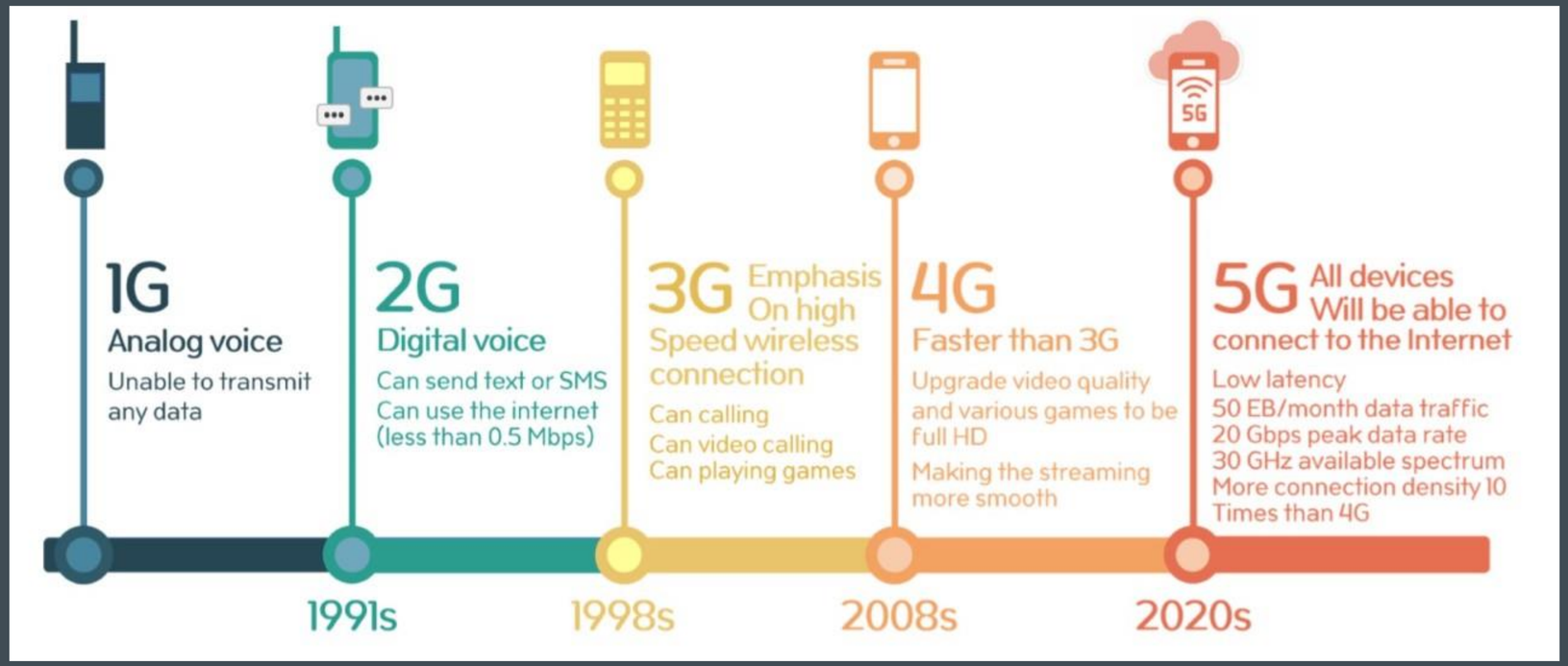
Electronic communications in flux (*all over again*)::.

An example: 5G

- performance: *data rate* ↑10x, *latency* ↓10x, *device density* ↑10x, *energy efficency* ↑3x
- assignment: large auctions for frequency use rights (~ 700 MHz, 3,6 GHz, 26 GHz)
- deployment: Asia > North America > Europe > South America > Africa

Evolution

Successive (partially overlapping) waves of transformation::.



Evolution

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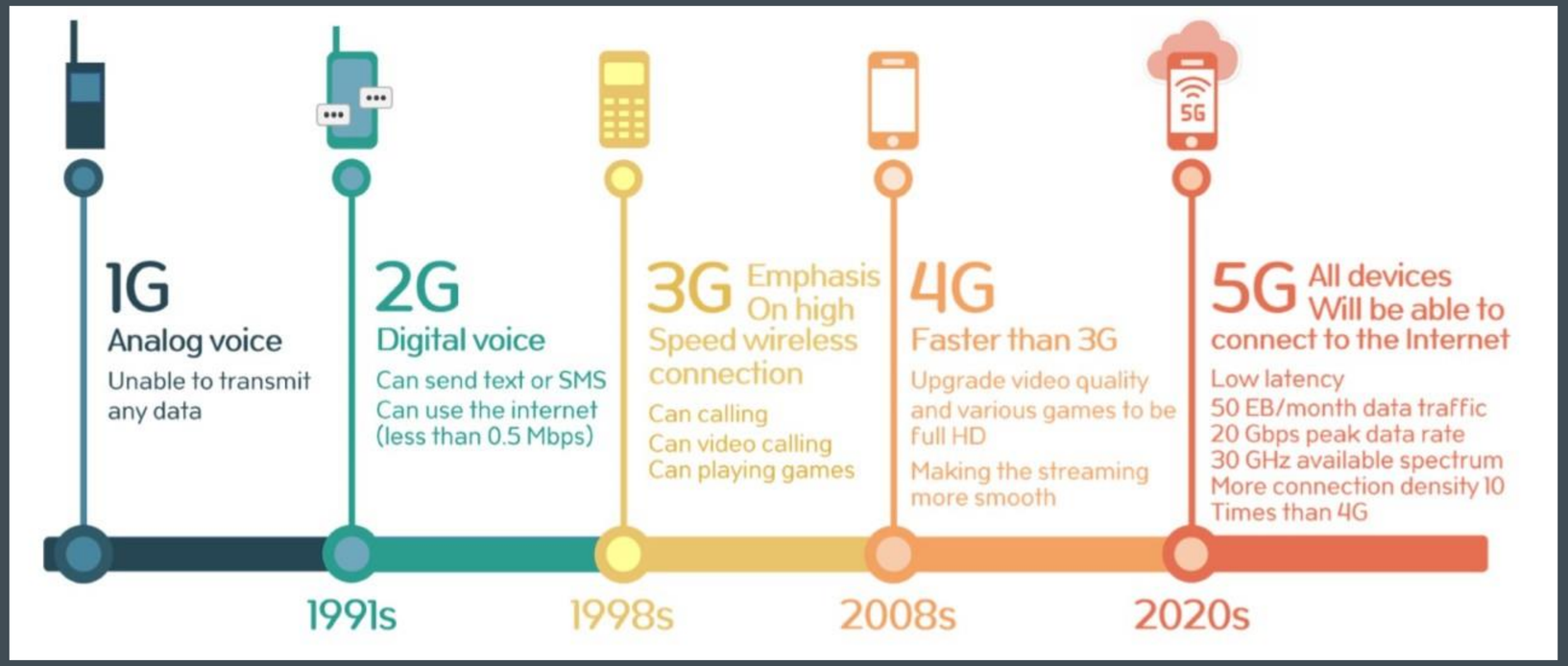


Use cases for 5G:

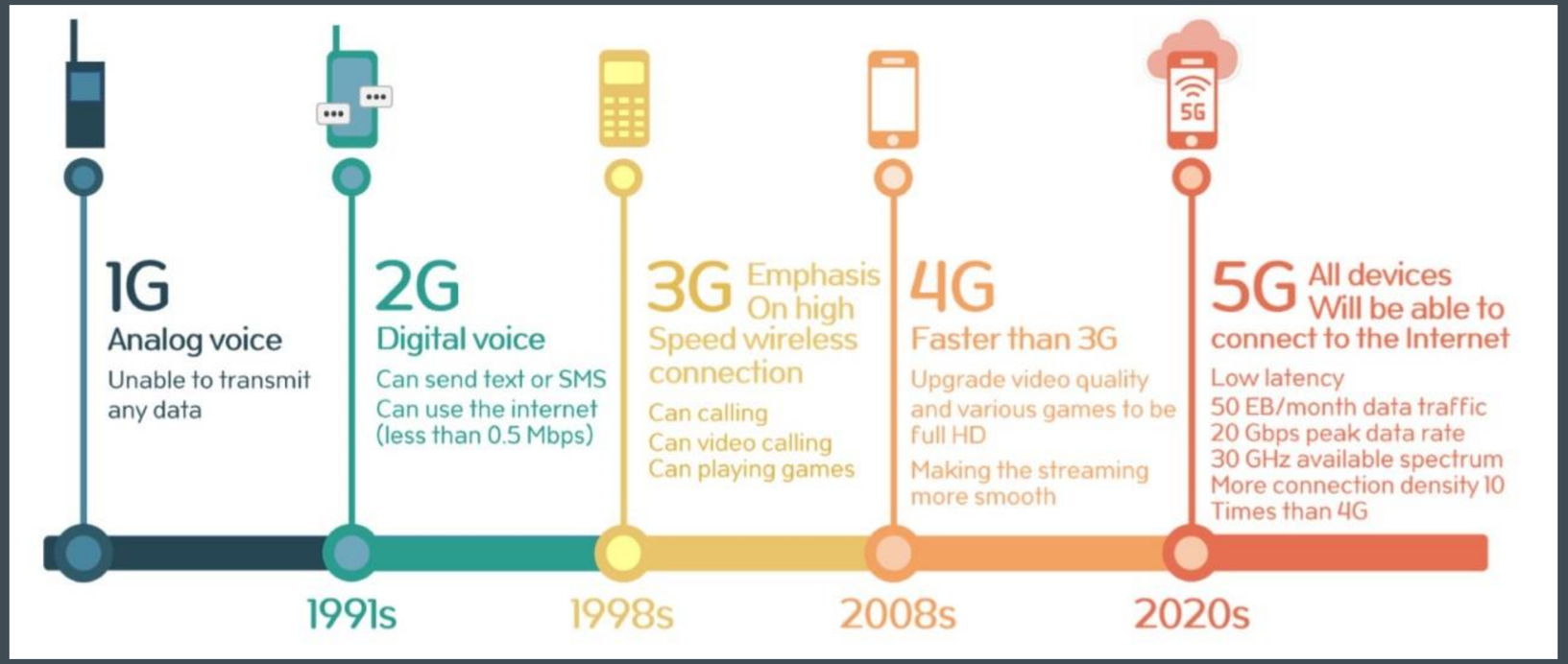
enhanced broadband (eMBB),

ultra-reliable and low latency (URLLC),

massive machine type comms (mMTC)

Evolution

Successive (partially overlapping) waves of transformation::.



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The rise of 5G technologies and systems: A quantitative analysis of knowledge production

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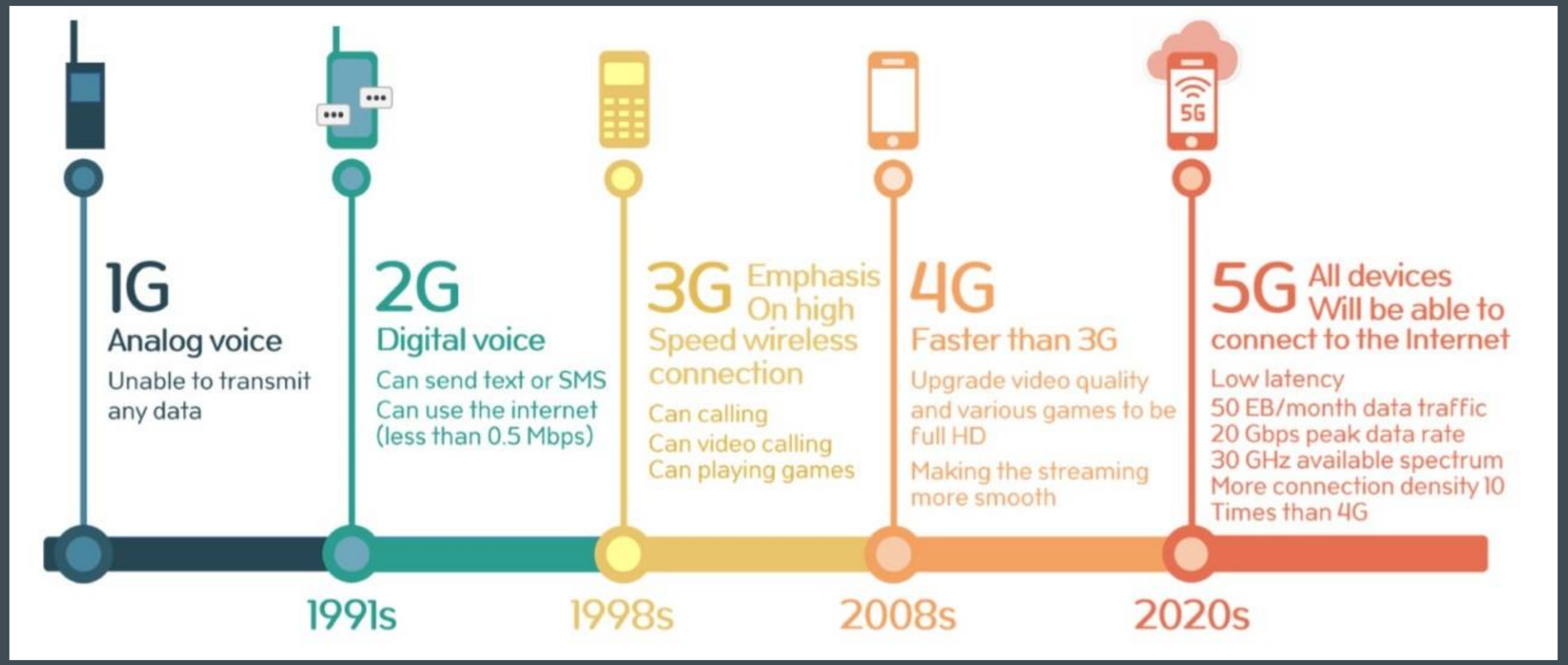
ABSTRACT

The advent of a new generation of wireless communications has punctuated the dawn of every decade in recent times. Upgrades to mobile electronic systems represent faster and more robust capabilities of data transfer but bring with it a wide set of complementary changes as they are underpinned by harmonised specific spectrum bands, fresh international technical standards, new network operation requirements, innovative cellular devices as well as new services and a broader array of potential commercial use applications. This paper presents a systematic outline of the development of 5G-related research until 2020 as revealed by over 10,000 science and technology publications. The exercise addresses the emergence, growth, and impact of this body of work and offers insights regarding disciplinary distribution, international performance, and historical dynamics. Findings reveal the progressive growth of the 5G research over the years after original contributions in 2010 and point to a "take-off" around 2014. A set of stylised facts regarding this technology since its infancy are of interest to engineers, regulators and innovation strategists and policy-makers.

Evolução

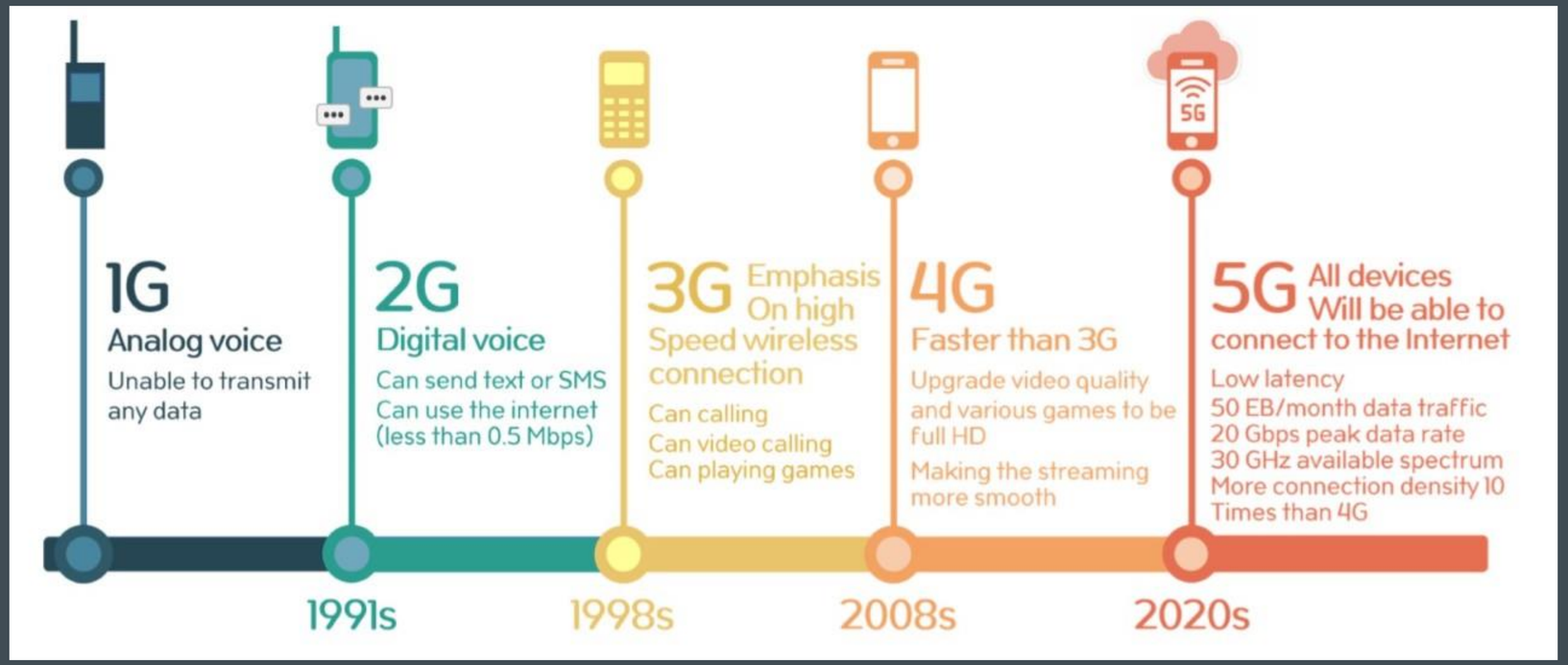
Next wave



6G?

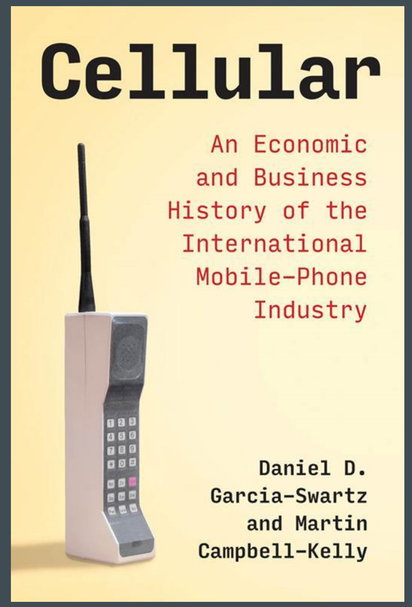
Evolução

Ondas de transformação::.



6G?

No just tech: telecoms as a market process



Some structural breaks

- US: 1982 break up of AT&T + 1994 spectrum auction
- EU: 1987 Green Paper + 1998 liberalization of voice telephony and infrastructure

Some architectural reconfigurations

- from monopoly, public ownership, national isolation…
- … to oligopoly (small numbers market), collective dominance (tacit collusion) vs dynamic competition (investment + innovation)
- pro-competitive deregulation + independent regulators

Some major concepts

- Effective competition (creating!)
- Essential facilities such as ducts and poles (asymmetric remedies!)
- SNIPP test (*small but significant and non-transitory increase in price*)
- Competition on infrastructure vs Competition over access

| 2. six gee

What?

Potential new services, trends and opportunities

The three usage scenarios described in IMT-2020, eMBB, mMTC and URLLC will still remain relevant. New use cases and applications should be considered for continuing evolution, especially for those driving the technologies development and reflecting the future requirements. Consequently, the following new services are envisioned as trends and opportunities:

– Holographic communication

Holographic displays are the next evolution in multimedia experience delivering 3D images from one or multiple sources to one or multiple destinations, providing an immersive 3D experience for the end user. Interactive holographic capability in the network will require a combination of very high data rates and ultra-low latency.

– Tactile and haptic Internet applications

Human operators can monitor the remote machines by virtual reality (VR) or holographic-communications, and are aided by tactile sensors which may also involve actuation and control via kinaesthetic feedback.

Tele-diagnosis, remote surgery and telerehabilitation are just some of the many potential applications in healthcare. Tele-diagnostic tools, medical expertise/consultation could be available anywhere and anytime regardless of the location of the patient and the medical practitioner. Remote and robotic surgery is an application where a surgeon gets real-time audio-visual feeds of the patient that is being operated upon in a remote location. The technical requirements for haptic internet capability cannot be fully provided by current systems.

– Network and computing convergence

Mobile edge computing (MEC) will continue being deployed towards future IMT networks. When clients request a low latency service, the network may direct this to the nearest edge computing site. Augmented reality/virtual reality (AR/VR) rendering, autonomous driving and holographic type communications are all candidates for edge cloud coordination.

– Extremely high-rate access

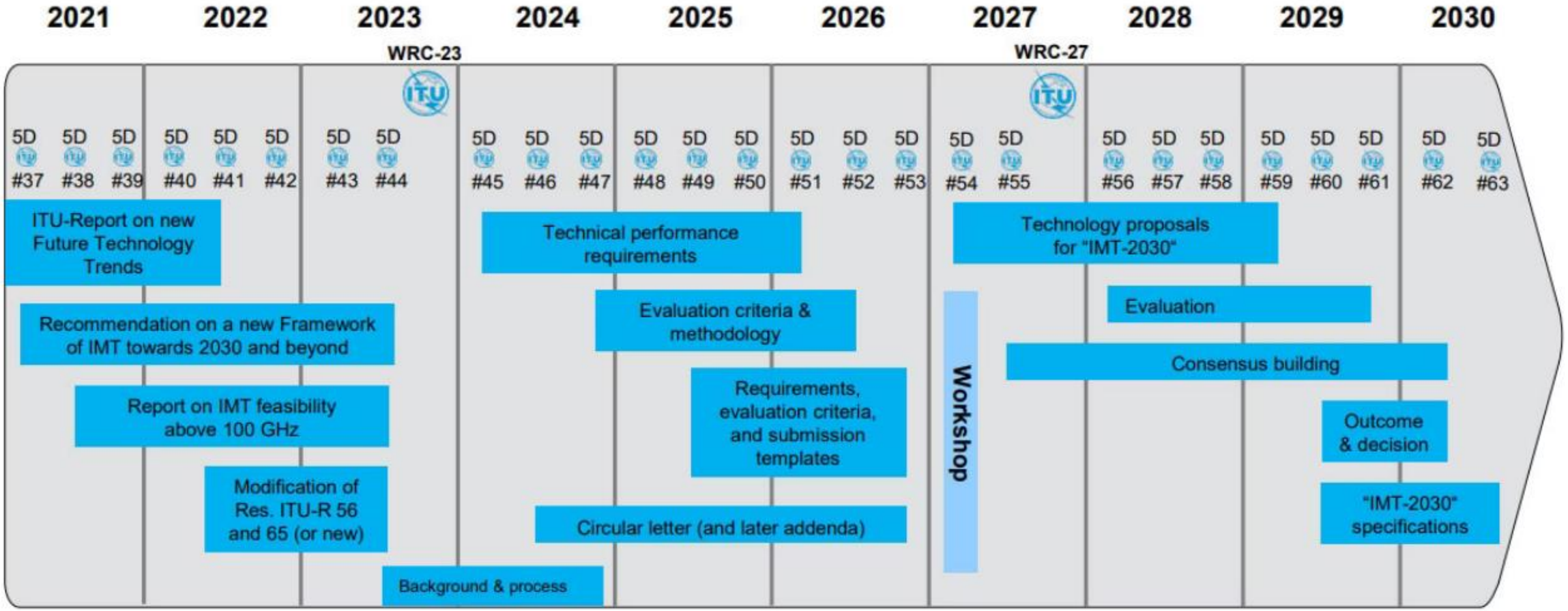
Access points (APs) in transport nodes, shopping malls, and other public places may form information access points. These access points will provide fibre-like speeds. They could also act as the backhaul needs of millimetre-wave (mmWave) small cells. Co-existence with cellular services as well as security appears to be the major issue requiring further attention in this direction.

– Connectivity for Everything

Scenarios include real-time monitoring of buildings, cities, environment, cars and transportation, roads, critical infrastructure, water and power amongst others. The Internet of bio-things through smart wearable devices, intra-body communications achieved via implanted sensors will drive the need of connectivity much beyond mMTC.

When?

ITU-R timeline for IMT-2030



Note 1: WP 5D #59 will additionally organize a workshop involving the Proponents and registered Independent Evaluation Groups (IEGs) to support the evaluation process

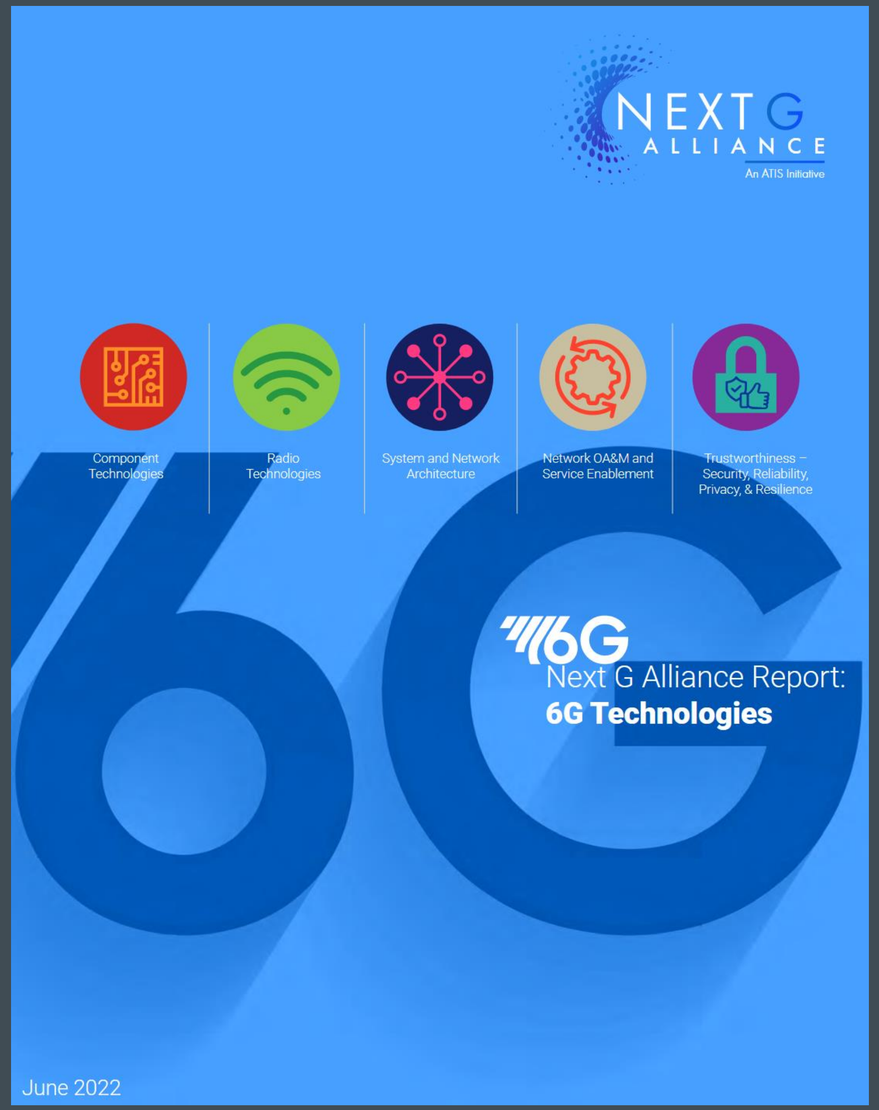
Note 2: While not expected to change, details may be adjusted if warranted. Content of deliverables to be defined by responsible WP 5D groups

***Note by the ITU-R Radiocommunication Bureaux:** This document is taken from Attachment 2.12 to Chapter 2 of Document 5D/1361 (Meeting report WP 5D #41, June 2022) and adjustments could be made in the future. ITU holds copyright in the information – when used, reference to the source shall be done.*

Resultado da 44ª reunião em Genebra, 22 Junho 2023.

WP 5D is responsible for the overall radio system aspects of the terrestrial component of International Mobile Telecommunications (IMT) system.

Who?!



“Building the Foundation for North American Leadership in 6G and Beyond”

ATIS launched initiative in 2020

First results in 2020: technological areas, applications, conditions

Forty-seven technological areas were identified spanning the domains of:

- Component technologies
- Radio technologies
- System and network architecture
- Network Operations, Administration, and Maintenance (OA&M) and service enablement
- Trustworthiness: security, reliability, privacy, and resilience

Although many of these technologies are starting to be discussed in 5G, they will likely not reach their full potential until 6G. Others represent fundamental departures from 6G’s concepts and architectures. Discussions of 6G are just starting, and although some of these research areas may not work out, most will.

These are the technologies that the NGA believes will be key for 6G. Having North America take a leading role in developing these technologies will ensure that the region is a leader in 6G.

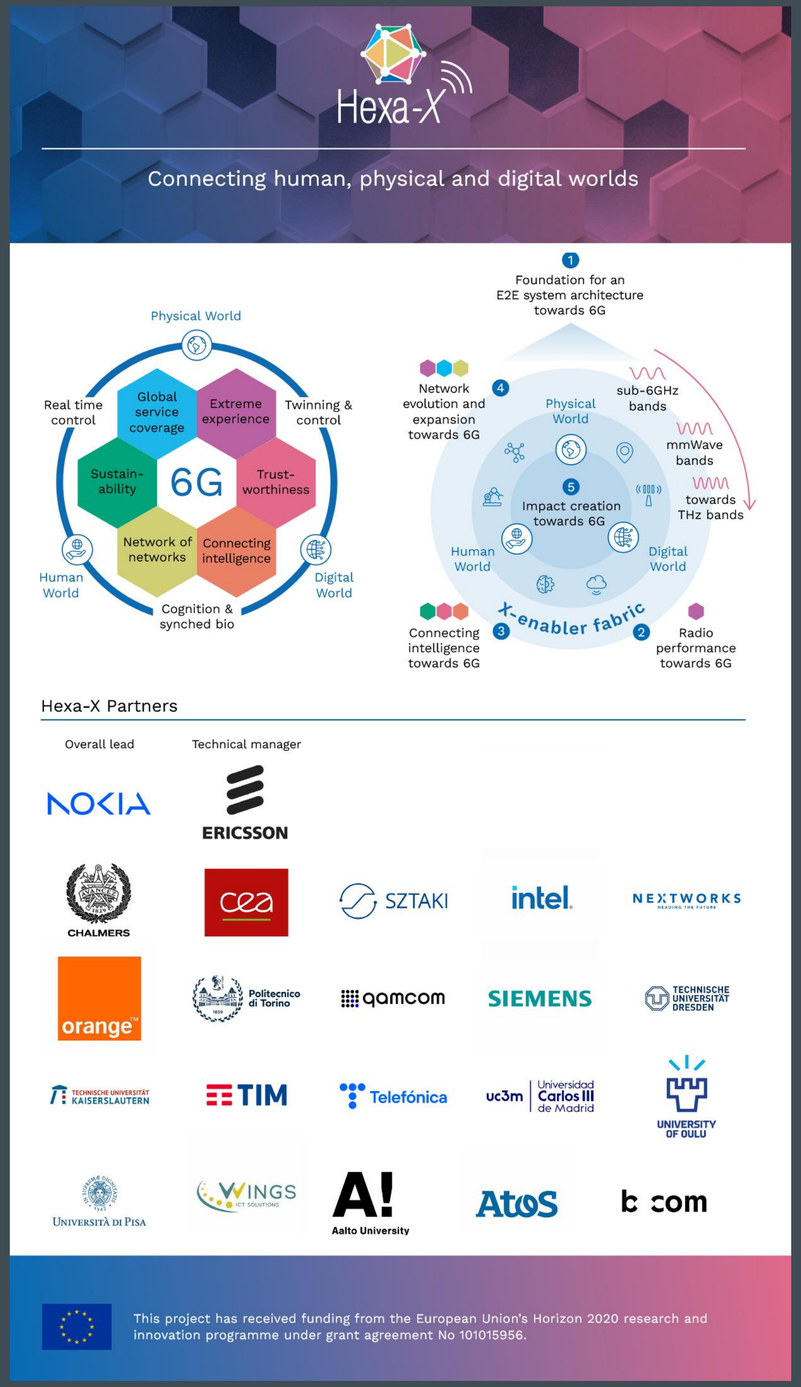
How?!

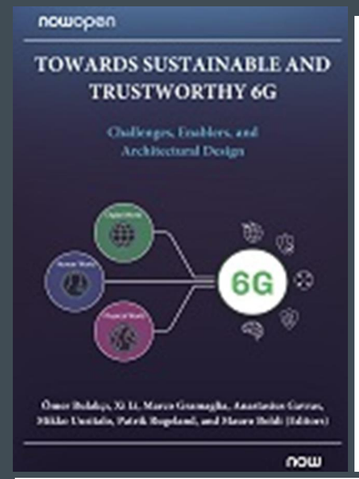
The defining 6G Flagship project Hexa-X-II for Europe (2023-2025, second phase).

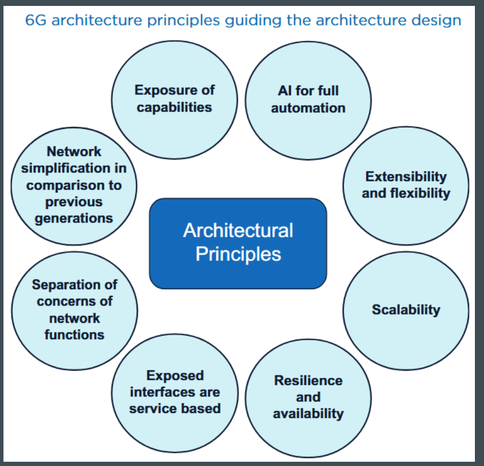
To design a system blueprint aiming at the sustainable, inclusive, and trustworthy 6G platform. Now includes 44 organisations.

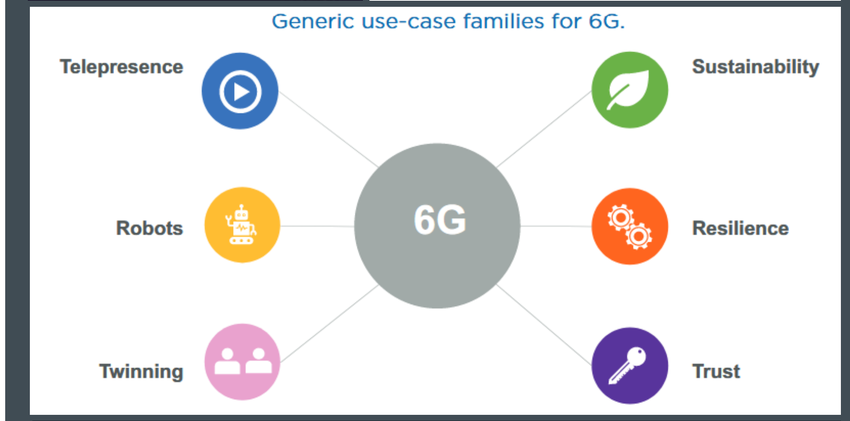
Fostering Europe’s technology sovereignty in 6G leading to conception and standardisation around 2025.

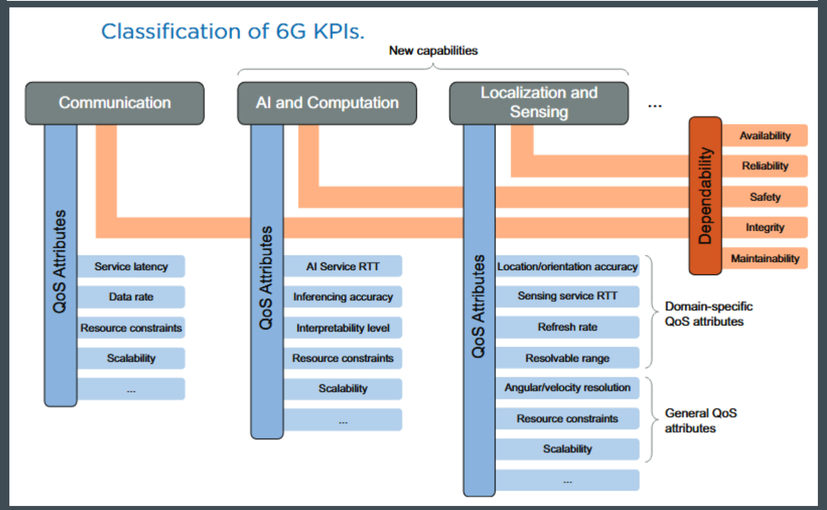
Hexa-X and Hexa-X-II aim to establish Europe as a 6G leader.











How?!

3GPP is planing Release 18 and is set on developing Release 19 with specification for “5G-Advanced”.

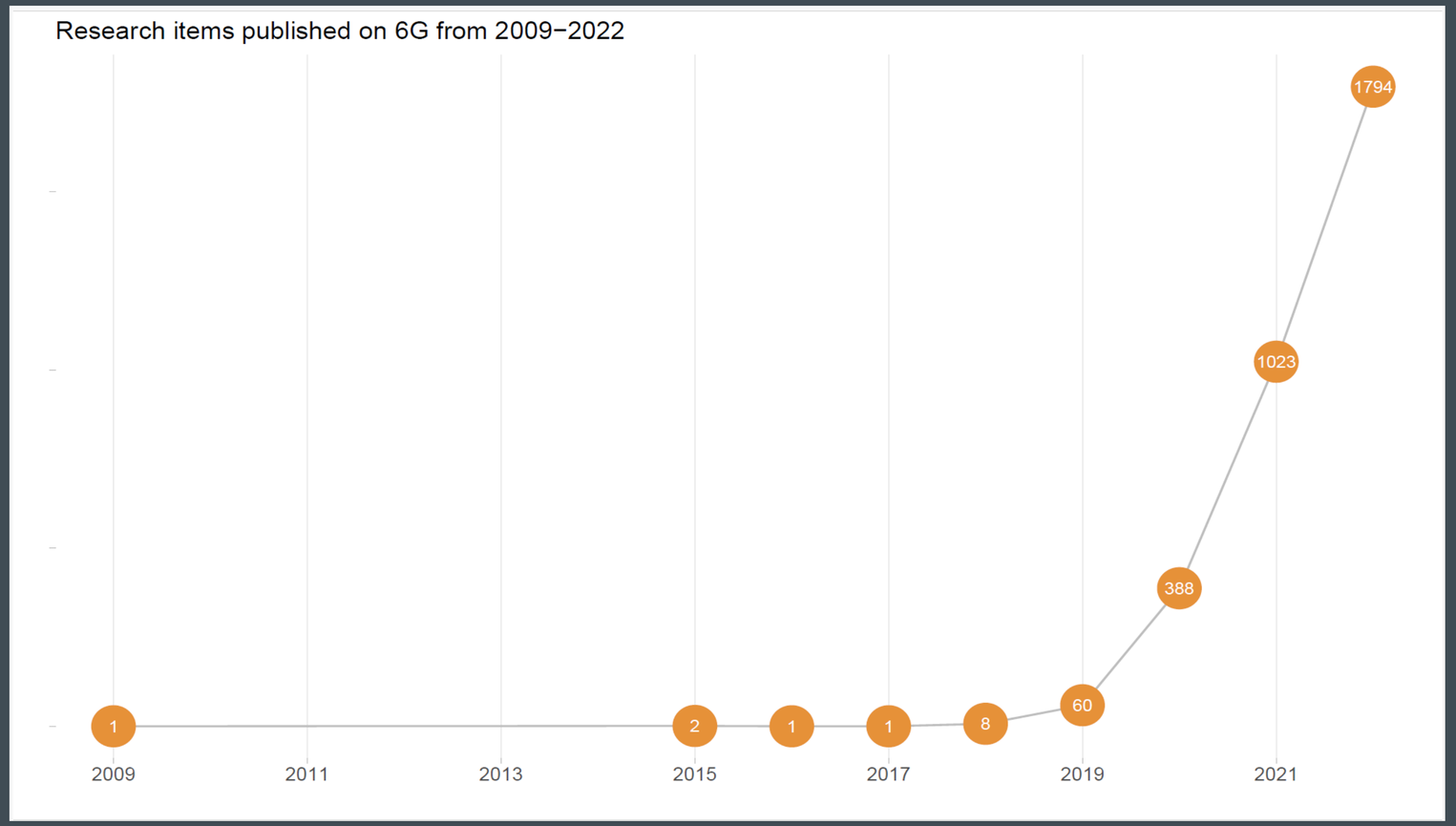
3GPP declared on 23 December, 2024, that is now about to kick-start the process leading to the 6G standards.

1999	ITU approved five IMT-2000 terrestrial radio interfaces for the 3rd Generation of mobile networks: WCDMA (3GPP), CDMA2000, TD-SCDMA, EDGE (3GPP), ETSI DECT.
2001	Early 3G releases (Rel-99 and Rel-4) see UMTS ready for implementation. Multiple Input Multiple Output antennas (MIMO) work starts
2002	Rel-5 introduces the IP Multimedia Subsystem (IMS) and High Speed Downlink Packet Access (HSDPA).
2003	Rel-6 included enhancements to the Multimedia Messaging Service (MMS), 3G/WLAN interworking.
2007	Rel-7 – sets UE Performance Requirements for MBMS.
2009	Rel-8 – first LTE Release completed; Evolved UTRAN + Evolved Packet Core (EPC).
2010	Rel-9 – VoLTE, eHNB for indoor and EMBS broadcast specifications approved.
2011	Rel-10 – LTE-Advanced brings Carrier Aggregation & HetNets; with improvement at cell-edge via enhanced Inter-Cell Interference Coordination (eICIC).
2012	ITU approves IMT-Advanced terrestrial radio interfaces for the 4th Generation of mobile networks: 3GPP LTE Release 10 & Beyond and IEEE WirelessMAN-Advanced (802.16m).
2013	Rel-11 Enhanced downlink control channel (E-PDCCH), Work on avoiding overloading networks with Machine-Type Communications (MTC).
2015	Rel-12 – First ‘vertical’ industry joins: Mission critical experts look to take-up Device to Device (D2D) and Proximity Services features. Work on WiFi integration.
2016	Rel-13 – LTE in unlicensed spectrum, Mission-critical Push-To-Talk. Creation of the LTE-Advanced Pro brand, to promote progress on features for professional user services.
2018	Rel-14 – Improvements of the Mission Critical (MCx) aspects, Vehicle-to-Everything (V2X), improvements for Cellular IoT, eLAA, 4 band & inter-band Carrier Aggregation.
2019	Rel-15 – first release of 5G-NR ready for implementation, in non-standalone networks.
2020	Rel-16 – 3GPP finalizes contribution for IMT-2020, submitting a single Radio Interface Technology (RIT) and combined Sets of 3GPP Radio Interface Technologies (SRIT).
2021	The complete 3GPP 5G proposal accepted by the ITU-R in ‘Detailed specifications of the radio interfaces of IMT-2020.’ (ITU-R M.[IMT-2020.SPECS]).
2022	Some important Rel-17 projects alongside 5G enhancements were: Reduced capability NR (Redap), NR to 71GHz, Non terrestrial Networks (NTN), IoT over NTN, RF reqs for NR FR2, Support for uncrewed aerial systems, Support for edge computing in 5GC, Proximity-based services in 5GS, Access traffic steering, switch and splitting (ATSSS), Support for the Industrial IoT, Advanced V2X...

| 3. going on

Start (2009) 2015

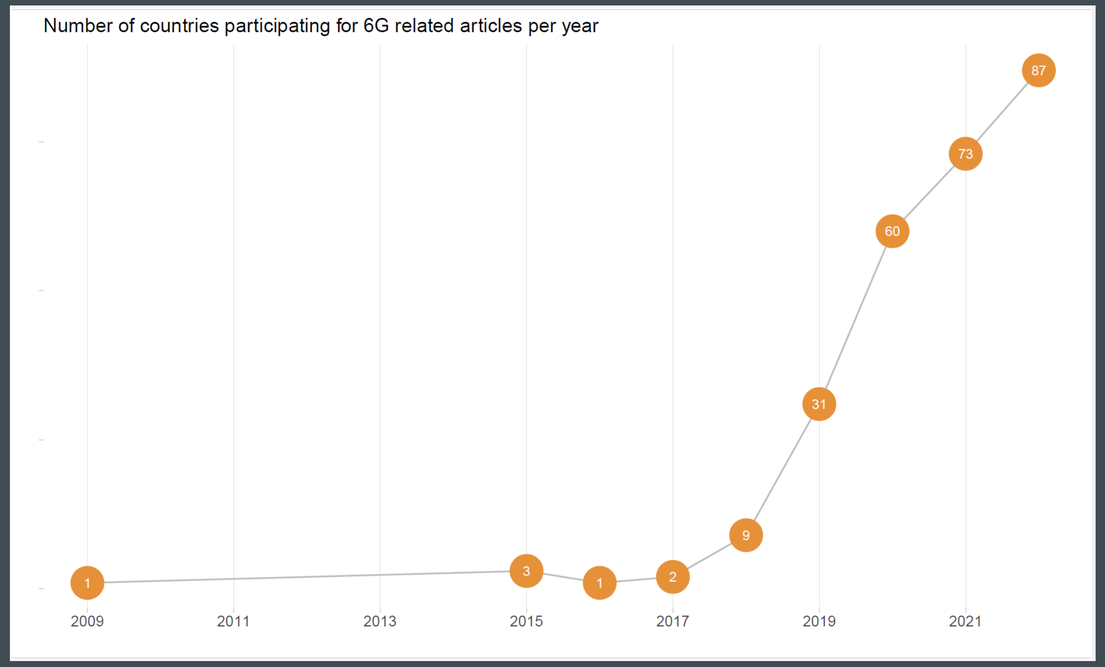
Take-off 2019



This results are subject to revision.

Joint work with
Marta Sacavém and
Bruno Damásio (Nova IMS)

International participation: Really up from 2018



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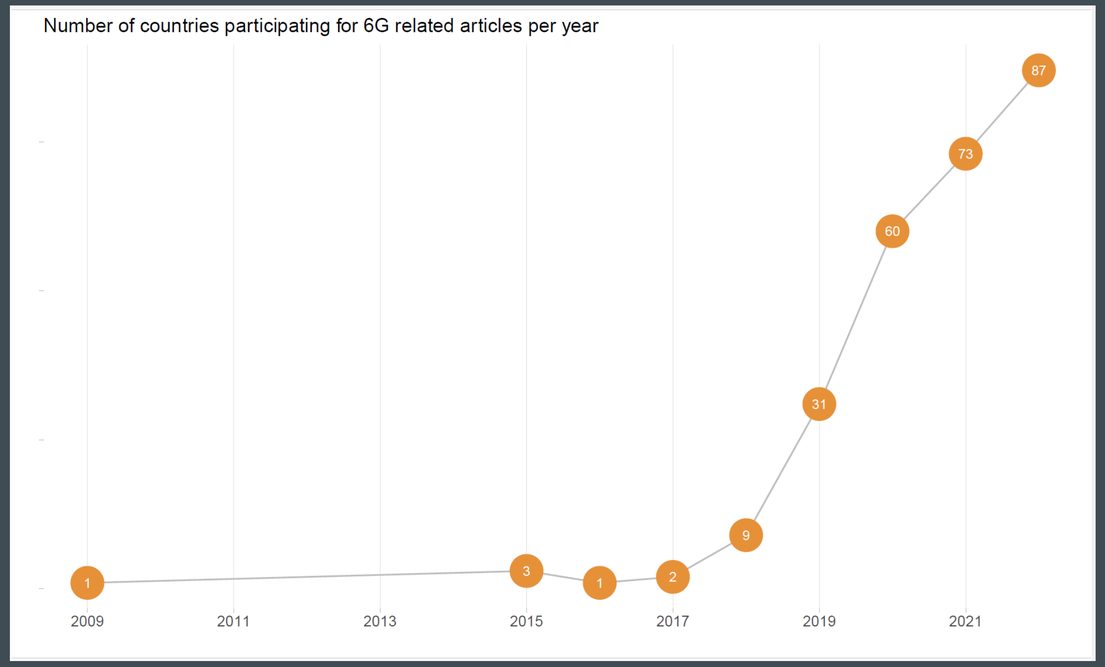
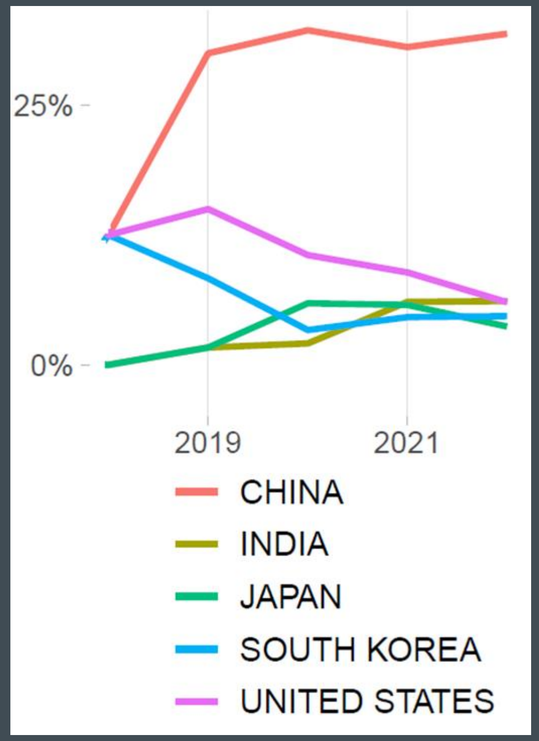
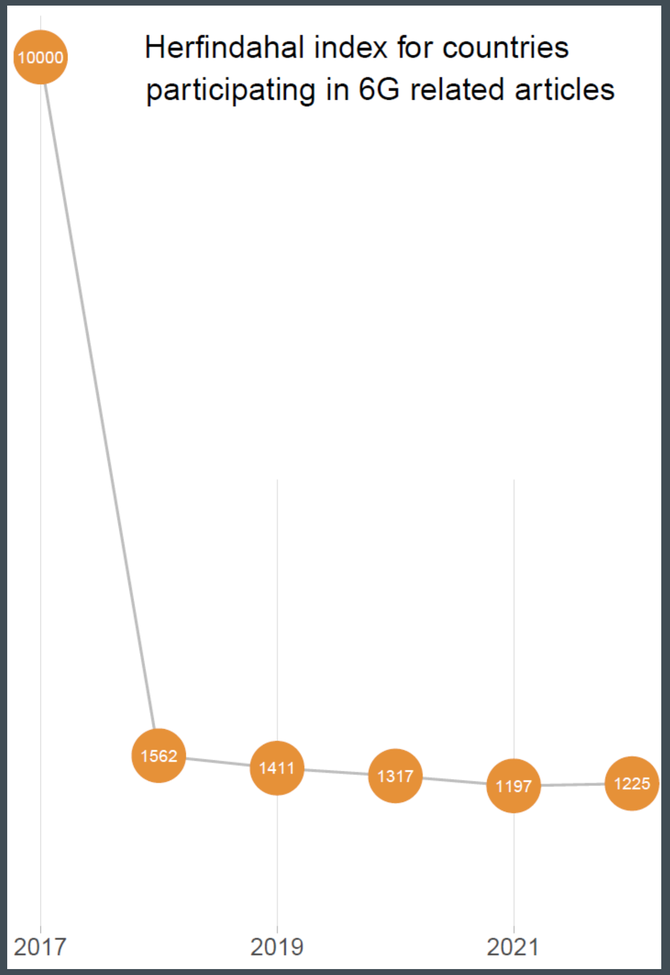


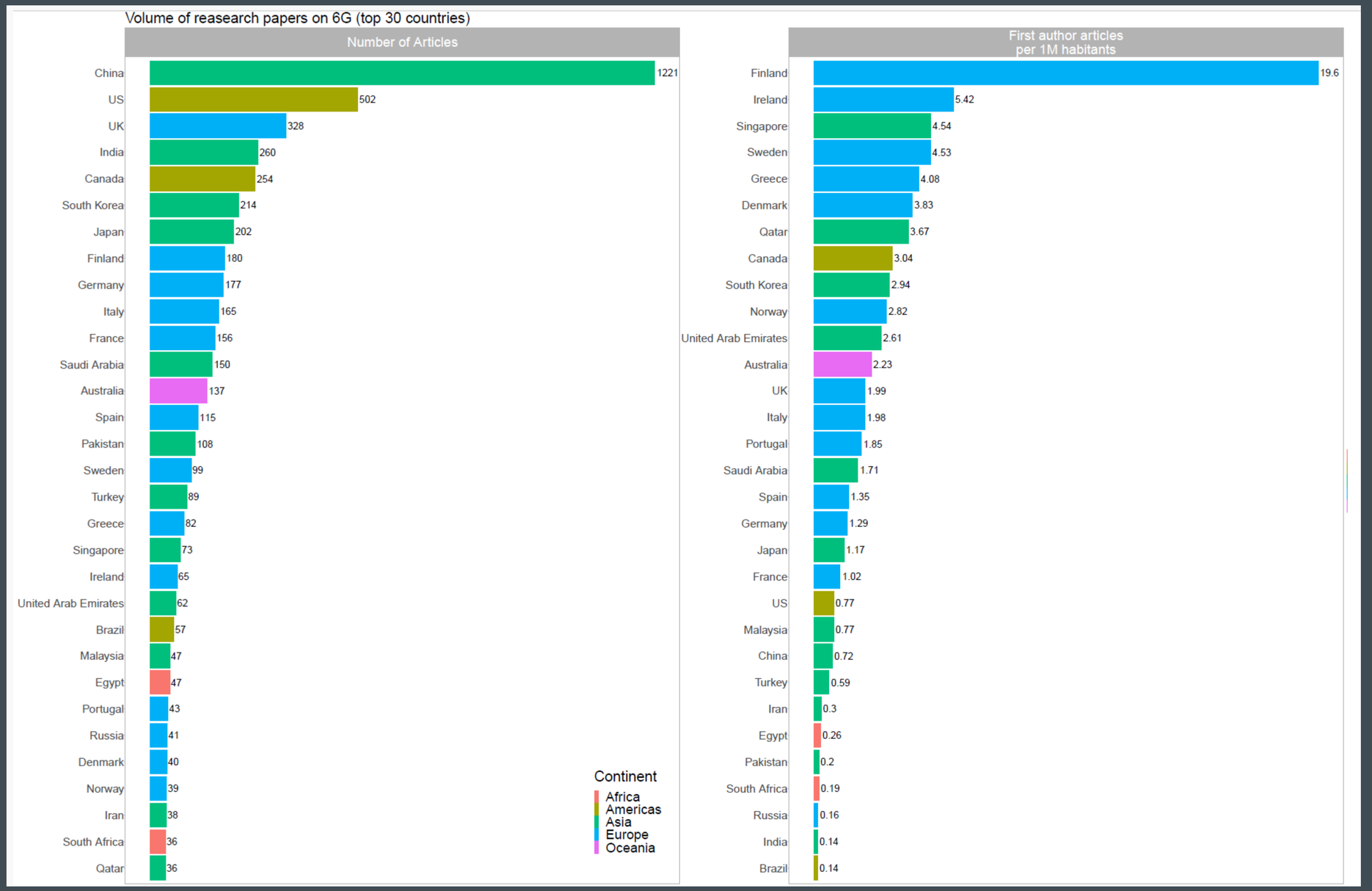
Country weights



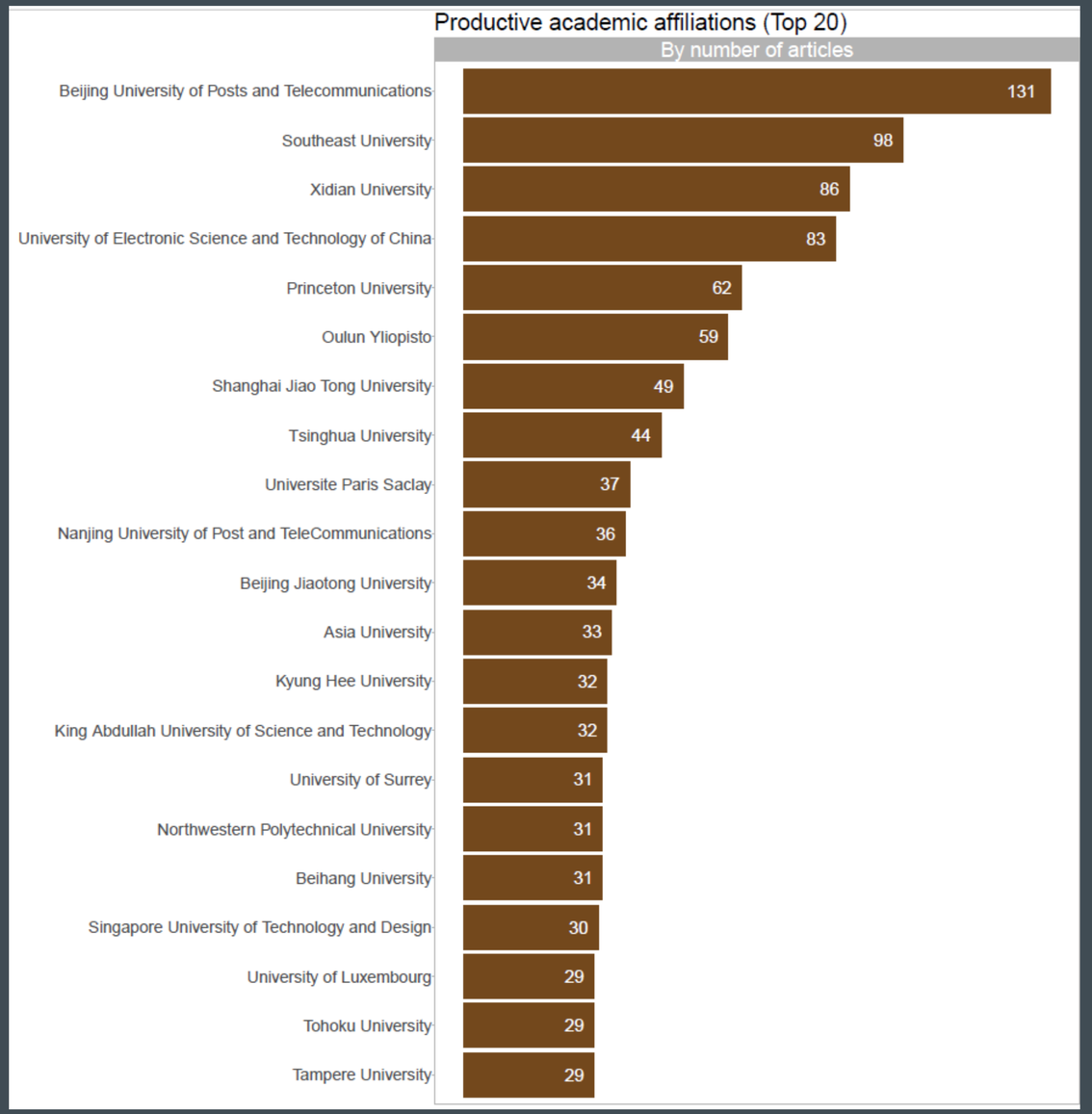
International knowledge diffusion

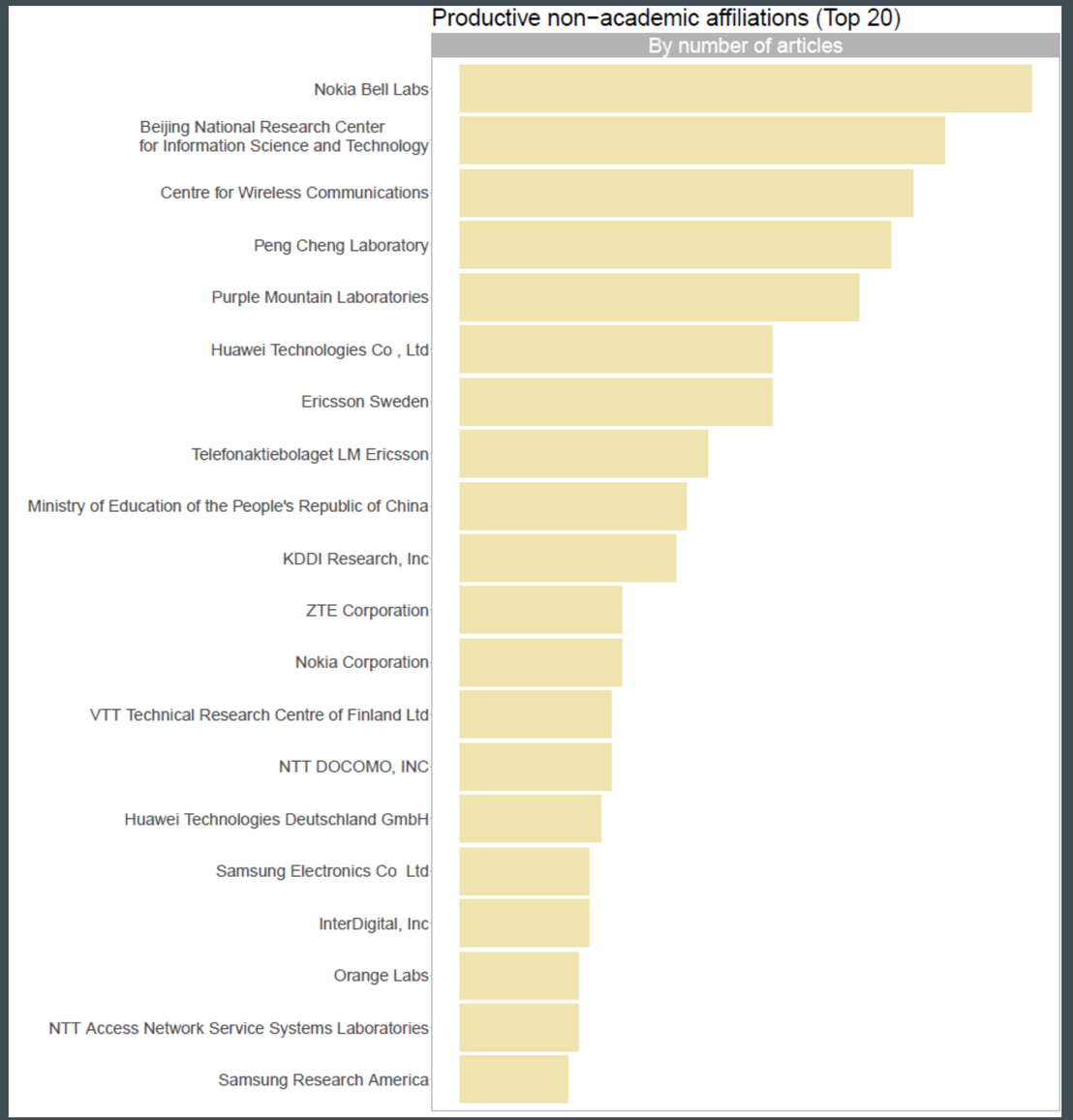


Production and protagonism

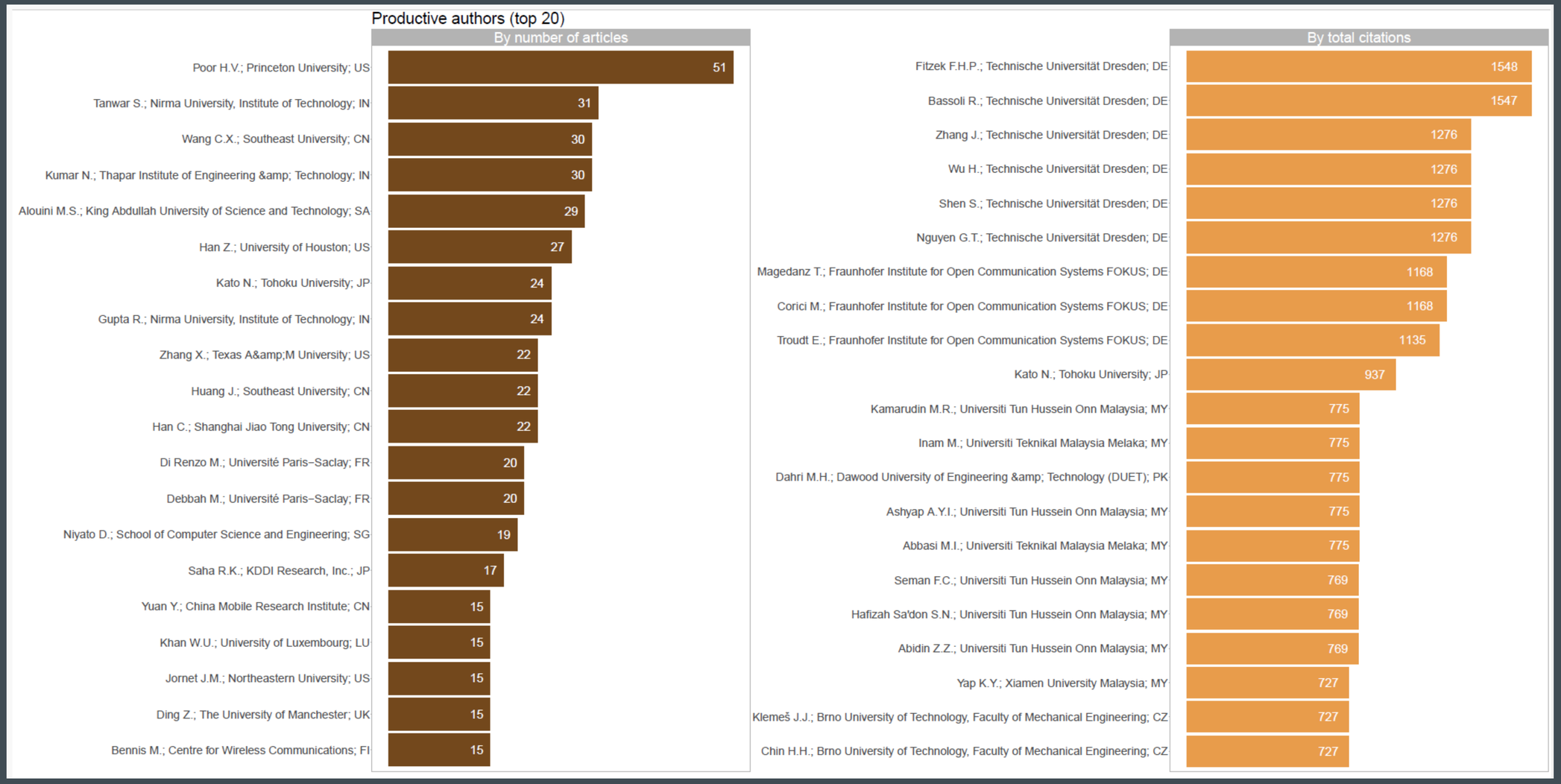


Institutional leadership

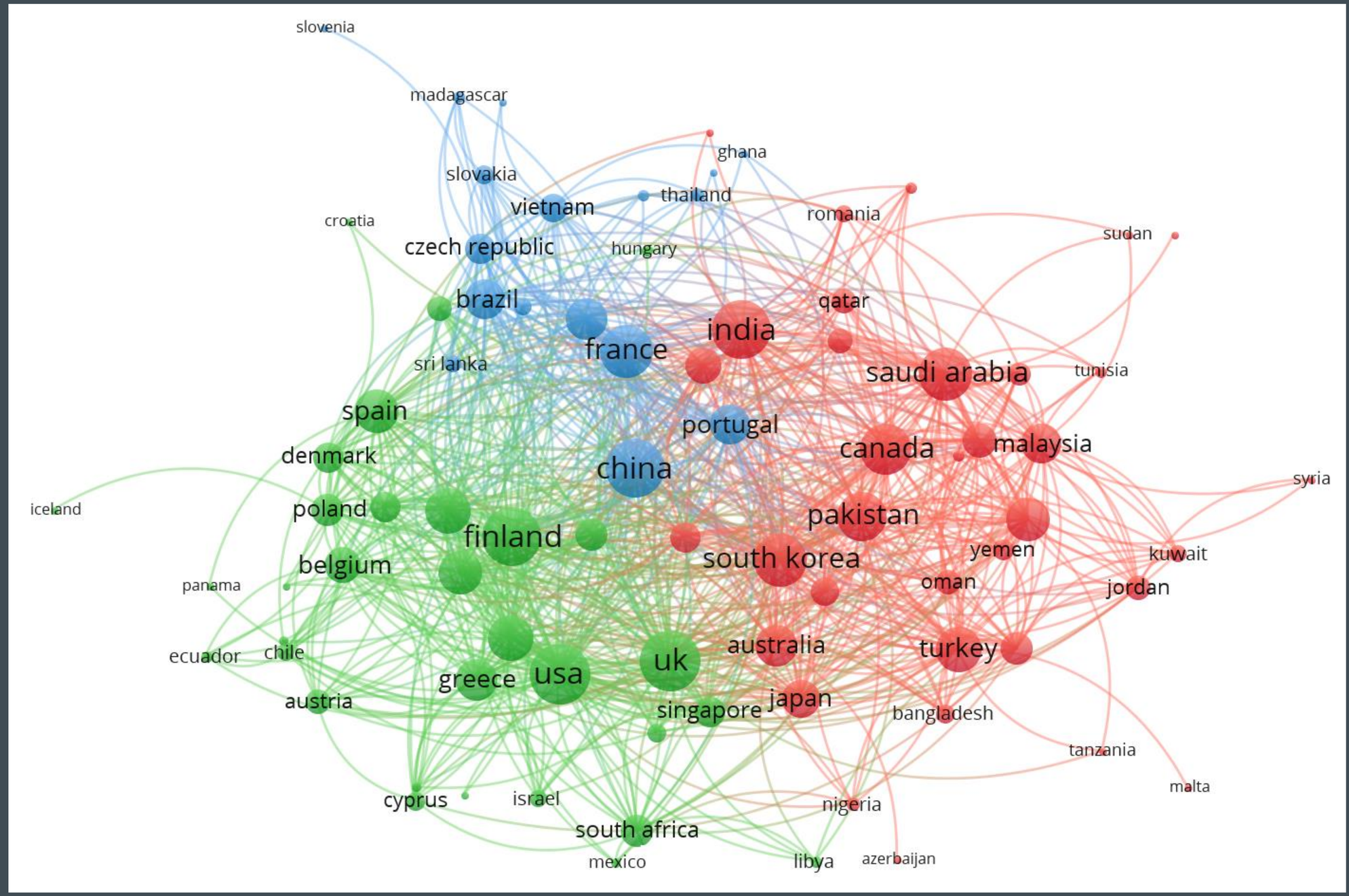




Produção individual de conhecimento



Technological cobbwebb: three groups



Case study: Brasil in the knowledge networks

Top 10 Collaborations for Brazil

5G		Papers
BRAZIL	PORTUGAL	67
BRAZIL	USA	43
BRAZIL	FINLAND	40
BRAZIL	UK	37
BRAZIL	SWEDEN	36
BRAZIL	CHINA	34
BRAZIL	GERMANY	34
BRAZIL	SPAIN	27
BRAZIL	FRANCE	25
BRAZIL	ITALY	25

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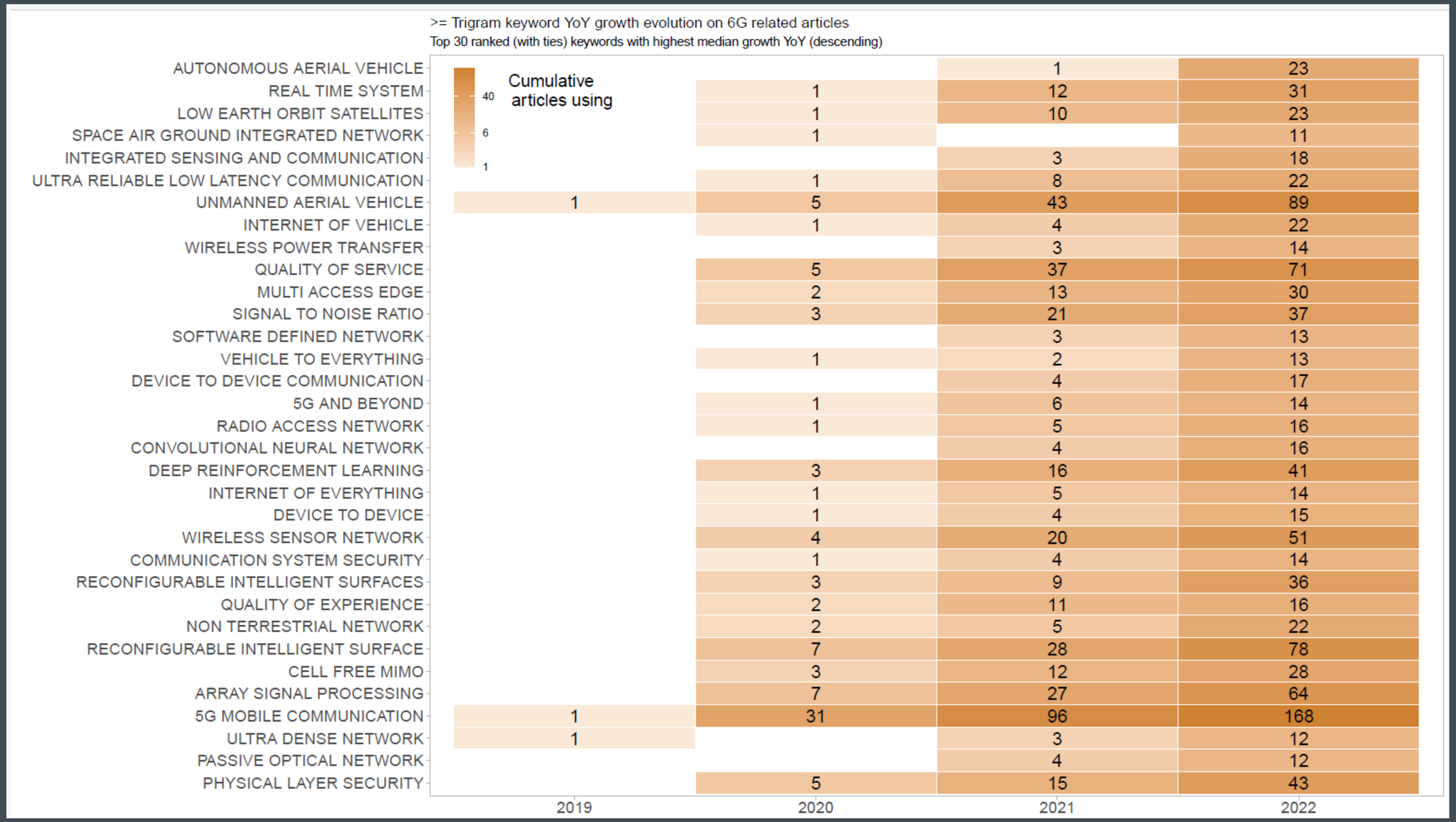
BRAZIL	FRANCE	25
BRAZIL	ITALY	25

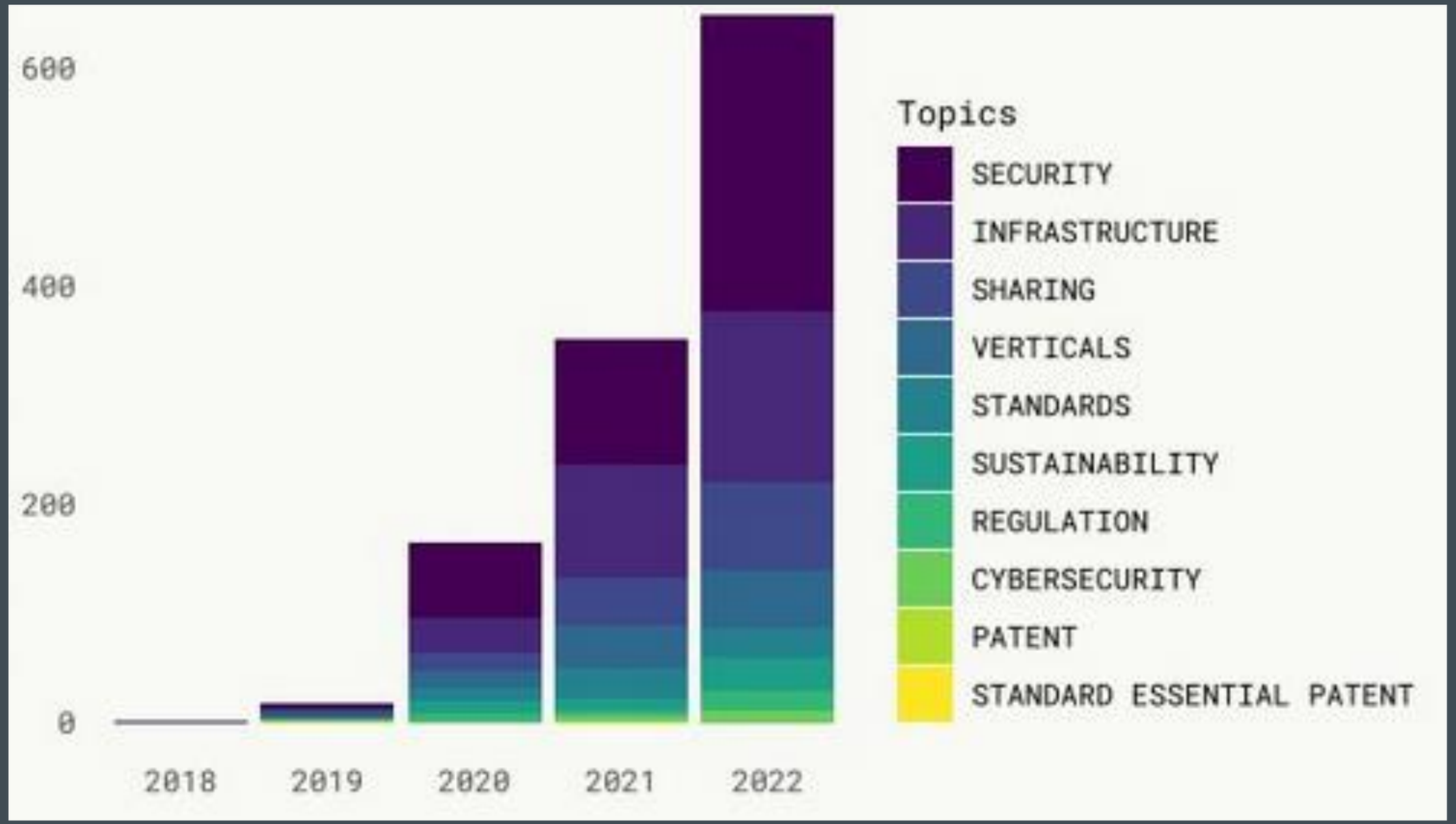
6G		Papers
FINLAND	BRAZIL	11
BRAZIL	CHINA	8
BRAZIL	PORTUGAL	7
BRAZIL	FRANCE	6
BRAZIL	USA	6
BRAZIL	UK	6
BRAZIL	PAKISTAN	5
BRAZIL	INDIA	4
BRAZIL	CANADA	4
BRAZIL	IRELAND	4

Technological trajectories



	2019	2020	2021	2022
AUTONOMOUS AERIAL VEHICLE			1	23
REAL TIME SYSTEM		1	12	31
LOW EARTH ORBIT SATELLITES		1	10	23
SPACE AIR GROUND INTEGRATED NETWORK		1		11
INTEGRATED SENSING AND COMMUNICATION			3	18
ULTRA RELIABLE LOW LATENCY COMMUNICATION		1	8	22
UNMANNED AERIAL VEHICLE	1	5	43	89
INTERNET OF VEHICLE		1	4	22
WIRELESS POWER TRANSFER			3	14
QUALITY OF SERVICE		5	37	71
MULTI ACCESS EDGE		2	13	30
SIGNAL TO NOISE RATIO		3	21	37
SOFTWARE DEFINED NETWORK			3	13
VEHICLE TO EVERYTHING		1	2	13
DEVICE TO DEVICE COMMUNICATION			4	17
5G AND BEYOND		1	6	14
RADIO ACCESS NETWORK		1	5	16
CONVOLUTIONAL NEURAL NETWORK			4	16
DEEP REINFORCEMENT LEARNING		3	16	41
INTERNET OF EVERYTHING		1	5	14
DEVICE TO DEVICE		1	4	15
WIRELESS SENSOR NETWORK		4	20	51
COMMUNICATION SYSTEM SECURITY		1	4	14
RECONFIGURABLE INTELLIGENT SURFACES		3	9	36
QUALITY OF EXPERIENCE		2	11	16
NON TERRESTRIAL NETWORK		2	5	22
RECONFIGURABLE INTELLIGENT SURFACE		7	28	78
CELL FREE MIMO		3	12	28
ARRAY SIGNAL PROCESSING		7	27	64
5G MOBILE COMMUNICATION	1	31	96	168
ULTRA DENSE NETWORK	1		3	12
PASSIVE OPTICAL NETWORK			4	12
PHYSICAL LAYER SECURITY		5	15	43

Strategic themes



| ... conclusions

- Decade-by-decade pulse
- 2023 marks na institutional turning-point for the 6G future
- So far the innovation process reveals:

  - Explosive growth since 2019
  - Extended geography of scientific and technical contributions
  - China with large volume and quite central in international partnerships
  - Very influential private Nordic organizations
  - Recent attention to non-terrestrial networks and robotics
  - Substantive directionality of the strategic theme of security (resilience, integrity)