# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Introduction*

ZAHID GHADIALY

JUNE 2021

@6Gtraining

@3g4gUK

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# Legal Disclaimer

This presentation is intended to stimulate discussion on some of the exciting current and future developments in digital communications technology and networks. It also contains some forward-looking statements, research and speculation that may never become part of standards.

It strives to provide the latest and most correct information. Due to the vastness of standards, constant change and revision, it is possible that the following information may not be entirely up to date or correct. E&OE.

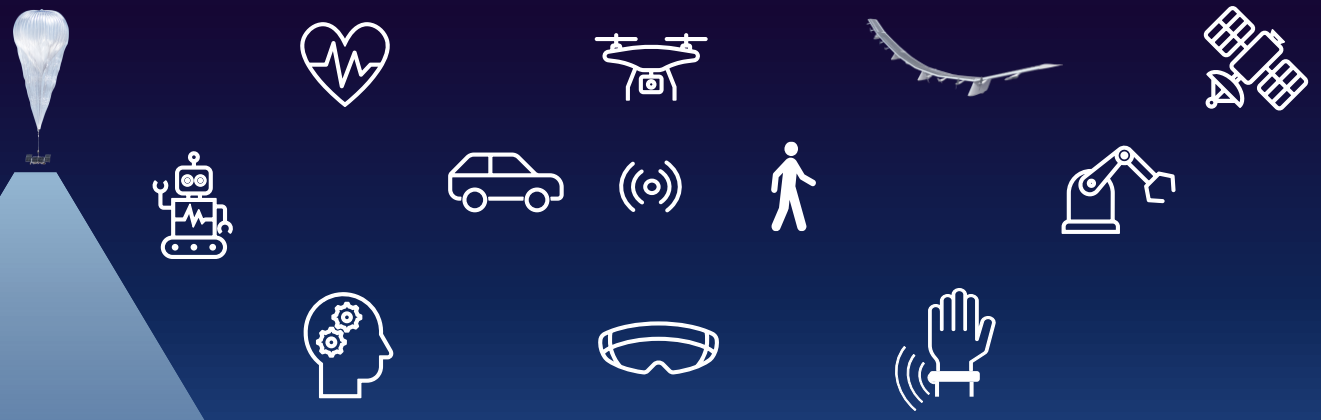
There are references to information in public domain (books, websites, standard documents, etc.) in this material. Attempt has been made to give credit to all such references wherever possible. The original copyright holders retain the copyright to their material.

It would not be prudent to make any financial or investment decisions based on this presentation.

# Before we begin

Please Note:

- This is a very basic introductory course.
- This is designed for people with deep understanding of the mobile wireless technology and ecosystem.
- Even if you are a beginner in this domain, you will learn somethings but not everything.
- There is no programming involved in any way.
- There are no review questions / answers.
- I will provide a lot of references that you can use to study this topic further.



# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 1: Introduction*

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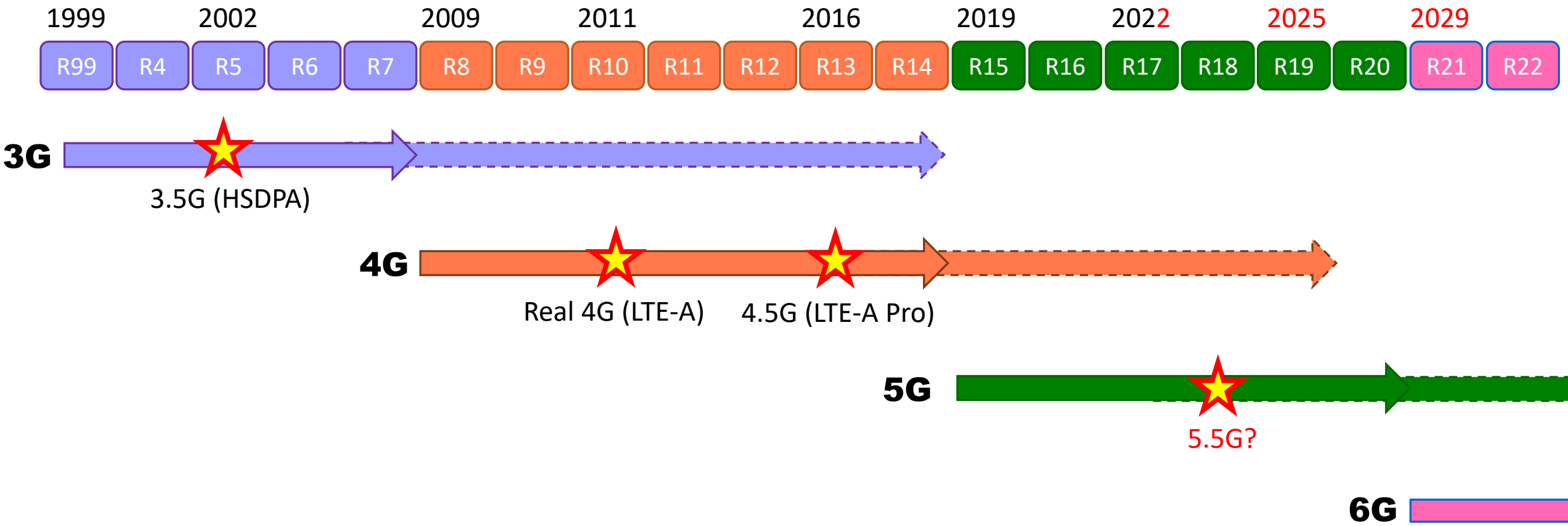
# Part 1 Video Link

# What exactly is 6G?

# When is 6G coming?

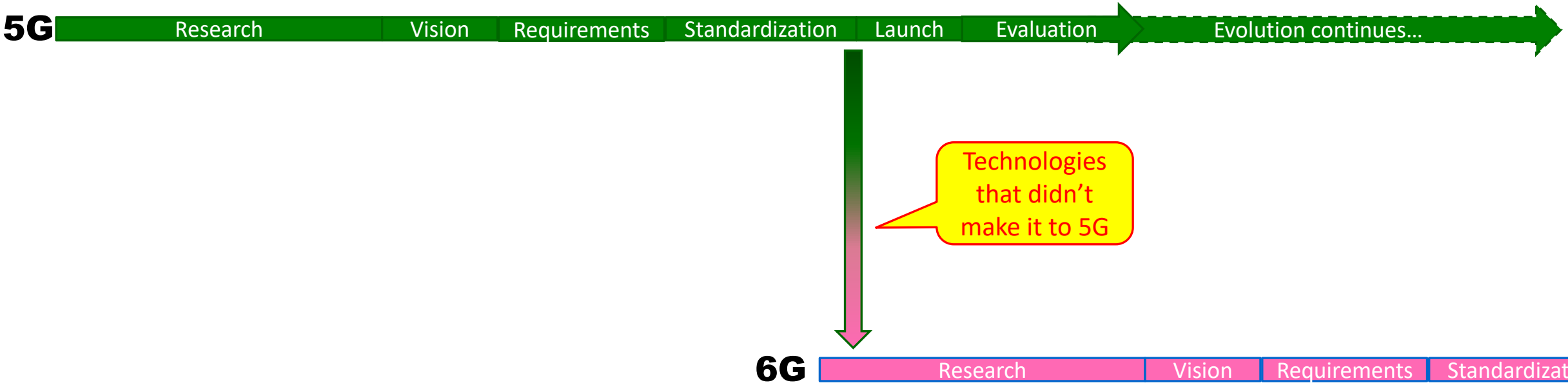
# 3GPP Releases Timeline




Red text indicates dates and features are not confirmed

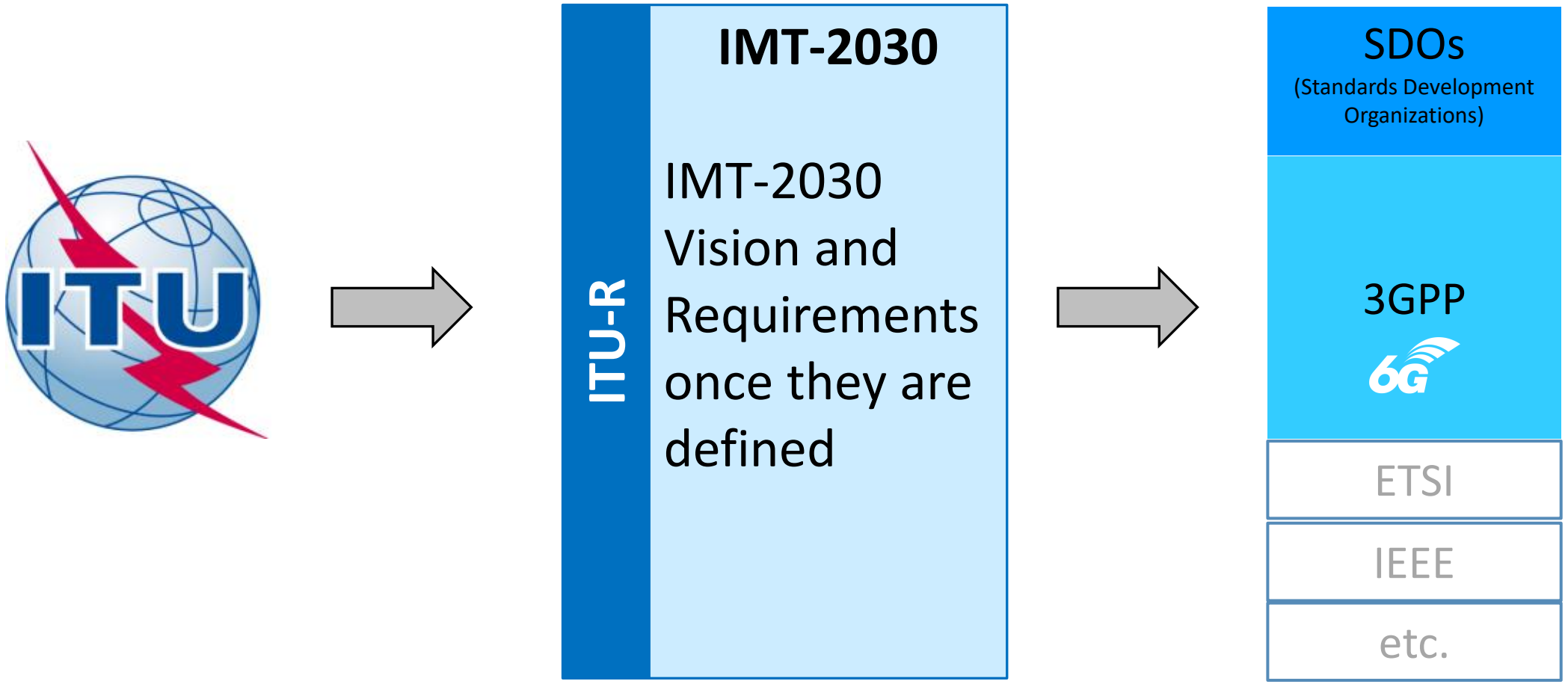
3GPP Release Dates on 3GPP Portal

# If 5G is being launched just now, why are we talking about 6G already?


5G
Research
Vision
Requirements
Standardization
Launch
Evaluation
Evolution continues…
Technologies that didn't make it to 5G
6G
Research
Vision
Requirements
Standardization

# Who is standardising 6G?

# Tentative 6G Standardisation Process



# Will 6G be called 6G?

# Will 6G be called 6G?

| Marketing Name | ITU Name | 3GPP Name | RAN Name | Core Name | System Name |
|---|---|---|---|---|---|
| **3G** | IMT-2000 | UMTS | UTRAN | UMTS Core | UMTS System |
| **3.5G** | Enhanced IMT-2000 | UMTS HSPA | UTRAN | UMTS Core | UMTS System |
| **4G** | IMT-Advanced | LTE-Advanced | E-UTRAN | Evolved Packet Core (EPC) | Evolved Packet System (EPS) |
| **5G** | IMT-2020 | 5G | New Radio (NR) | 5G Core (5GC) | 5G System (5GS) |
| **6G** | IMT-2030 | 6G | ? | ? | ? |

Red text indicates that the names have not been confirmed.

# Course Outline!

# Course Outline: An Introduction to 6G Wireless

- Part 1: Introduction
- Part 2: 6G Vision
- Part 3: 6G Use Cases & Applications
- Part 4: 6G Timeline
- Part 5: 6G Requirements
- Part 6: 6G Groups
- Part 7: 6G Technologies
- Part 8: 6G Devices
- Part 9: Course Summary and Conclusion

# Background Material

- The 3G4G Blog: 3G -> 3.9G, May 2007 (link)
- The 3G4G Blog: IMT Advanced = 4G, June 2007 (link)
- The 3G4G Blog: Revised paper on “4G” by 3G Americas, Aug 2008 (link)
- 3GPP system standards heading into the 5G era, Spring 2014 (link)
- The 3G4G Blog: What is (pre-5G) 4.5G?, Oct 2014 (link)
- ITU: ITU agrees on key 5G performance requirements for IMT-2020, Feb 2017 (link)
- The 3G4G Blog: IMT-2020 (5G) Requirements, March 2017 (link)
- ITU IMT-2020 Page (link)
- 3GPP Release-15 Page (link)

# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 2: 6G Vision*

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# Part 2 Video Link

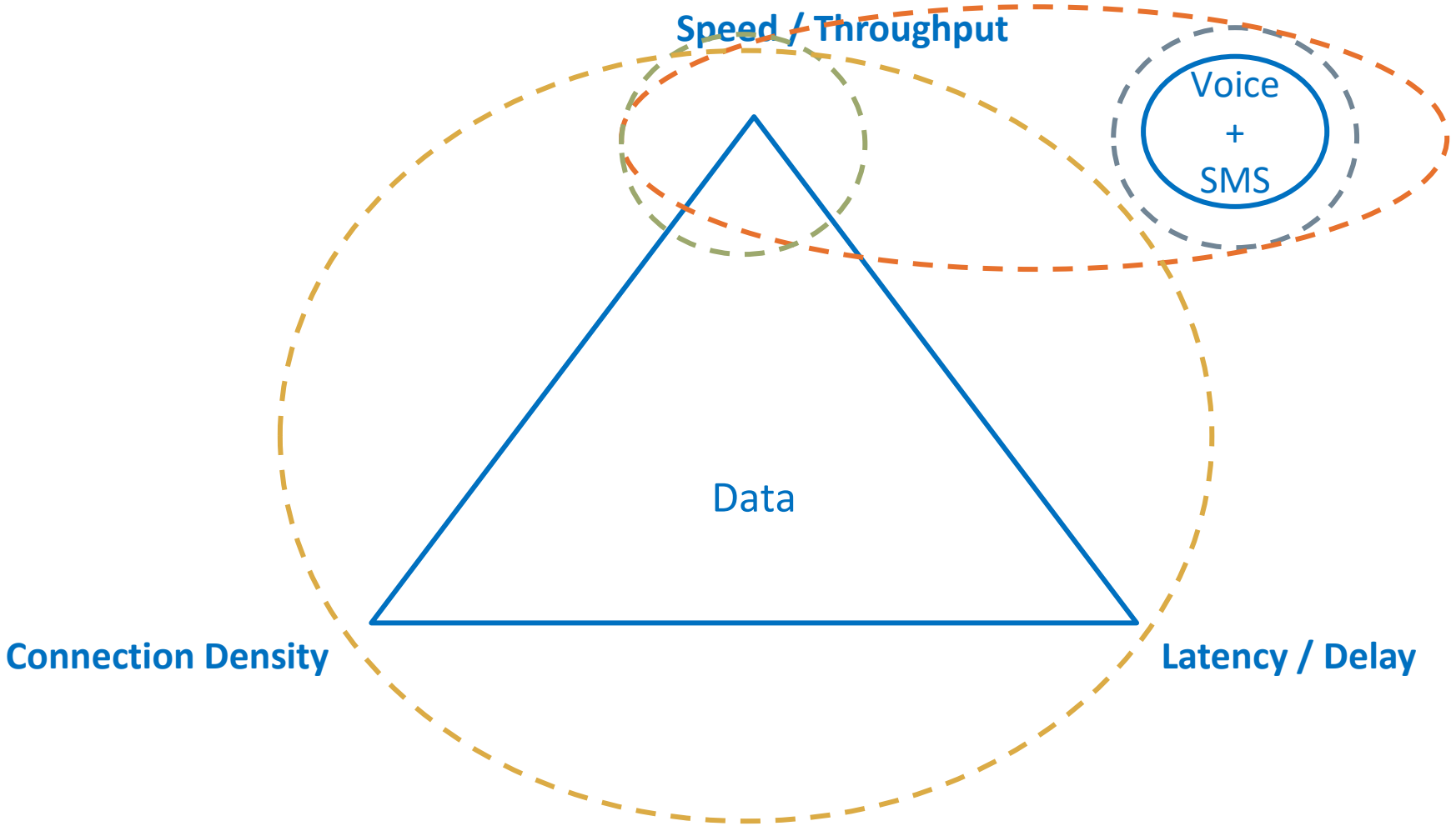
# Focus area for different technology generations

2G Focus area

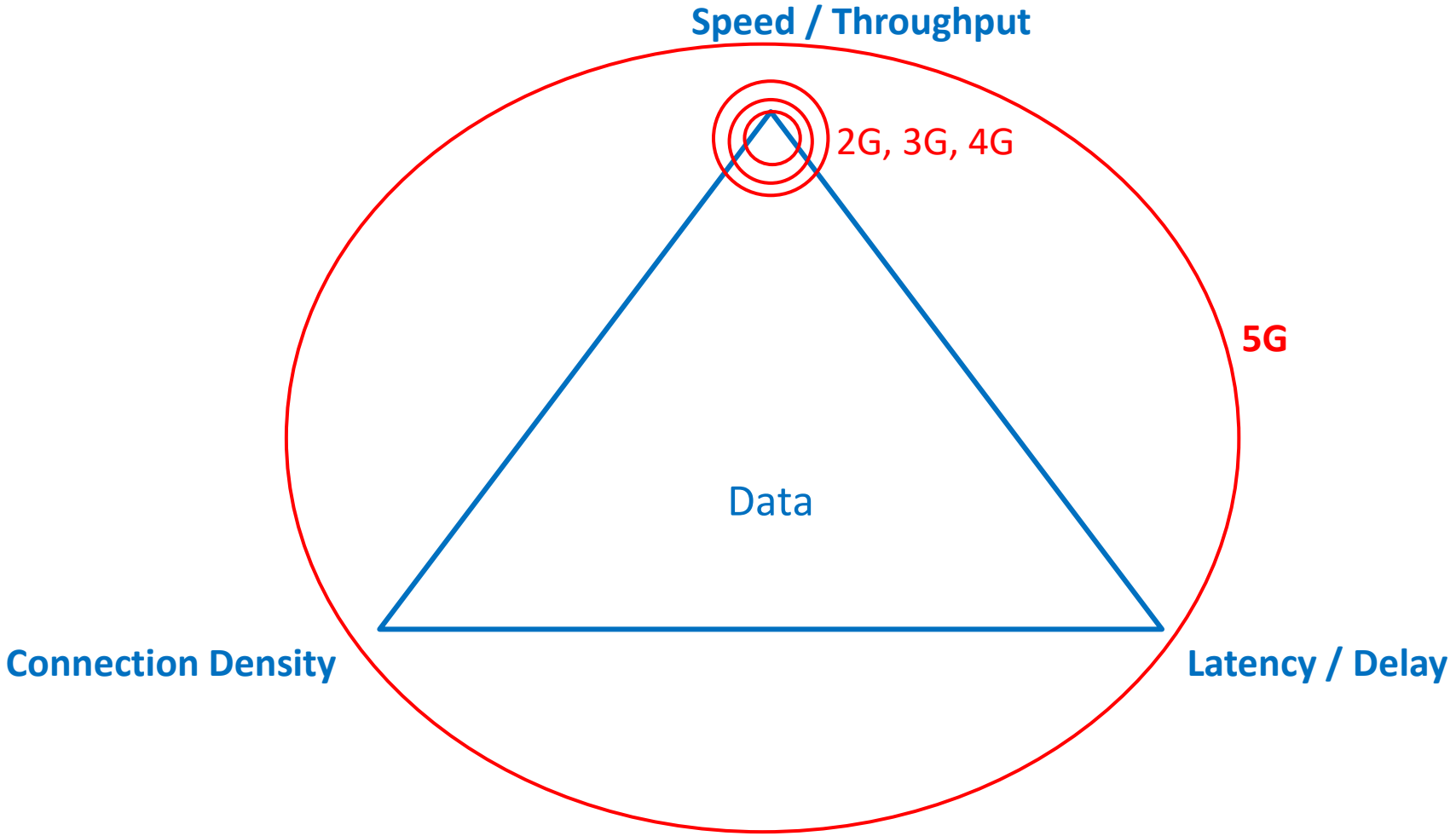
3G Focus area

4G Focus area

5G Focus area



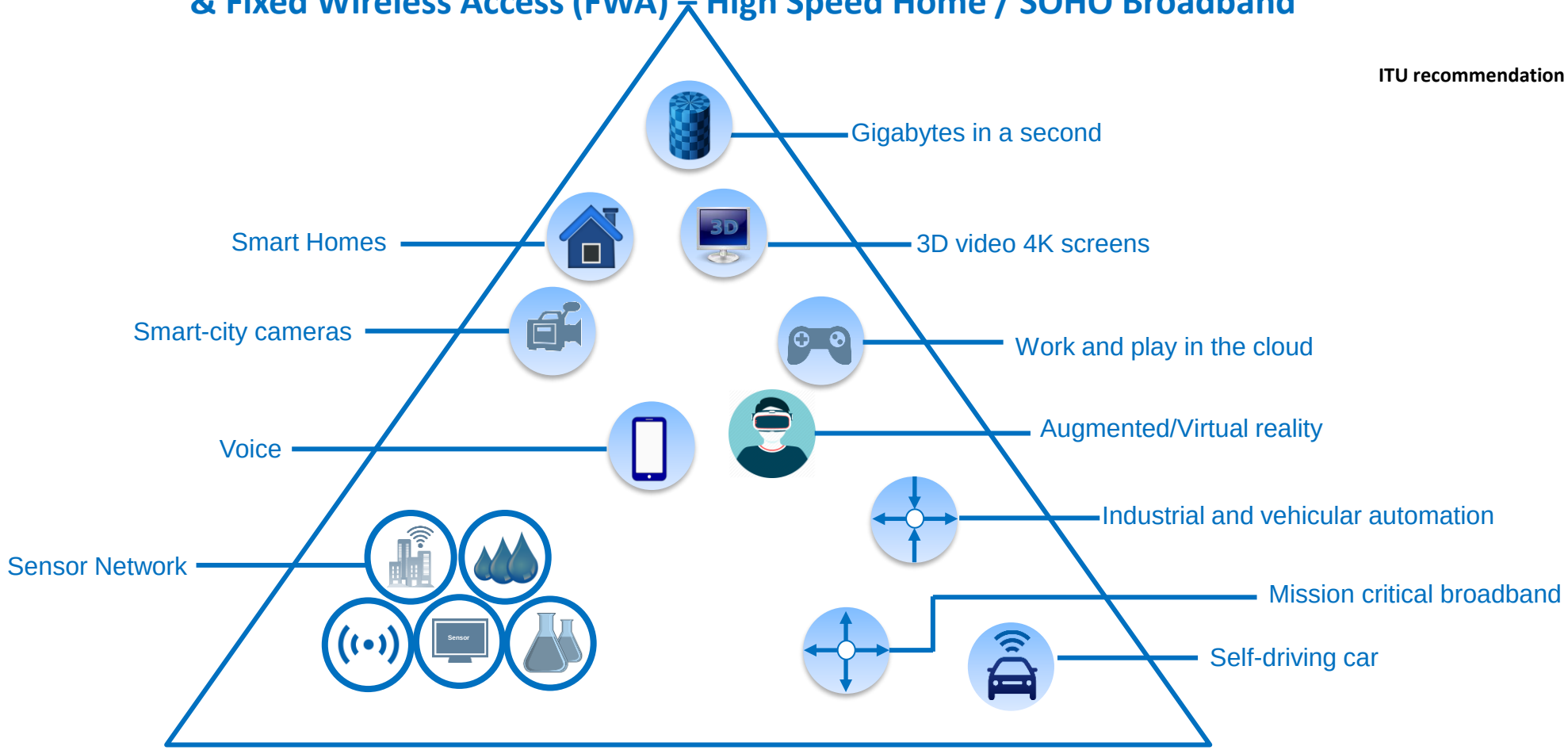
# Focus area for different technology generations



# IMT-2020 High Level Vision

**eMBB (enhanced Mobile Broadband) – Capacity Enhancement**
**& Fixed Wireless Access (FWA) – High Speed Home / SOHO Broadband**

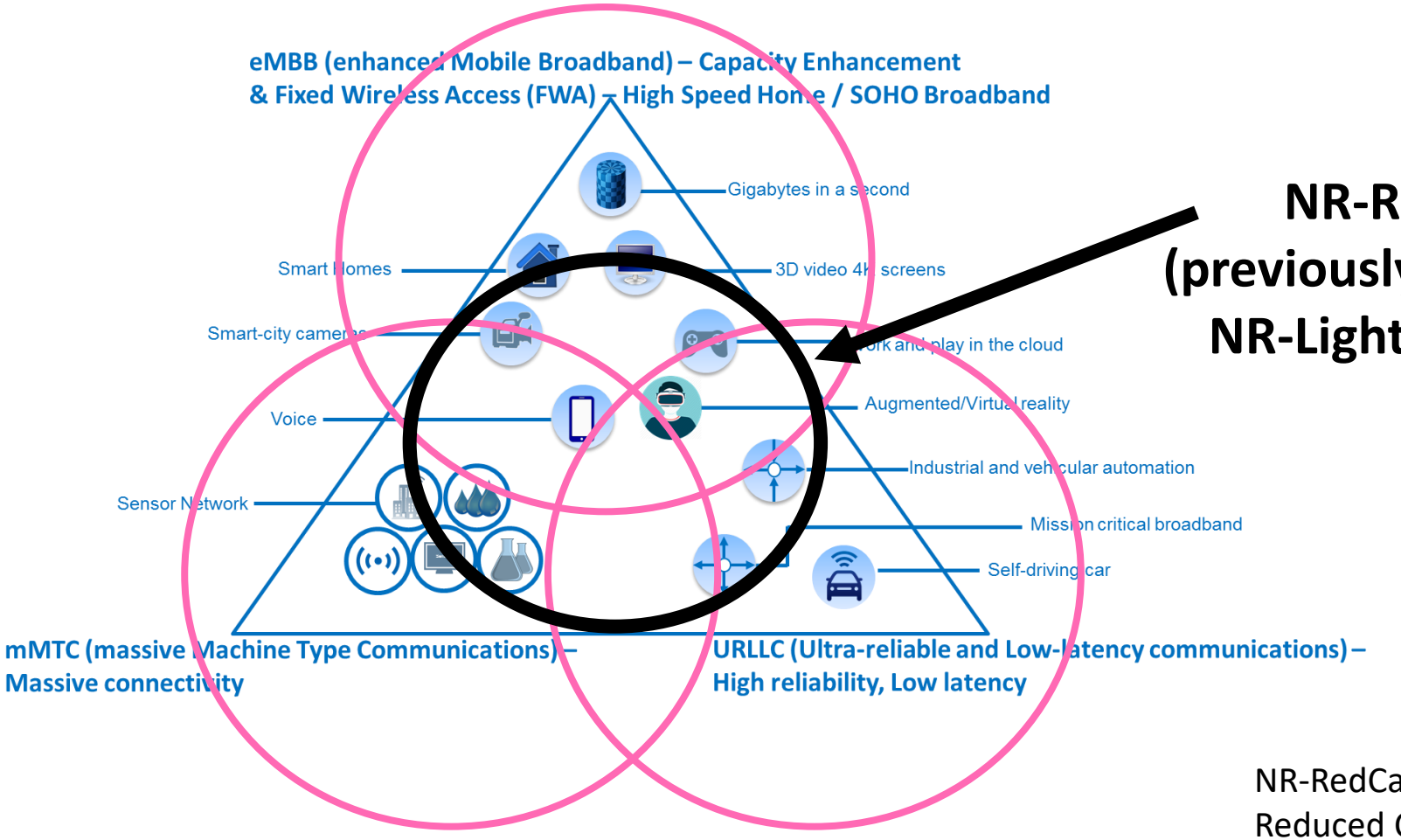
**ITU recommendation ITU-R M.2083-0**




**mMTC (massive Machine Type Communications) – Massive connectivity**

**URLLC (Ultra-reliable and Low-latency communications) – High reliability, Low latency**

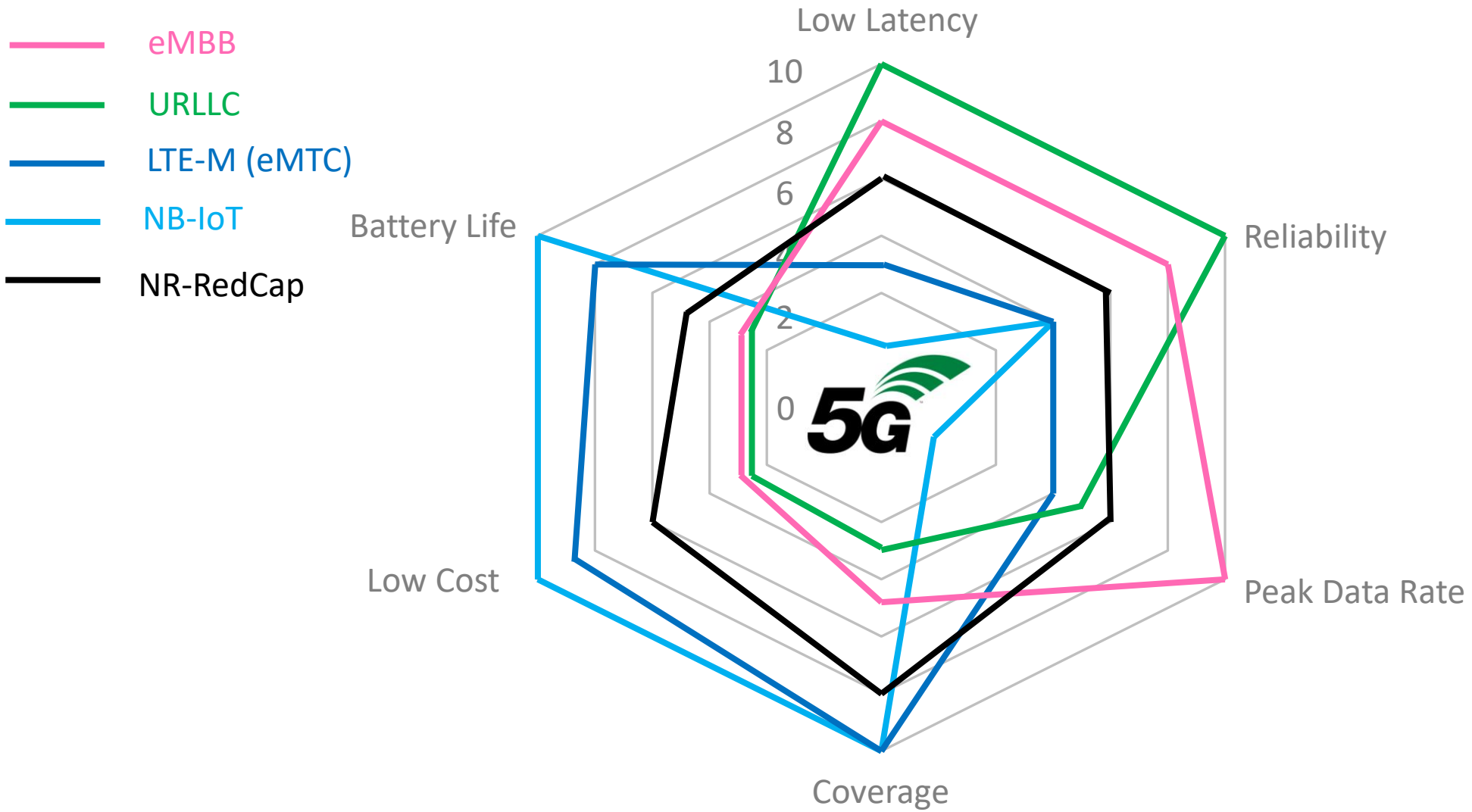
# Motivation for NR-RedCap in Release-17



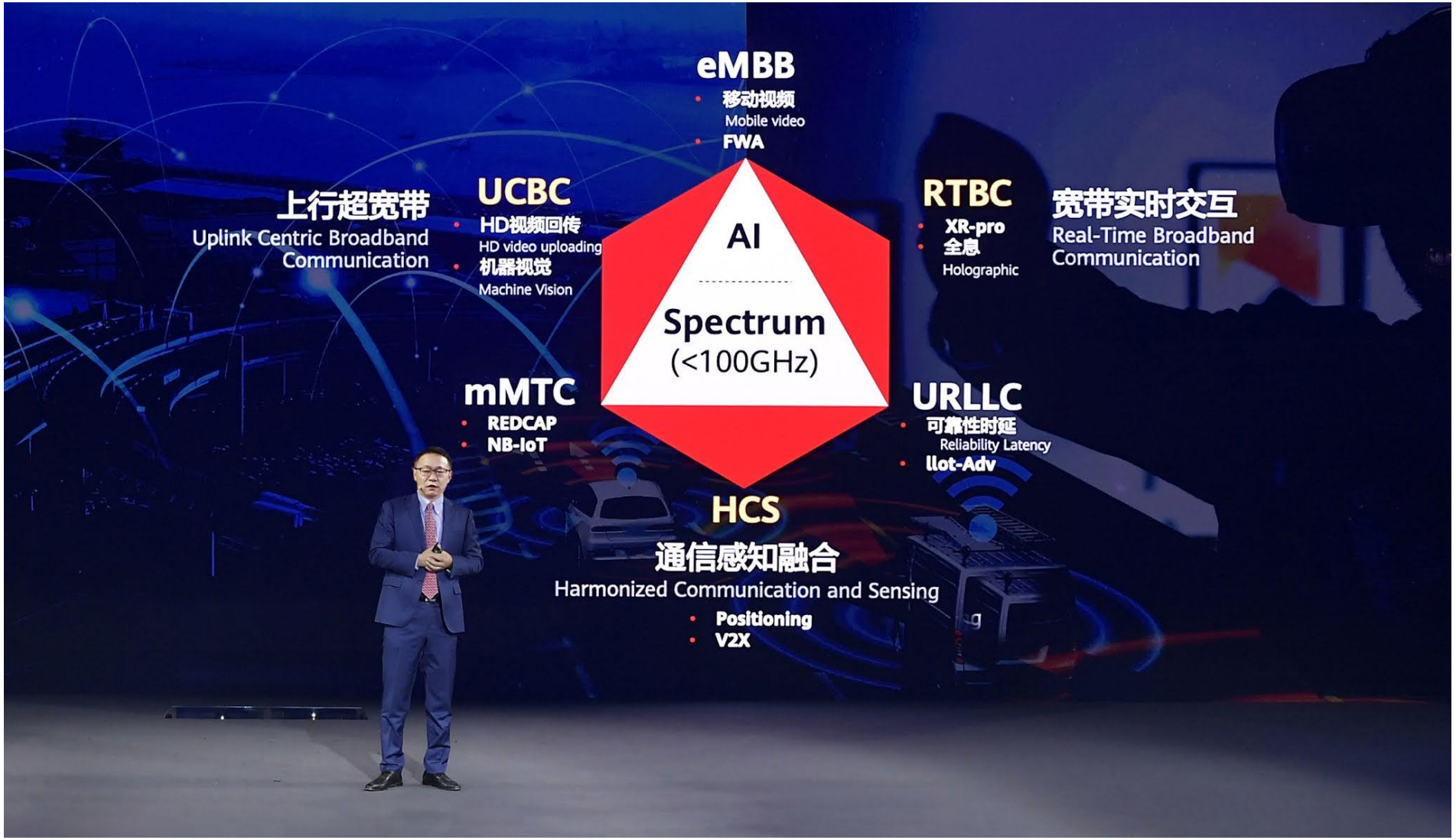

**NR-RedCap (previously known as NR-Light, NR-Lite)**

NR-RedCap (New Radio Reduced Capability Device)

# Motivation for NR-RedCap in Release-17



# Huawei 5.5G Vision




Source

# NTT Docomo's 6G Vision

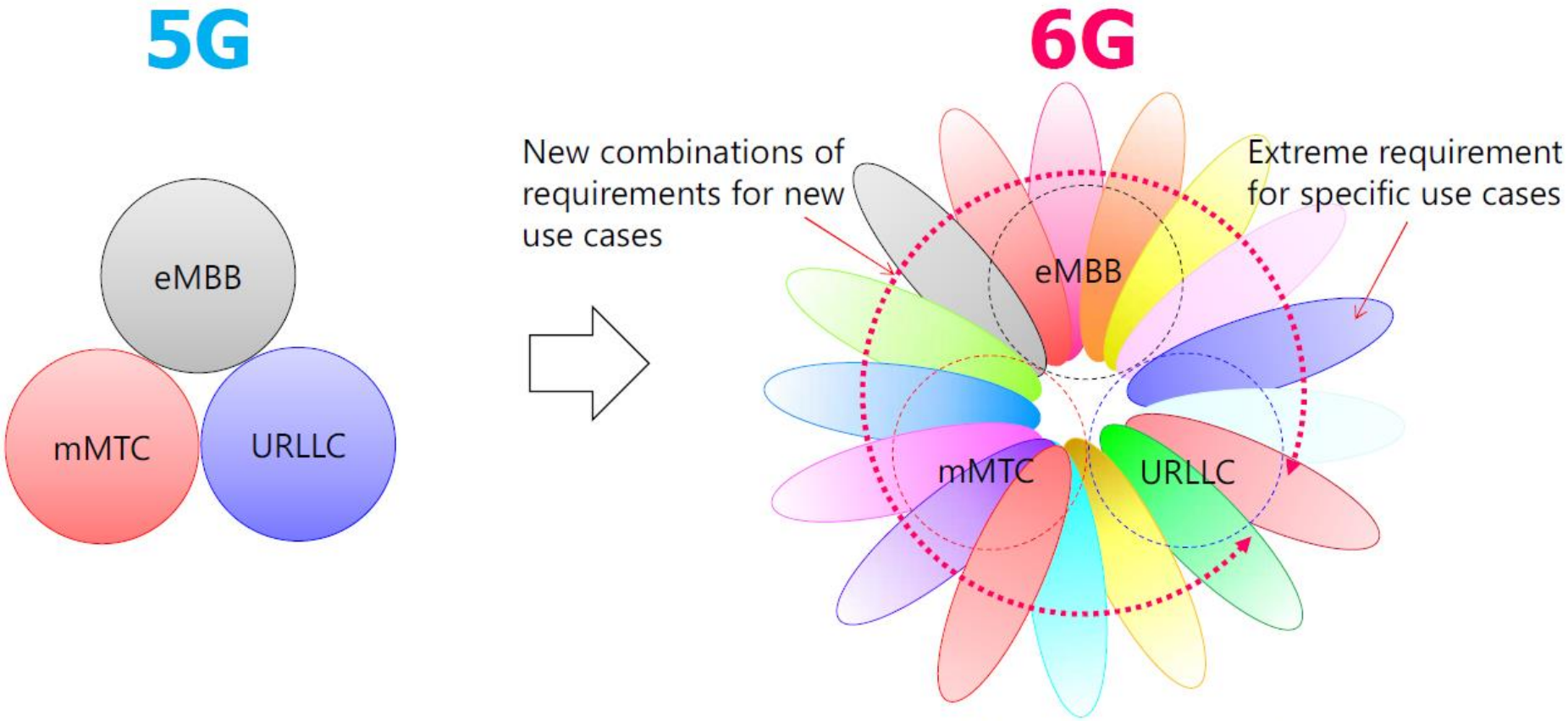
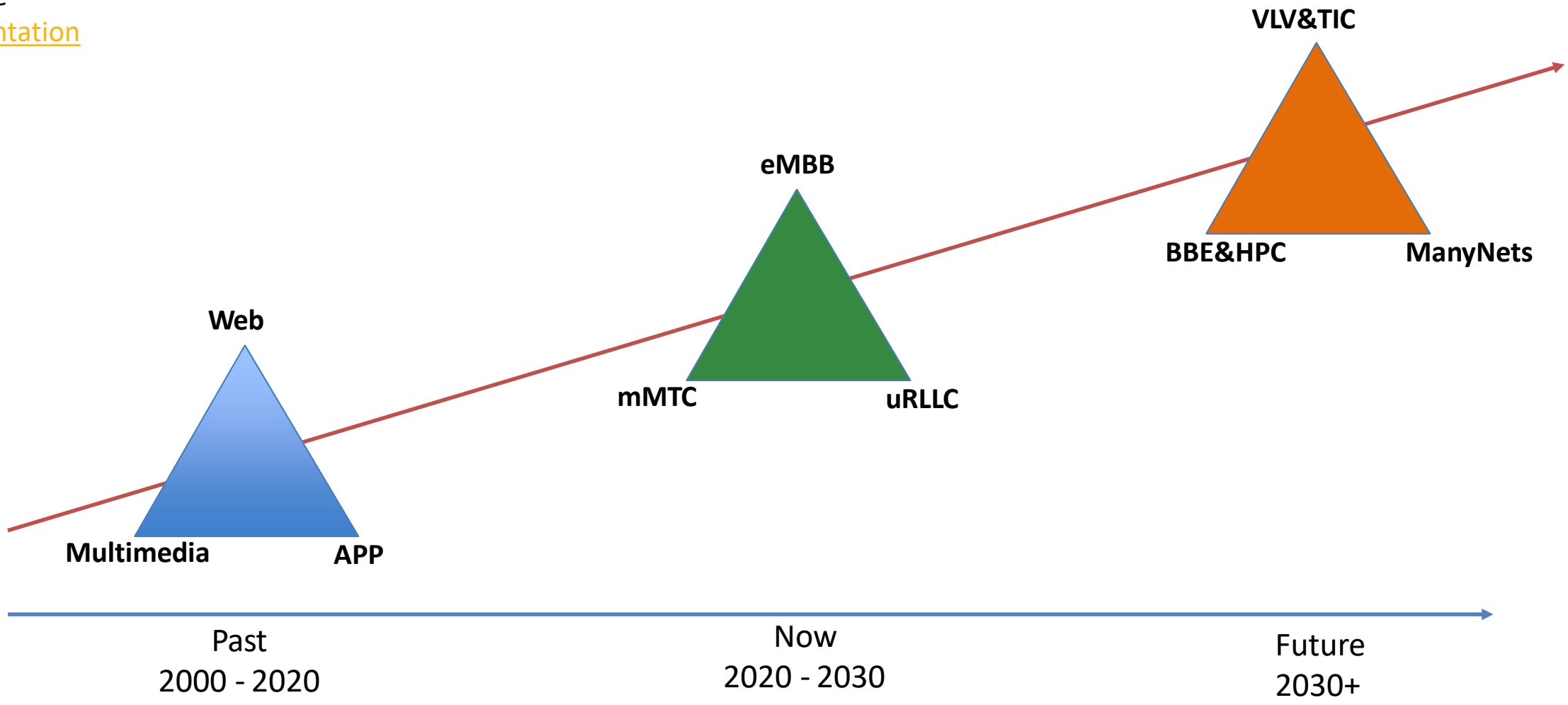



Figure 2-5. Image of technological development toward 6G

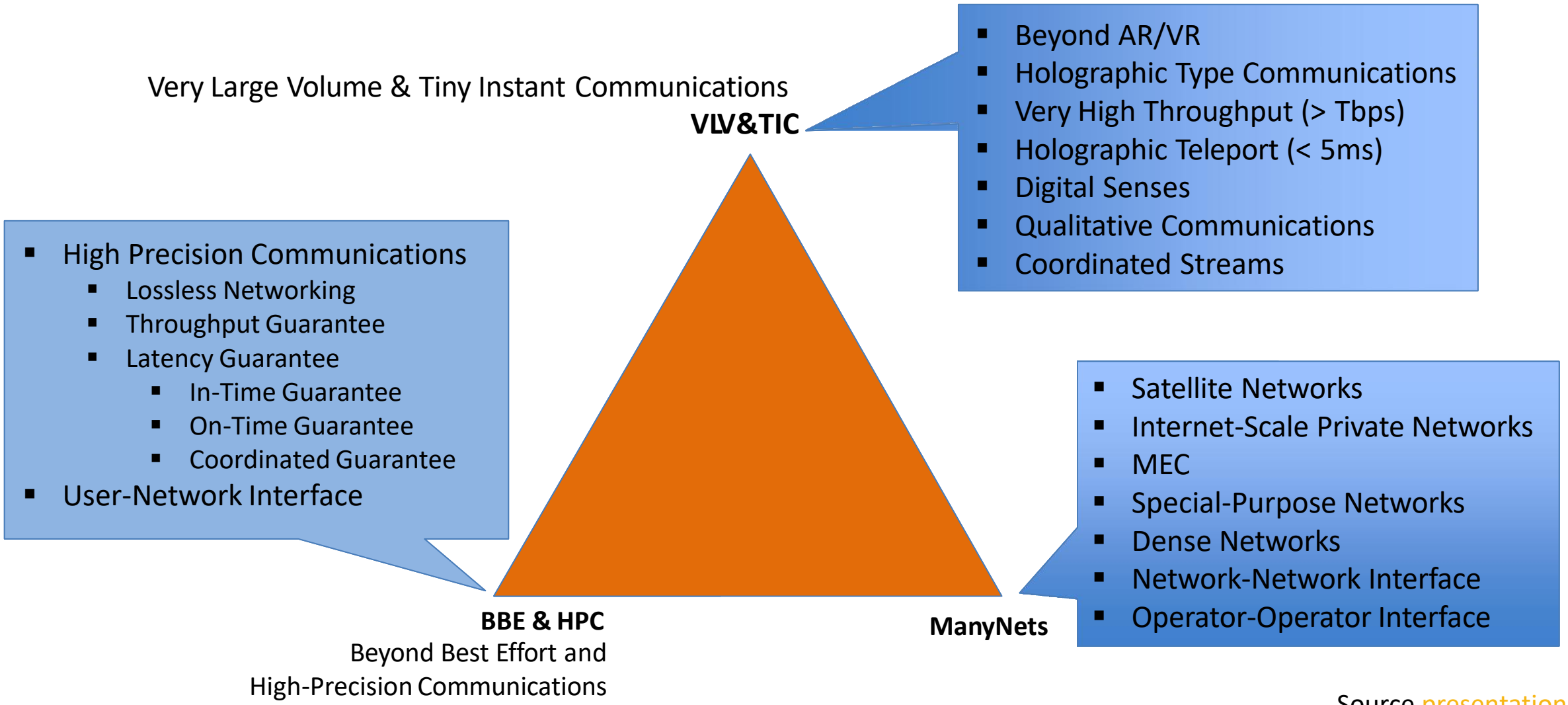
NTT Docomo 6G whitepaper

# ITU FG NET-2030 Vision

Source
presentation



# ITU FG NET-2030 Vision




Source presentation

# ITU FG NET-2030 Vision

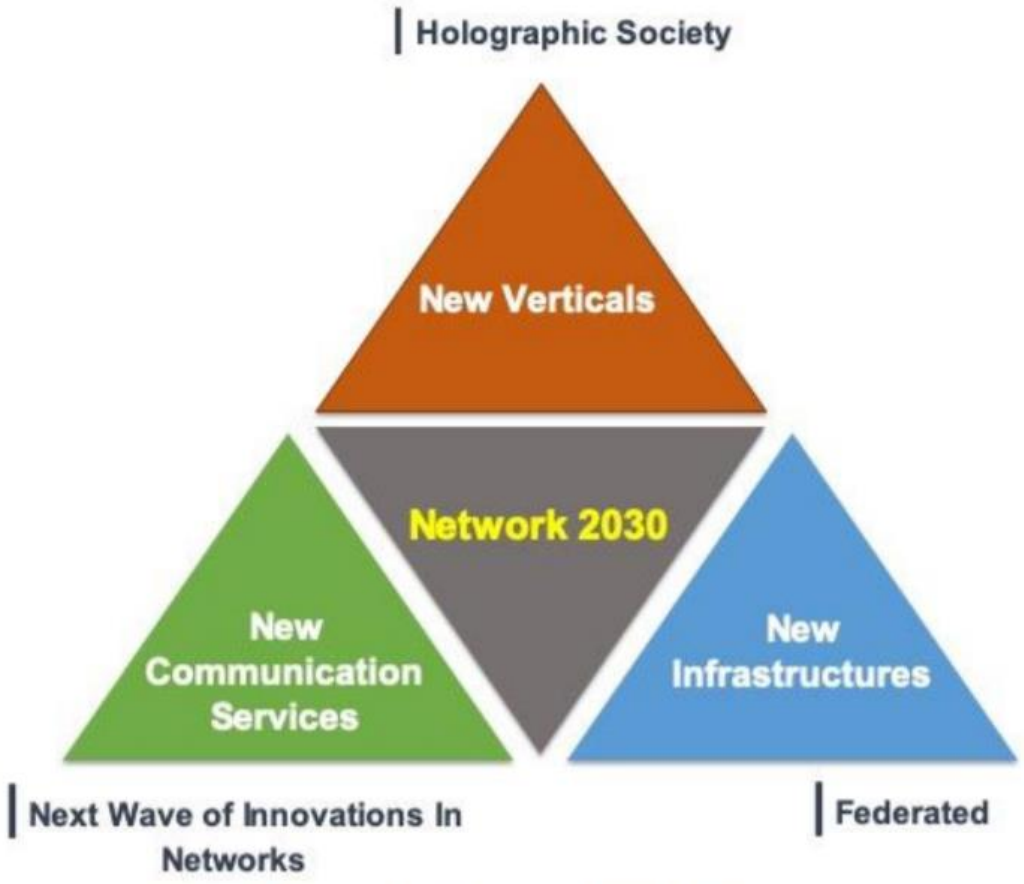



Figure 3: Network 2030 Vision

Source whitepaper

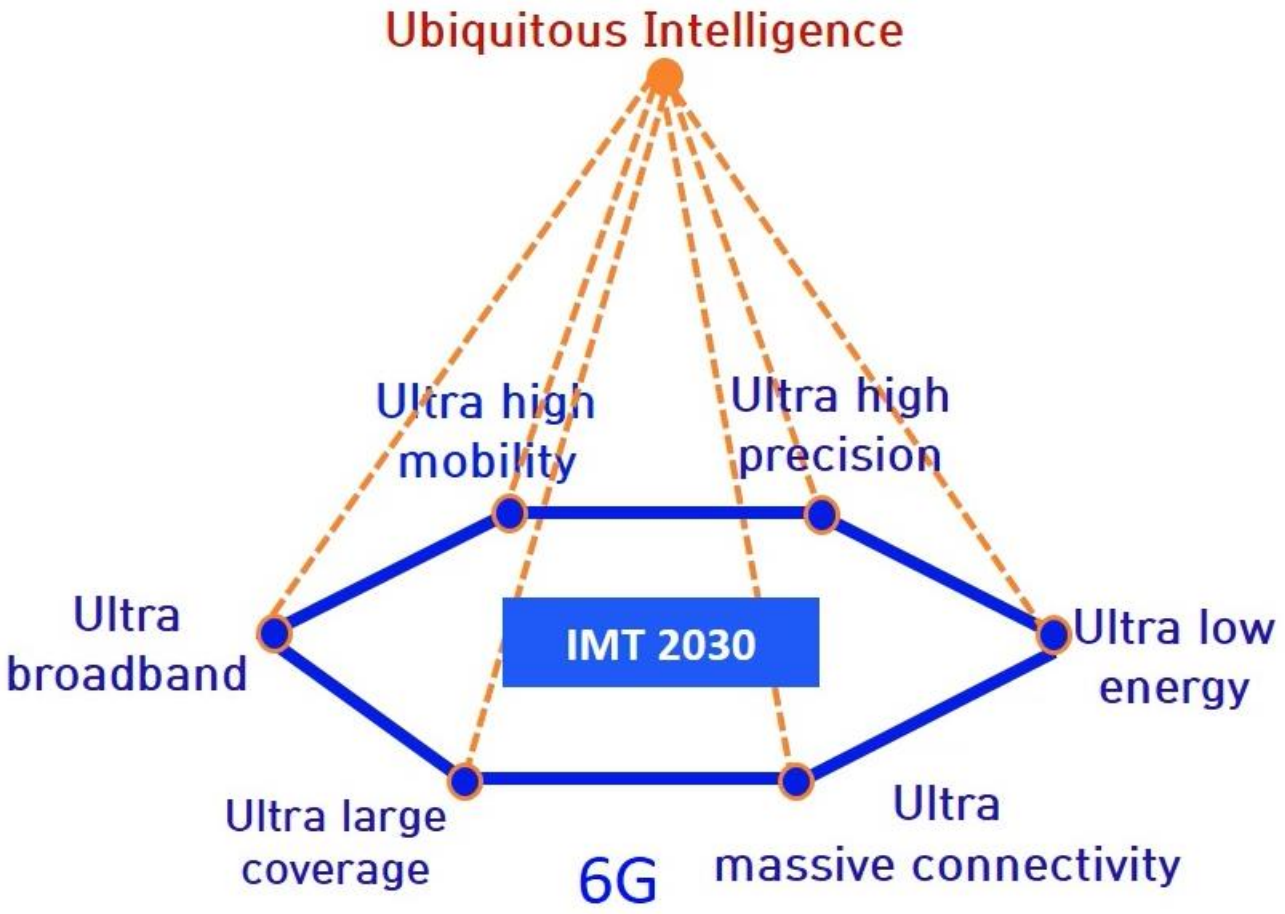
# Samsung: 6G ‘Connected Machines’ Vision

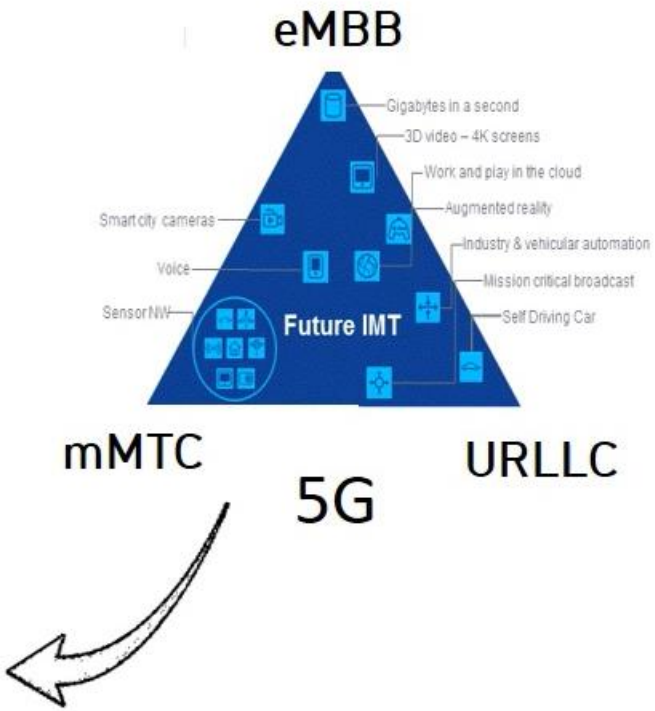
**Figure 1**

Evolution of mobile devices and connected machines.


Samsung 6G Vision Whitepaper

# ETRI: 6G Usage Elements and Scenarios




Source: ETRI, South Korea (link)

# ETRI: 6G Usage Elements and Scenarios

| Use Cases | 6G Usage Elements | | | | | |
|---|---|---|---|---|---|---|
| | uBroadband | uPrecision | uMC | uMobility | uCoverage | uEnergy |
| Live sports/concert broadcasting | √ | √ | √ | | | √ |
| 6 DoF XR, Hologram, Perceptual Illusion | √ | | | | | √ |
| In-flight broadband internet | | | | √ | √ | |
| Gbps for high-speed trains | | | | √ | | |
| Digital twin (tourism, gaming, automotive) | √ | √ | | | | √ |
| Digital twin (4IR) | √ | √ | | | | |
| Self-driving car/PAV | | √ | | √ | √ | |
| Smart factory | | √ | √ | | | |
| Smart city | | | √ | | | √ |
| Tele-presence | √ | √ | | | | |

Source: ETRI, South Korea (link)

# 6GIC 6G Vision

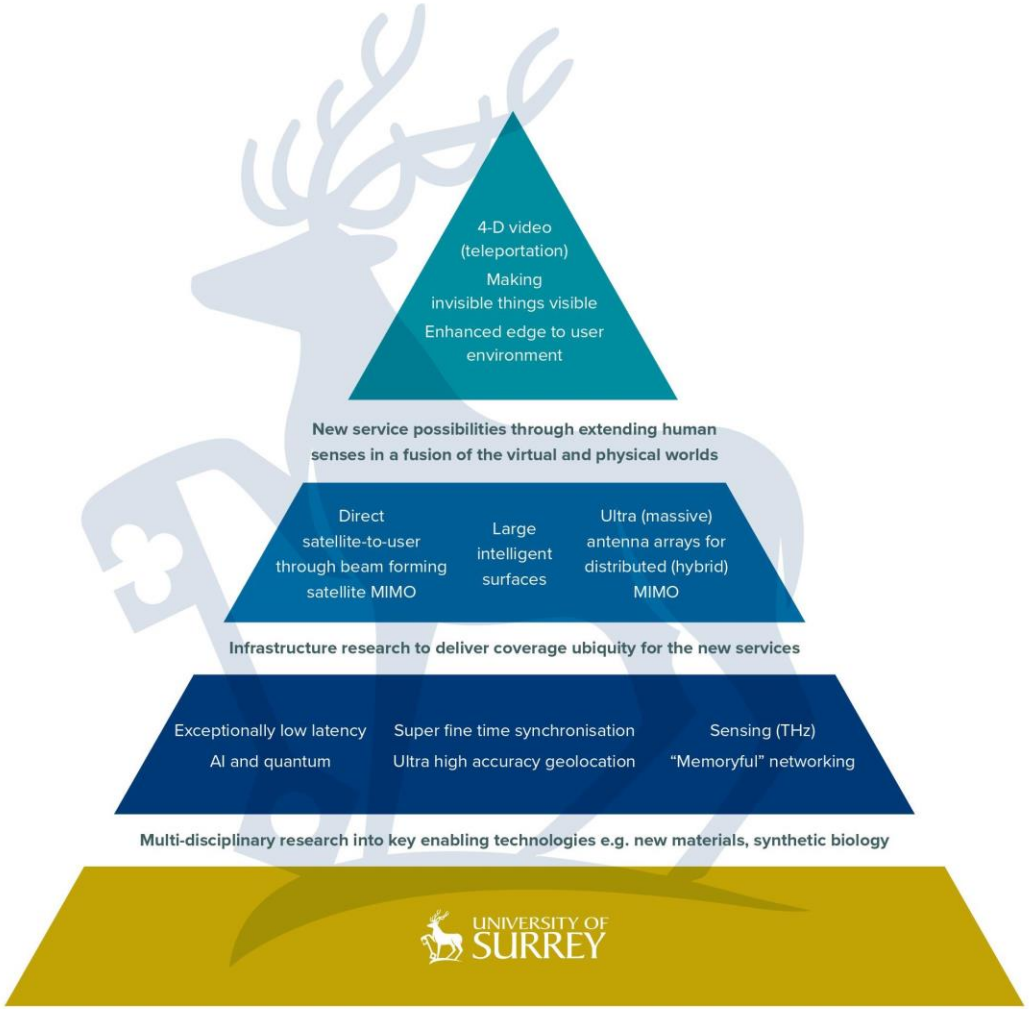
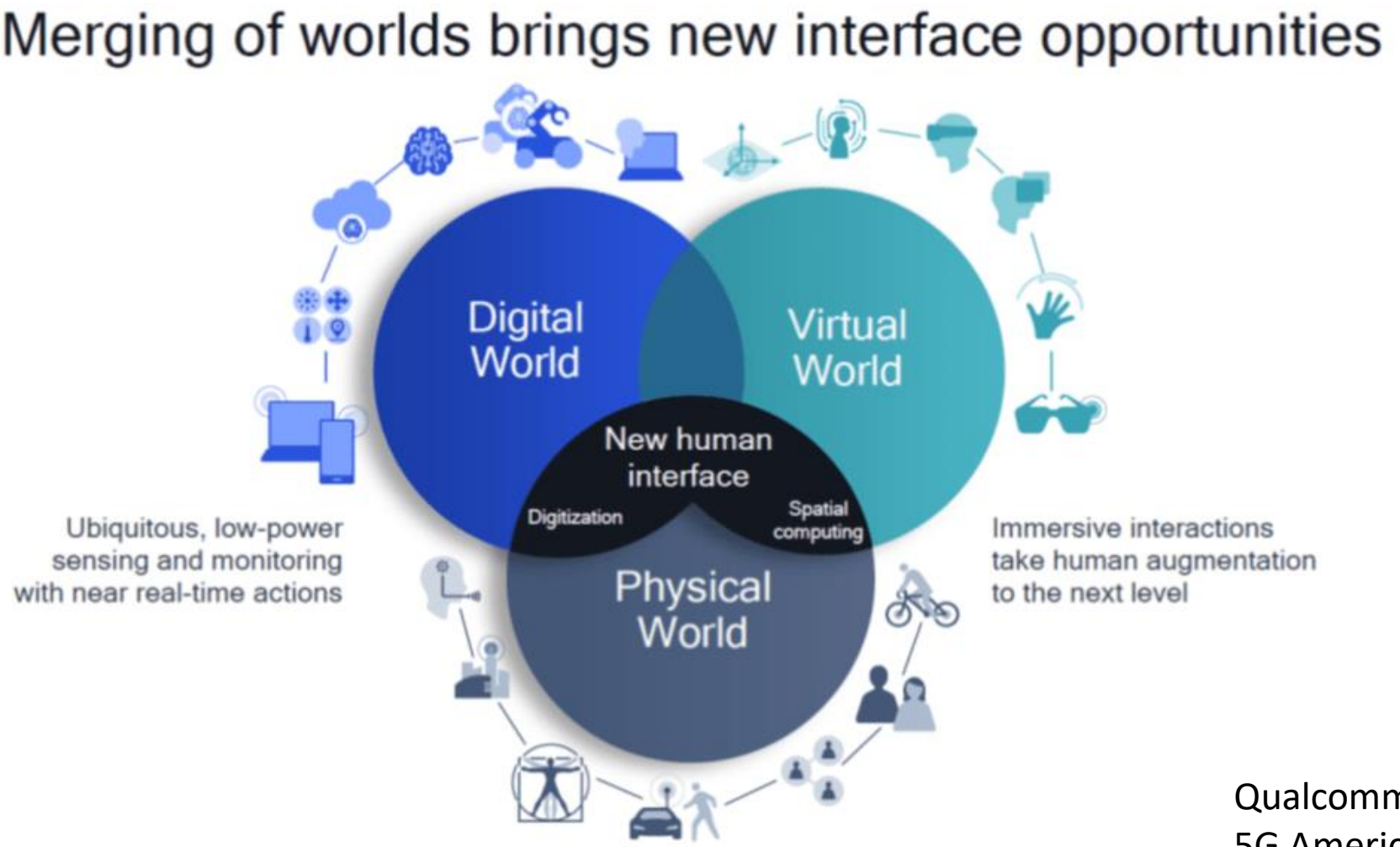



Figure 1: 6G vision supported by new cross-functional research and development programme

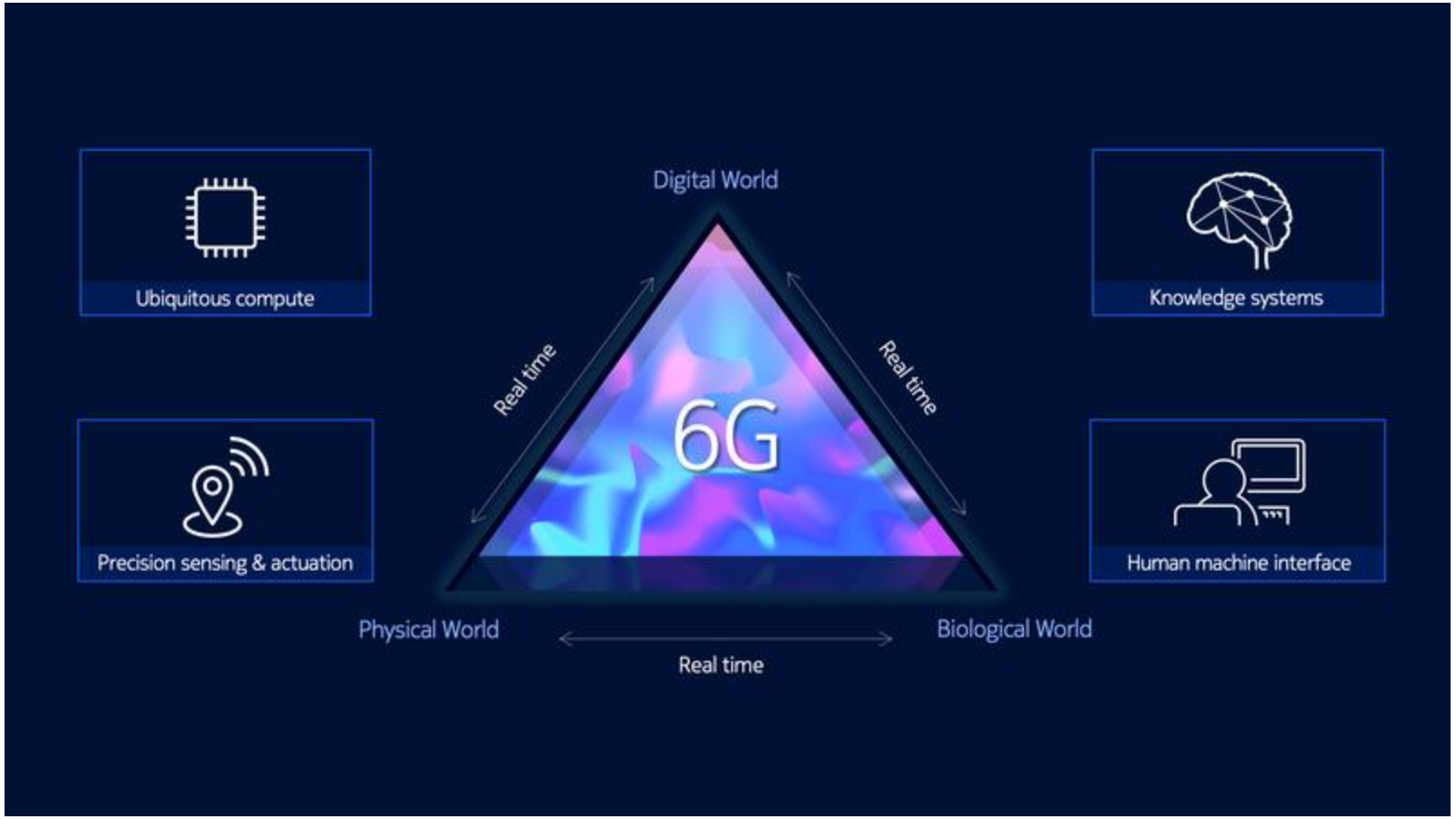
Source [whitepaper]

# Qualcomm’s 6G Vision



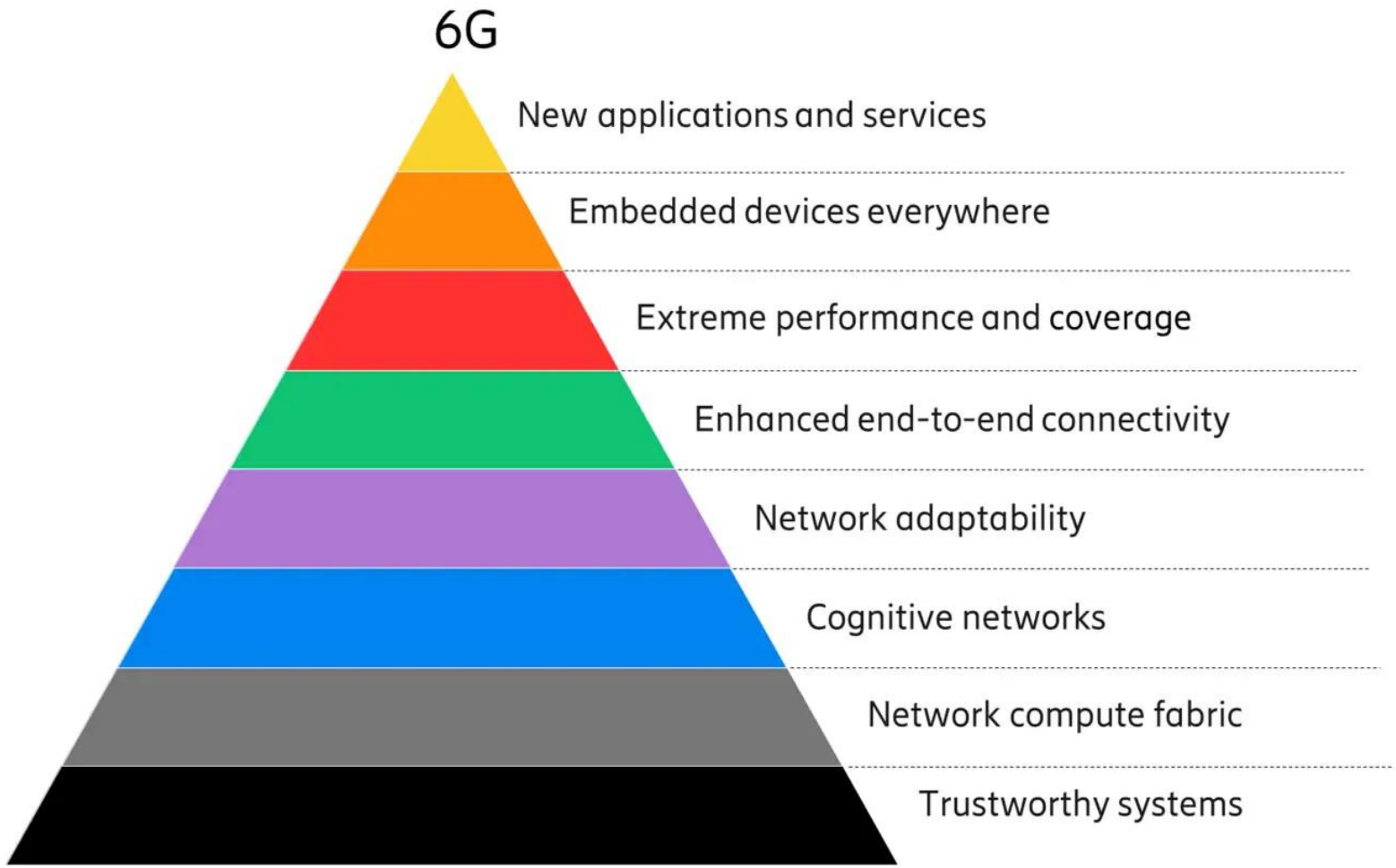

Qualcomm’s 6G Vision, via 5G America’s 6G whitepaper

# Nokia’s 6G Vision




Source: Nokia Bell Labs

# Ericsson’s 6G Vision




Source: Free 6G Training

# Background Material

- The 3G4G Blog: IMT-2020 (5G) Requirements (link)
- The 3G4G Blog: Introduction to Fixed Wireless Access (FWA) (link)
- The 3G4G Blog: 5G Enhanced URLLC (eURLLC) (link)
- The 3G4G Blog: Ultra Reliability: 5x9s (99.999%) in 3GPP Release-15 vs 6x9s (99.9999%) in 3GPP Release-16 (link)
- The 3G4G Blog: 5G and Industry 4.0 (link)
- The 3G4G Blog: New 3GPP Release-17 Study Item on NR-Lite (a.k.a. NR-Light) (link)*
- 3G4G: Introduction to NR-Light a.k.a. NR-Lite (link)*
- The 3G4G Blog: What is Industrial IoT (IIoT) and how is it different from IoT? (link)

* NR-Lite / NR-Light is now known as NR-RedCap (New Radio Reduced Capability Device)

# Further Reading & References

- The 3G4G Blog - ITU 'Network 2030': Initiative to support Emerging Technologies and Innovation looking beyond 5G advances (link)
- ITU News: ITU launches new study on networks & technologies for 2030 and beyond, Aug 2018 (link)
- ITU FG NET-2030: Focus Group on Technologies for Network 2030 (link)
- NTT Docomo white paper: 5G Evolution and 6G, January 2020 (link)
- Free 6G Training: 6G Usage Elements and Scenarios (link)
- Free 6G Training: '6G Vision for 2030+' from 6th Generation Innovation Centre (6GIC) (link)
- Free 6G Training: Huawei talks about Beyond 5G, 5.5G and 6G (link)
- University of Surrey, 6GIC – 6G Wireless: A New Strategic Vision (link)
- Samsung 6G Vision Whitepaper, July 2020 (link)

# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 3: 6G Use Cases & Applications*

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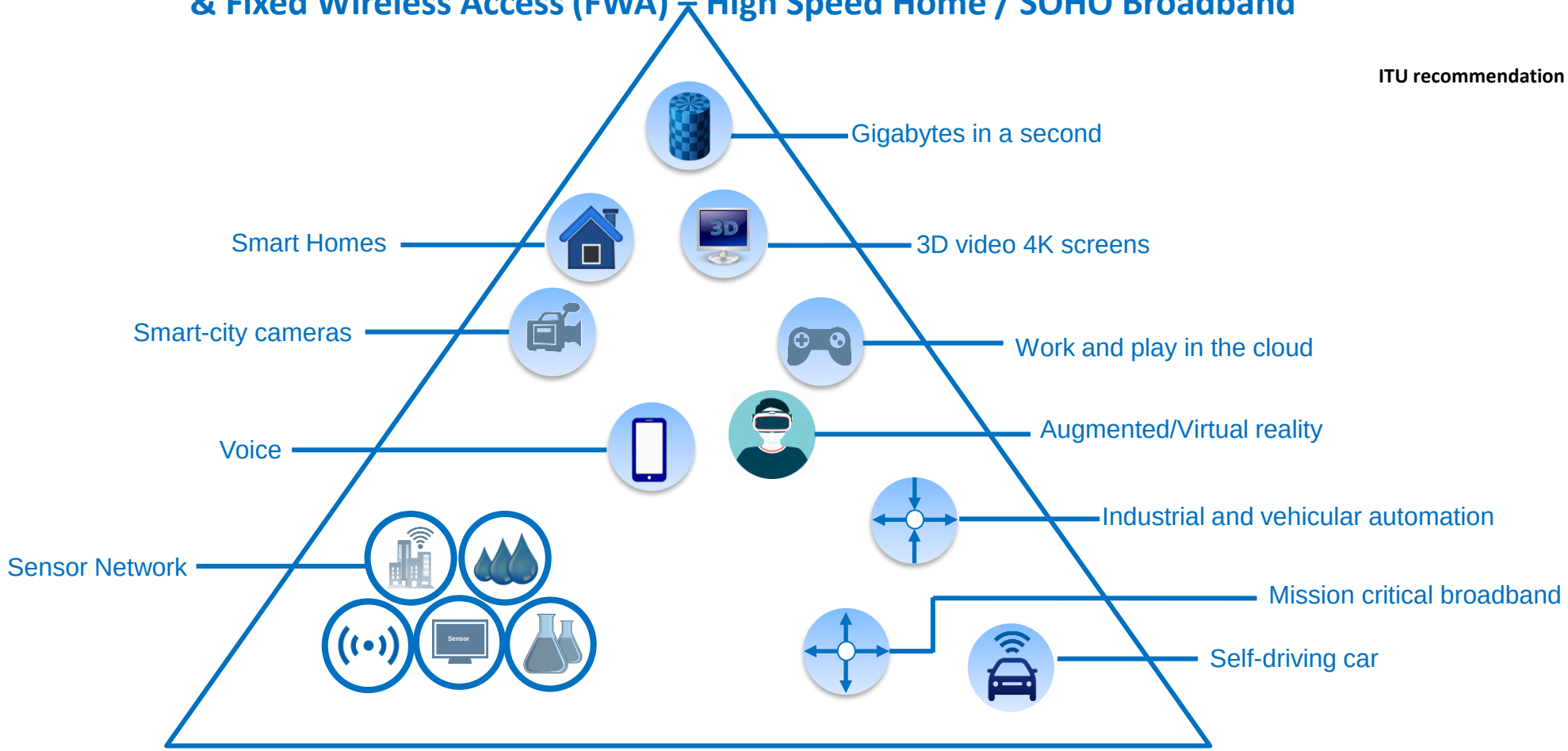
# Part 3 Video Link

# 5G High Level Vision & Use Cases

**eMBB (enhanced Mobile Broadband) – Capacity Enhancement**
**& Fixed Wireless Access (FWA) – High Speed Home / SOHO Broadband**

**ITU recommendation ITU-R M.2083-0**




**mMTC (massive Machine Type Communications) – Massive connectivity**

**URLLC (Ultra-reliable and Low-latency communications) – High reliability, Low latency**

# Augmented reality (AR)

In Augmented Reality (AR), virtual information and objects are overlaid on the real world. This experience enhances the real world with digital images, text, and animation.

LG U+ AR Dance-Off

# Virtual Reality (VR)

In a Virtual Reality (VR) experience, users are fully immersed in a simulated digital environment. Users must put on a VR headset or head-mounted display (HMD) to get a 360 -degree view of an artificial world

NTT Docomo VR Example

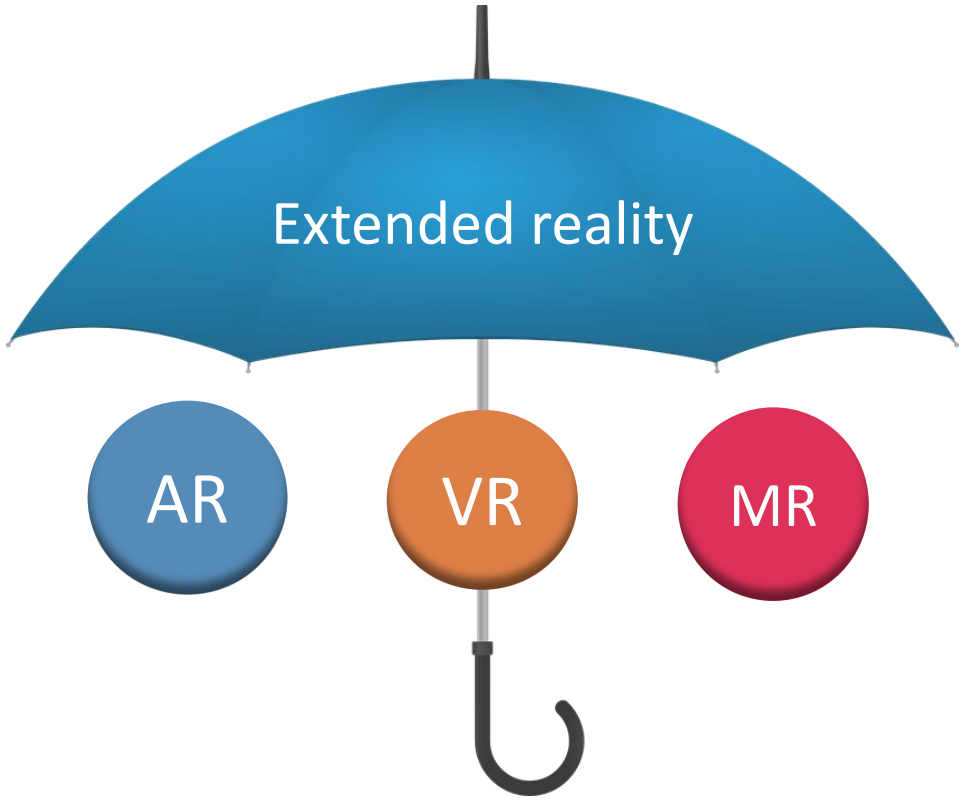
# Mixed Reality (MR)

In Mixed Reality (MR), digital and real-world objects co-exist and can interact with one another in real-time. This is the latest immersive technology and is sometimes referred to as hybrid reality.


Microsoft HoloLens MR Example

# Extended Reality (XR)?

Extended Reality (XR) is an umbrella term for all the immersive technologies.



# Transform how  children learn and play

Source: NTT Docomo

# Tourists Exploring Historical Sites with XR


Source: BBC - How we streamed AR & VR at the Roman Baths (link)

# XR for Work Life Balance

Source: NTT Docomo

# 5G skiing Use Case by Vodafone


Use case details here, video here.

# XR will impact everyone and everything

Transform how children learn and play


Children chasing virtual characters/immersive gaming, students using VR aids

Tourists exploring historical sites

Exploring historical sites through VR seeing them in their original state

Families communicating

Families bought together with life-like communication

Working Professionals

Engineers collaborating on shared design to improve efficiency

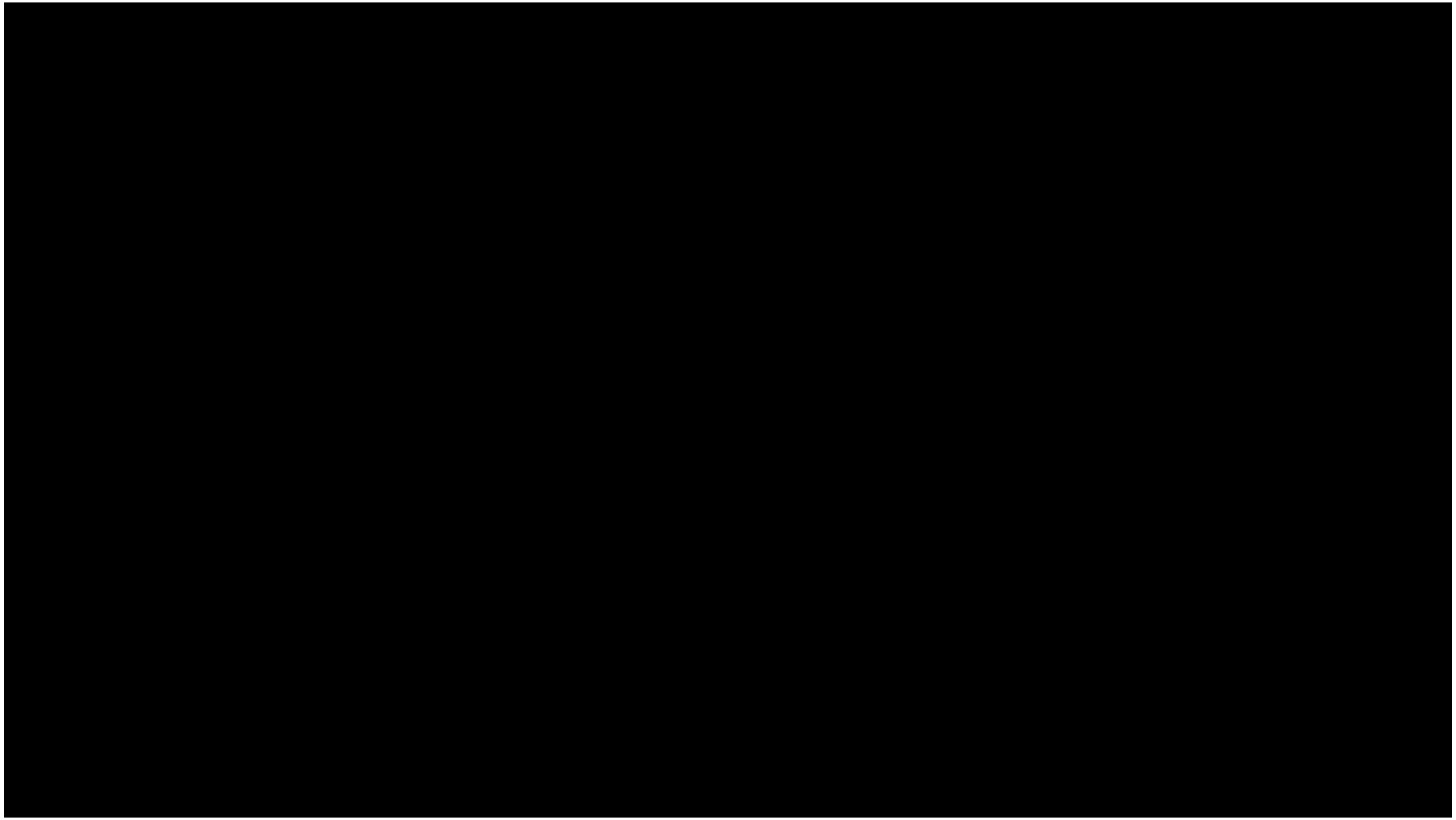
Health and Fitness

Virtual trainers to motivate fitness groups

People with disabilities

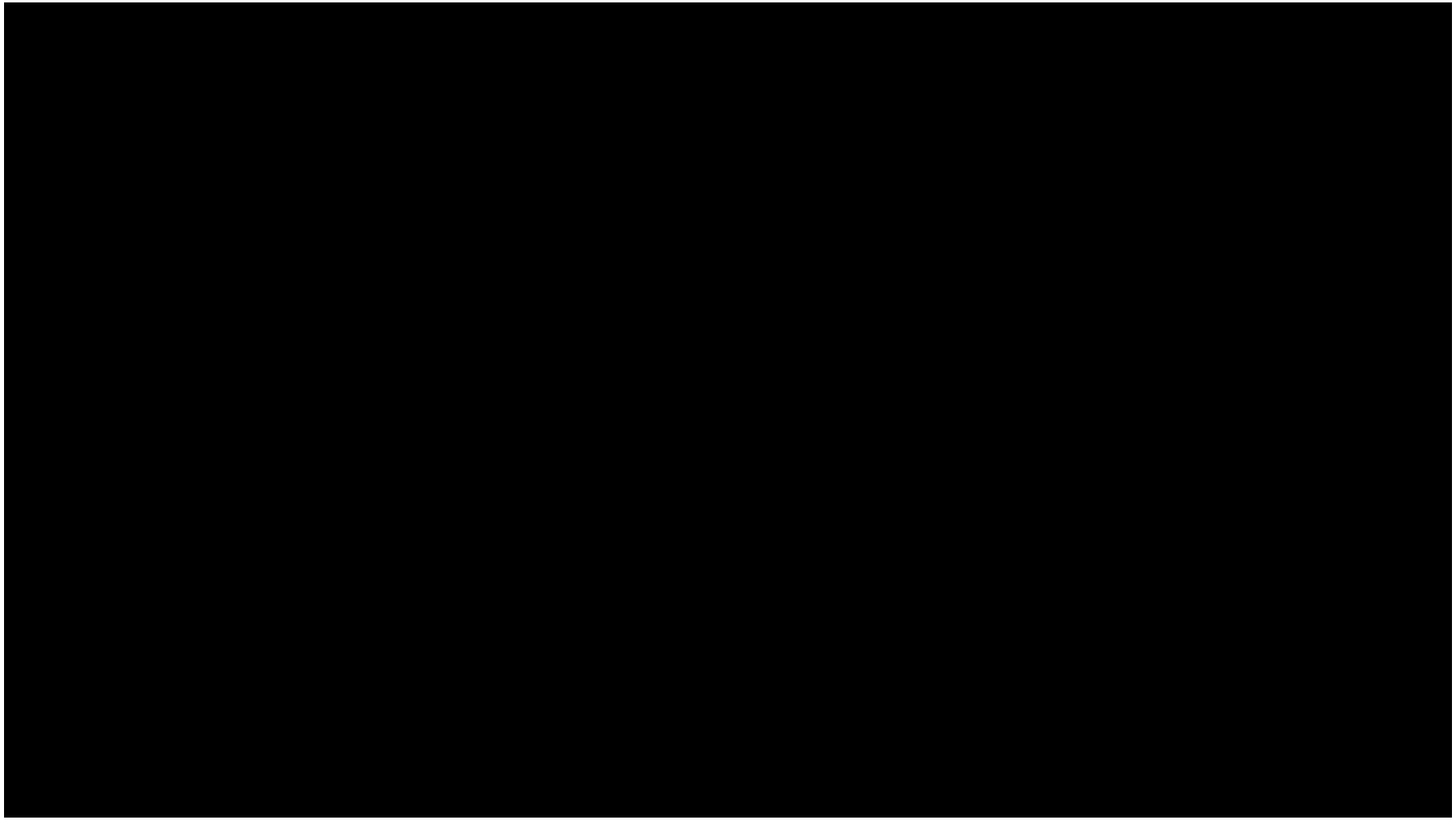
Experiences that might be impossible or unsafe for them in real life. They can run, ski, ride bikes, and climb mountains.

# Collaboration Over Immersive XR



Source: Qualcomm

# Digital Twins

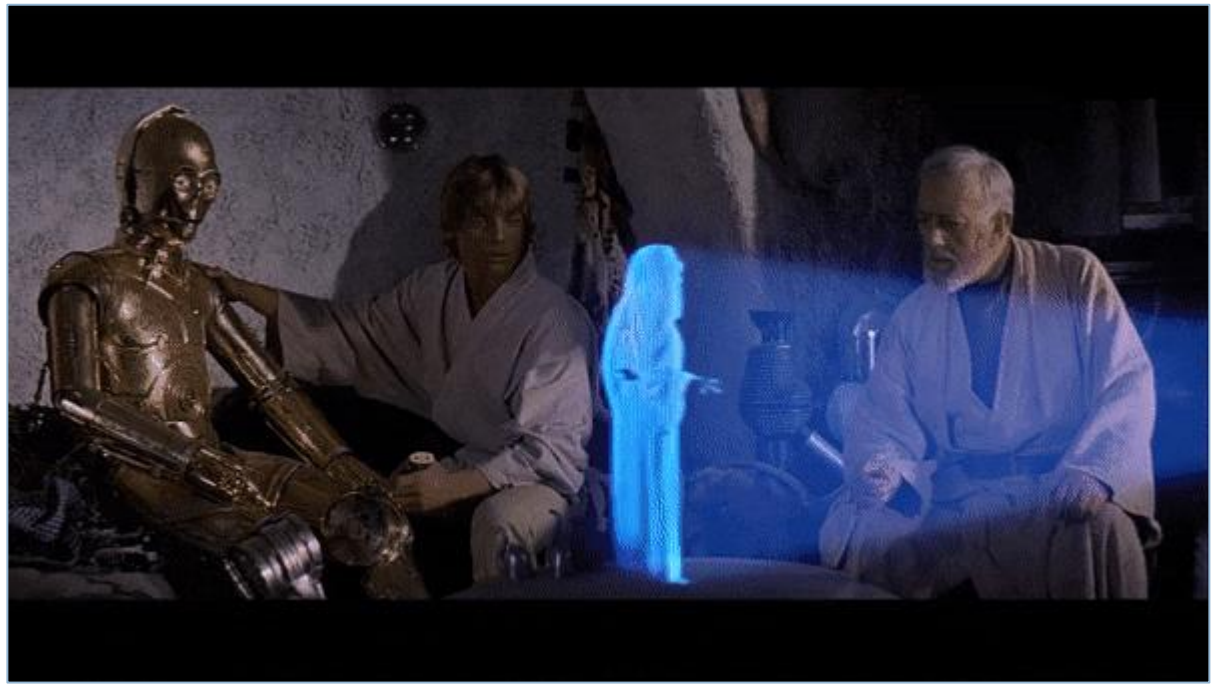


Source: Siemens

# Digital Twins

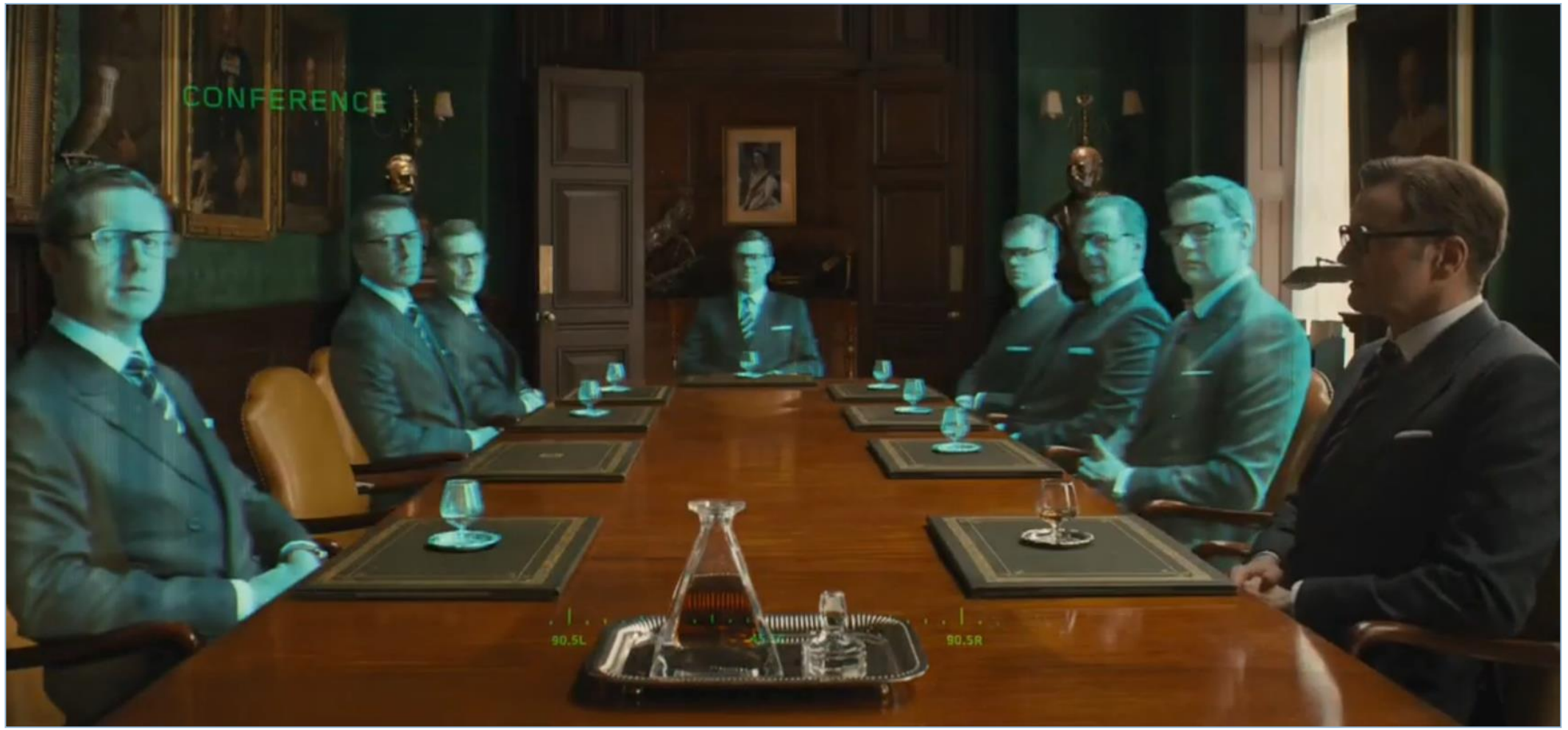
NTT IOWN: Digital twin computing (Concept video)

# Hologram



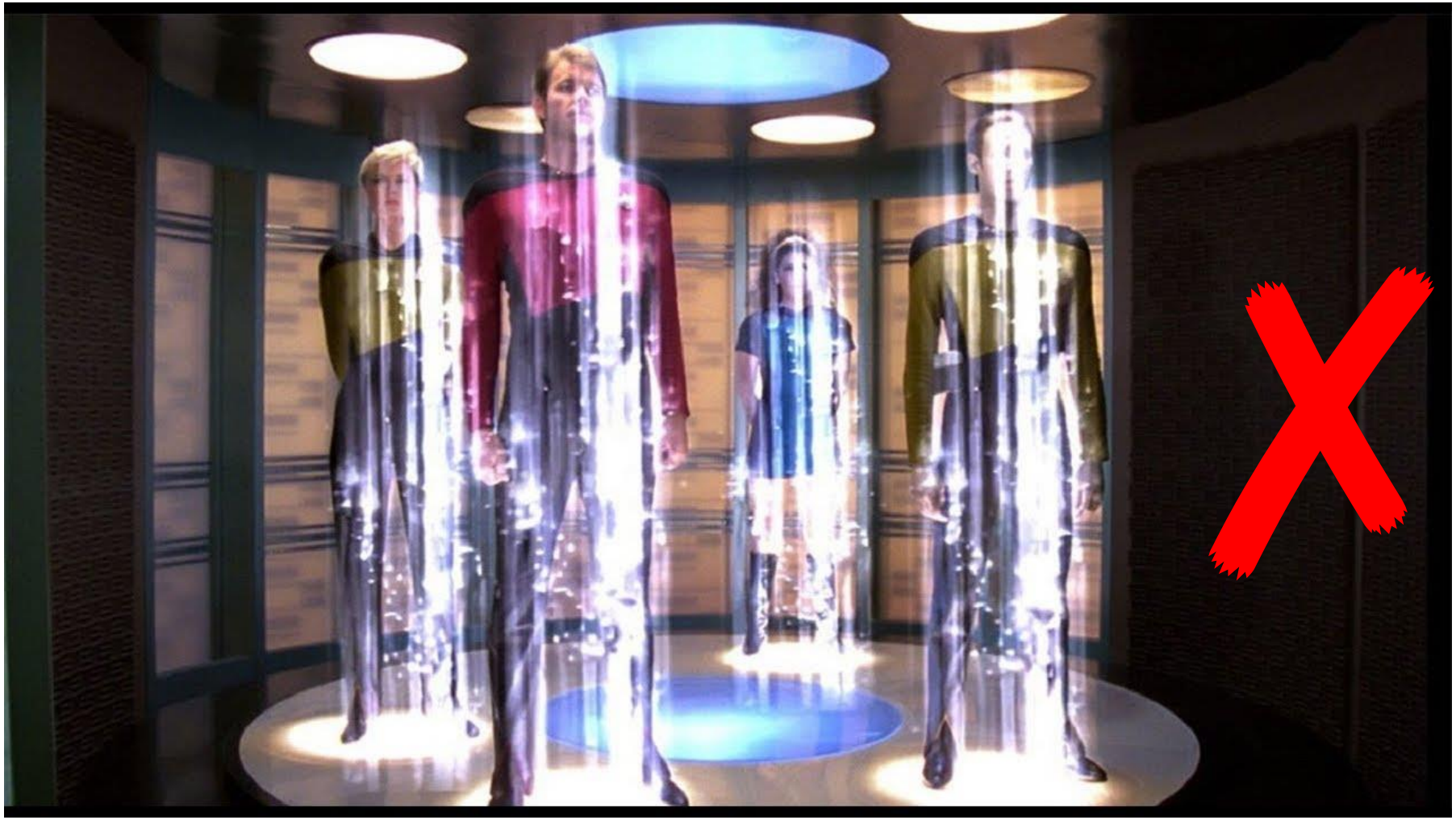
Hologram example from Star Wars Episode IV: A New Hope

# Holoportation / ‘Holographic Telepresence’




Holoportation example from movie Kingsman: The Secret Service (see video)

# Teleportation



See Transporter in Star Trek video

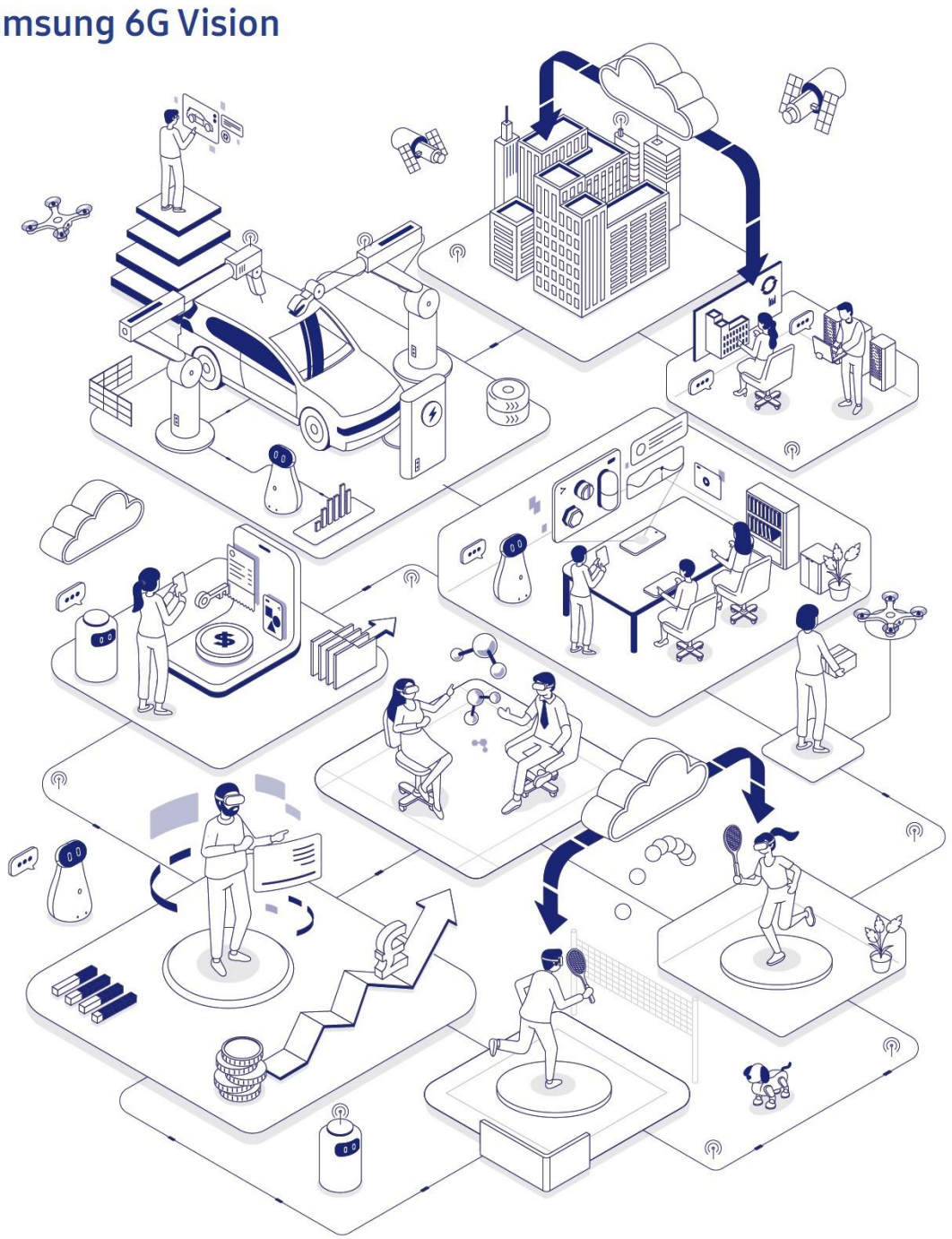
# Teleportation

From the movie, Surrogates (2009), see trailer video

# Samsung 6G Vision

Samsung whitepaper highlights three key 6G services:

- Truly Immersive XR
- High-Fidelity Mobile Hologram
- Digital Replica

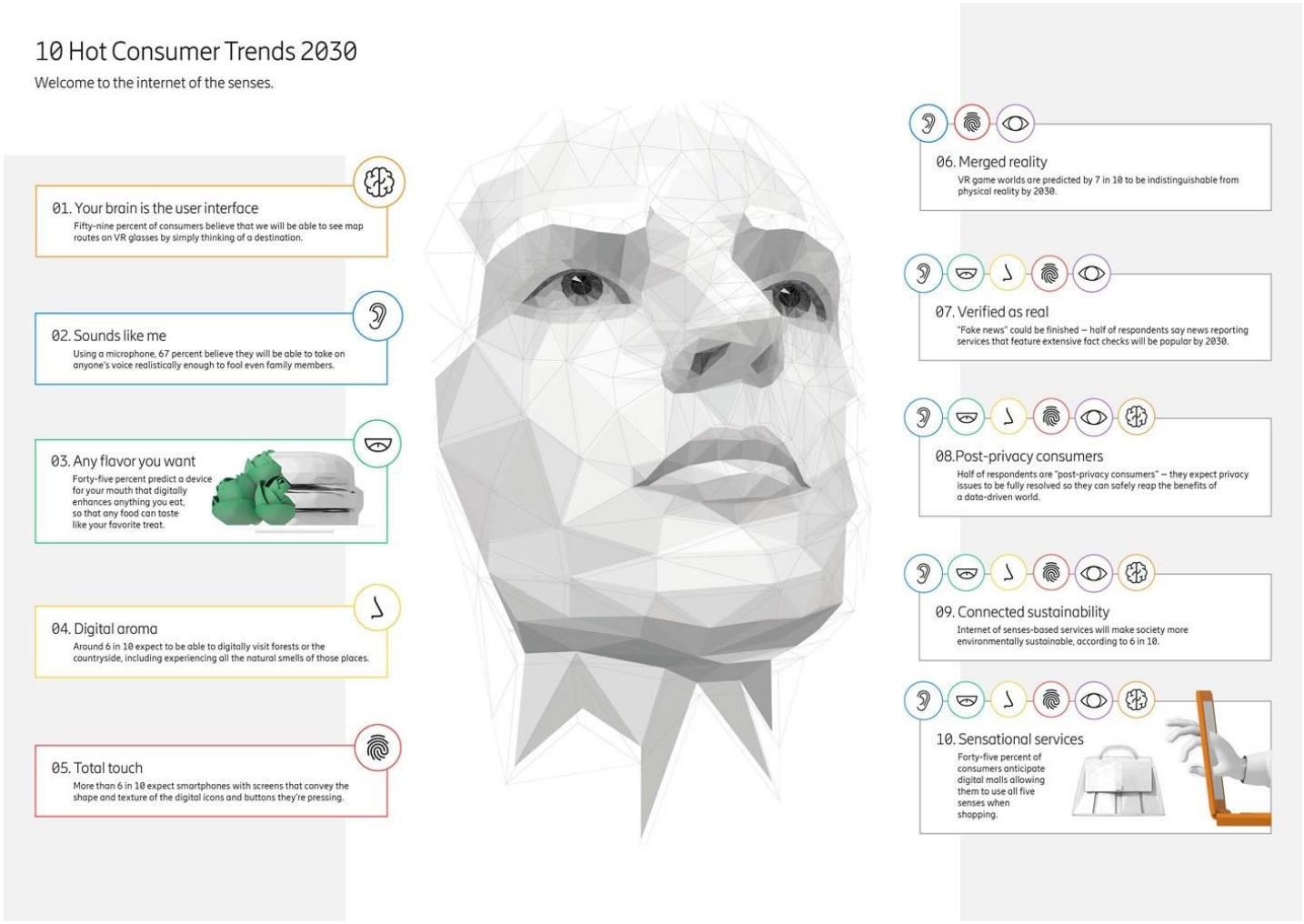


# NTT Docomo 6G Use Cases


Source: ANN News Channel (link)

More details in the NTT Docomo 6G Whitepaper

# Ericsson’s 2030 Trends: Internet of Senses




Watch the ‘Internet of senses’ video here

# Enabling Vertical Markets with Network 2030

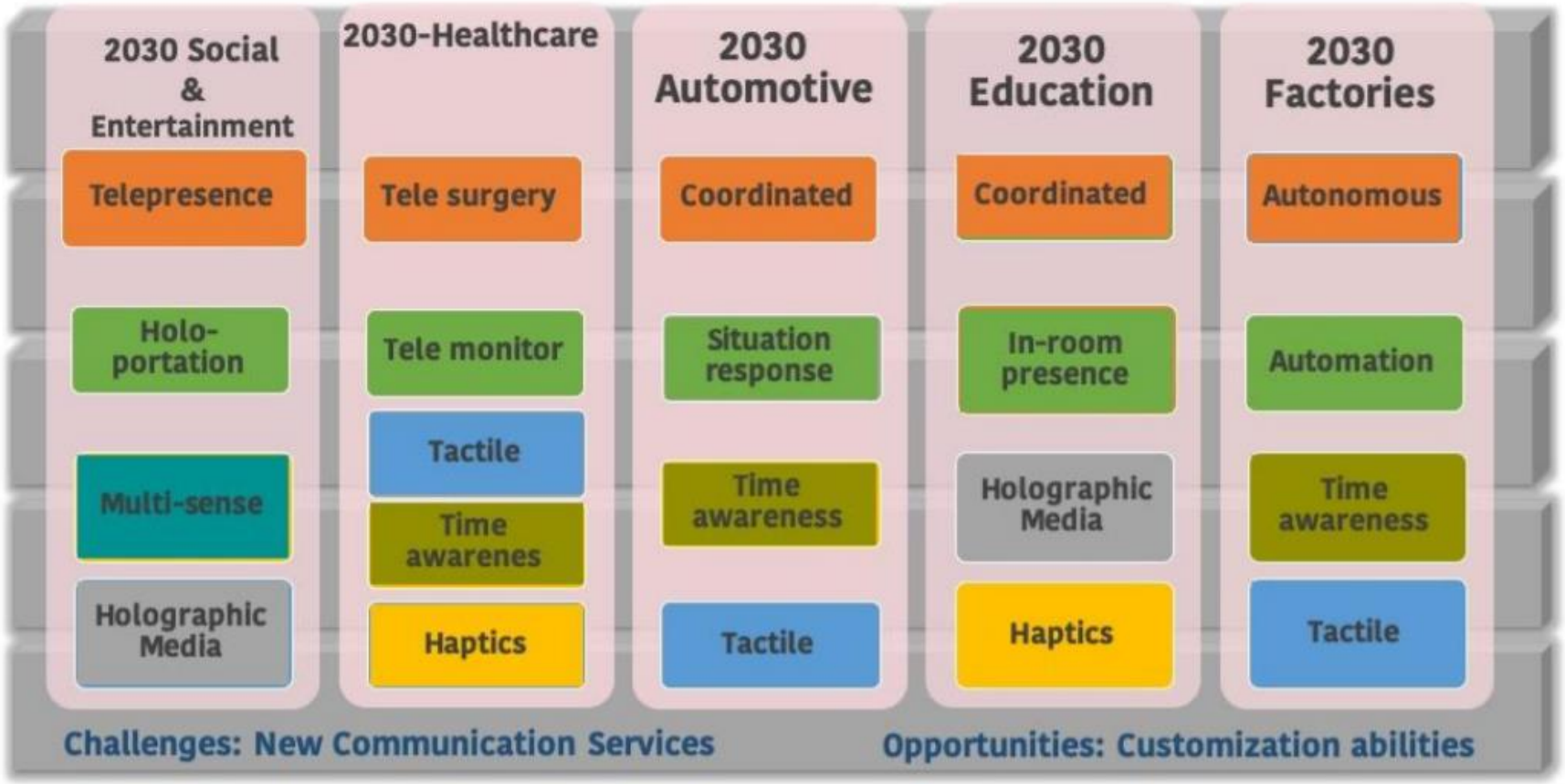



Figure 5: Enabling Vertical Markets with Network 2030

Source: FG NET-2030 Whitepaper

# ETRI: 6G Usage Elements and Scenarios

| Use Cases | 6G Usage Elements | | | | | |
|---|---|---|---|---|---|---|
| | uBroadband | uPrecision | uMC | uMobility | uCoverage | uEnergy |
| Live sports/concert broadcasting | √ | √ | √ | | | √ |
| 6 DoF XR, Hologram, Perceptual Illusion | √ | | | | | √ |
| In-flight broadband internet | | | | √ | √ | |
| Gbps for high-speed trains | | | | √ | | |
| Digital twin (tourism, gaming, automotive) | √ | √ | | | | √ |
| Digital twin (4IR) | √ | √ | | | | |
| Self-driving car/PAV | | √ | | √ | √ | |
| Smart factory | | √ | √ | | | |
| Smart city | | | √ | | | √ |
| Tele-presence | √ | √ | | | | |

Source: ETRI, South Korea (link)

# Scenarios for 6G business

Source: 6G Flagship Whitepapers

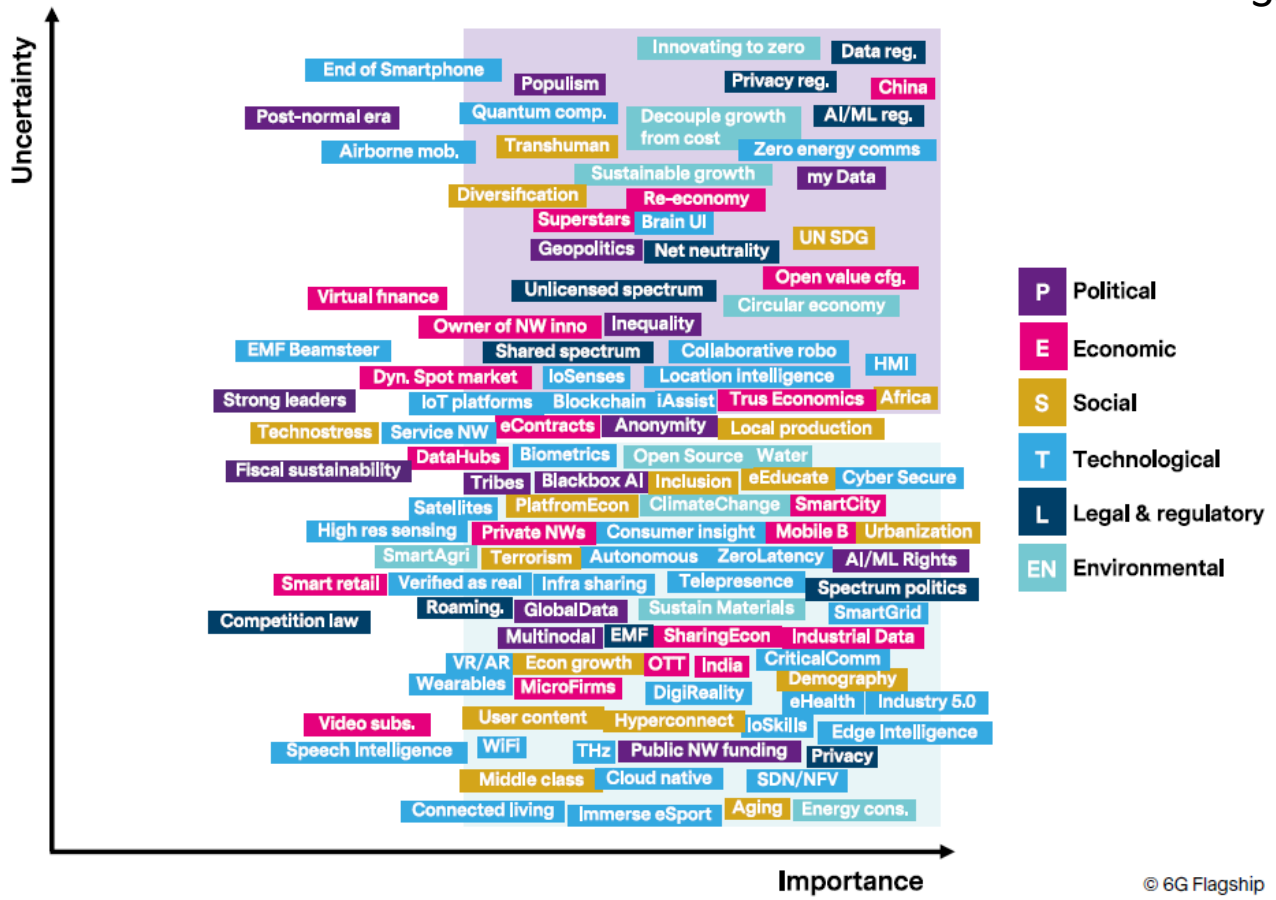



Figure 2. Summary of the evaluation of forces on uncertainty and importance

See, 6G Vision for 2030 video from University of Oulu / 6G Flagship here.

# 5G vs 6G Use Case Comparison

| Use case (capability) | 5G | 6G |
|---|---|---|
| **Augmented Reality for Industry** | Low resolution / high level tasks | High resolution, multi-sensory / detailed tasks, co-design |
| **Telepresence (capacity)** | High video quality, limited scale | Mixed reality / Holographic |
| **Security surveillance, defect detection (positioning & sensing)** | External sensing, limited automation | Integrated radio sensing, fully automated |
| **Distributed computing, Automation (time synchronization)** | Microsecond-level tasks | Higher precision nanosecond-level tasks |
| **Dynamic digital twins and virtual worlds (real-time, multi-sensory mapping and rendering)** | No | Yes |
| **Wireless in Data Center (peak rate and capacity)** | No | Yes |
| **Zero Energy Devices (back scatter communications)** | No | Yes |
| **Swarms of robots or drones** | Maybe | Yes |
| **Bio sensors and AI** | Limited | Yes |

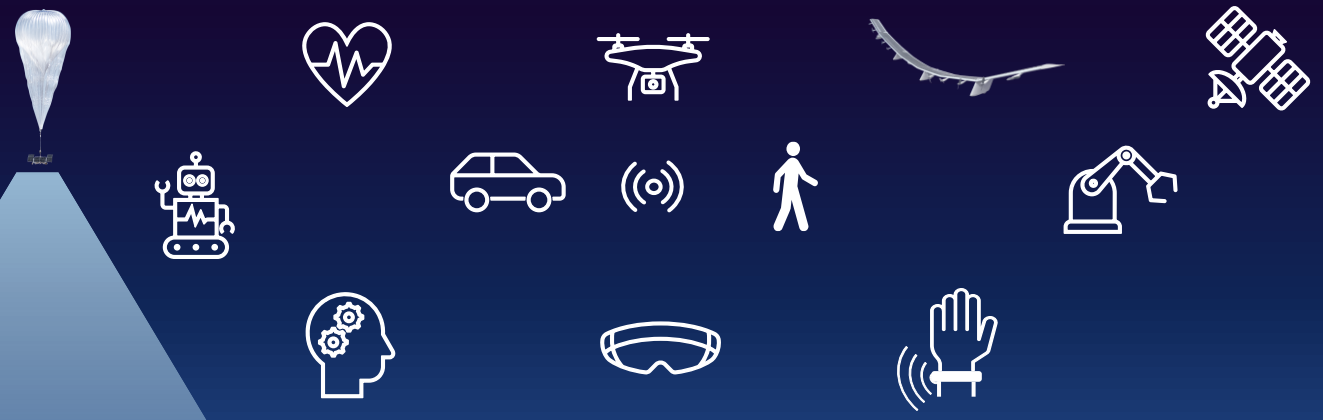
From Nokia Bell Labs 6G whitepaper

# Background Material

- The 3G4G Blog: 5G eXtended Reality (5G-XR) in 5G System (5GS) (link)
- The 3G4G Blog: 5G and Industry 4.0 (link)
- The 3G4G Blog: What is Industrial IoT (IIoT) and how is it different from IoT? (link)
- The 3G4G Blog: Challenges and Future Perspectives of Industrial 5G (link)
- 3G4G: What are Telepresence Robots? (Presentation, Video)

# Further Reading

- 6G Research Visions: White paper 1 on Key drivers and research challenges for 6G ubiquitous wireless intelligence, Sep 2019 (link)
- 6G Research Visions: White paper 2 on 6G Drivers and The UN SDGs, June 2020 (link)
- 6G Research Visions: White Paper 3 on Business of 6G, June 2020 (link)
- 6G Research Visions: White Paper 4 on Validation and Trials for Verticals towards 2030's, June 2020 (link)
- NTT announces new R&D projects of Digital Twin Computing, Nov 2020 (link)
- NTT Docomo white paper: 5G Evolution and 6G, January 2020 (link)
- University of Surrey, 6GIC – 6G Wireless: A New Strategic Vision (link)
- Samsung 6G Vision Whitepaper, July 2020 (link)
- Free 6G Training: 6G may just make Teleportation a Reality (link)
- Ericsson: 10 Hot Consumer Trends 2030 (link)
- FG-NET-2030 Whitepaper (link)
- Enabling holographic media for future applications: Missing pieces and limitations in networks, SIGCOMM, Aug 2019 (link)
- Holographic Type Communication, Kiran Makhijani, Future Networks, Futurewei, Oct 2019 (link)
- Nokia Bell Labs: Communications in the 6G Era Whitepaper, Sep 2020 (link)
- Virtual Reality Book by Steven M. LaValle (link)



# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 4: 6G Timeline*

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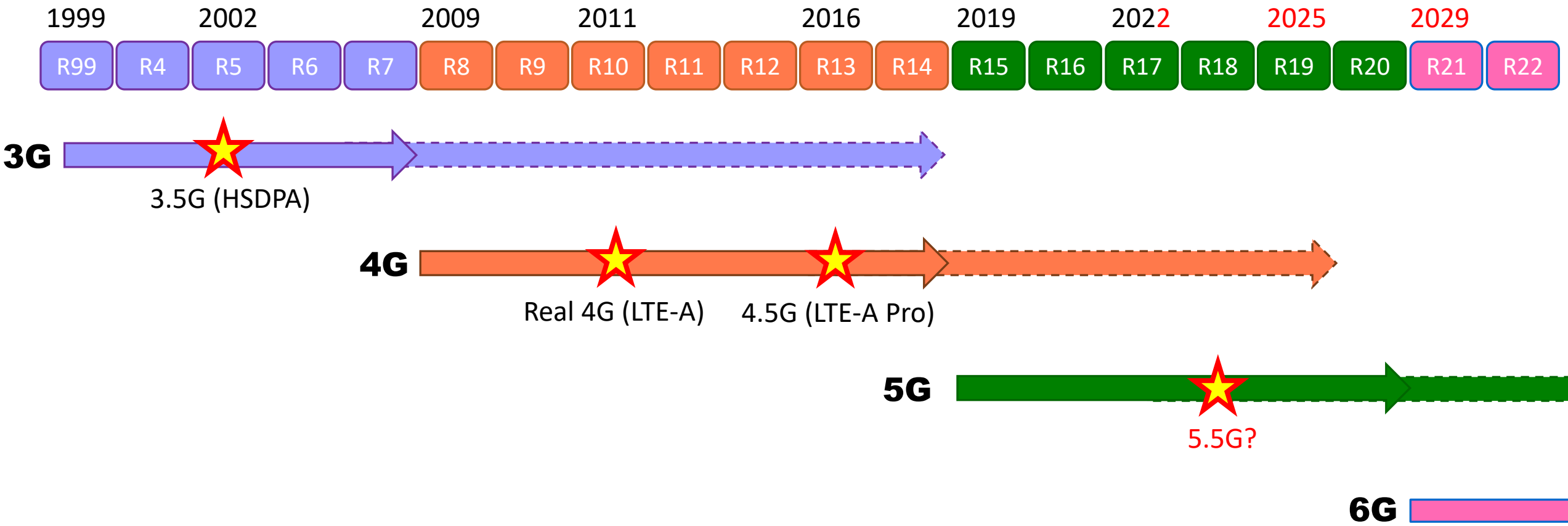
**#Free6Gtraining**

# Part 4 Video Link

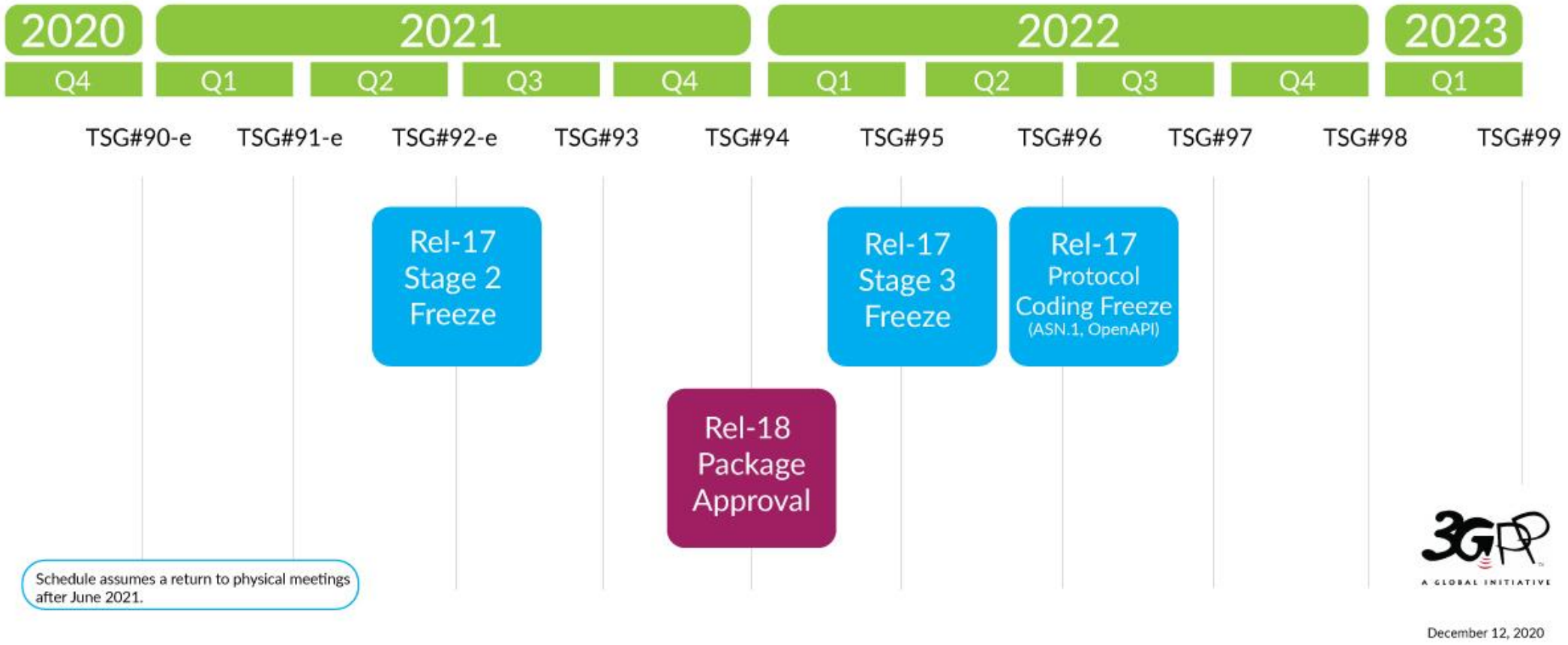
# 3GPP Releases Timeline




Red text indicates dates and features are not confirmed

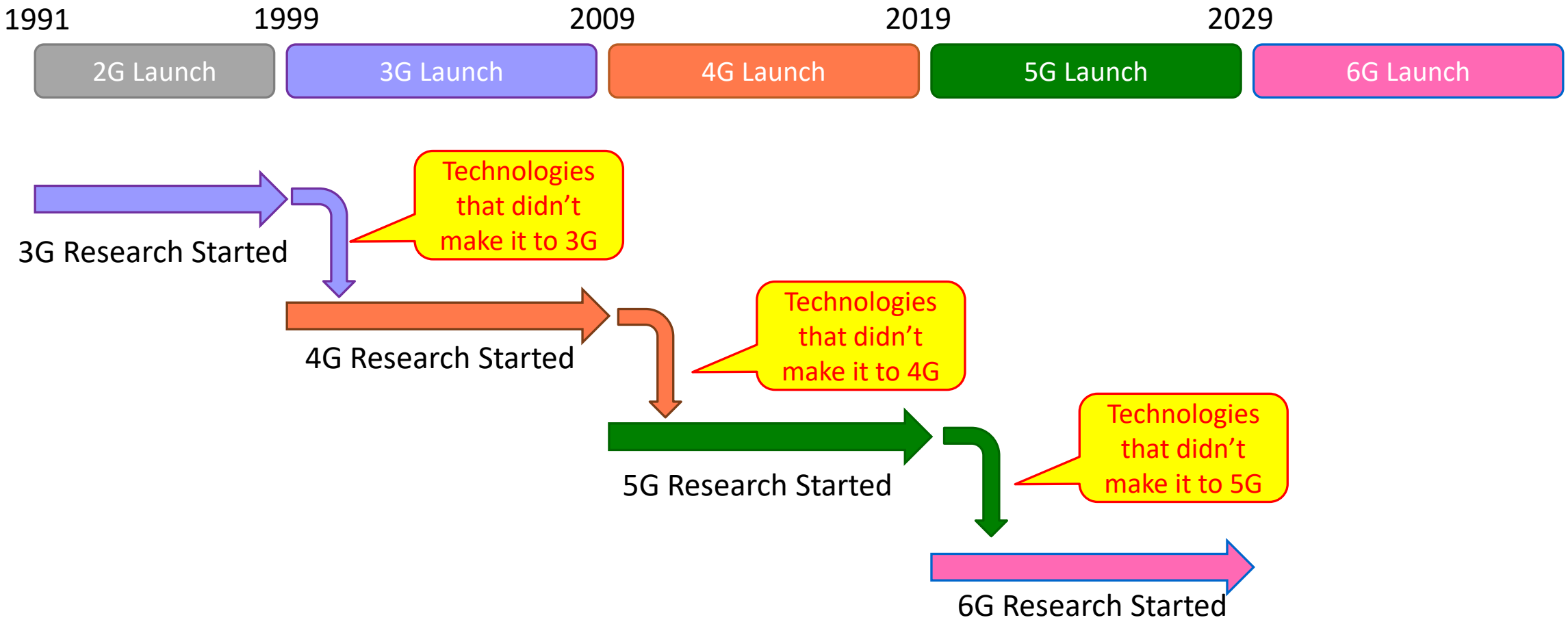
3GPP Release Dates on 3GPP Portal

# 3GPP Release 17 timeline agreed

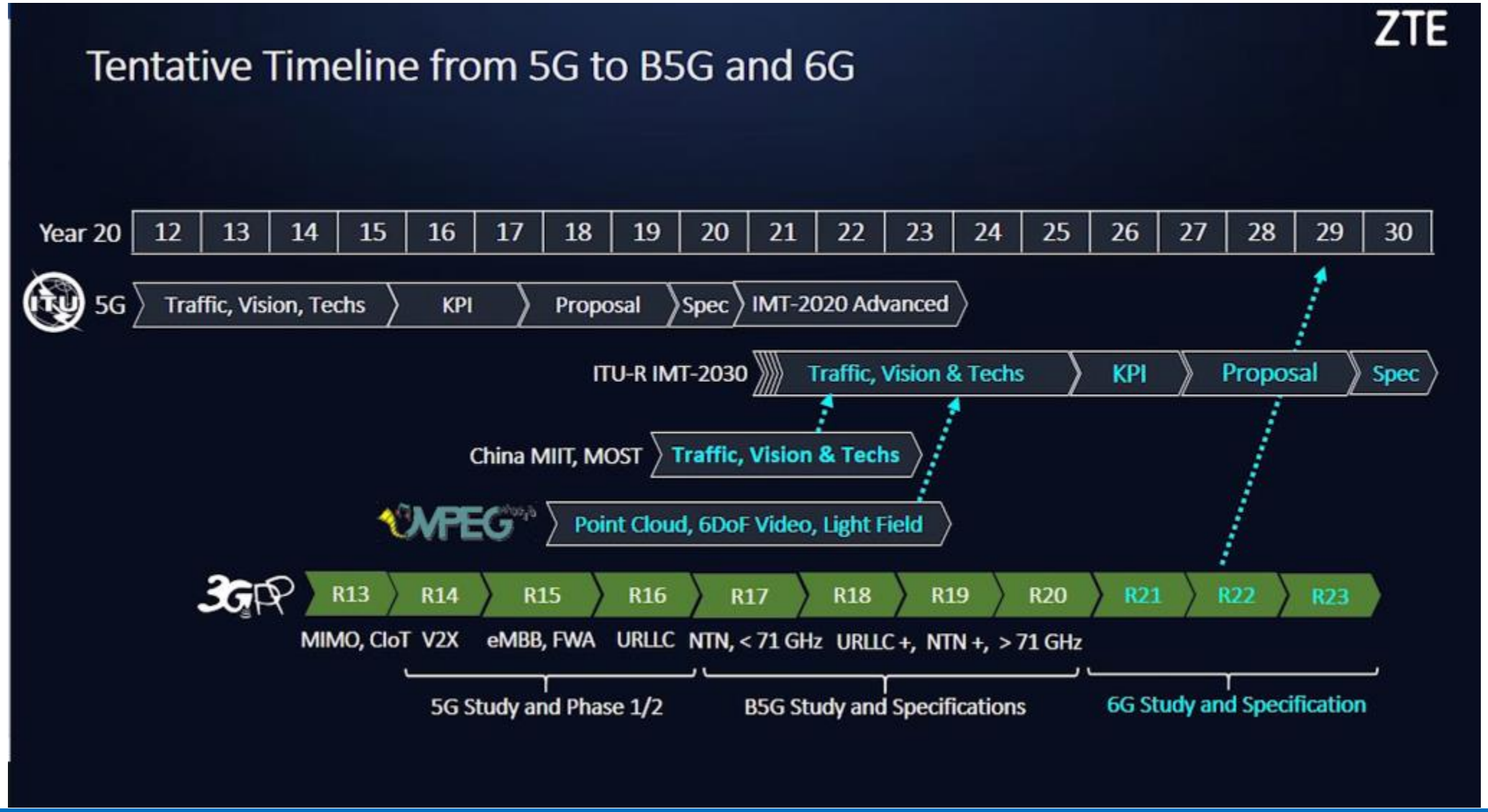



Source: 3GPP

# Technologies Research Timeline

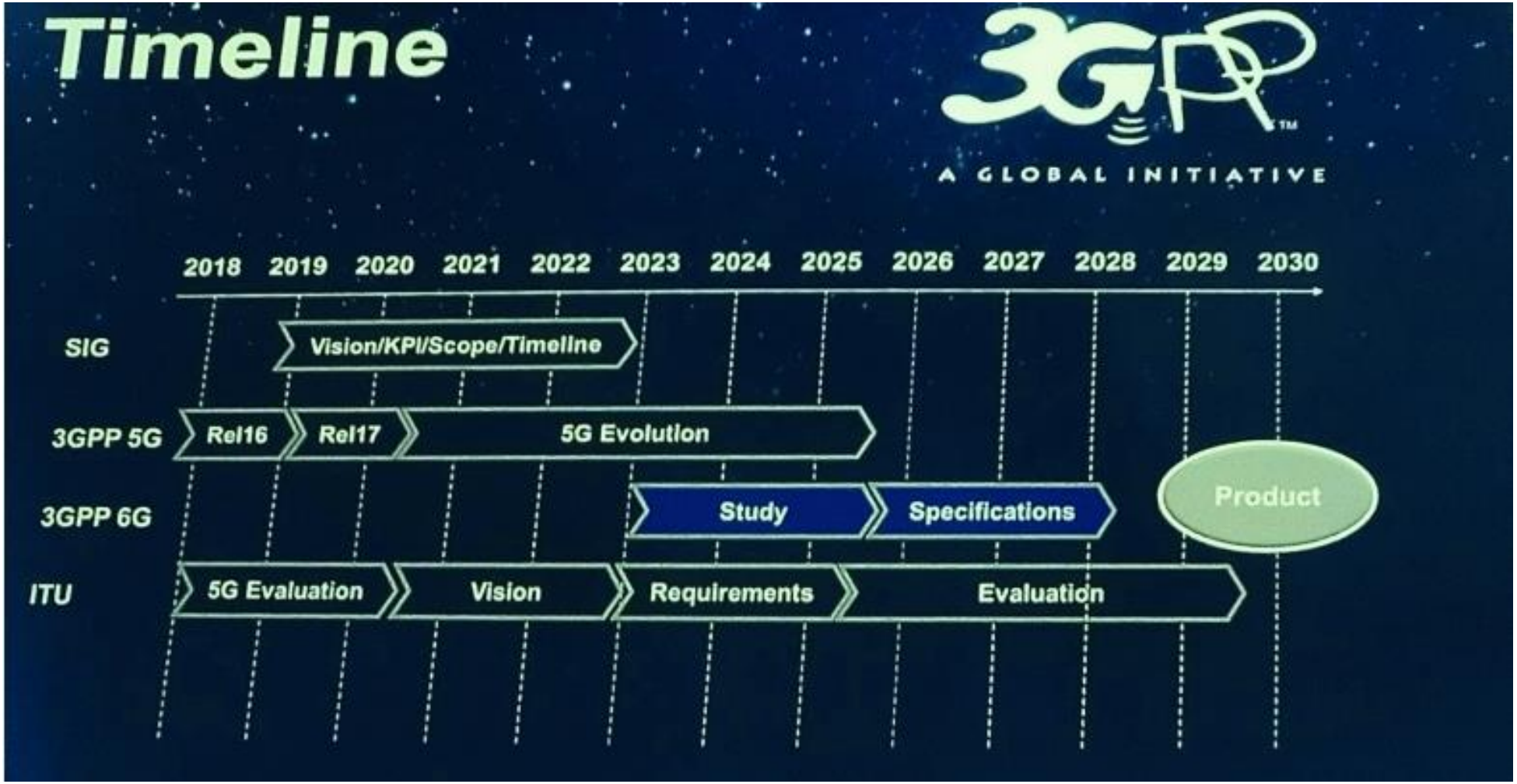


# ZTE's 6G Timeline from March 2020



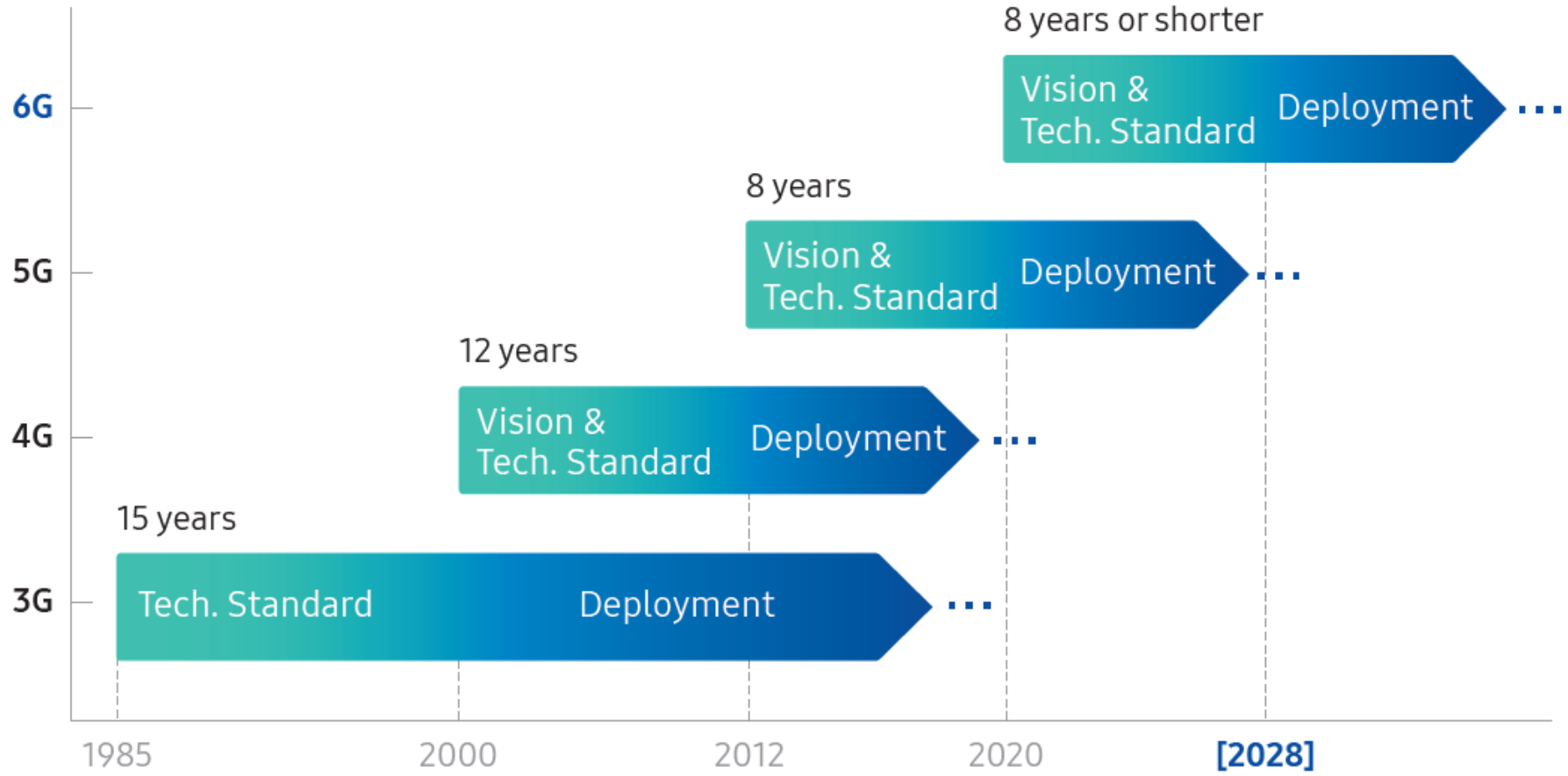

Source

# 6G Flagship Suggested Timeline

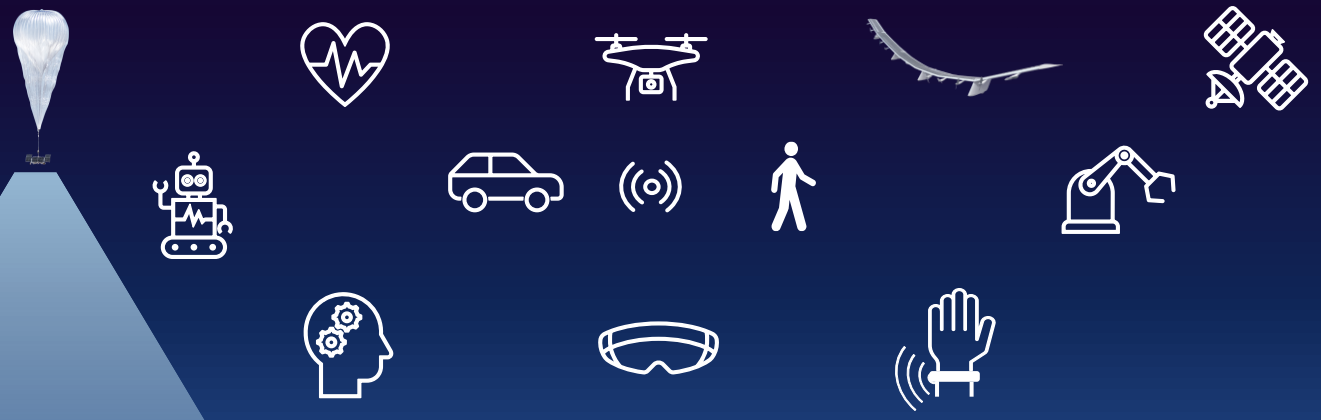



Source

# 6G Timeline from Samsung Whitepaper




Samsung 6G Vision Whitepaper



# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 5: 6G Requirements*

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@3g4gUK

**#Free6Gtraining**

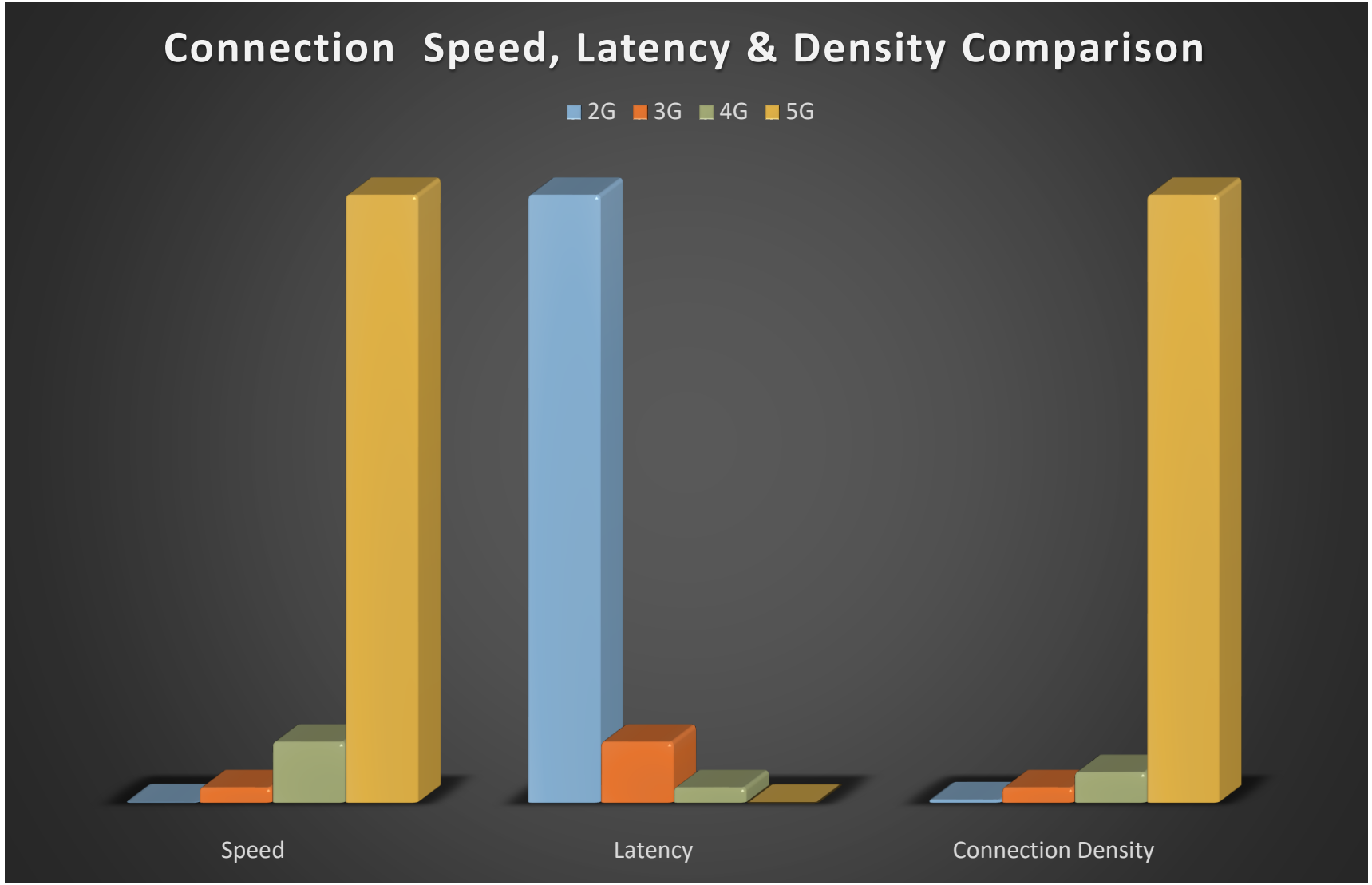
# Part 5 Video Link

# Comparison* of different Technology Generations

| | 2G | 3G (HSPA+) | 4G | 5G |
|---|---|---|---|---|
| **Year** | 1990 | 2000 | 2010 | 2020 |
| **Max DL Speed (theoretical)** | 473.6 Kbps | 42 Mbps | 3 Gbps | 20 Gbps |
| **Avg DL Speed (practical)** | 50 Kbps | 8 Mbps | 100 Mbps | 300 Mbps |
| **Max UL Speed (theoretical)** | 473.6 Kbps | 11.5 Mbps | 1.5 Gbps | 10 Gbps |
| **Avg UL Speed (practical)** | 50 Kbps | 2 Mbps | 50 Mbps | 100 Mbps |
| **E2E Latency (practical)** | 600 ms | 120 ms | 30 ms | 10 ms |
| **Reliability** | 99% | 99.9% | 99.99% | 99.999% |
| **Connection Density** | N/a | N/a | $10^5$ devices/km$^2$ | $10^6$ devices/km$^2$ |
| **Mobility** | 150 km/h | 300 km/h | 350 km/h | 500 km/h |

* Approximate values to show comparisons.

# Comparison of 2G, 3G, 4G & 5G technologies




Example only.
Not according to scale

# 5G (IMT-2020) Requirements

**ITU-R IMT-2020 requirements**

>10 Gbps
Peak data rates

100 Mbps
Whenever needed

100 x
More devices than 4G

10000 x
More traffic than 4G

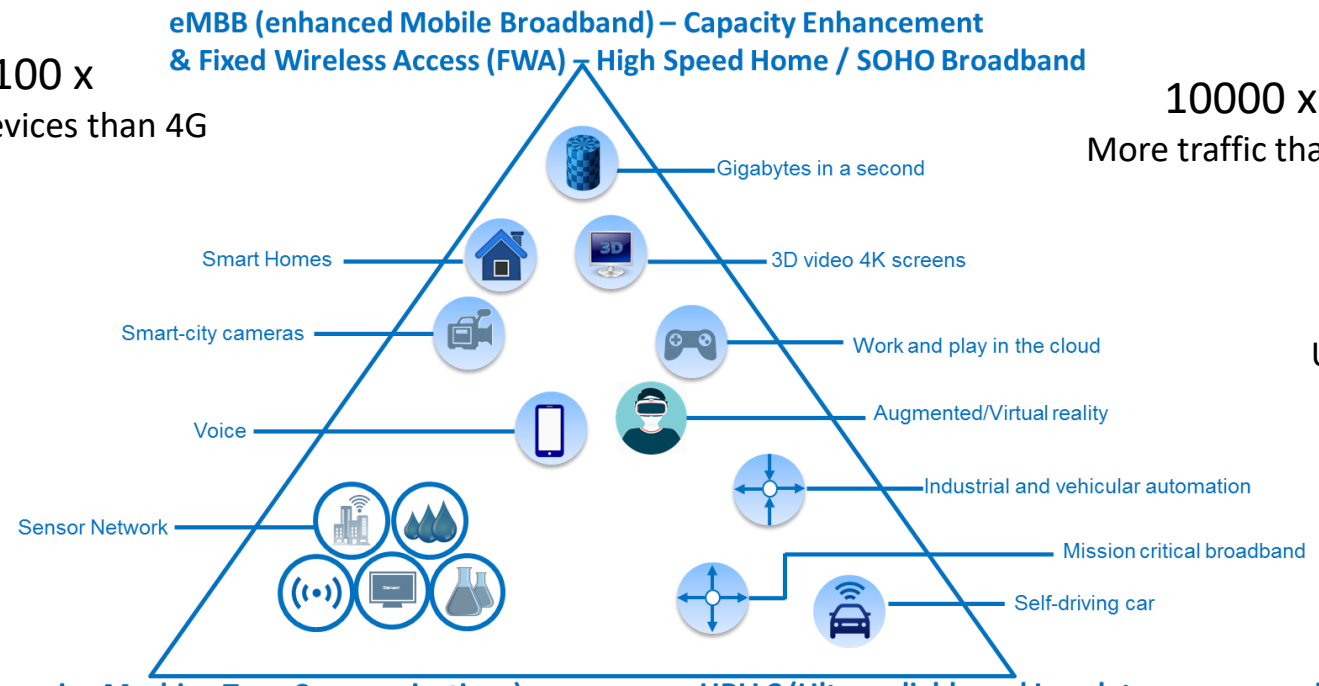
M2M
Ultra low cost

UR
Ultra-Reliable
(99.999%)

10 years
battery life

1,000,000
devices per km$^2$

< 1 ms
Low latency on
radio interface



# 5G Americas Next G Requirements

*4.2.10 Summary: Use Cases to Tech Requirements*

| Technology Requirement | Use Case(s) | Notes |
|---|---|---|
| 4.2.1 Very High Bandwidth | 4.1.1 Holographic Communications<br>4.1.2 Tactile/Haptic Communications<br>Appendix - Digital Twins | BW 0.5 – 1.0 Tbps |
| 4.2.2. Very Wide Coverage | 4.1.3 Ubiquitous Services<br>Appendix - Massive Scale IoT Networks<br>Appendix - Agriculture & Livestock | Gbps coverage everywhere with new coverage areas, e.g., sky (10000 m), sea (200 NM), space etc. |
| 4.2.3 Enhanced Reliability | Appendix - Augmented Reality/ Virtual Reality/Mixed Reality<br>Appendix - Digital Twins<br>4.1.2 Tactile/Haptic Communications<br>4.1.4 Medical/Health<br>Appendix – Telesurgery<br>4.1.5 Government/National Security<br>4.1.7 First Responder/Emergency Services<br>4.1.9 Transportation Vertical | "seven 9's" availability (99.99999%) |
| 4.2.4 High Density of Endpoints | Appendix - Massive Scale IoT Networks<br>Appendix - Smart Agriculture & Livestock | 10 million devices/km$^2$ |
| 4.2.5. Synchronization of Multiple Flows to Multiple Devices | Appendix - Augmented Reality/ Virtual Reality/Mixed Reality<br>4.1.1 Holographic Communications<br>Appendix - Digital Twins<br>4.1.2 Tactile/Haptic Communications<br>Appendix - Telesurgery | synchronized parallel media streams, originating in different points of network |
| 4.2.6 Time Sensitive Operations | Appendix - Digital Twins<br>4.1.2 Tactile/Haptic Communications<br>Appendix - Telesurgery<br>4.1.9 Transportation Vertical | air interface latency < 10 ns, E2E latency < 100 µs<br>Jitter order of µs |
| 4.2.7. Precise Location Tracking | Appendix - Augmented Reality/ Virtual Reality/Mixed Reality<br>4.1.2 Tactile/Haptic Communications<br>4.1.9 Transportation Vertical | Six degrees of motion: (x,y,z) plus pitch, yaw, and rotation |
| 4.2.8. Extremely Low Power and Resource Constrained Devices | Appendix - Use Case: Massive Scale IoT Networks<br>Appendix - Smart Agriculture & Livestock | Extremely low power including devices never to be charged (e.g., absorbing energy from its environment) |
| 4.2.9 General Industry Requirements | 4.1.8 Cyber-Physical Systems/ Manufacturing | |

5G Americas Whitepaper: Mobile Communications Beyond 2020 - The Evolution of 5G Towards the Next G

# NTT Docomo 6G Requirements

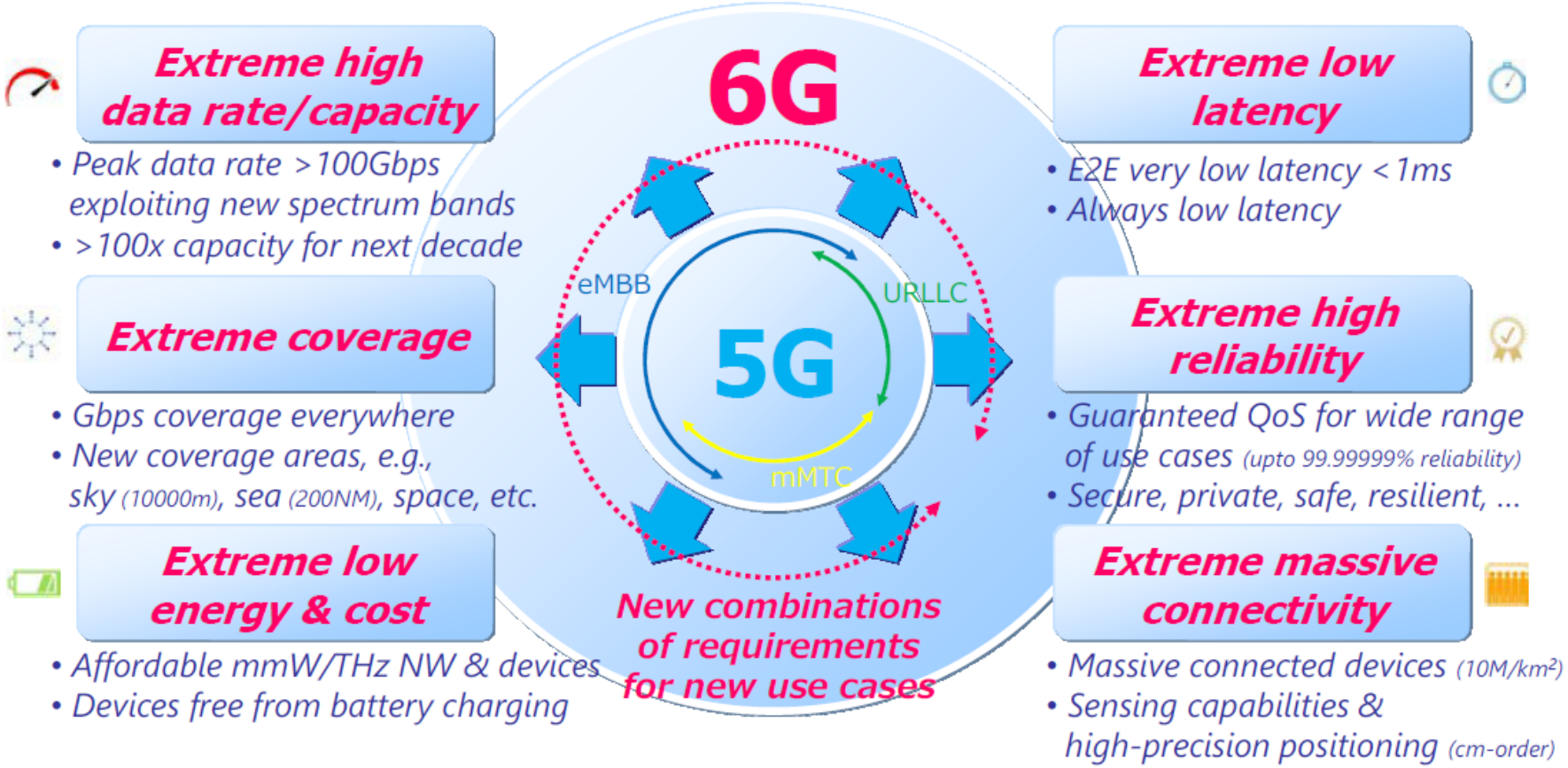



Figure 3-1. Requirements for 6G wireless technology

Source: NTT Docomo 6G Whitepaper, Jan 2020

# 6G Research Visions, 5G & 6G KPIs Comparison

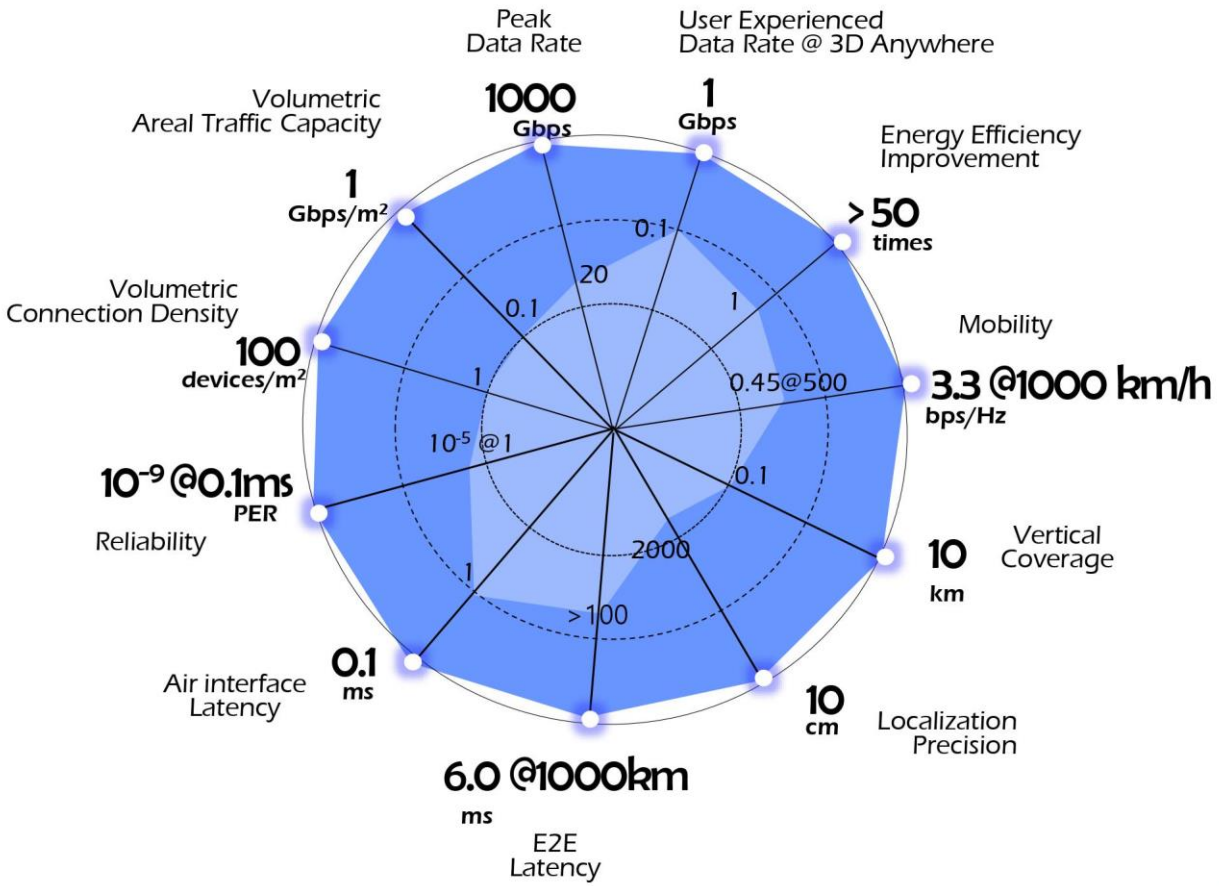
| KPI | 5G | 6G |
|---|---|---|
| Peak data rate | 20 Gb/s | 1 Tb/s |
| Experienced data rate | 0.1 Gb/s | 1 Gb/s |
| Peak spectral efficiency | 30 b/s/Hz | 60 b/s/Hz |
| Experienced spectral efficiency | 0.3 b/s/Hz | 3 b/s/Hz |
| Maximum bandwidth | 1 GHz | 100 GHz |
| Area traffic capacity | 10 Mb/s/$m^2$ | 1 Gb/s/$m^2$ |
| Connection density | $10^6$ devices/$km^2$ | $10^7$ devices/$km^2$ |
| Energy efficiency | not specified | 1 Tb/J |
| Latency | 1 ms | 100 µs |
| Reliability | $1\text{-}10^{-5}$ | $1\text{-}10^{-9}$ |
| Jitter | not specified | 1 µs |
| Mobility | 500 km/h | 1000 km/h |



Table 1: A comparison of 5G and 6G KPIs [4–6,9].

6G Research Visions: White Paper 10 on Broadband Connectivity in 6G

# ETRI: 6G KPIs




Source: ETRI, South Korea (link)

**6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies**
**Zhengquan Zhang; YUE XIAO; Zheng Ma; Ming Xiao; Zhiguo Ding; Xianfu Lei; George K Karagiannidis; Pingzhi Fan**
**https://ieeexplore.ieee.org/document/8766143/**



| | | 4G | 5G | 6G |
|---|---|---|---|---|
| Usage Scenarios | | • MBB | • eMBB • URLLC • mMTC | • FeMBB • ERLLC • umMTC<br>• LDHMC • ELPC |
| Applications | | • High-Definition Videos<br>• Voice<br>• Mobile TV<br>• Mobile Internet<br>• Mobile Pay | • VR/AR/360° Videos<br>• UHD Videos<br>• V2X<br>• IoT<br>• Smart City/Factory/Home<br>• Telemedicine<br>• Wearable Devices | • Holographic Verticals and Society<br>• Tactile/Haptic Internet<br>• Full-Sensory Digital Sensing and Reality<br>• Fully Automated Driving<br>• Industrial Internet<br>• Space Travel<br>• Deep-Sea Sightseeing<br>• Internet of Bio-Nano-Things |
| Network Characteristics | | Flat and All-IP | • Cloudization<br>• Softwarization<br>• Virtualization<br>• Slicing | • Intelligentization<br>• Cloudization<br>• Softwarization<br>• Virtualization<br>• Slicing |
| Service Objects | | People | Connection (People and Things) | Interaction (People and World) |
| KPI | Peak Data Rate | 100 Mb/s | 20 Gb/s | ≥1 Tb/s |
| | Experienced Data Rate | 10 Mb/s | 0.1 Gb/s | 1 Gb/s |
| | Spectrum Efficiency | 1× | 3× that of 4G | 5–10× that of 5G |
| | Network Energy Efficiency | 1× | 10–100× that of 4G | 10–100× that of 5G |
| | Area Traffic Capacity | 0.1 Mb/s/$m^2$ | 10 Mb/s/$m^2$ | 1 Gb/s/$m^2$ |
| | Connectivity Density | $10^5$ Devices/$km^2$ | $10^6$ Devices/$km^2$ | $10^7$ Devices/$km^2$ |
| | Latency | 10 ms | 1 ms | 10–100 $\mu$s |
| | Mobility | 350 km/h | 500 km/h | ≥1,000 km/h |
| Technologies | | • OFDM<br>• MIMO<br>• Turbo Code<br>• Carrier Aggregation<br>• Hetnet<br>• ICIC<br>• D2D Communications<br>• Unlicensed Spectrum | • mm-wave Communications<br>• Massive MIMO<br>• LDPC and Polar Codes<br>• Flexible Frame Structure<br>• Ultradense Networks<br>• NOMA<br>• Cloud/Fog/Edge Computing<br>• SDN/NFV/Network Slicing | • THz Communications<br>• SM-MIMO<br>• LIS and HBF<br>• OAM Multiplexing<br>• Laser and VLC<br>• Blockchain-Based Spectrum Sharing<br>• Quantum Communications and Computing<br>• AI/Machine Learning |

*FIGURE 2* The network features of 4G, 5G, and the future 6G. AR: augmented reality; ELPC: extremely low-power communications; eMBB: enhanced mobile broadband; ERLLC: extremely reliable and low-latency communications; FeMBB: further-enhanced mobile broadband; LDHMC: long-distance and high-mobility communications; mMTC: massive machine-type communications; NFV: network function virtualization; SDN: software-defined networking; UHD: ultrahigh definition; umMTC: ultra-massive machine-type communications; URLLC: ultrareliable and low-latency communications; VR: virtual reality; V2X: vehicle to everything; KPI: key performance indicator; LDPC: low-density parity check codes.

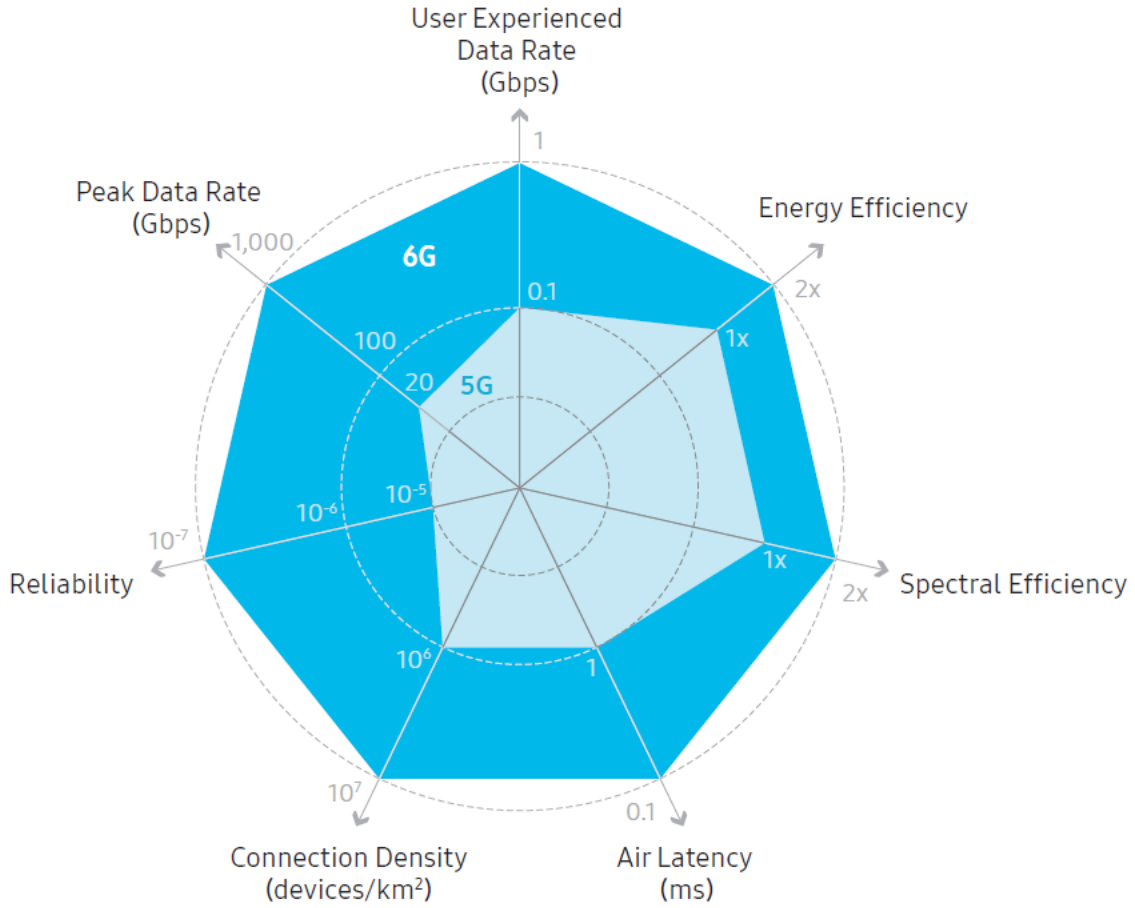


Source

# 5G vs 6G Key Performance Requirements Comparison

**Figure 7**

Comparison of key performance requirements between 5G and 6G.




Samsung 6G Vision Whitepaper

# Comparison* of different Technology Generations

| | 2G | 3G (HSPA+) | 4G | 5G | 6G** |
|---|---|---|---|---|---|
| **Year** | 1990 | 2000 | 2010 | 2020 | 2030 |
| **Max DL Speed (theoretical)** | 473.6 Kbps | 42 Mbps | 3 Gbps | 20 Gbps | 1 Tbps |
| **Avg DL Speed (practical)** | 50 Kbps | 8 Mbps | 100 Mbps | 300 Mbps | 1 Gbps |
| **Max UL Speed (theoretical)** | 473.6 Kbps | 11.5 Mbps | 1.5 Gbps | 10 Gbps | 10 Gbps |
| **Avg UL Speed (practical)** | 50 Kbps | 2 Mbps | 50 Mbps | 100 Mbps | 1 Gbps |
| **E2E Latency (practical)** | 600 ms | 120 ms | 30 ms | 10 ms | 1 ms |
| **Reliability** | 99% | 99.9% | 99.99% | 99.999% | 99.99999% |
| **Connection Density** | N/a | N/a | $10^5$ devices/km$^2$ | $10^6$ devices/km$^2$ | $10^7$ devices/km$^2$ |
| **Mobility** | 150 km/h | 300 km/h | 350 km/h | 500 km/h | 1000 km/h |

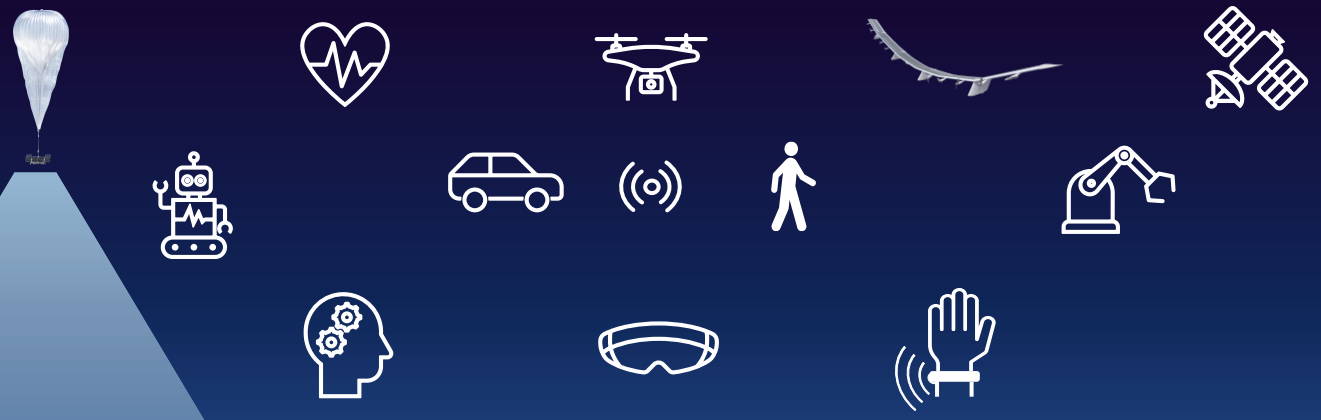
* Approximate values to show comparisons. **Subject to change when standards process starts.

# Background Material

- 3G4G: Bandwidth, Throughput, Latency & Jitter in mobile networks (link)
- 3G4G: Reliability - 5x9s vs 6x9s (link)

# Further Reading

- 5G Americas: Mobile Communications Beyond 2020 – The Evolution of 5G Towards Next G, Dec 2020 (link)
- 6G Research Visions: White Paper 4 on Validation and Trials for Verticals towards 2030's, June 2020 (link)
- NTT Docomo white paper: 5G Evolution and 6G, January 2020 (link)
- 6G Research Visions: White Paper 10 on Broadband Connectivity in 6G, June 2020 (link)
- Z. Zhang et al., "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," in IEEE Vehicular Technology Magazine, 28-41, Sept. 2019 (link)
- The 3G4G Blog: NTT Docomo's Vision on 5G Evolution and 6G (link)



# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 6: 6G Groups*

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# Part 6 Video Link

# 6G Activities in China

www.miit.gov.cn

中华人民共和国工业和信息化部

Ministry of Industry and Information Technology of the People's Republic of China

## China's IMT-2030 (6G) Promotion Group Approach 6G research

**6G Expertise Committee**

- Requirement WG
- Wireless Tech. WG
- Network Tech. WG
- Spectrum WG
- Standards & International Corp. WG

- 57 member in the IMT-2030 promotion group, world members are welcomed, Samsung, DoCoMo, Ericsson, etc.

| Research institution | Operator | System equipment provider | Chipset and terminal provider | University |
|---|---|---|---|---|
| CAICT, 国家无线电监测中心, ICT, TD Industry Alliance, WiCo | 中国移动通信 CHINA MOBILE, 中国电信 CHINA TELECOM, China unicom中国联通, docomo | HUAWEI, CICT 中国信科, ZTE中兴, ERICSSON, NOKIA, SAMSUNG | HISILICON, Lenovo, 紫光展锐 UNISOC, vivo, oppo | |

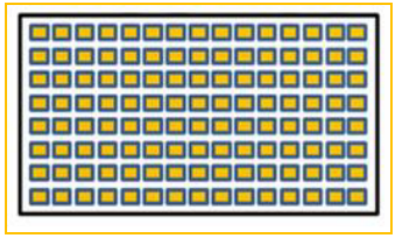
6


Slide Source: MIIT

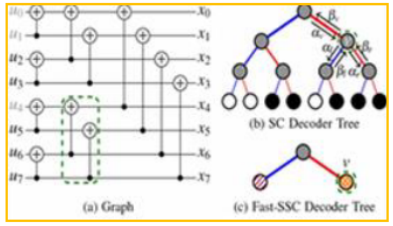
# 6G Activities in China

## Some Potential Key Technologies for 6G

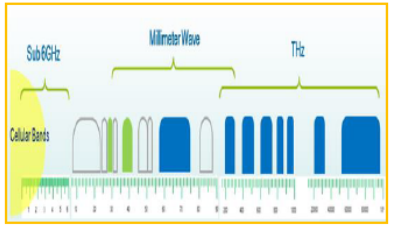
### Wireless Key Technologies



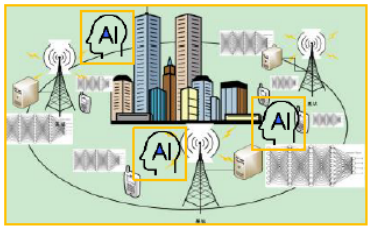
Extreme-MIMO




Advanced modulation and coding schemes

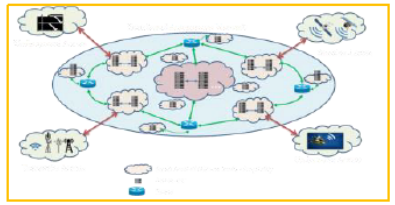



Tera-Hertz (THz) communications

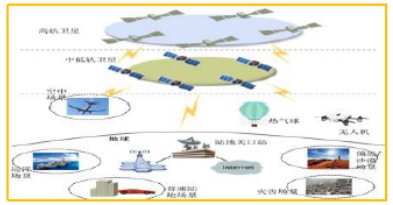



The integration of AI and communication

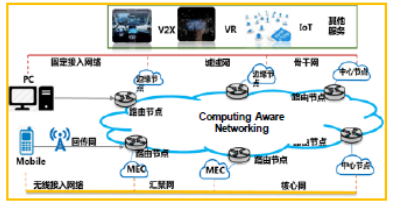
### Network Key Technologies



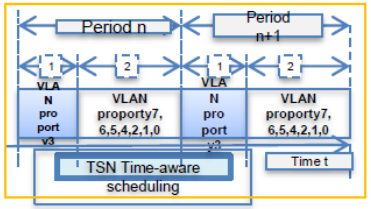
Network architecture



Air, space and earth integrated network




Computing power networking




Deterministic network

Slide Source: CAICT

# 6G Activities in Japan

NIKKEI Asia

Japan readies $2bn to support industry research on 6G tech

TELECOM TV
WHERE TELECOMS CONNECTS

Japan eyes 6G as a way of making up lost ground

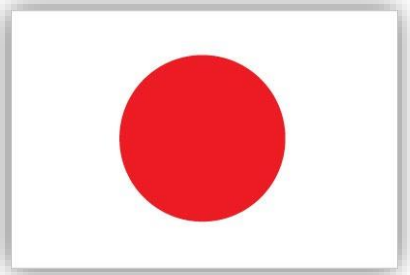
NIKKEI Asia

Race for 6G: Japan plays catch-up via infrastructure

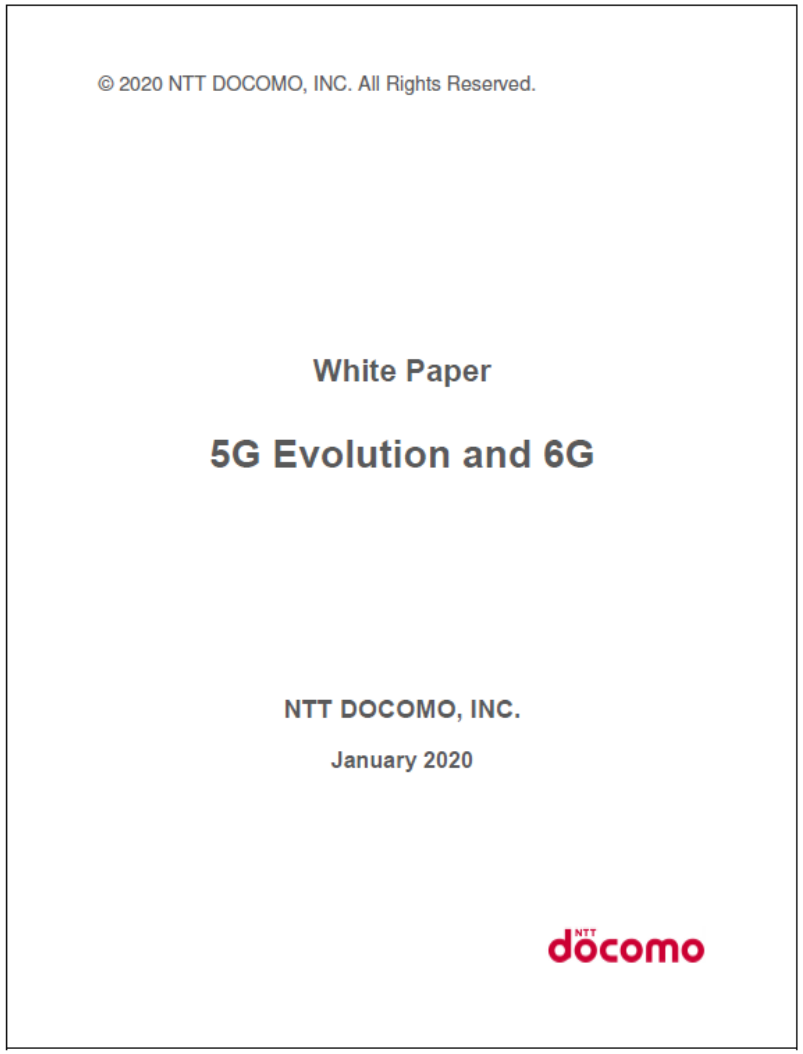
the japan times

Japan to earmark ¥50 billion for 6G development

(Click on the name of the newspaper to visit the link)



# NTT Docomo 6G Activities



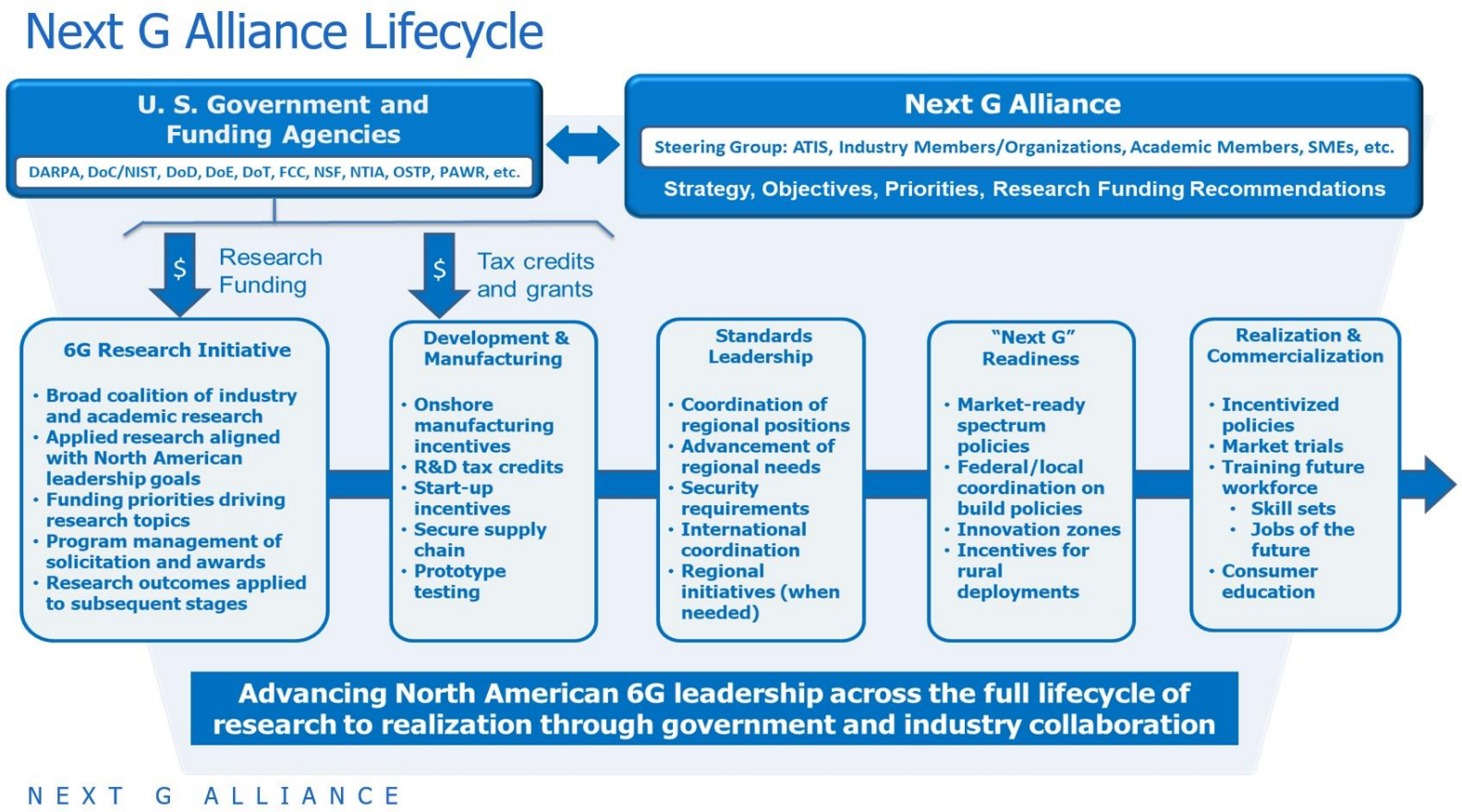

DOCOMO will continue its research into and development of 5G evolution and 6G technology, aiming to realize technological advances including:

- the achievement of a combination of advances in connectivity, including ultra-high speed, large capacity and low latency
- the pioneering of new frequency bands, including terahertz frequencies
- the expansion of communication coverage in the sky, at sea and in space
- the provision of ultra-low-energy and ultra-low-cost communications
- the ensuring of highly reliable communications
- the capability of massive device-connectivity and sensing

# 6G Activities in South Korea

- Jan 2019: LG set up a 6G Research Center at KAIST (Korean Advanced Institute of Science and Technology).
- Samsung also opened an Advanced Communications Research Center in Seoul to focus on 6G during early 2019.
- The South Korean government expects 6G services could be commercially available in Korea between 2028 and 2030
- The government of Korea reportedly expects to invest a total of KRW 200 billion ($169 million) between 2021 and 2026 period to secure basic 6G technology.

# North America: Next-G Alliance

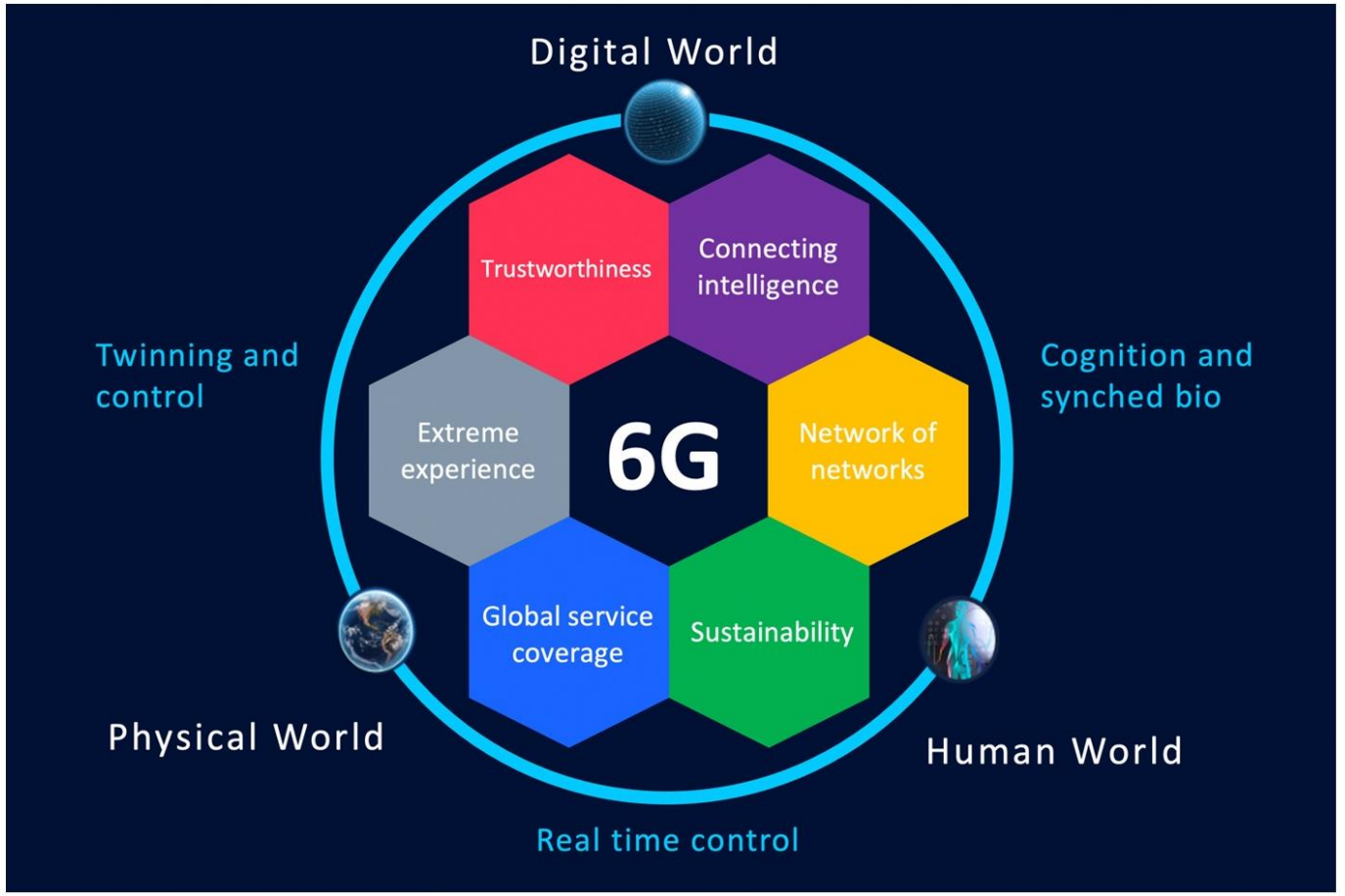



https://nextgalliance.org/

# US Universities 6G Activities

- NYU Wireless Research (link) - Terahertz, 6G & Beyond research
- ComSenTer (Communications Sensing TeraHertz) (link) - innovation in microelectronics-based technologies, including wireless communications.
- mmWave Networking Group at the University of Padova (link) - focused on mmWaves and THz
- The Institute for the Wireless Internet of Things (WIOT) at Northeastern University (link)

# Hexa-X: European 6G flagship research project




Hexa-X website

# 6G Flagship at University of Oulu, Finland


6G Flagship Website

# 6G Innovation Centre (6GIC), University of Surrey, UK


Institute for Communication Systems (ICS) Website

# Further Reading

- 5G Americas - Mobile Communications Beyond 2020: The Evolution of 5G Towards the Next G (link)
- Nokia: 6G technology leadership in the US, Nov 2020 (link)
- Free 6G Training: Nokia to lead the EU's 6G project Hexa-X, Dec 2020 (link)
- Presentations from the What Next for Wireless Infrastructure Summit, Nov 2020 (link)
- ETSI Virtual Event on Boosting the Impact of Research & Innovation through Standardization conference, Nov 2020 (link)

# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 7: 6G Technologies*

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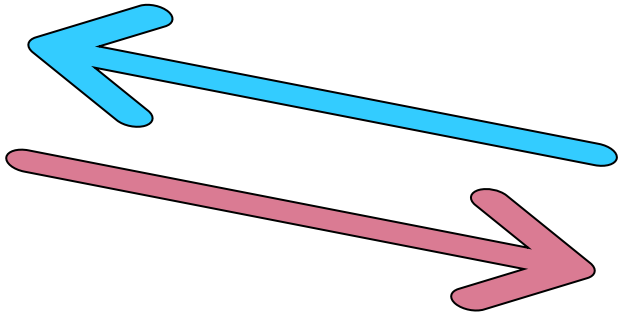
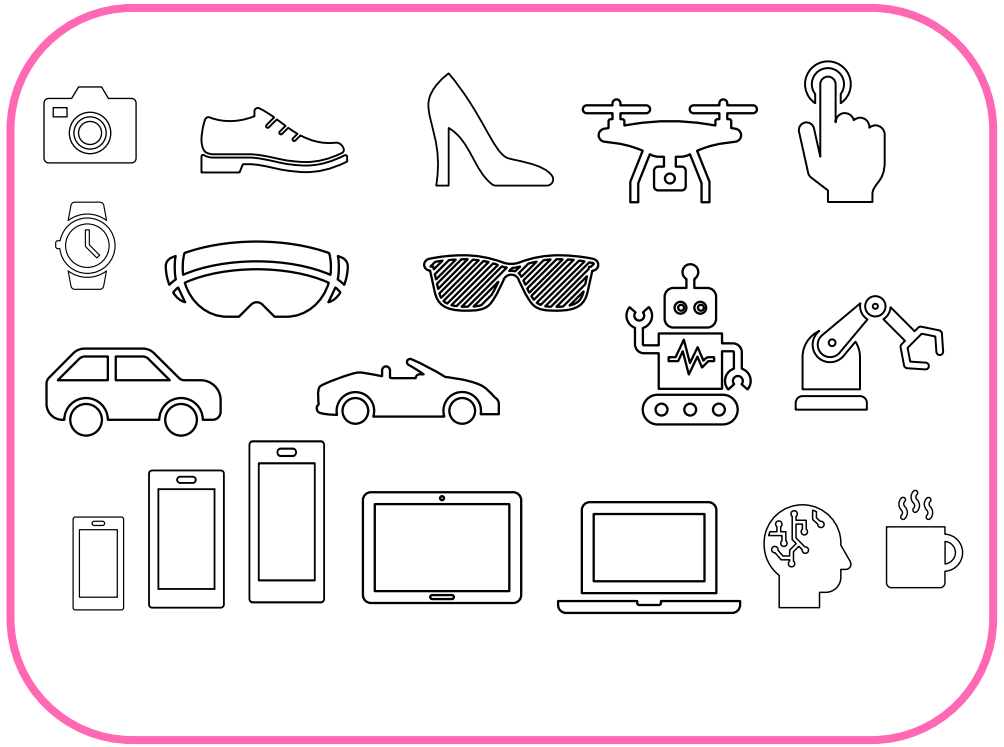
**#Free6Gtraining**

# Part 7 Video Link





6G Network

6G Connectivity

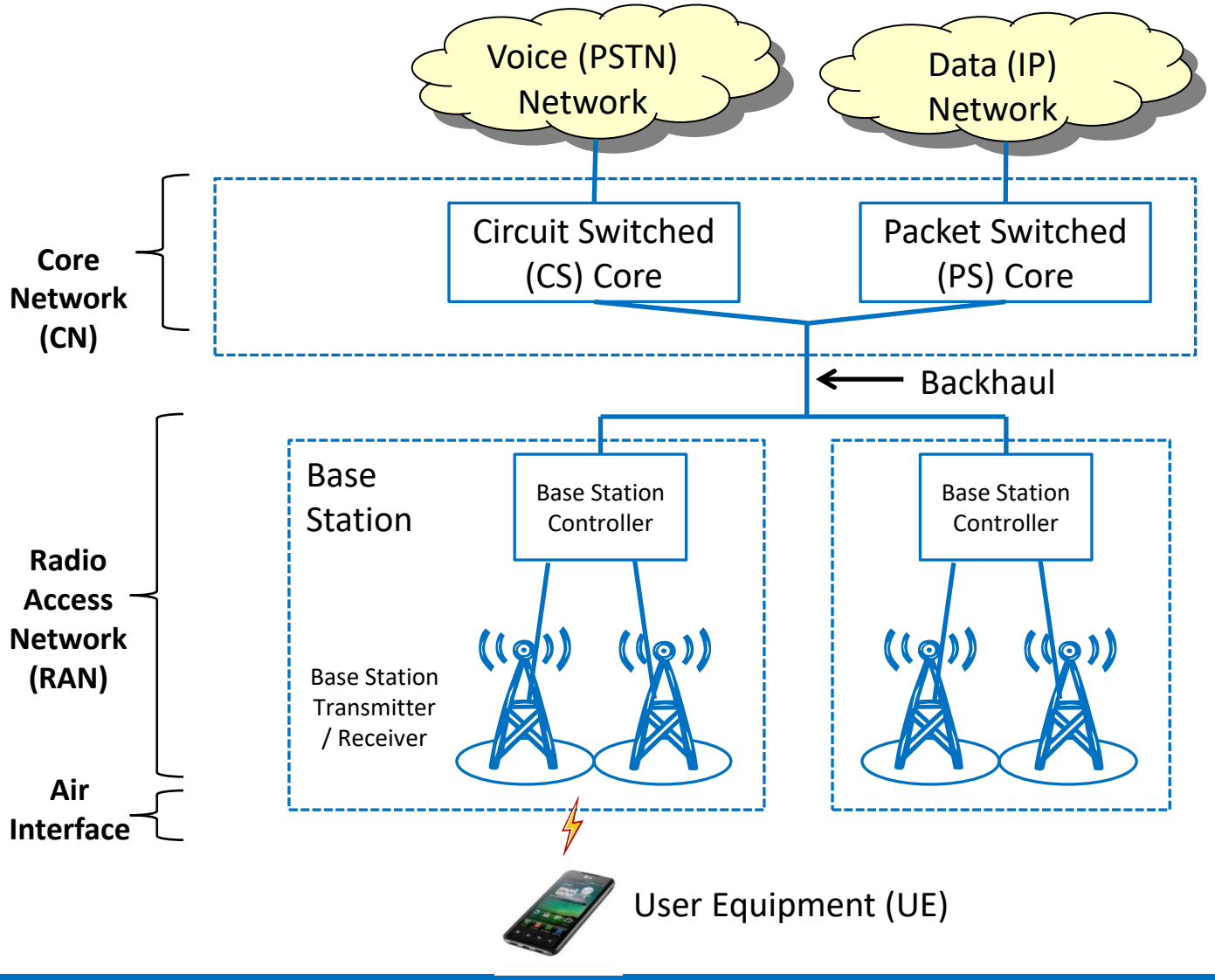
6G Devices

# Core Network and Network Architecture Evolution

SUMMARY

- Recap of existing core networks
- Control and User Plane Separation (CUPS)
- Service Based Architecture (SBA) in 5G
- 5G Network Architecture
- RAN-Core Convergence

# 2G / 3G Mobile Network Architecture




**Core Network**

- Connects to voice and data networks
- Provides Security and Authentication
- Billing / Charging
- Roaming

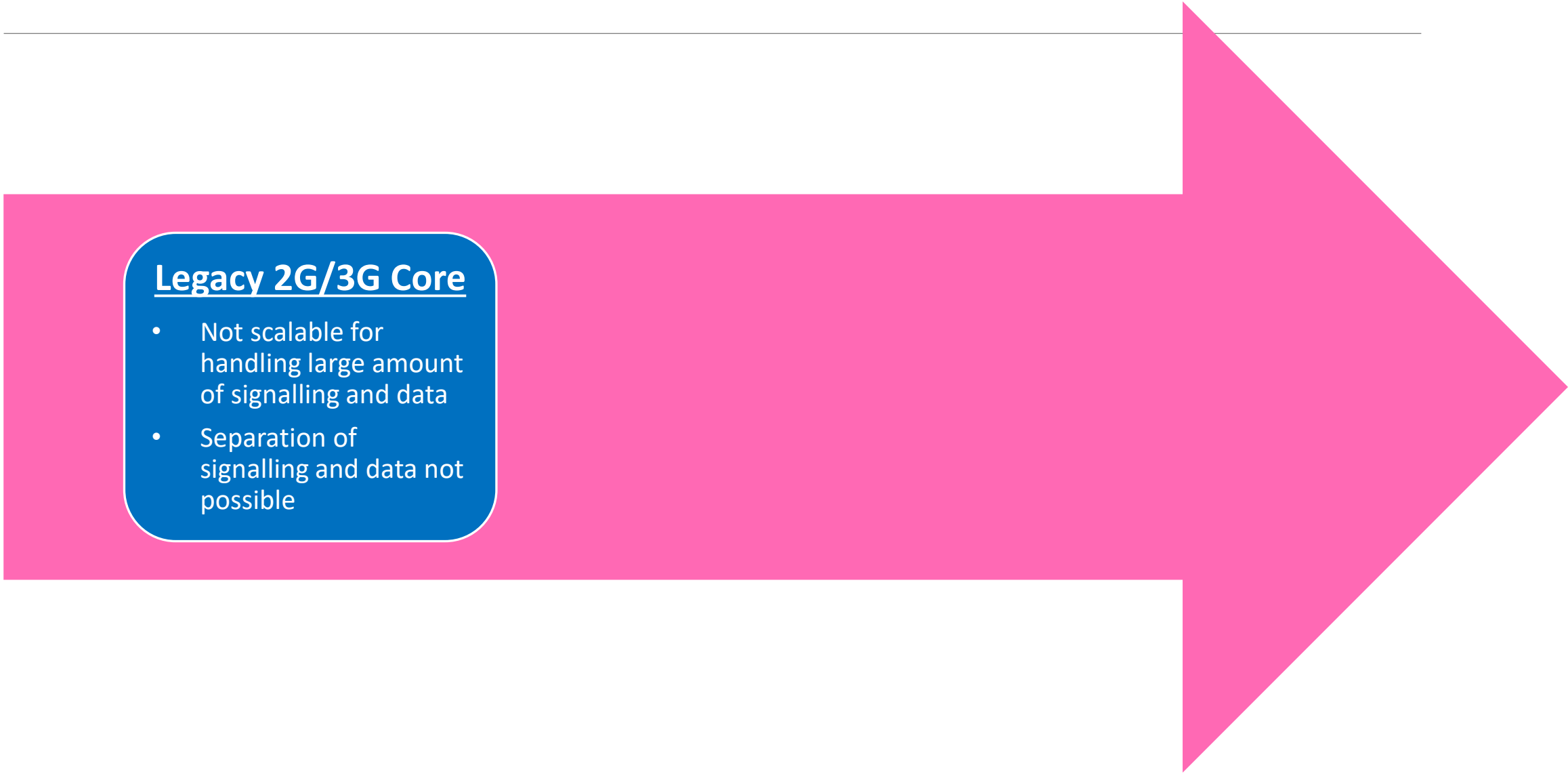
**Backhaul**

- Connects access network with core network
- Example: Fiber, microwave, satellite, mesh, etc.

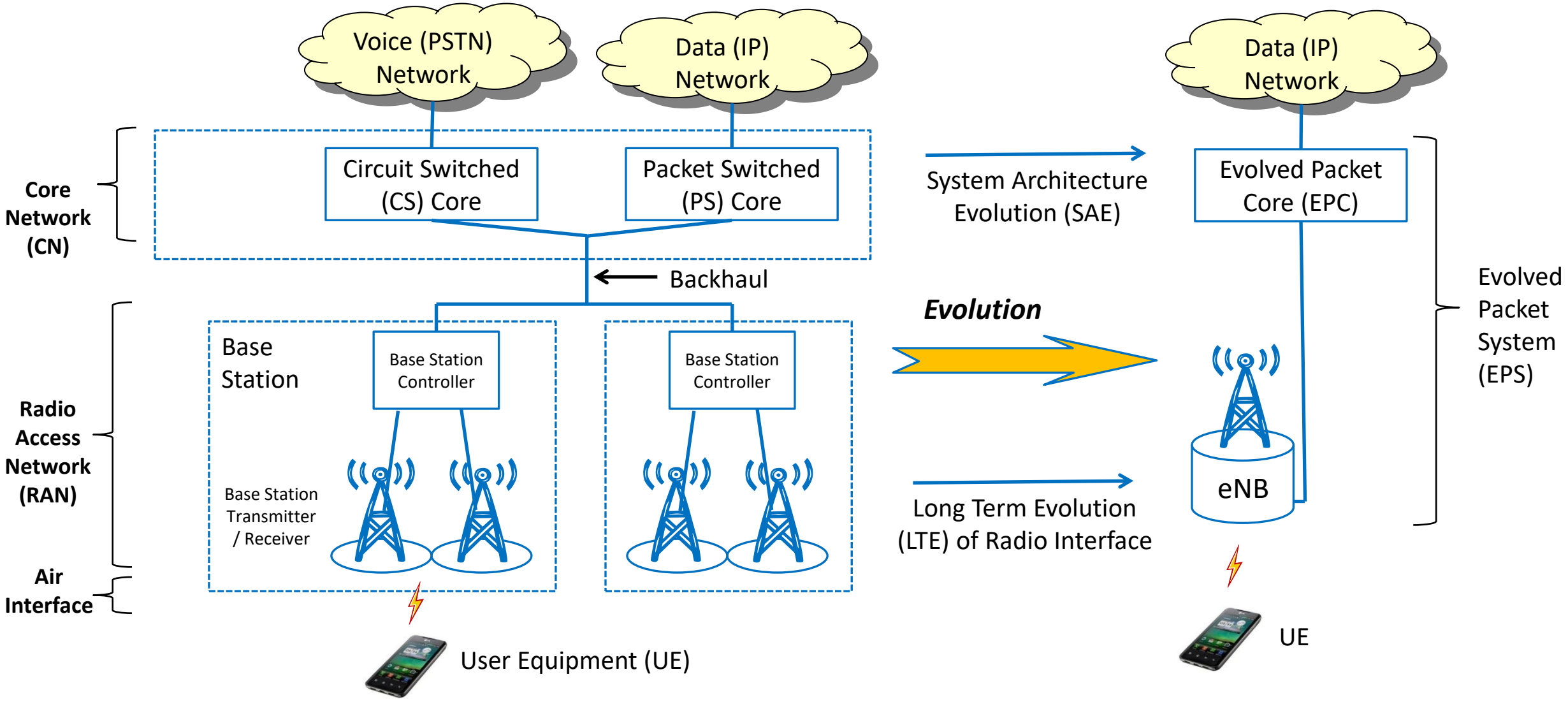
**Access Network**

- Connects devices over the air
- Allows mobility and handovers

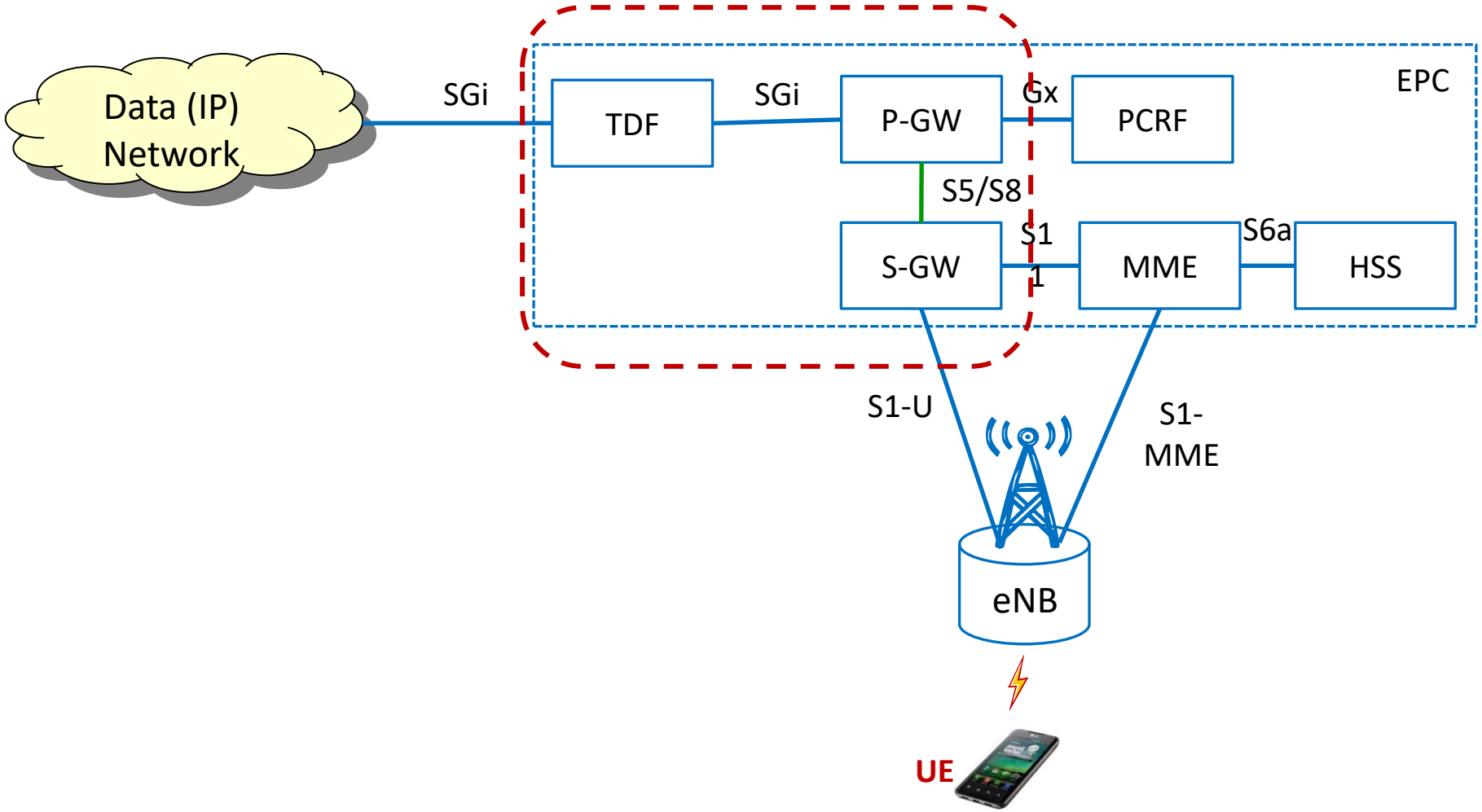
# Evolution of Packet Mobile Core



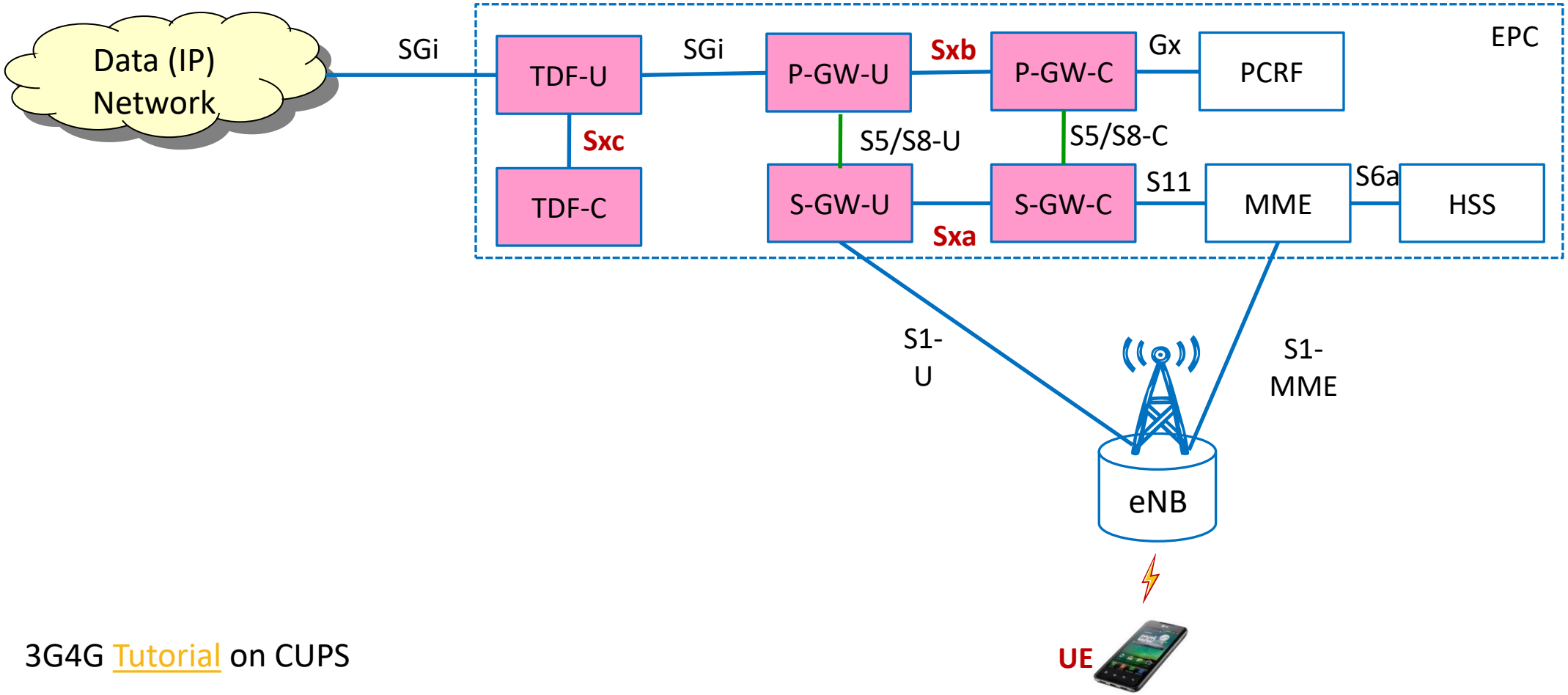
# 4G Mobile Network Architecture



# EPC before CUPS (Control and User Plane Separation of EPC nodes)

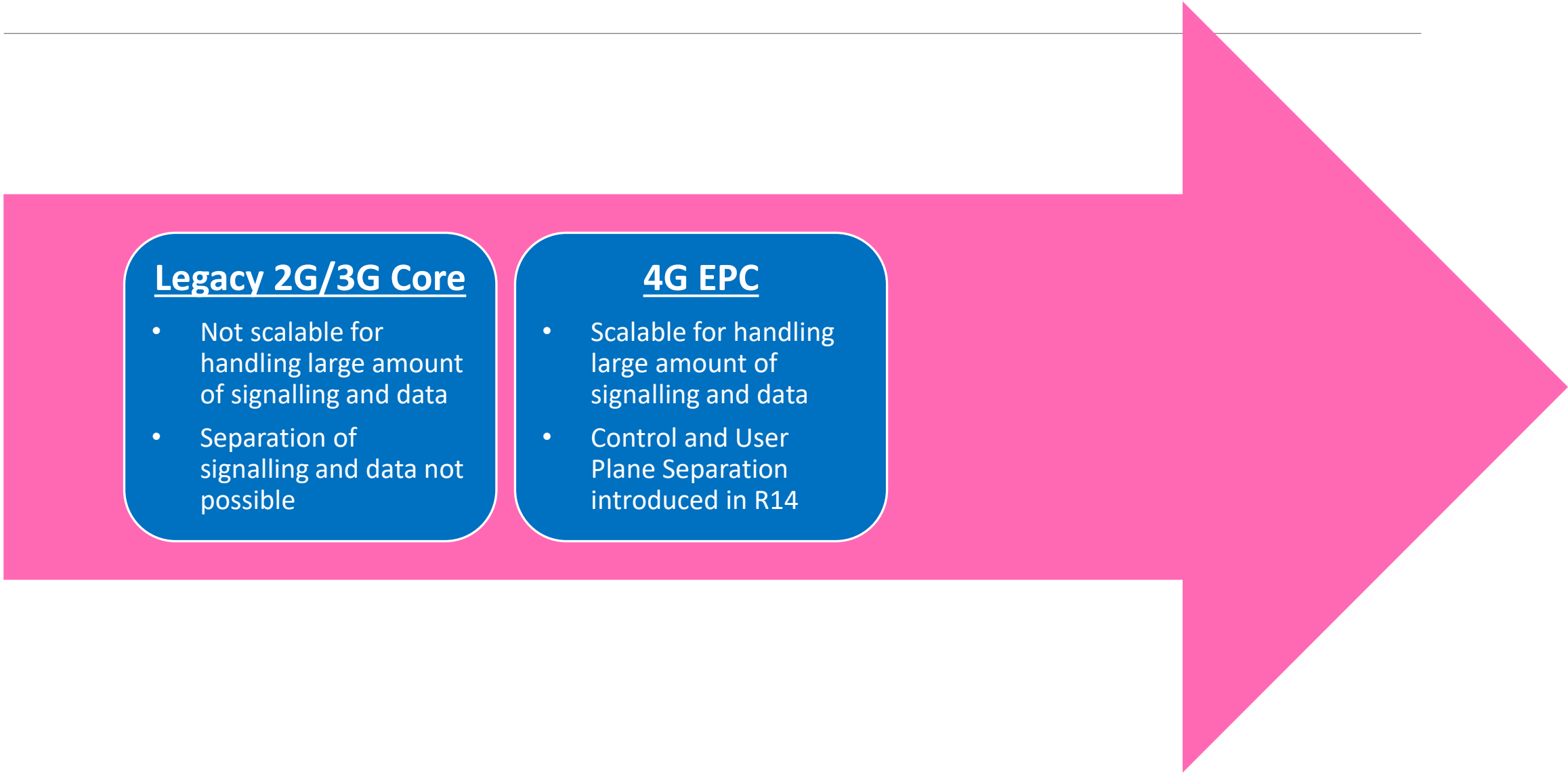


# EPC after CUPS

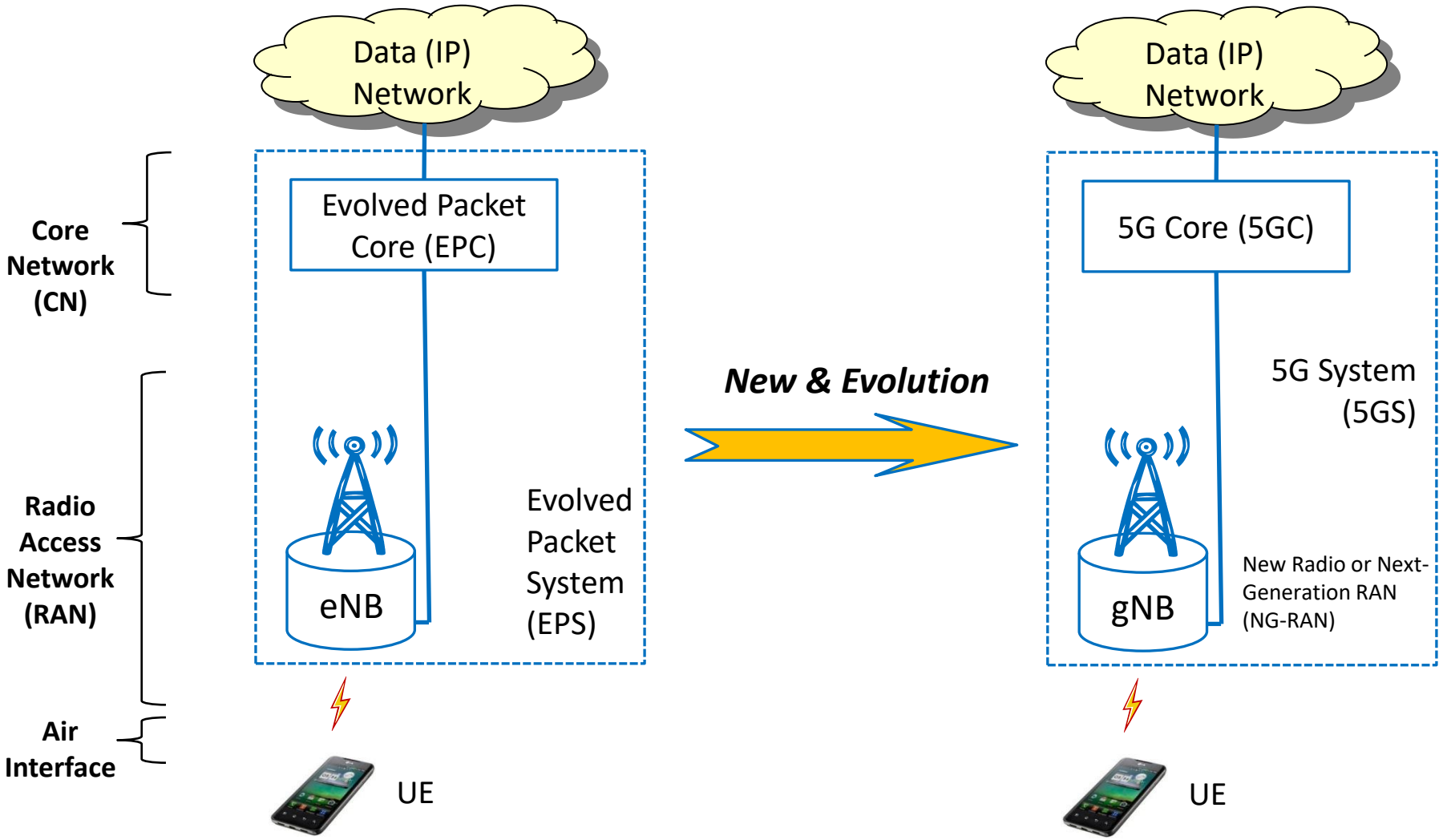



3G4G Tutorial on CUPS

# Evolution of Packet Mobile Core



# 5G Mobile Network Architecture

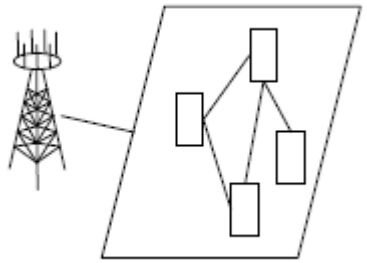



5G System is defined as 3GPP system consisting of 5G Access Network (AN), 5G Core Network and UE. The 5G System provides data connectivity and services.

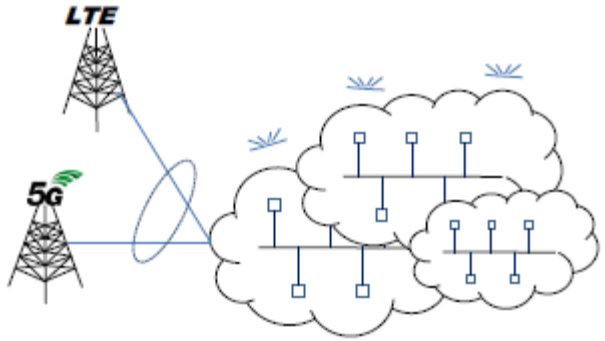
3GPP TS 23.501: System Architecture for the 5G System; Stage 2

3GPP TS 23.502: Procedures for the 5G System; Stage 2

# Core Network Architecture Evolution in 5G



5G

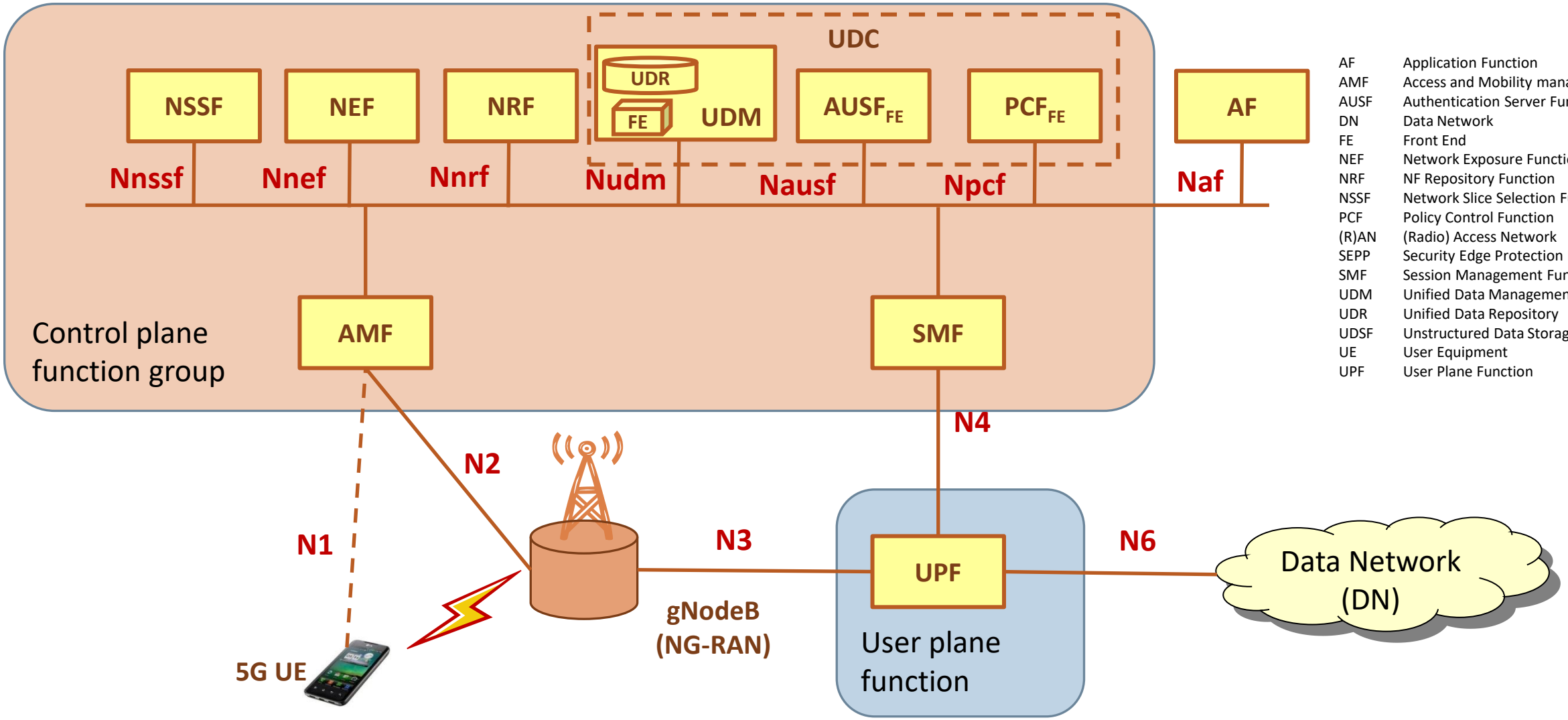



- Functional entities
- Single Core
- Dedicated protocols

- Service Based (SBA/SBI/NAPS)
- Virtualization & Slicing
- Softwarization/ Cloudification
- Application Programming Interfaces
- Harmonized protocols (HTTP …)
- Exposure to 3rdParties
- Backward & Forward Compatibility

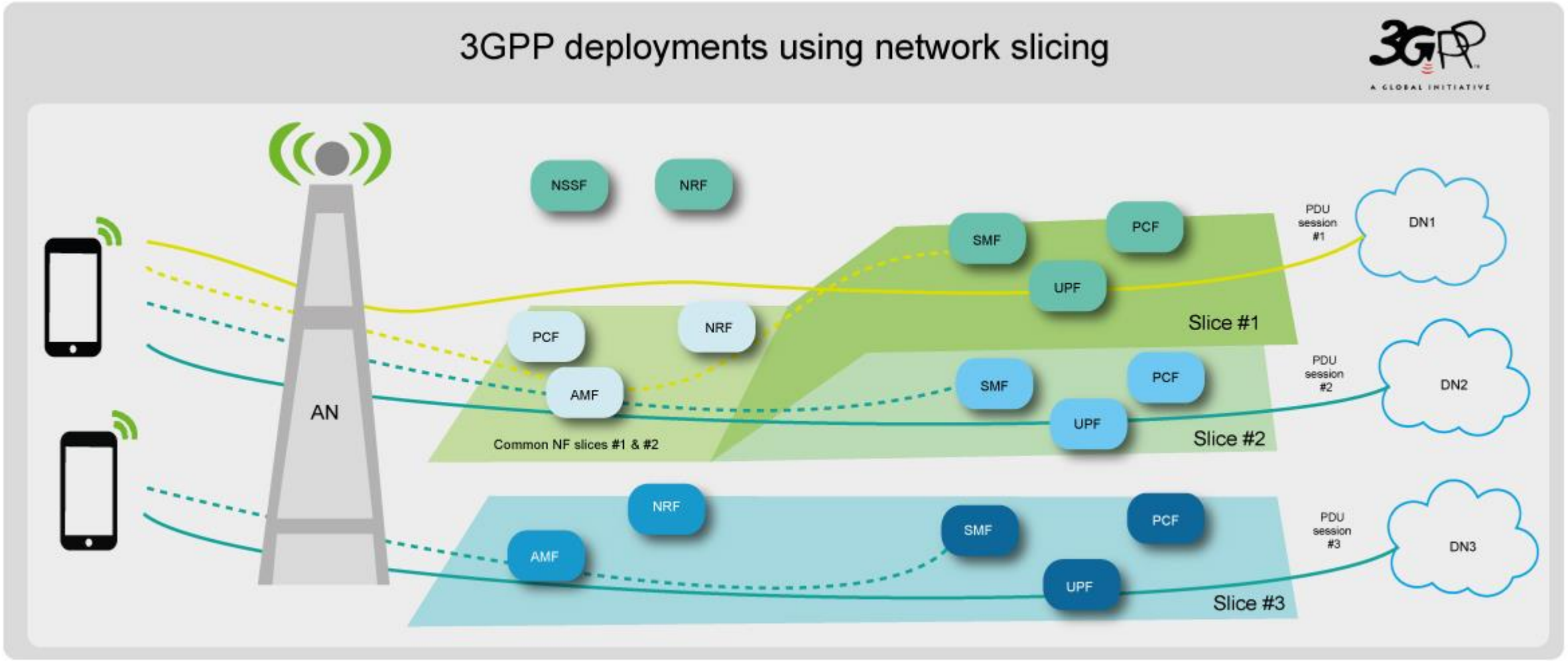
Source: Georg Mayer

# 5GS Service Based Architecture (SBA)



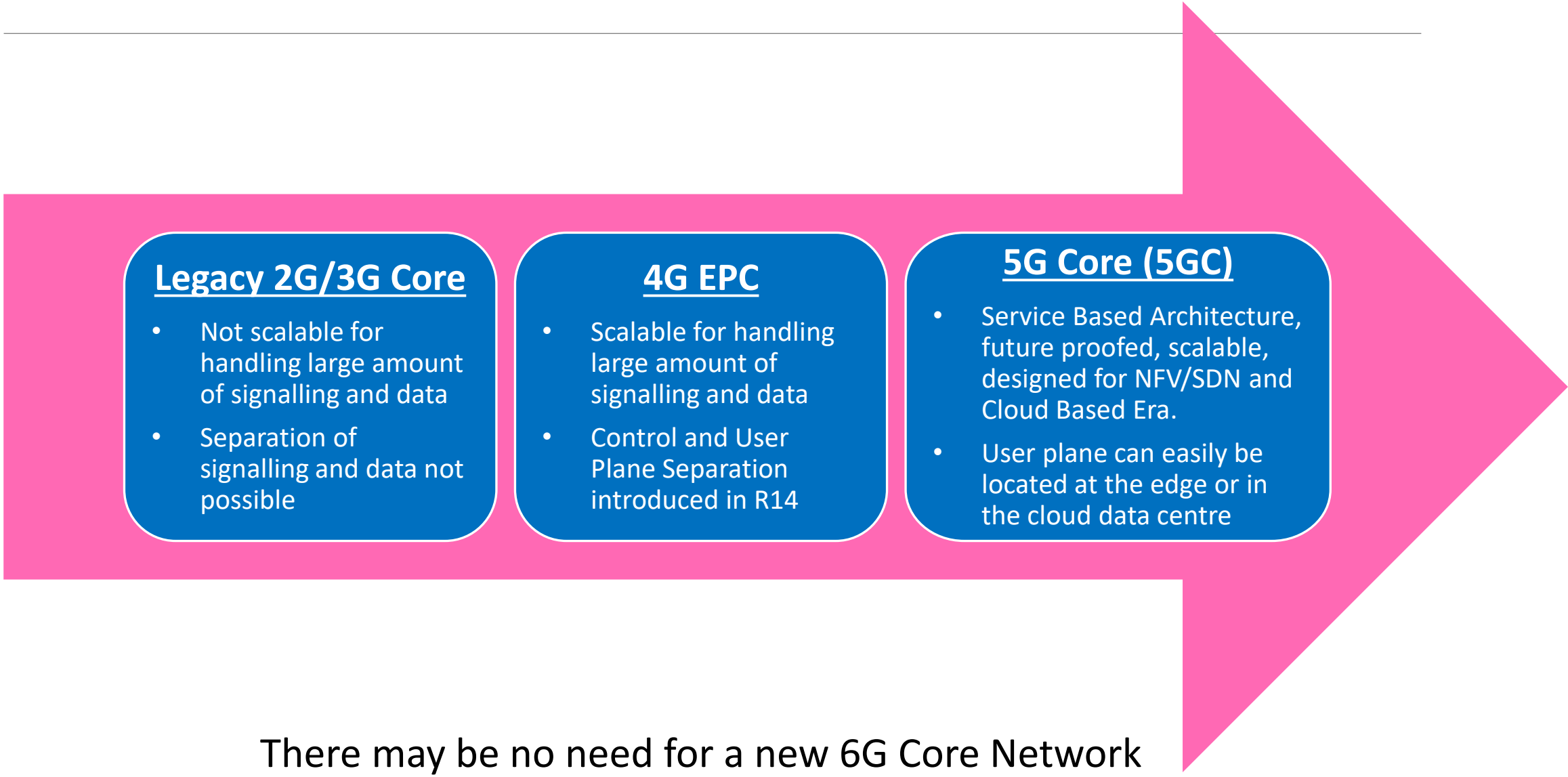

| | |
|---|---|
| AF | Application Function |
| AMF | Access and Mobility management Function |
| AUSF | Authentication Server Function |
| DN | Data Network |
| FE | Front End |
| NEF | Network Exposure Function |
| NRF | NF Repository Function |
| NSSF | Network Slice Selection Function |
| PCF | Policy Control Function |
| (R)AN | (Radio) Access Network |
| SEPP | Security Edge Protection Proxy |
| SMF | Session Management Function |
| UDM | Unified Data Management |
| UDR | Unified Data Repository |
| UDSF | Unstructured Data Storage Function |
| UE | User Equipment |
| UPF | User Plane Function |

# 5GS using Network Slicing



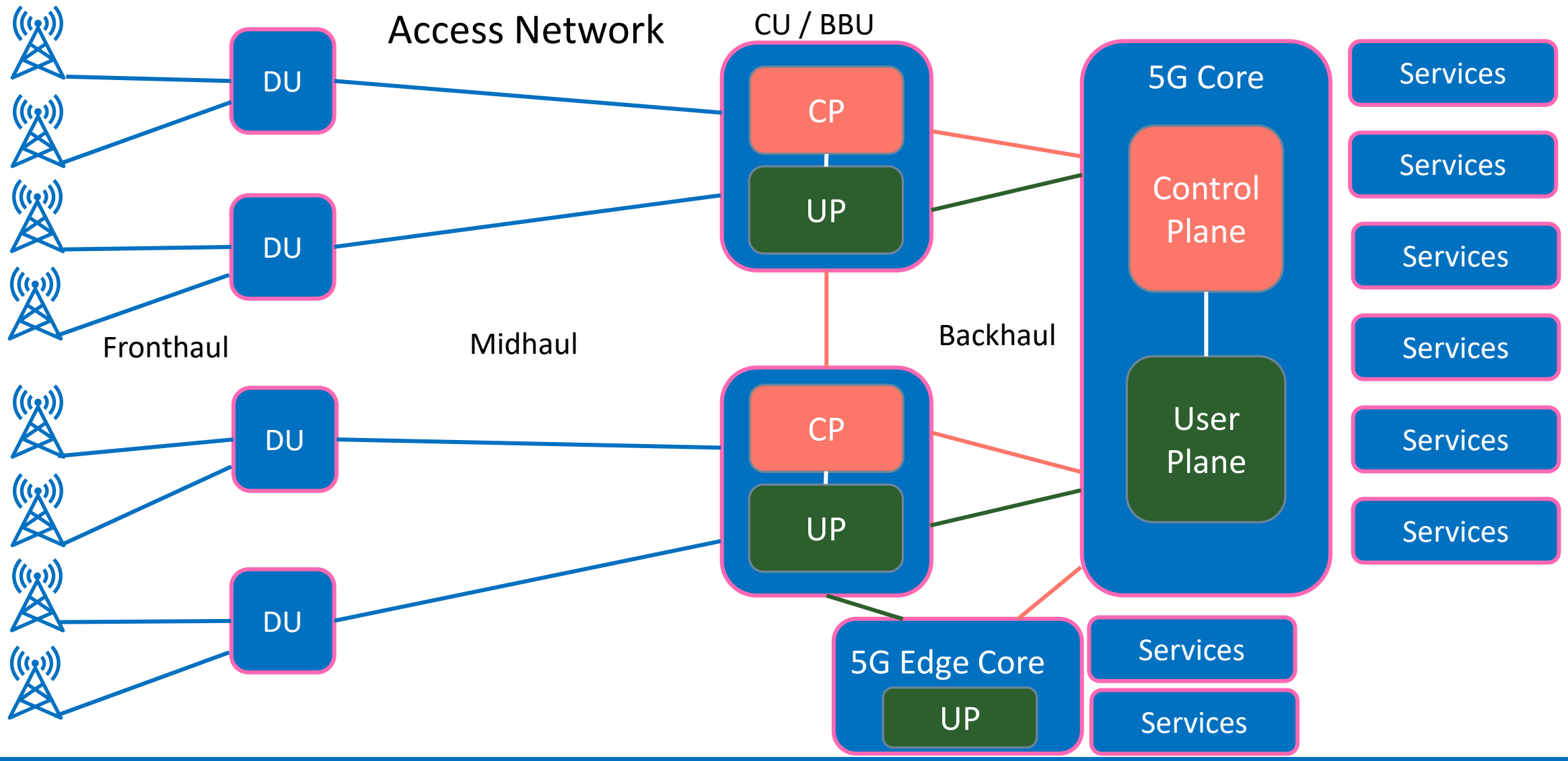

Source: 3GPP

# Evolution of Packet Mobile Core

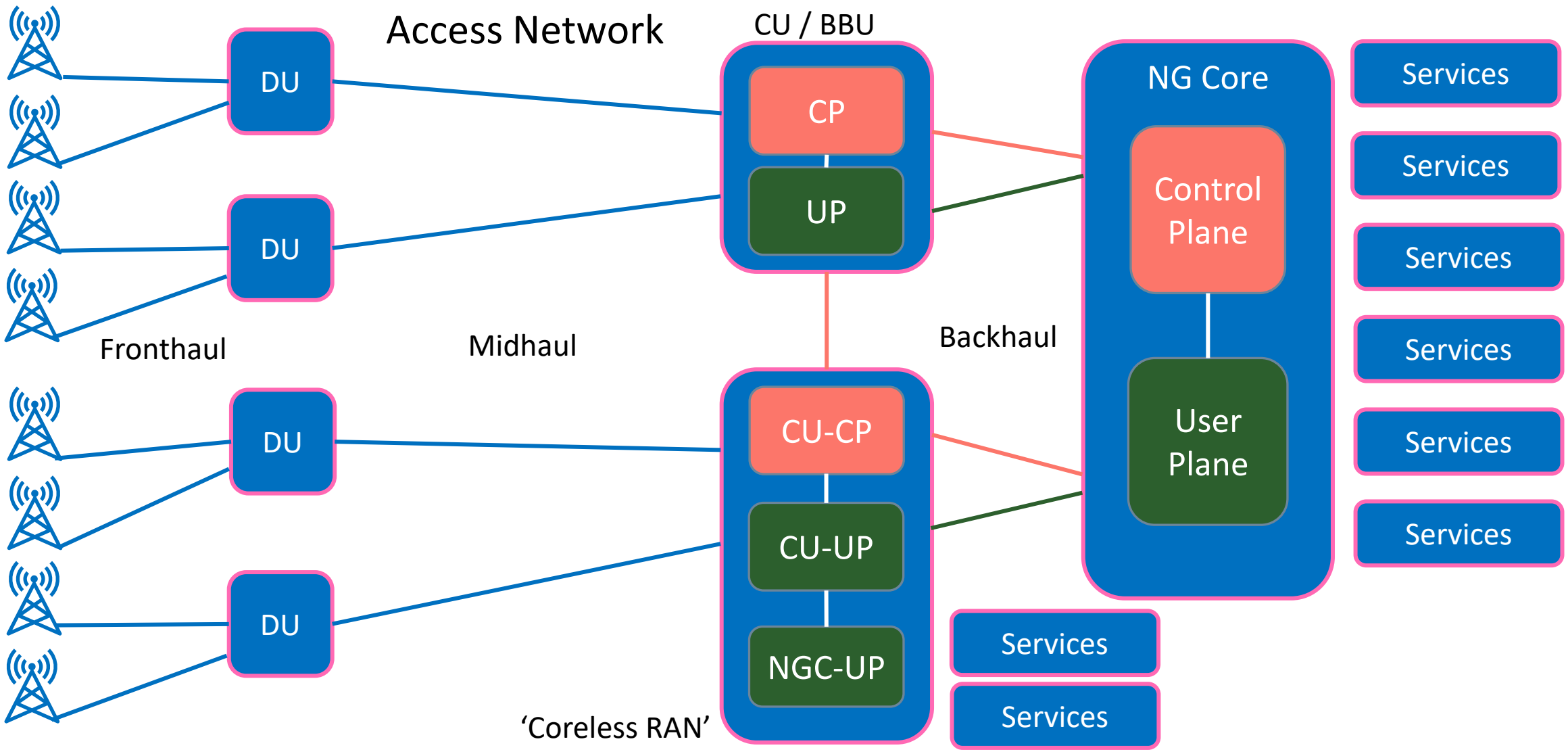



There may be no need for a new 6G Core Network

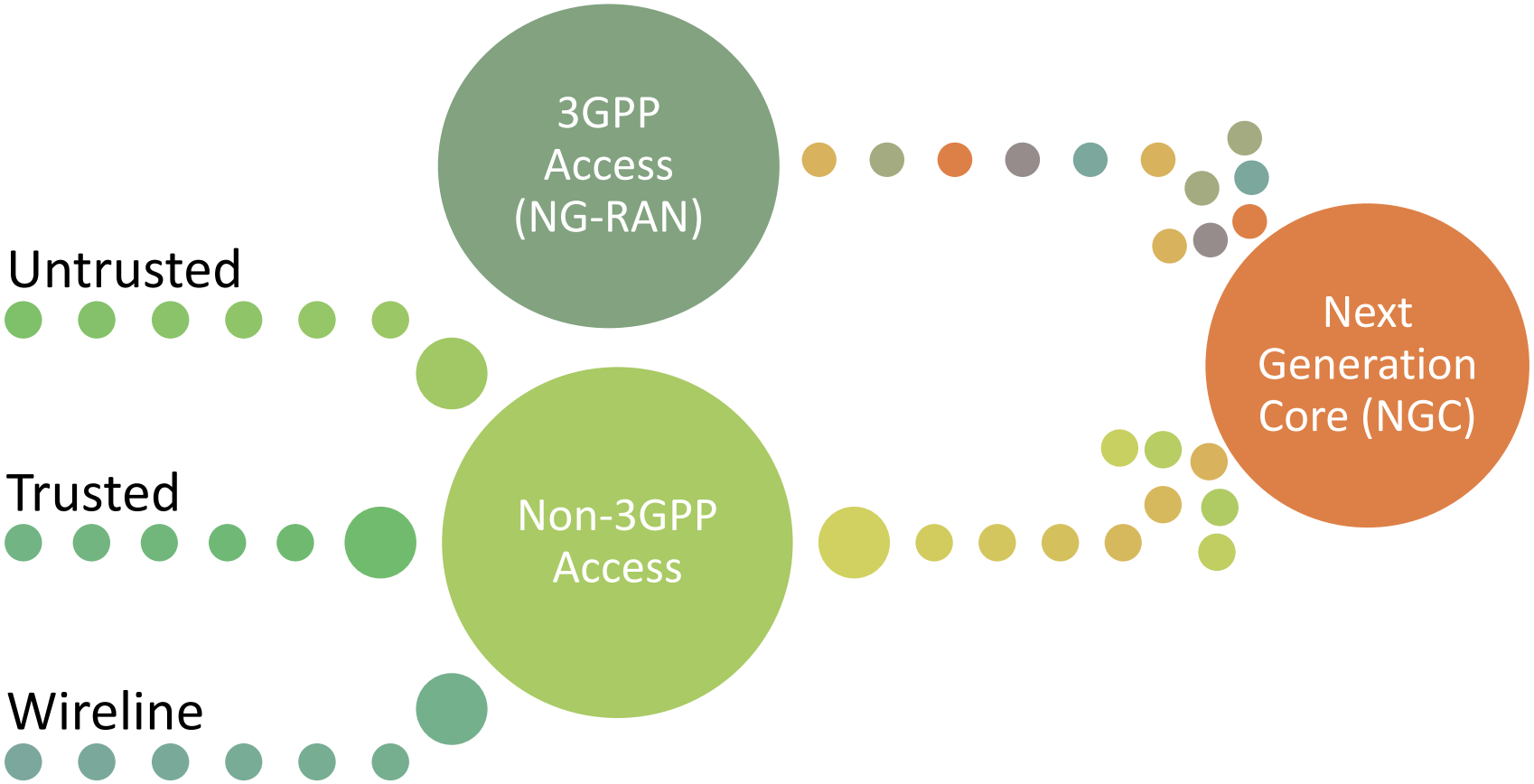
# 5G Network Architecture



# RAN–Core convergence



# Support of non-3GPP access




Complete Tutorial here

# Further Reading

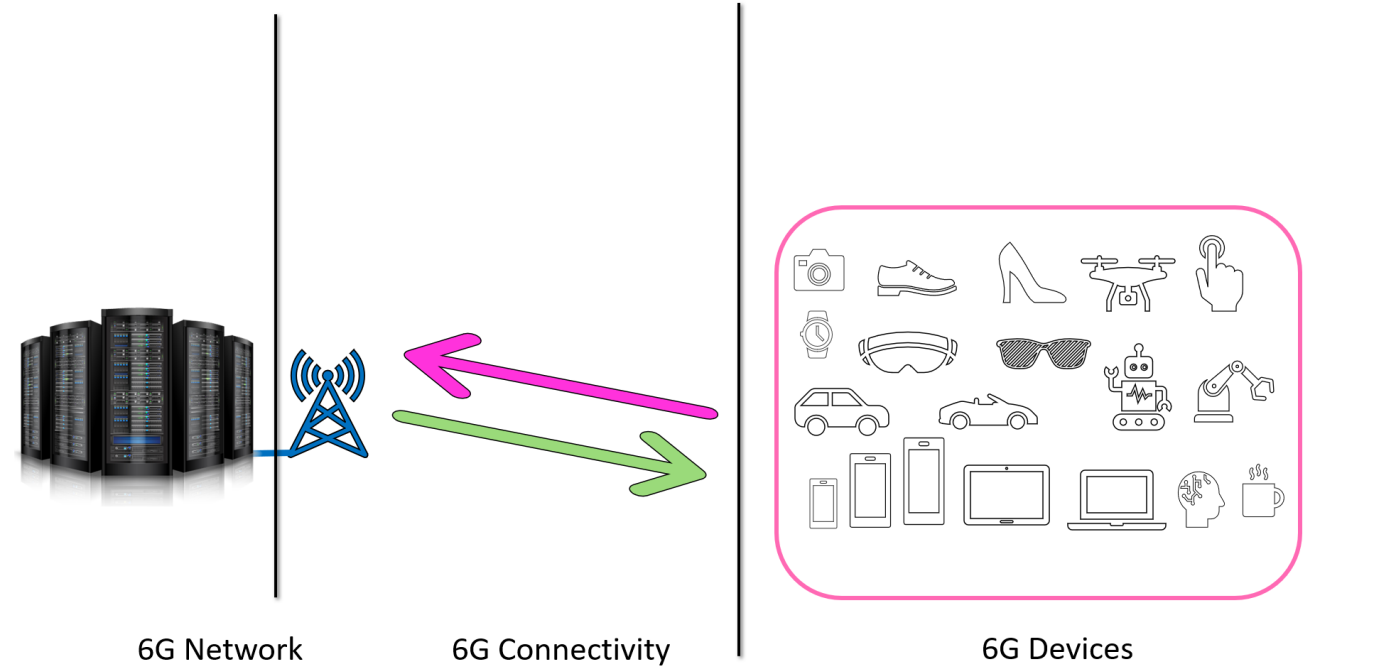
RAN-CORE CONVERGENCE

- 5G Americas: Mobile Communications Beyond 2020 – The Evolution of 5G Towards Next G, Dec 2020 (link)
- Nokia Bell Labs: Communications in the 6G Era Whitepaper, Sep 2020 (link)

WIRELESS WIRELINE CONVERGENCE (WWC)

- The 3G4G Blog: Three New Standards to Accelerate 5G Wireless Wireline Convergence (WWC), Nov 2020 (link)
- Connectivity Technology Blog: 5G Wireline Access Architecture, Sep 2020 (link)
- The 3G4G Blog: Exploring Network Convergence of Mobile, Broadband and Wi-Fi, Dec 2019 (link)
- The 3G4G Blog: Introduction to 5G ATSSS - Access Traffic Steering, Switching and Splitting, Nov 2019 (link)
- The 3G4G Blog: 5G and Fixed-Mobile Convergence (FMC), Sep 2019 (link)

# 6G Connectivity Technologies



# NTT Docomo's view of 6G Technologies

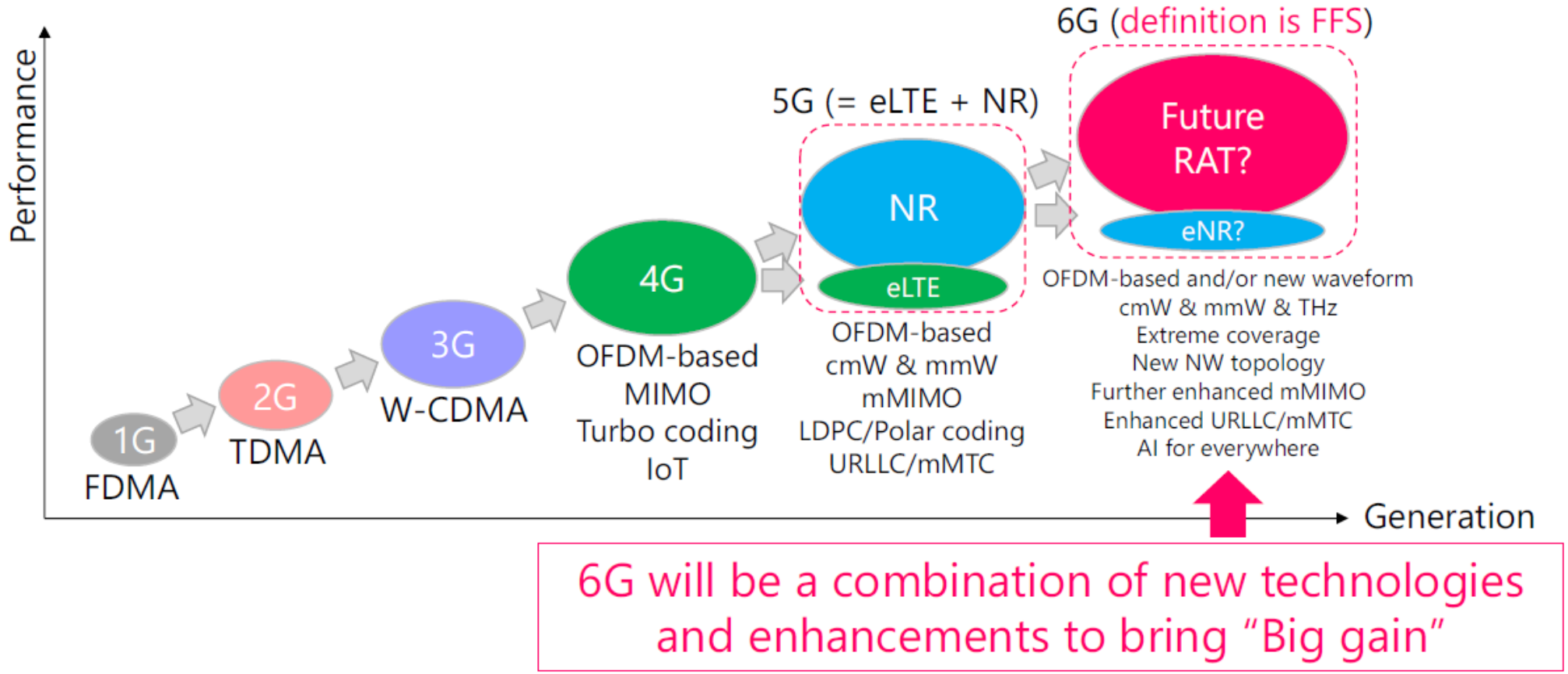



Figure 4-1. Technological evolution up to 6G in mobile communications

Source: NTT Docomo 6G Whitepaper

# NTT Docomo 5G Evolution & 6G Summit

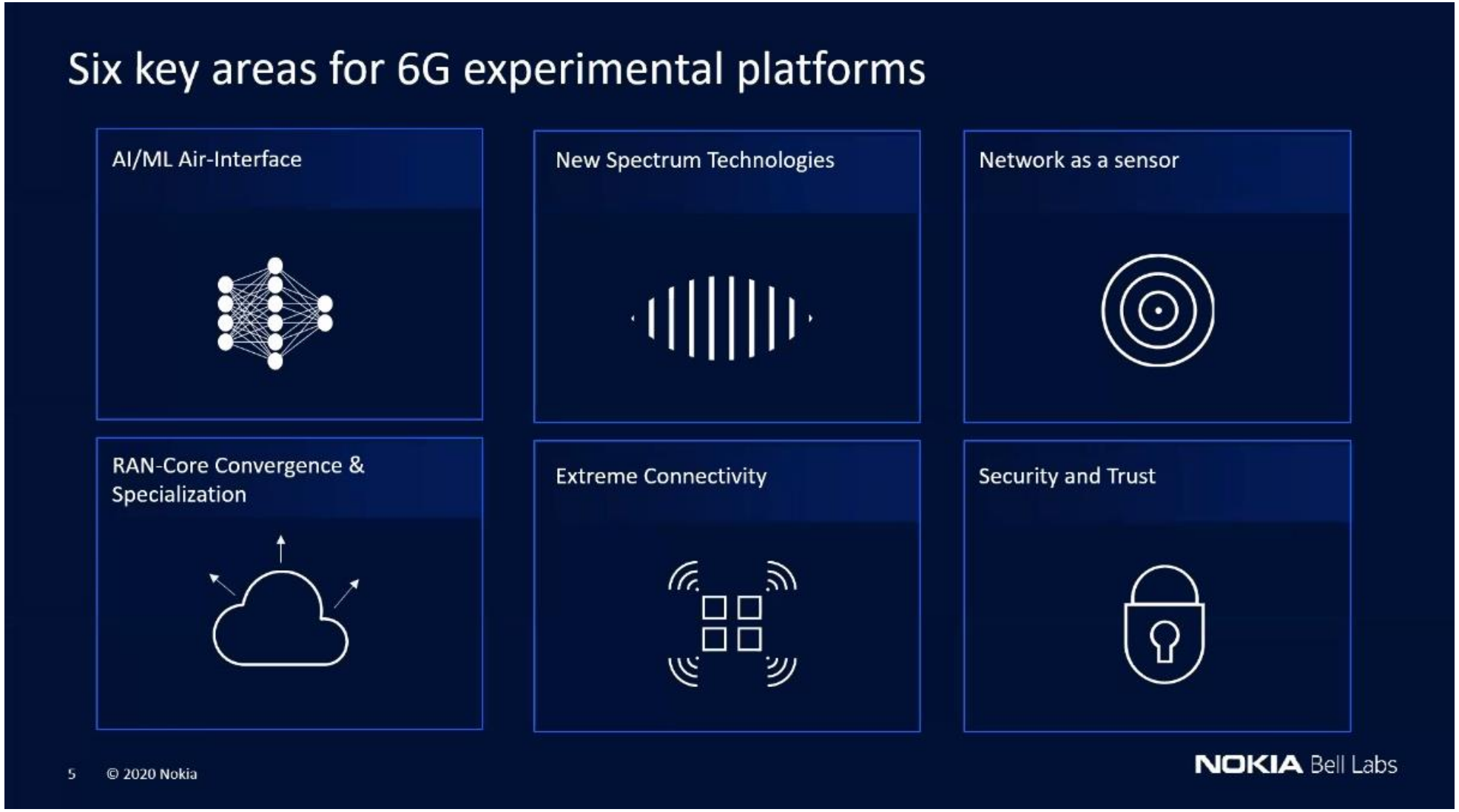
Table 2 Part 2 exhibitions

| Network technologies | | Use cases |
|---|---|---|
| 5G Evolution & 6G Overall Image | Coverage Extension: Reflective Plate | Mobile SCOT Remote Medicine Experience |
| HAPS | Coverage Extension: Repeater | Remote Control of Construction Equipment |
| 94 GHz Band Transmission Power Amplifier | Undersea Ultrasonic High-speed Wireless Transmission Technology | Transmission of High-presence Sensations Using 8K Video |
| 150 GHz Transmission System | Use of Satellite Communications for Extreme Coverage Extension | Variable-rate Video Transmission |
| National R&D Project on Millimeter-wave High-speed Mobility | Analog RoF-Mobile Front Haul for Extreme Distributed Antennas | In-vehicle Infotainment Experience |
| Bended Dielectric Waveguide as Leaky-wave Antennas | Extreme-high-speed IC Technology for 300 GHz Band Radio Transmission | Sense-of-presence Communication Experience |
| AI for RAN (AI-based radio network) | OAM-MIMO Radio Multiplexing Transmission Technology | Introduction to Activities and Conversations with Experts in Human Augmentation (3 videos) |
| NOPHY (Non orthogonal PHY) | Multi-radio Proactive Control Technology: Cradio | Introduction to Activities and Conversations with Experts in Brain Technologies (2 videos) |
| Smart Factory: Social Implementation | Virtual Massive MIMO (VM-MIMO) Technology | |
| Smart Factory: High-accuracy Simulations | Introduction to Activities and Conversations with Experts in the Space Industry (2 videos) | |
| Smart Factory: Enhanced Transmission Technologies | | |



Source: NTT Docomo Technical Journal, Jan 2021

# Nokia: 6 Key Areas for 6G




Details in Nokia's 6G whitepaper

# 6G Flagship's view on Possible 6G Technologies

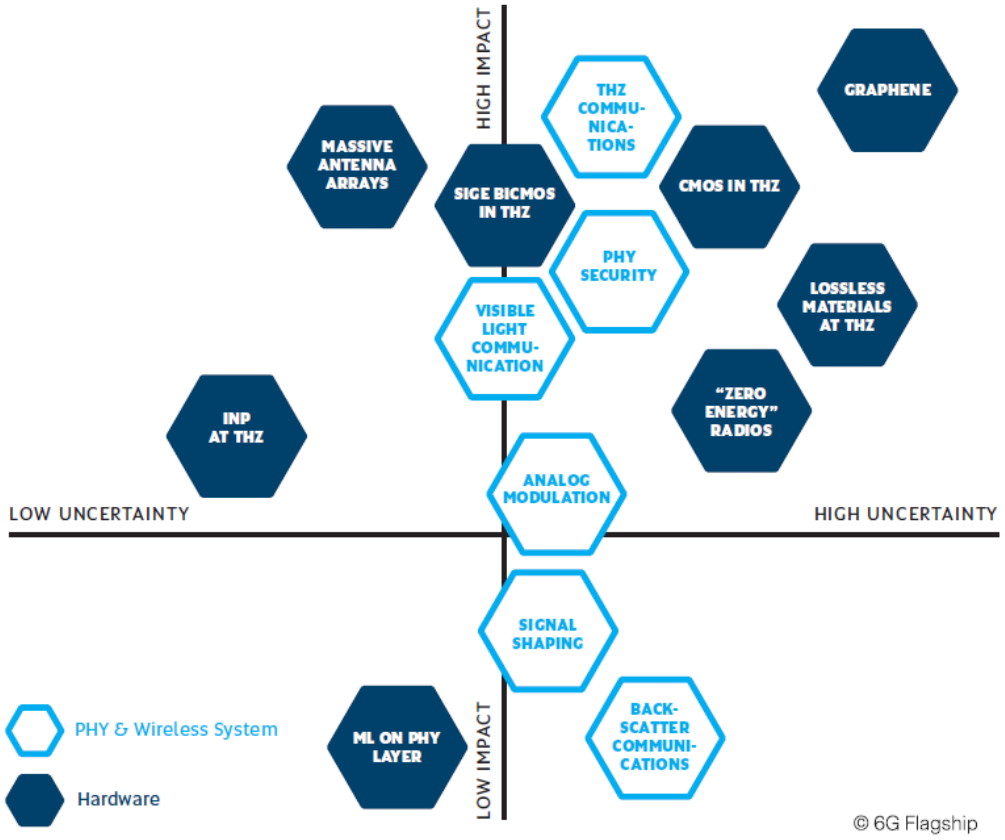



Figure 2. New wireless hardware and physical layer technologies.

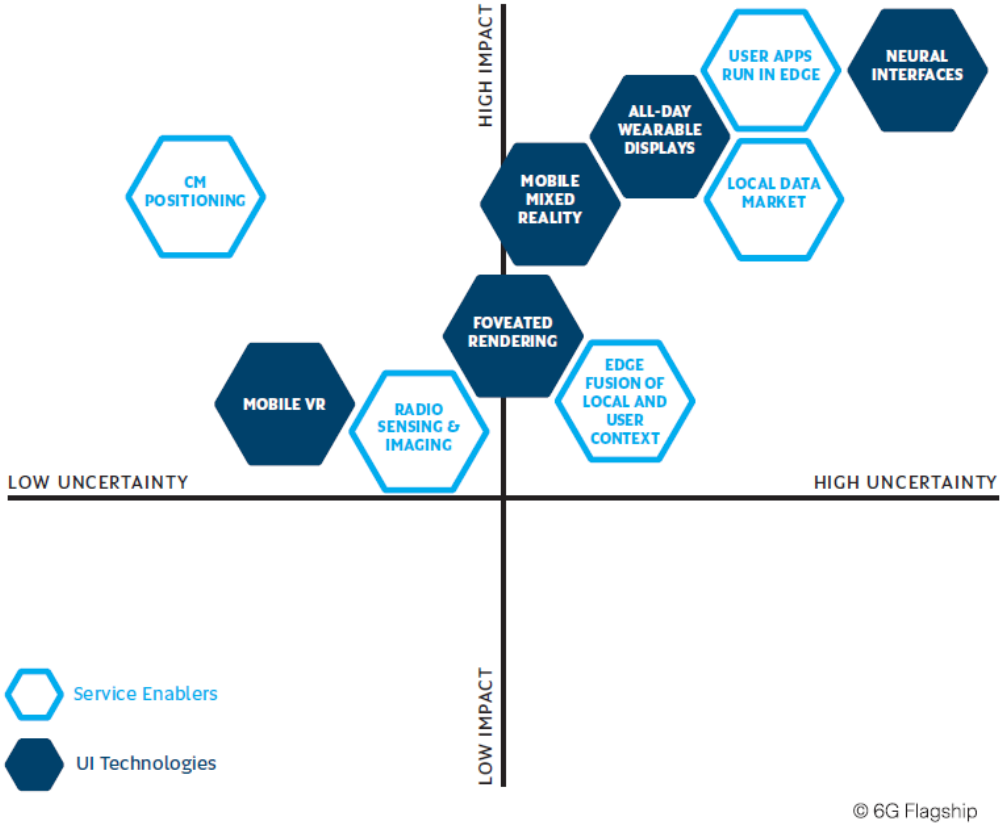



Figure 3. Possible technologies for user interface and service enablers.

Source: 6G Flagship Whitepaper #1

# 6GIC 6G Technologies

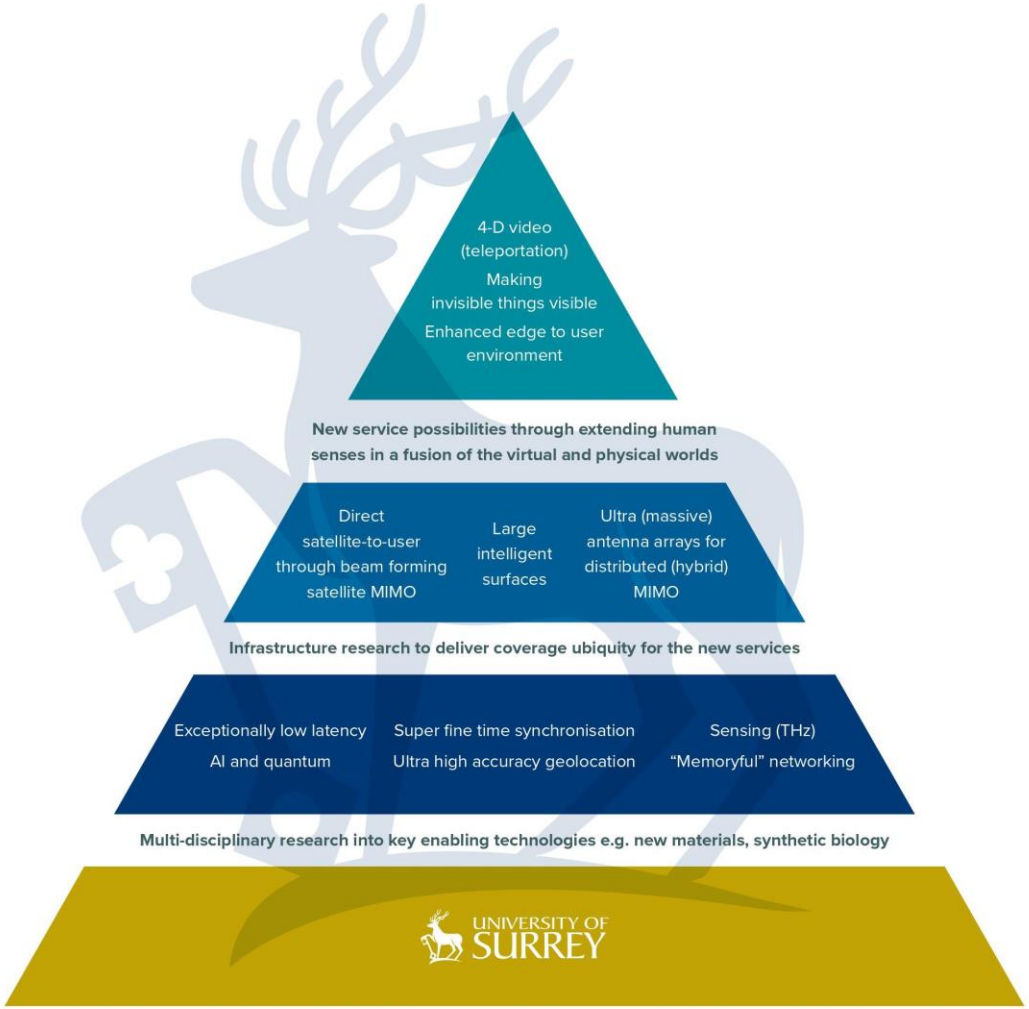
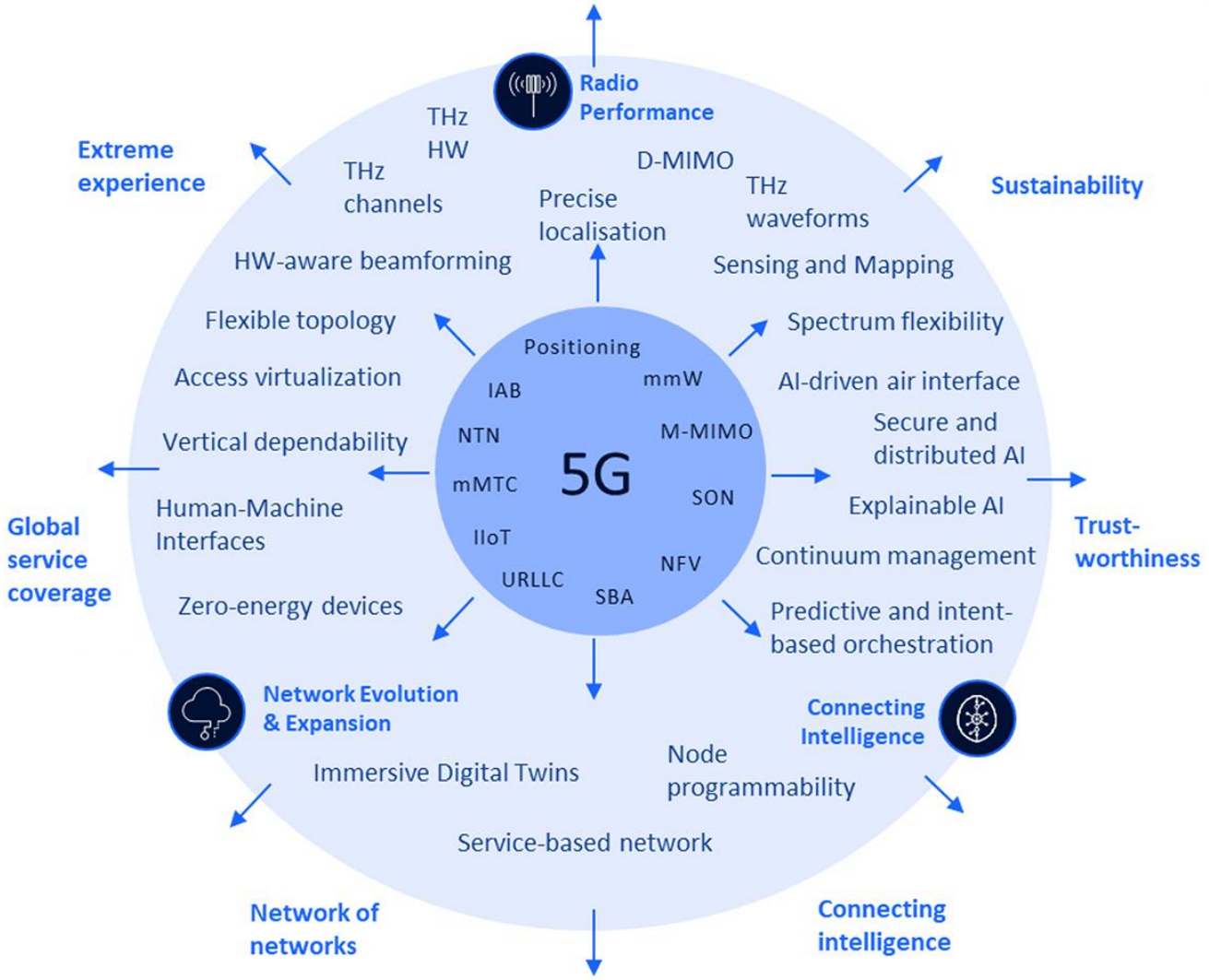



Figure 1: 6G vision supported by new cross-functional research and development programme

Source whitepaper

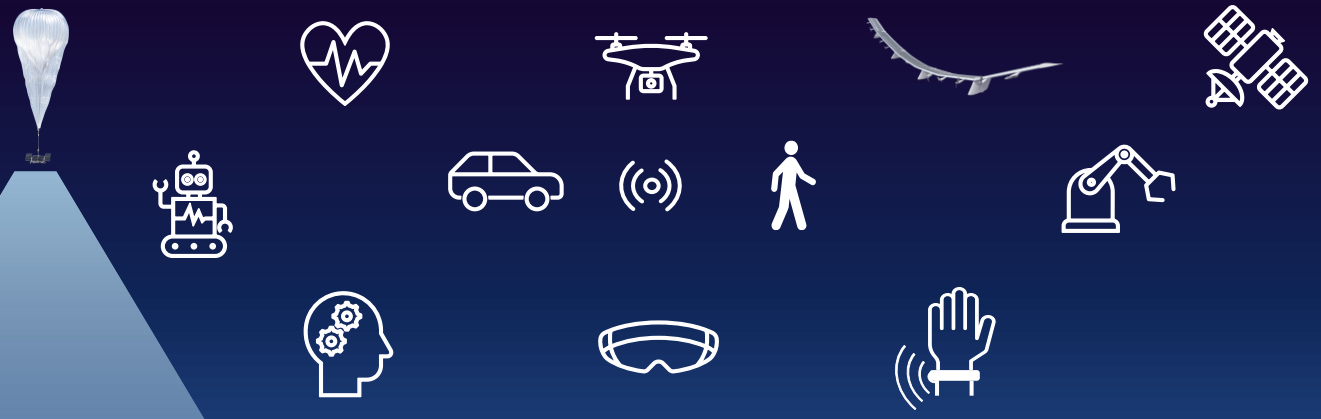
# Hexa-X 6G Technological Areas




Source: Hexa-X

# List of Probable 6G Technologies

| | | | |
|---|---|---|---|
| Spectrum | THz | mmWave | |
| Spectrum Sharing | | | |
| Antenna Technologies | OAM | RIS | Metamaterials |
| Evolution of Duplex | Half Duplex FDD | In-band Full Duplex (IBFD) | |
| Evolution of Network Topology | HAPS, Satellites, NTN | Wireless Wireline Convergence | |
| Comprehensive AI/ML | AI/ML Air Interface | AI/ML at Edge | AI/ML in RAN |
| Split Computing | | | |
| High Precision Network | | | |
| Communications & Sensing | | | |
| Extreme Connectivity/Networking | Extreme URLLC | | |
| Industrial IoT | Sub-Networks | | |
| Localization & Sensing | | | |
| Security & Trust | | | |
| Fully Service Based, Cloud Native Networking and RAN-Core Convergence | | | |
| Expanded integration of variable wireless technologies | | | |
| Open Platforms | | | |



# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 8 - 6G Devices*

@6Gtraining

@3g4gUK

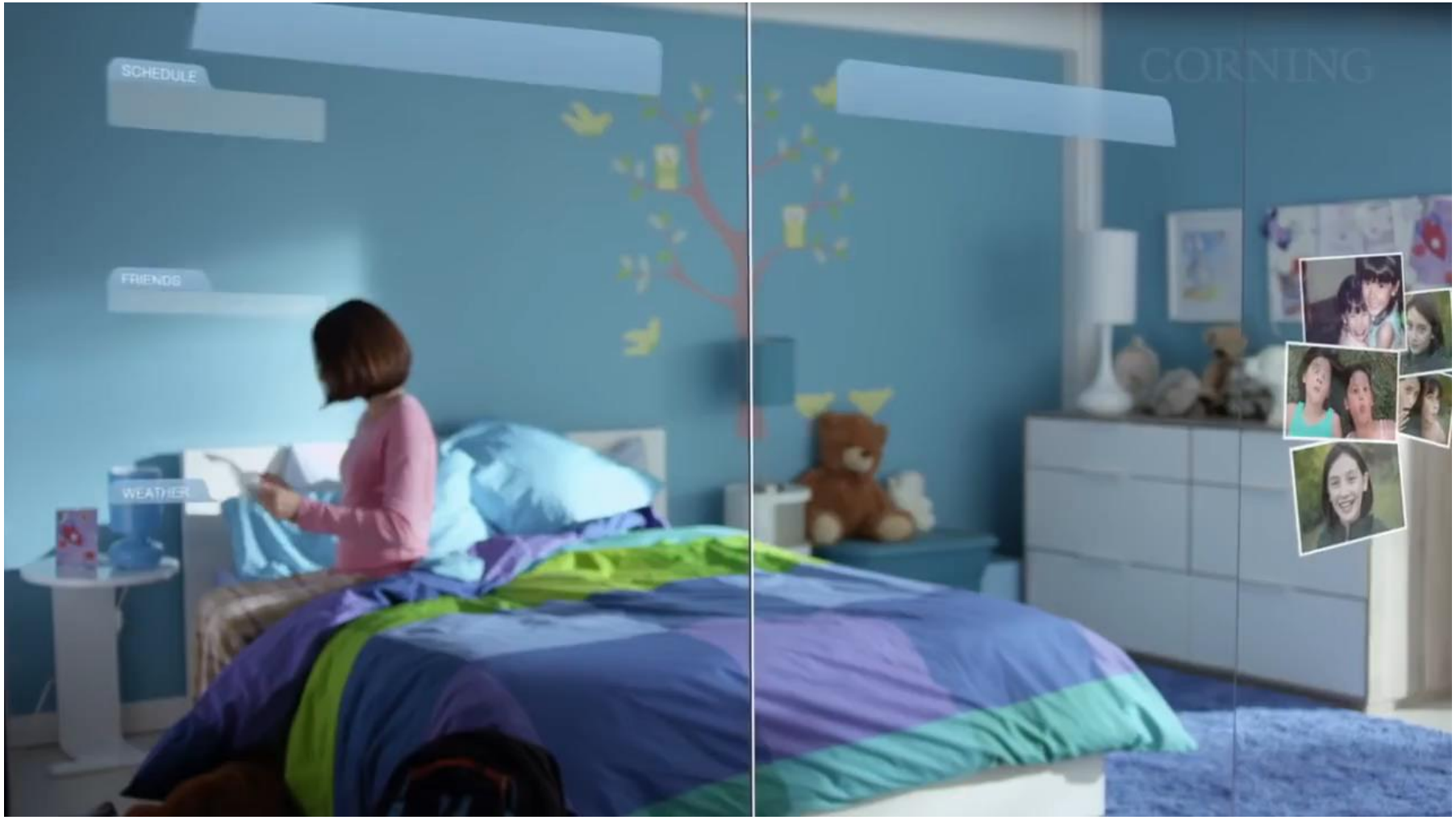
**#Free6Gtraining**

# Part 8 Video Link

# What do you think are 6G Devices?

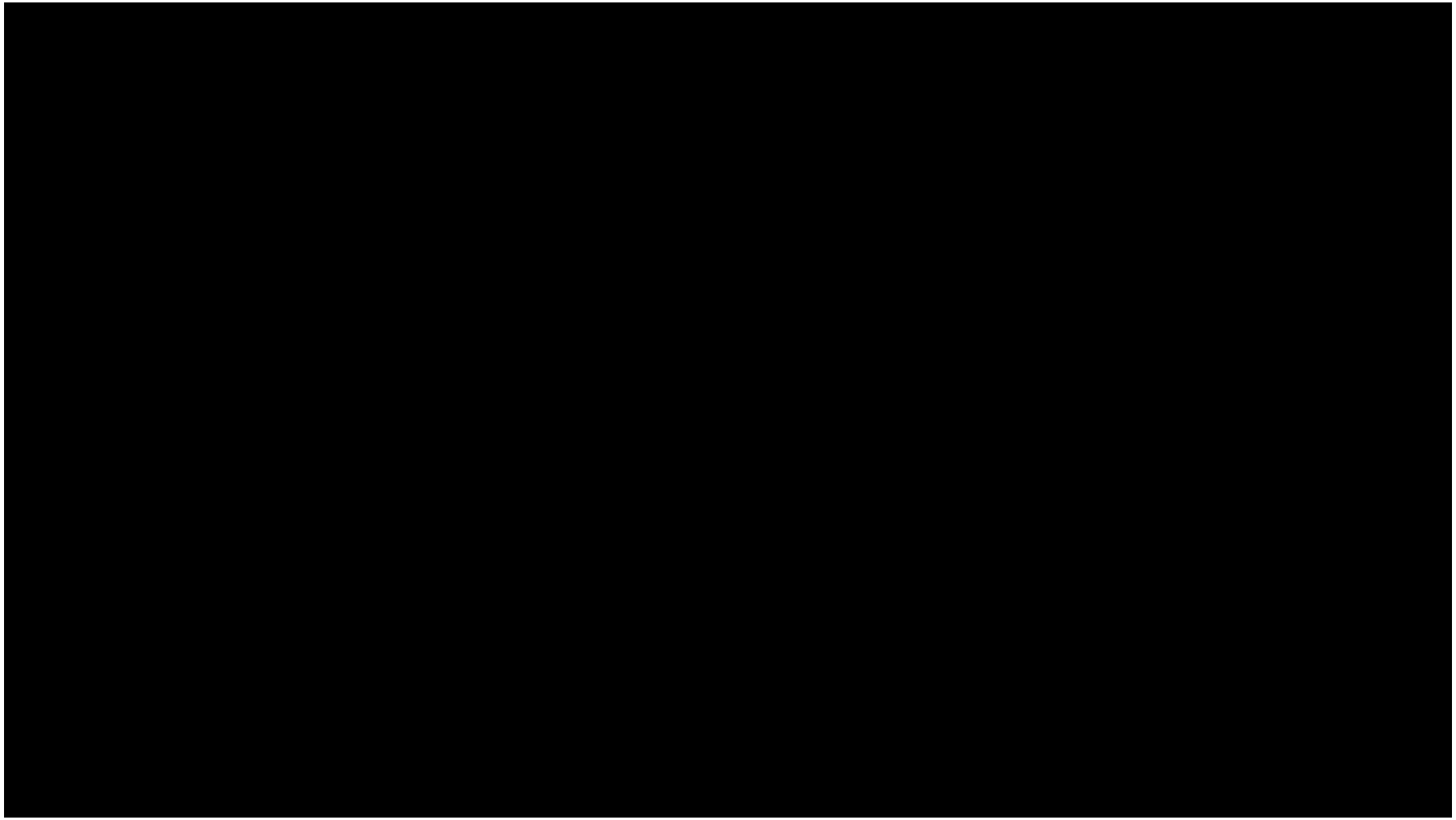

Source: Microsoft HoloLens MR Video link

# What do you think are 6G Devices?



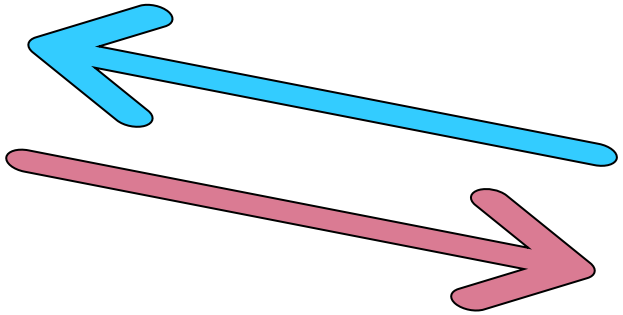

Source: Corning - A Day Made of Glass

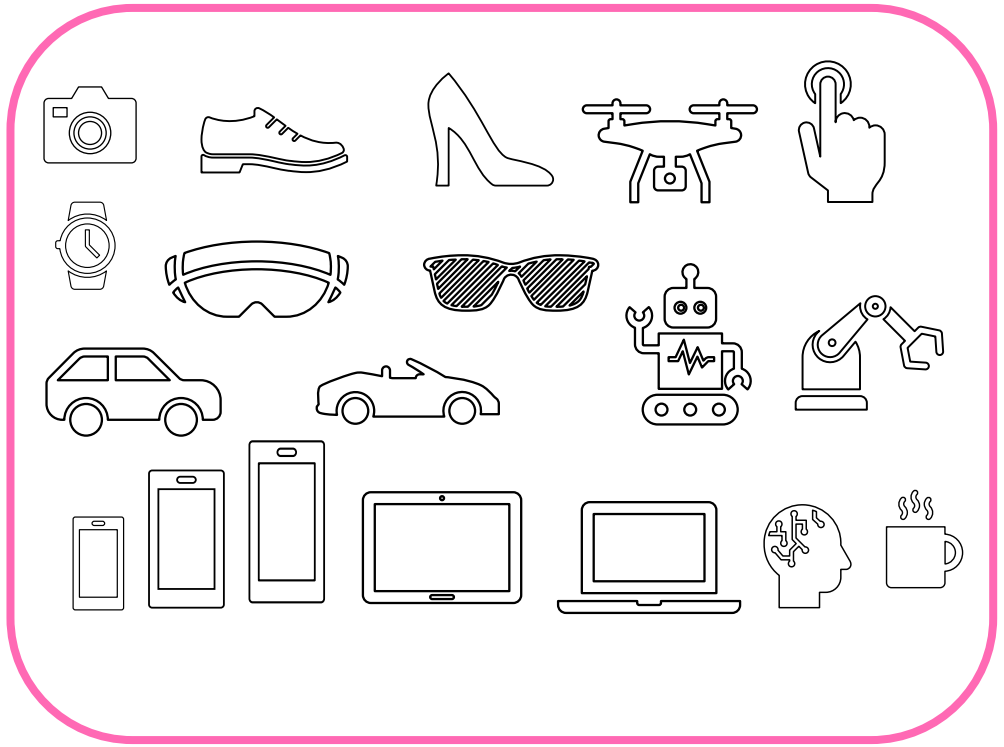
# What do you think are 6G Devices?



Source: Ericsson - A Social Web of Things

# What’s stopping us from turning Science Fiction into Reality?





6G Network

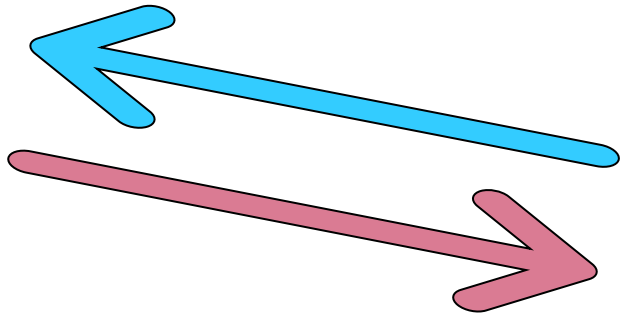
6G Connectivity

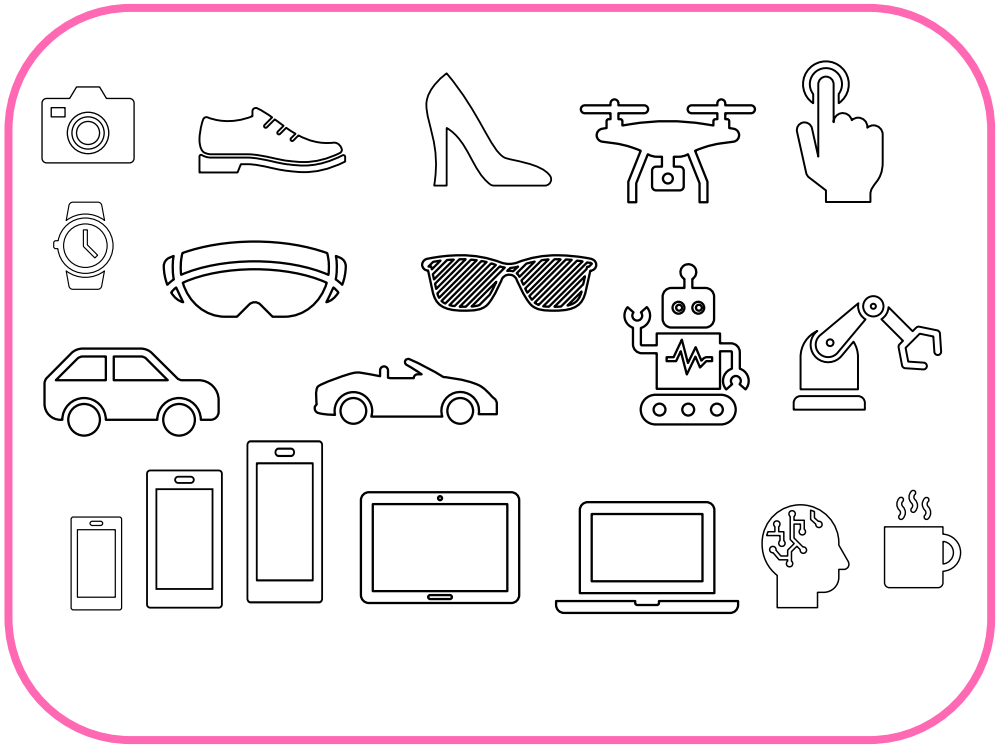
6G Devices

Network & Architecture Evolution

Access Network Evolution

Devices and Components Evolution

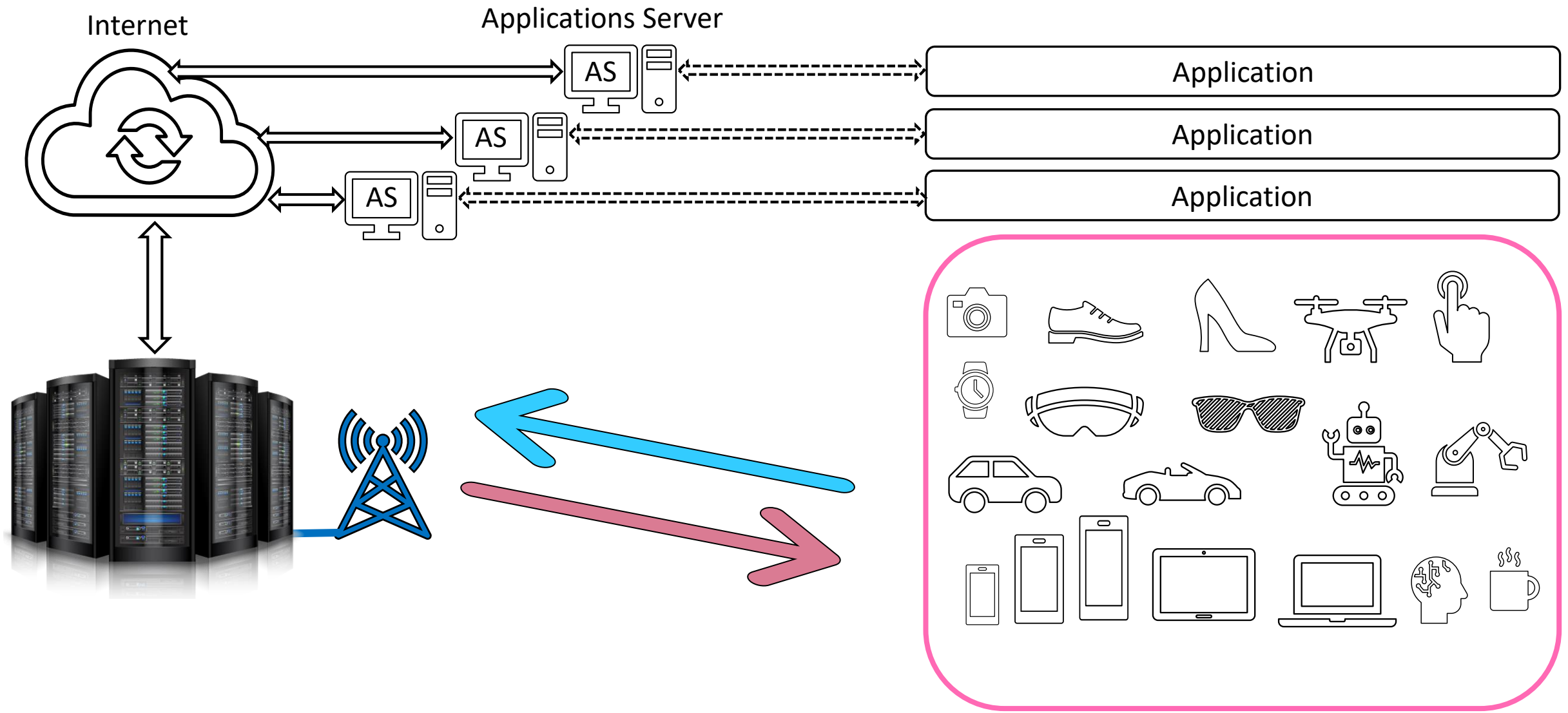




6G Network

6G Connectivity

6G Devices



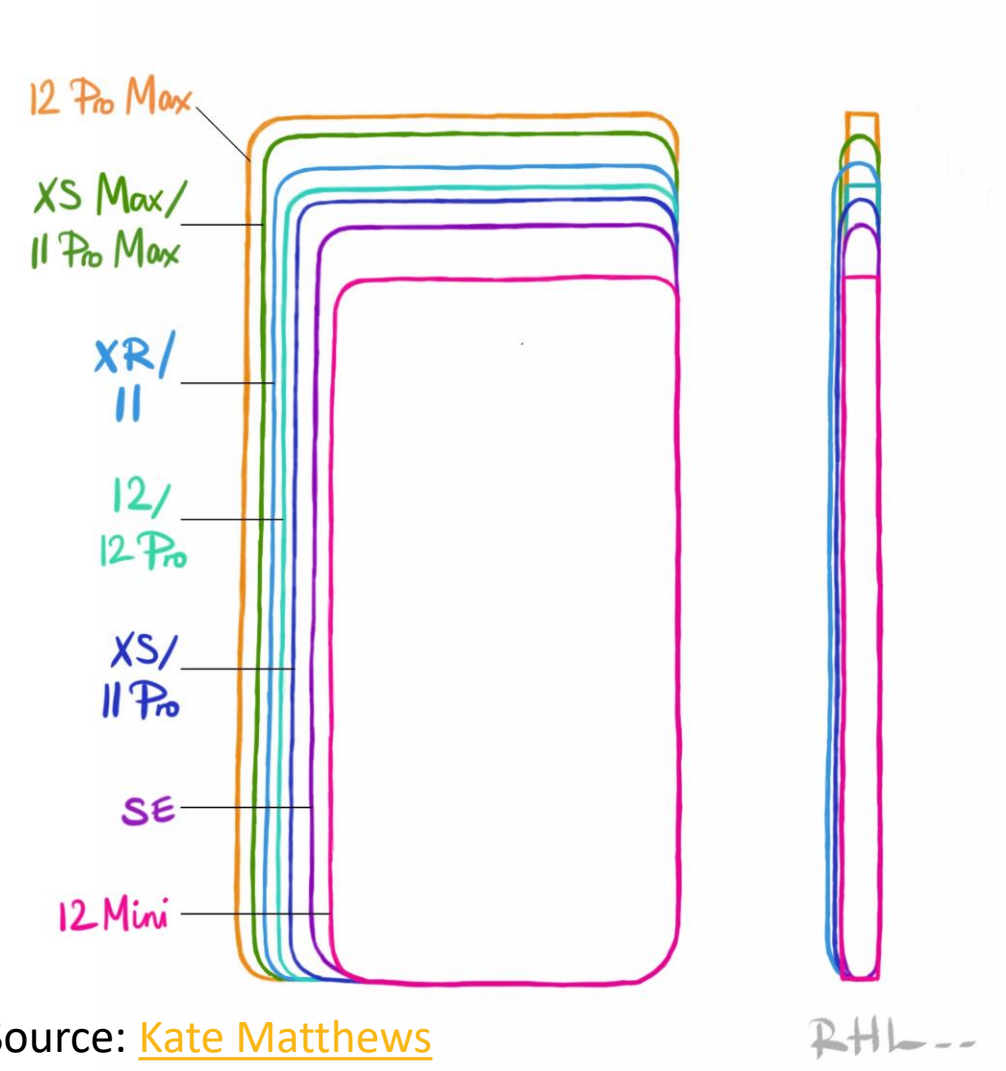

6G Network

6G Connectivity

6G Devices

# From Phones to Smartphones and Smart Featurephones

# iPhone Size Comparison Over the Years




Source: Kate Matthews

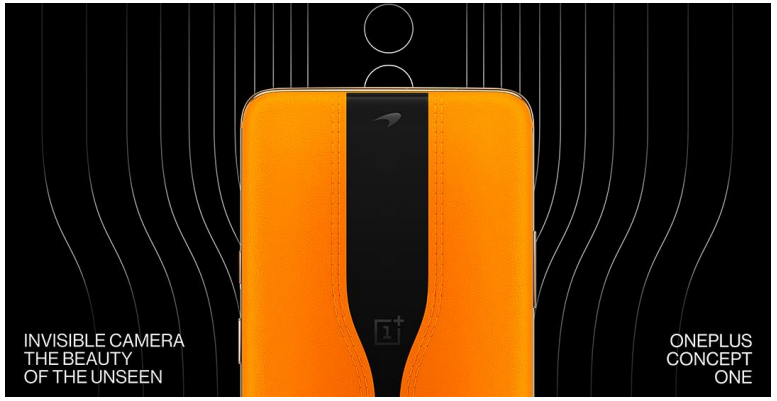

Picture Source

Good summary of history of iPhones and evolution (link)
Comparison of iPhone 12 with the original iPhone SE (link)

# Smartphones Innovation in 2020

(Click on the picture to read more about them)

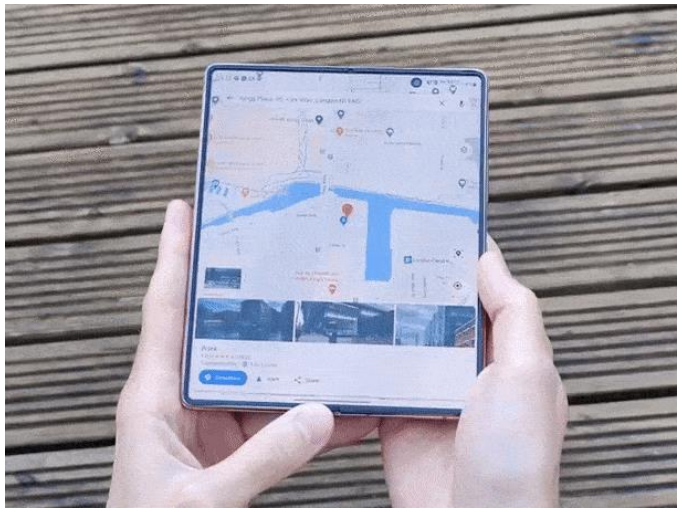
Based on article from TechRadar




Oneplus Concept One


Motorola Razr Foldable

LG Wing 5G



Samsung Galaxy Z Fold 2


ZTE Axon 20 5G

Oppo X Nendo

# Tablets & Laptops

Surface Book 3

MacBook Pro

Lenovo Tab P11 Pro

Dell 2-in-1

iPad

Samsung Galaxy Tab A7

# Rise of the Companion Devices

## What exactly are Companion Devices?

Companion Devices are designed to work with a ‘main’ or ‘parent’ device which generally needs to accompany them.

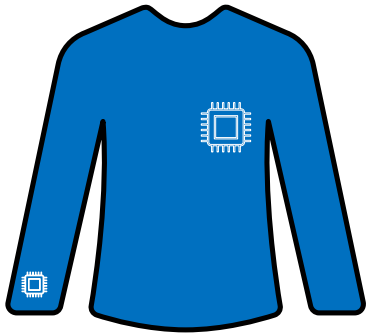
Examples of companion devices could be smartwatches or Bluetooth headset or any other wearables, wherein they generally only work with a Smartphone or a Tablet, which is the main device.

# Example of Companion Devices

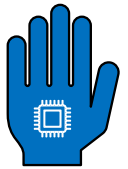
Smaller Companion Phones

Smart Watches and Fitness Trackers

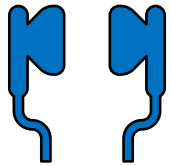
XR Headsets



Smart Clothing



Electronic Skin Patches



Hearables

# Apple Watch Healthcare



## Compare Apple Watch Models

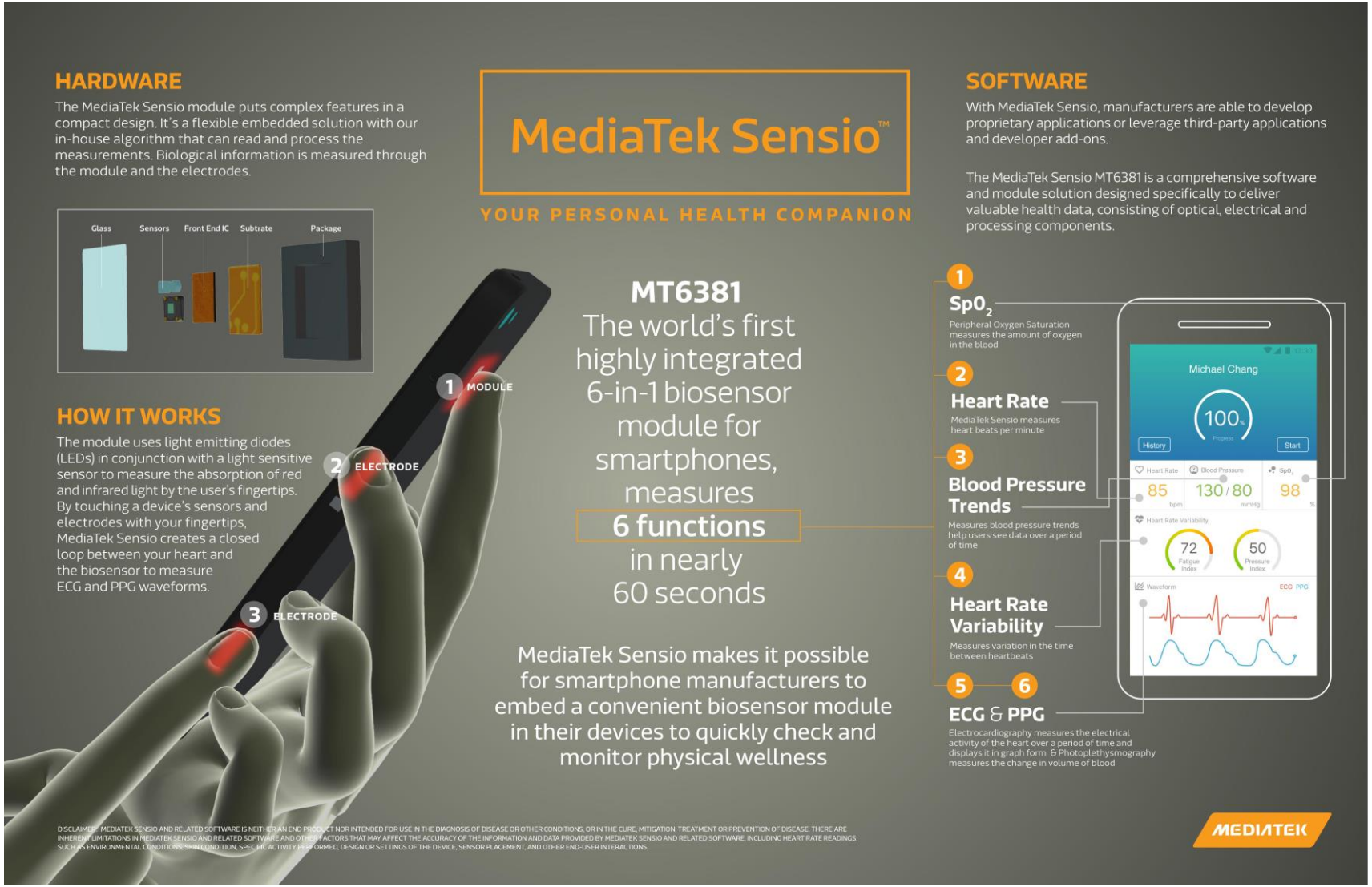
| | High Heart Rate Notification | Low Heart Rate Notification | Irregular Rhythm Notification | ECG App | Fall Detection |
|---|---|---|---|---|---|
| Sensors | Optical heart sensor / PPG | Optical heart sensor / PPG | Optical heart sensor / PPG | Electrical heart sensor / electrodes | Next-generation accelerometer and gyroscope |
| Apple Watch Series 1, 2, 3 | ✓ | ✓ | ✓ | ✗ | ✗ |
| Apple Watch Series 4 or later | ✓ | ✓ | ✓ | ✓ | ✓ |

Note: Original Apple Watch does not support these functions




Source: Apple

# MediaTek Sensio™: Your Personal Health Companion




Source: MediaTek

# Wearable 360° Cameras

## NEXX360

NEXX360 Details

See Linkflow

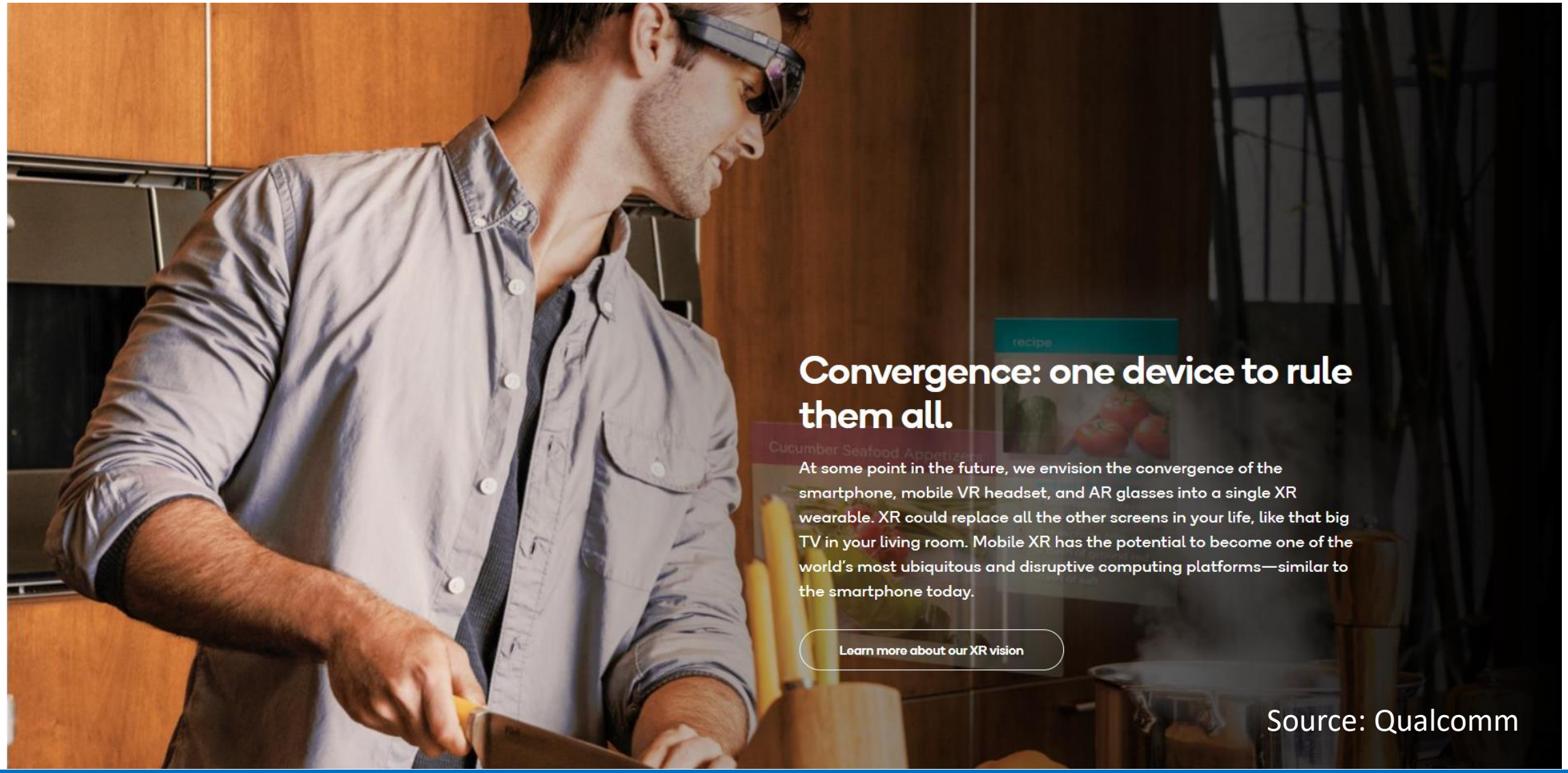
## FITT360

FITT360 Details

# 360° Camera Usage Example

Source: KT

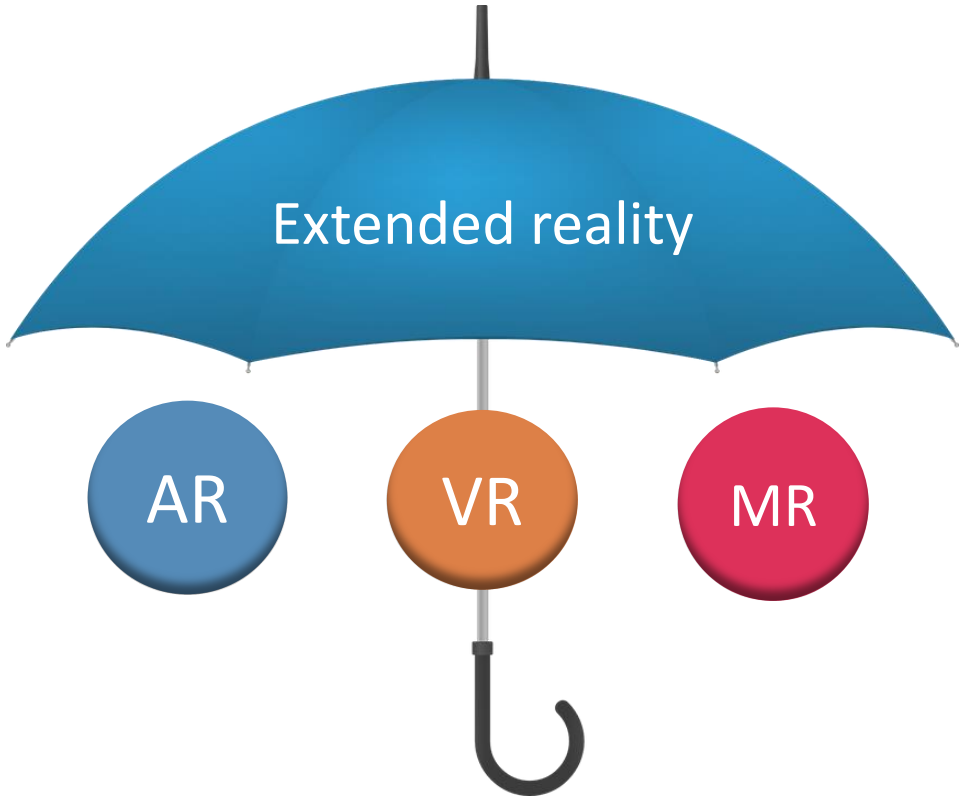
# Qualcomm’s Vision: one XR device to rule them all!




Source: Qualcomm

# Extended Reality (XR)!

Extended Reality (XR) is an umbrella term for all the immersive technologies.



# VIRTUAL REALITY HEAD MOUNTED DEVICES


OCULUS

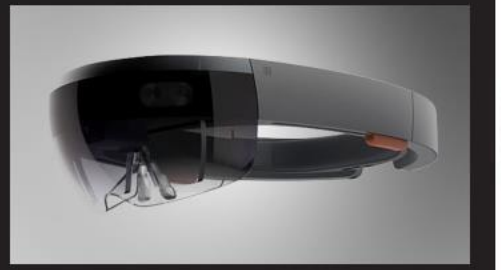

HTC VIVE

SAMSUNG GEAR


GOOGLE CARDBOARD


POWIS CARDBOARD

# AUGMENTED REALITY HEAD MOUNTED DEVICES



MICROSOFT HOLOLENS

MAGIC LEAP

MIRA PRISM

# Nreal Mixed Reality Glasses Kit




**Nreal Light Dev Kit**

- Nreal Light Glasses x 1
- Nreal Light Computing Unit x 1
- Nreal Light Controller x 1
- Corrective Lens Frames x 1
- The Clip x 1
- Nose Pads x 3
- USB-C Cable x 1
- Charger x 1
- Nreal Light Glasses Cleaning Cloth x 1
- User Guide x 1

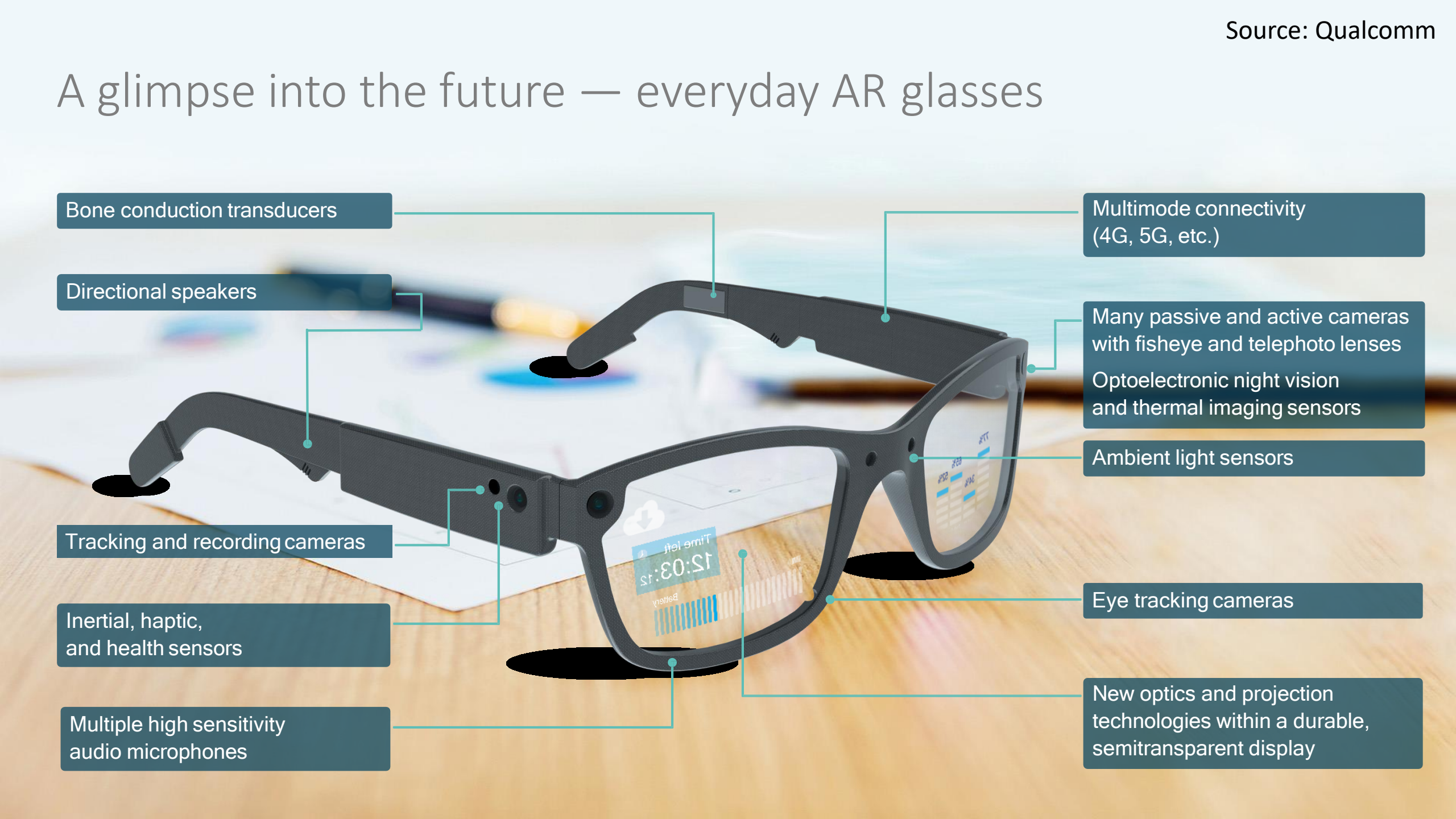
Unit Price: **$1,199**

Quantity: − **0** + **$0**

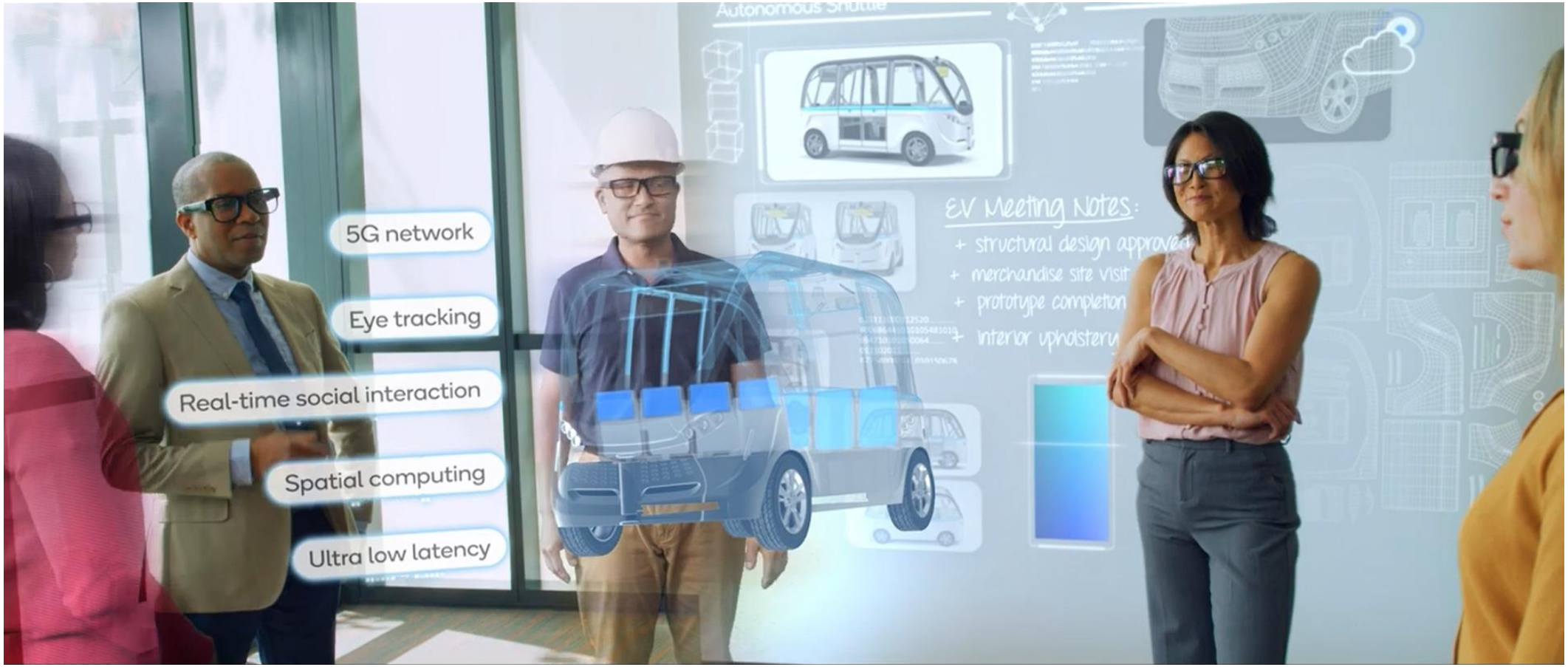
Source: Nreal

Source: Qualcomm

# A glimpse into the future — everyday AR glasses



# Collaboration Over Immersive XR

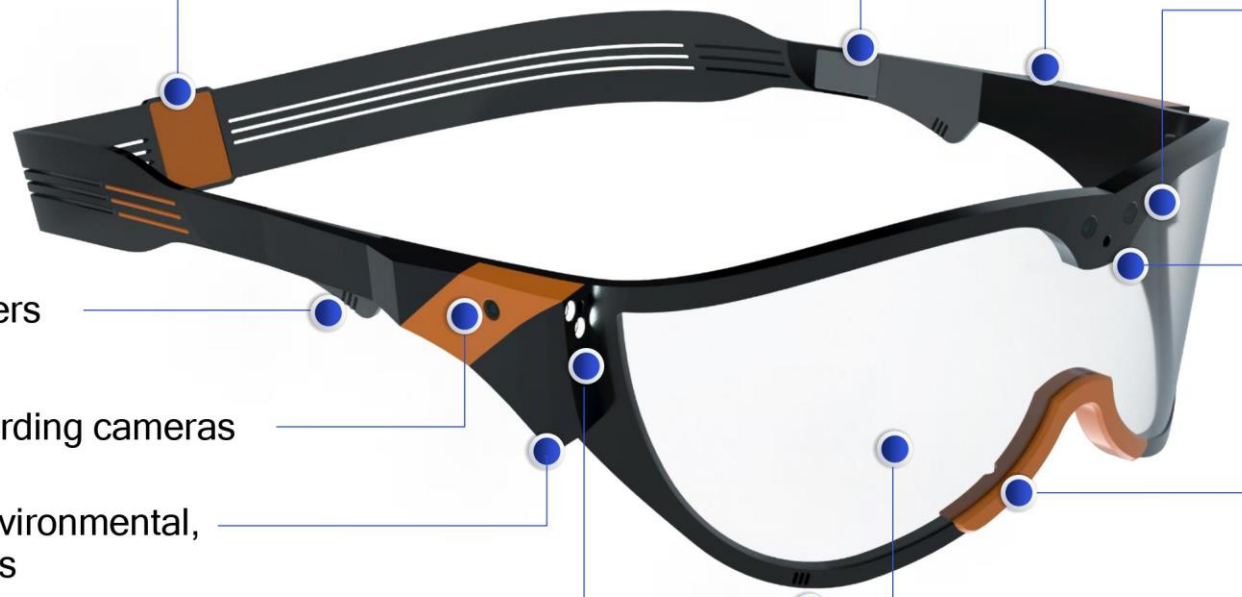



Source: Qualcomm

Source: Qualcomm

# A glimpse into the future

## First responder XR glasses



Bone conduction transducers

Rear camera

Directional speakers

Tracking and recording cameras

Inertial, haptic, environmental, and health sensors

Ultra-bright LED lights

Multiple high sensitivity audio microphones

Multimode connectivity (4G, 5G, etc.)

- Many passive and active cameras with fisheye and telephoto lenses
- Optoelectronic night vision and thermal imaging sensors

Ambient light sensors

Eye tracking cameras

New optics and projection technologies within a durable, semitransparent display

# XR Devices and Form Factors

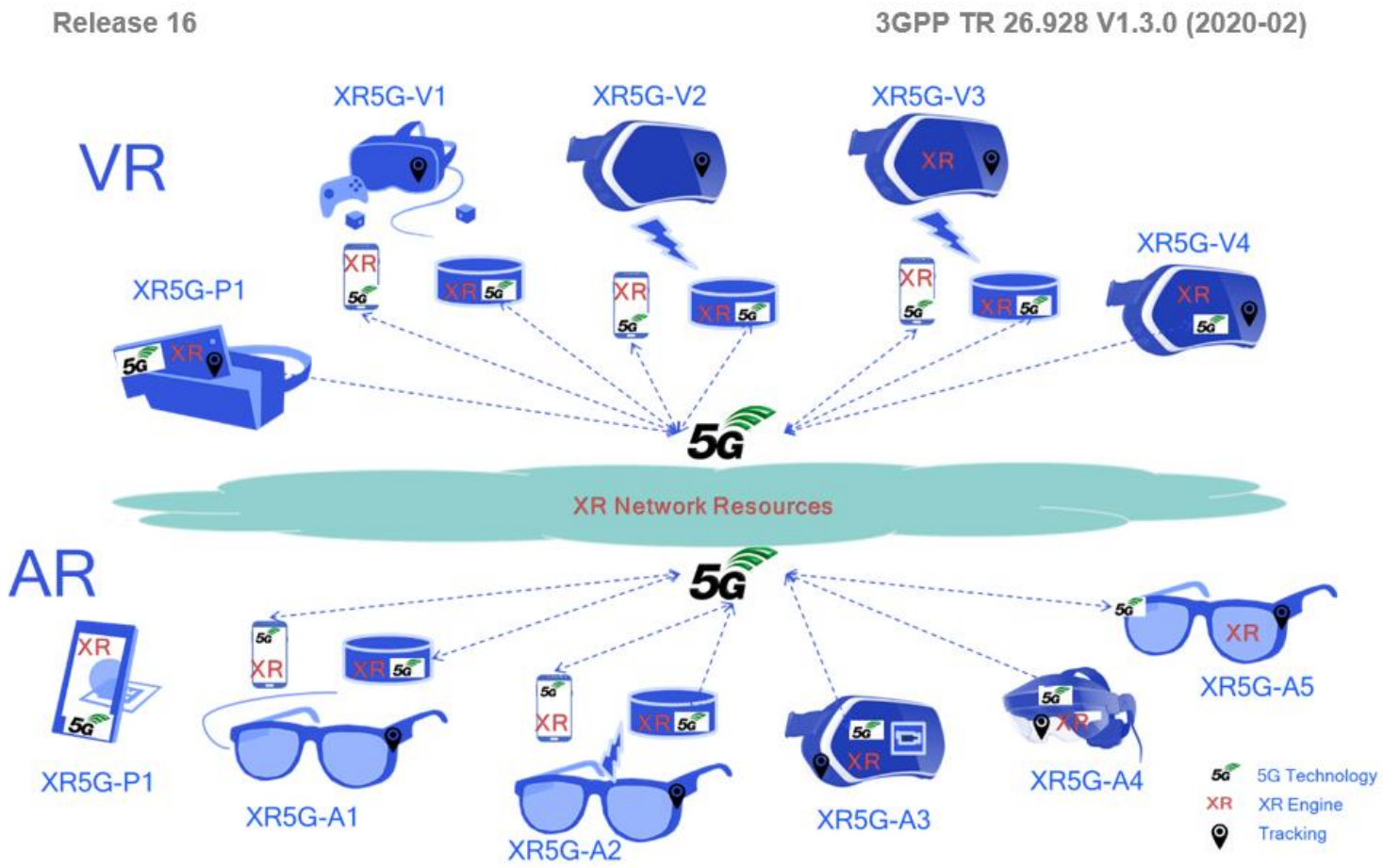



**Figure 4.8-1: XR Form Factors**

# XR Devices and Form Factors

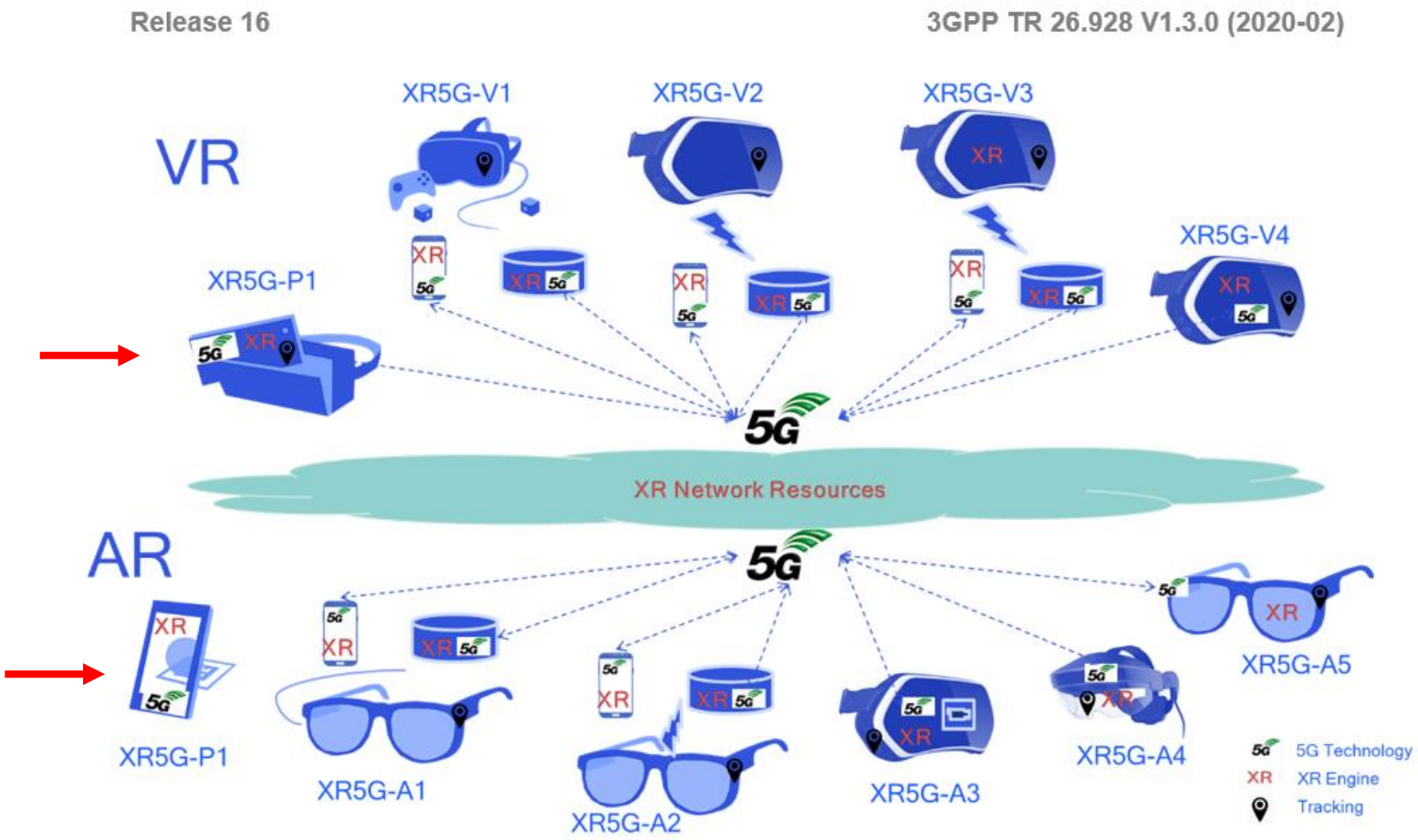



**Figure 4.8-1: XR Form Factors**

# XR Devices and Form Factors

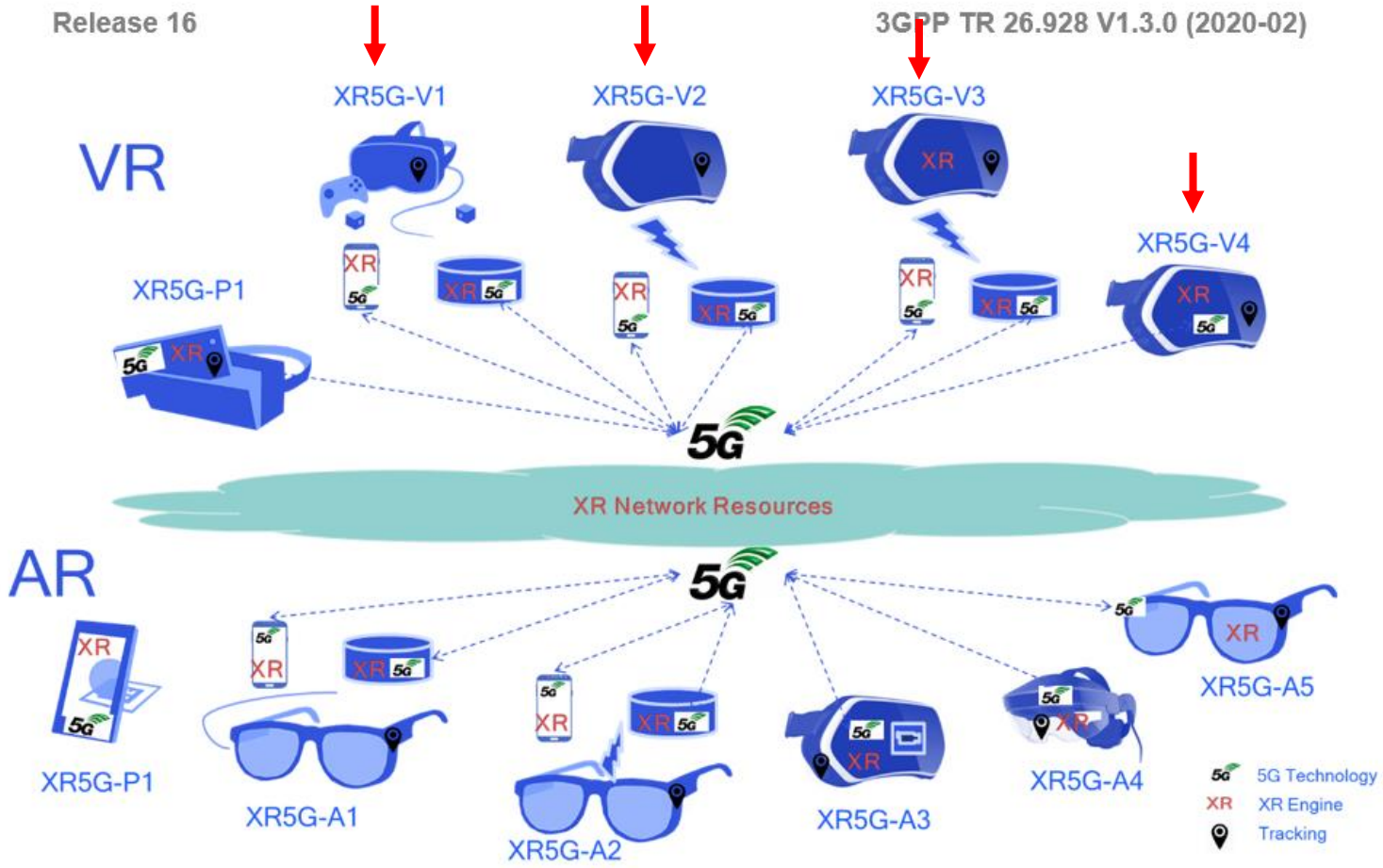



**Figure 4.8-1: XR Form Factors**

# XR Devices and Form Factors

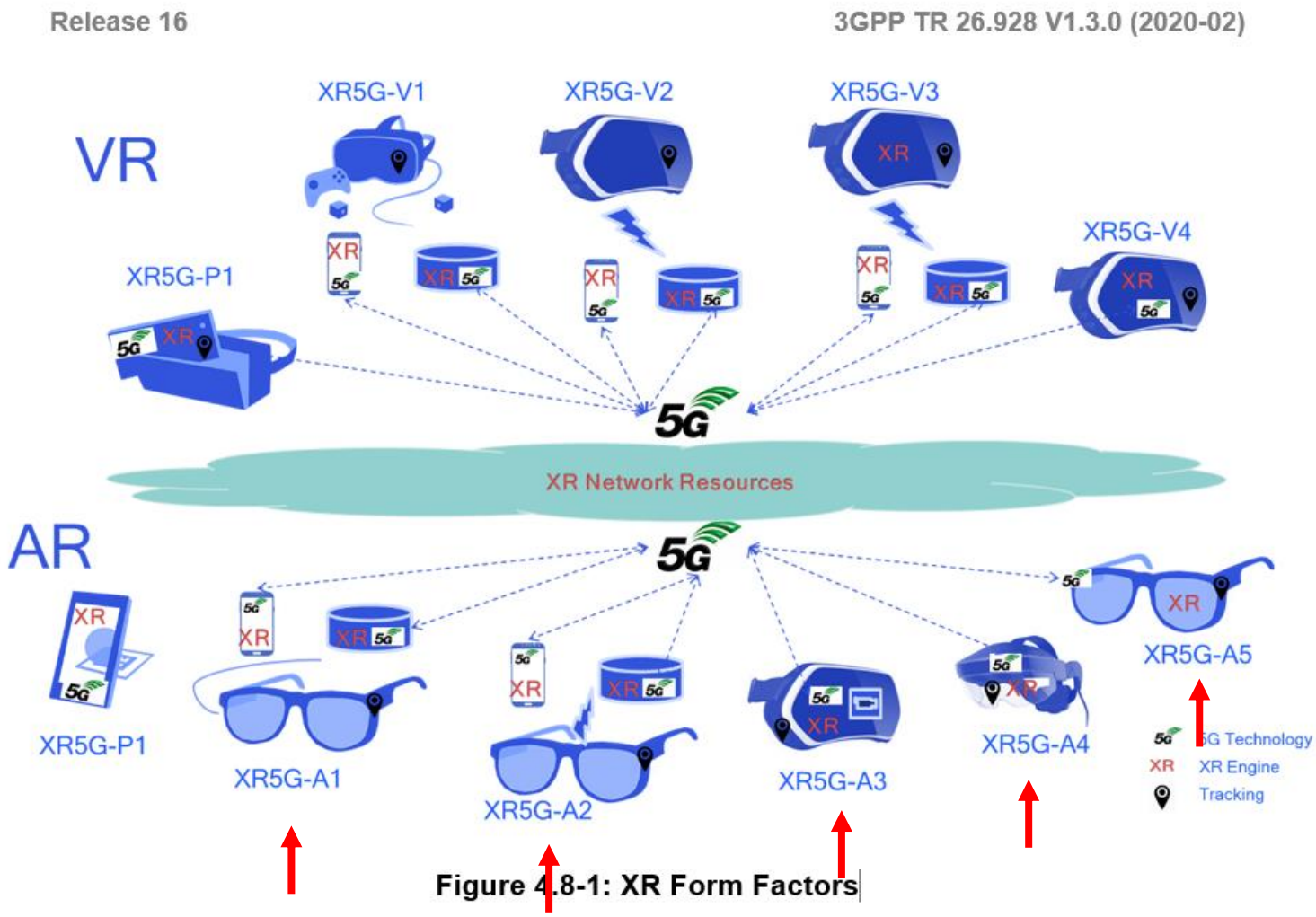


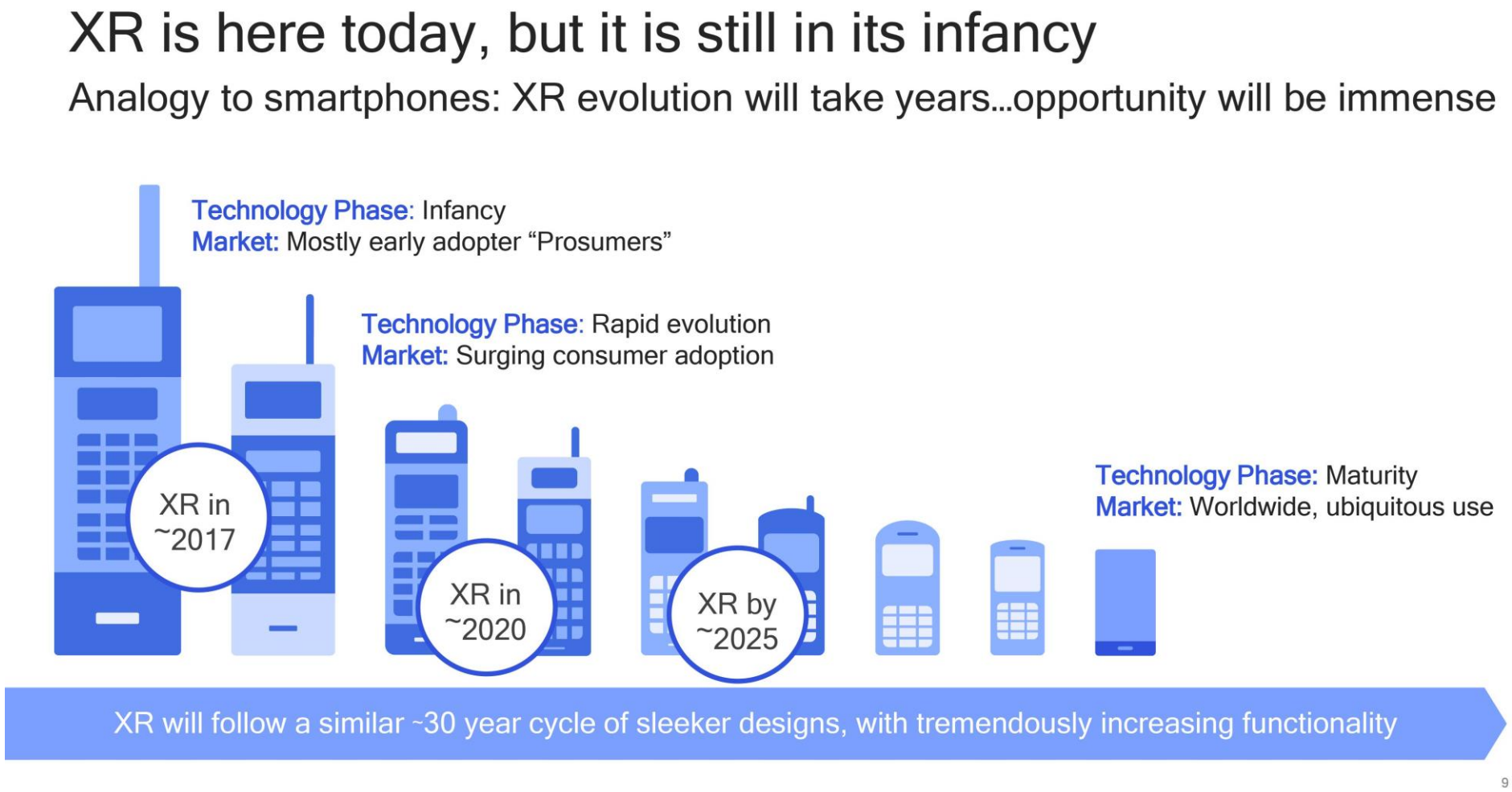

**Figure 4.8-1: XR Form Factors**

# Summary of XR Device Types (3GPP TR 26.928)

| XR Type Number | XR Device Type Name | Tethering Examples | 5G Uu Modem | XR Engine Localization | Power Supply | Typical Max Avail Power |
|---|---|---|---|---|---|---|
| XR5G-P1 | Phone | n/a | XR device | XR device or split | Internal | 3-5 W |
| XR5G-V1 | Simple VR Viewer wired tethering | USB-C | External | External | External | 2-5 W |
| XR5G-V2 | Simple VR Viewer wireless tethering | 802.11ad/y, 5G sidelink, etc. | External | External | Internal | 2-3 W |
| XR5G-V3 | Smart VR Viewer wireless tethering | 802.11ad/y, 5G sidelink, etc. | External | XR device or Split | Internal | 2-3 W |
| XR5G-V4 | VR HMD Standalone | n/a | XR device | XR device or Split | Internal | 3-7 W |
| XR5G-A1 | Simple AR Wearable Glass wired tethering | USB-C | External | External | External | 1-3 W |
| XR5G-A2 | Simple AR Wearable Glass wireless tethering | 802.11ad/y, 5G sidelink. etc. | External | External | Internal | 0.5 – 2 W |
| XR5G-A3 | Smart AR HMD see-through standalone | n/a | XR device | XR device or Split | Internal | 3-7 W |
| XR5G-A4 | AR Wearable Glass standalone | n/a | XR device | XR device or Split | Internal | 2 - 4 W |
| XR5G-A5 | Smart AR Wearable Glass wireless tethering | 802.11ad/y, 5G sidelink. etc. | External | XR device or Split | Internal | 0.5 – 2 W |

# XR Evolution Roadmap

Source: Qualcomm



# Outstanding Challenges with XR Evolution

- Virtual Objects look Fake
- Improvements needed in motion tracking
  - Improved head/body tracking
  - Improved eye tracking
- Poor Battery Life
- Charging time
- Fast Switch-on
- Able to handle large amount of computation, without getting hot
- High speed connectivity, indoors and outdoors
- Low latency (zero lag)
- Weight
- High Cost

# Wearables – TESLASUIT (link)

68
Haptic ponts

Haptic Animations

Real-time
Simulations

Weight Simulation

User calibration
profiles

Capillary system

Haptic Library

Users can create
custom animations
with Haptic Editor
application

Pic source

Teslasuit relies on 2.4GHz Wi-Fi for connectivity today. Could it be using 5G/6G in future?

# World's first 5G haptic rugby tackle by VF UK

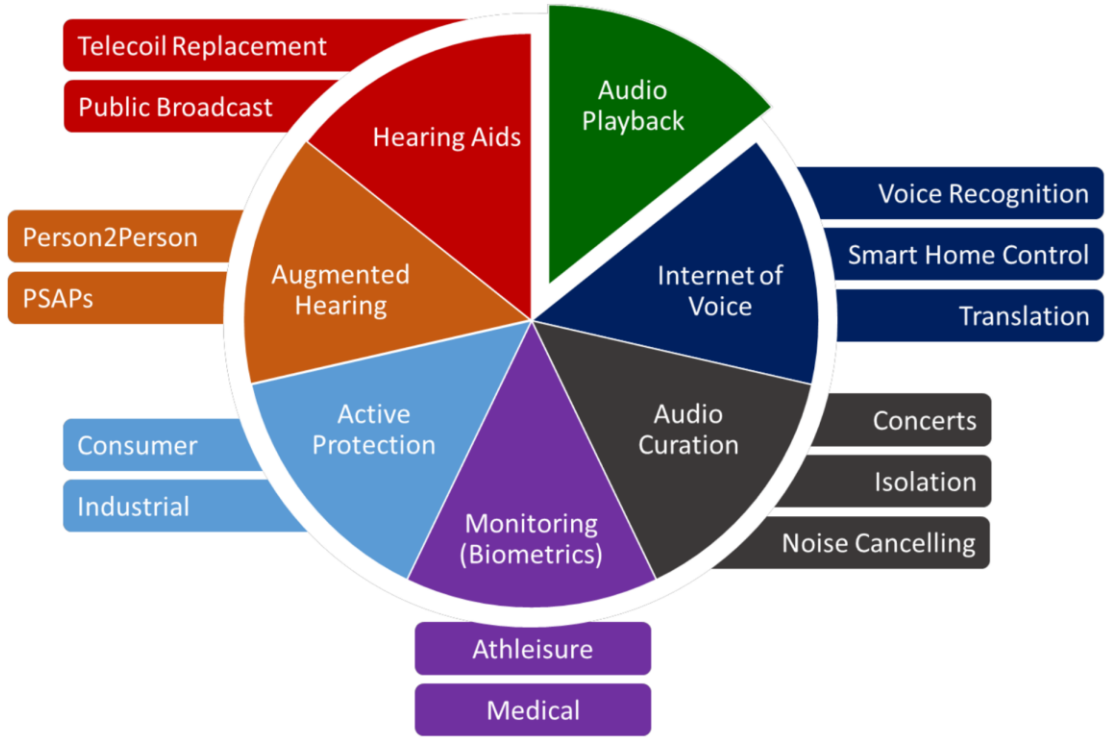

Source: Vodafone UK YouTube

# Wearables – Contextually-Aware Fragrances


More Details: escent.ai

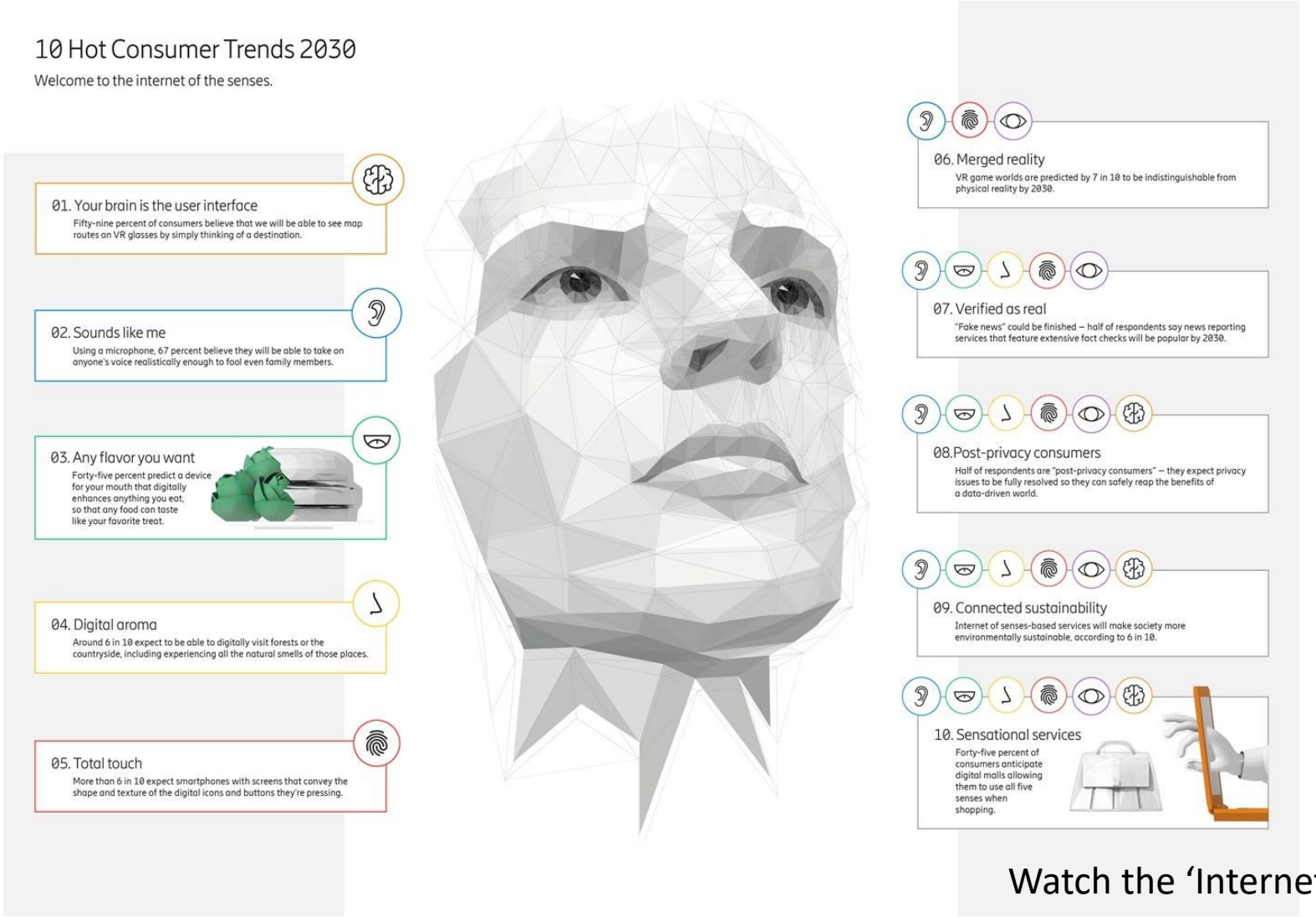
See this presentation on CW

# Hearables

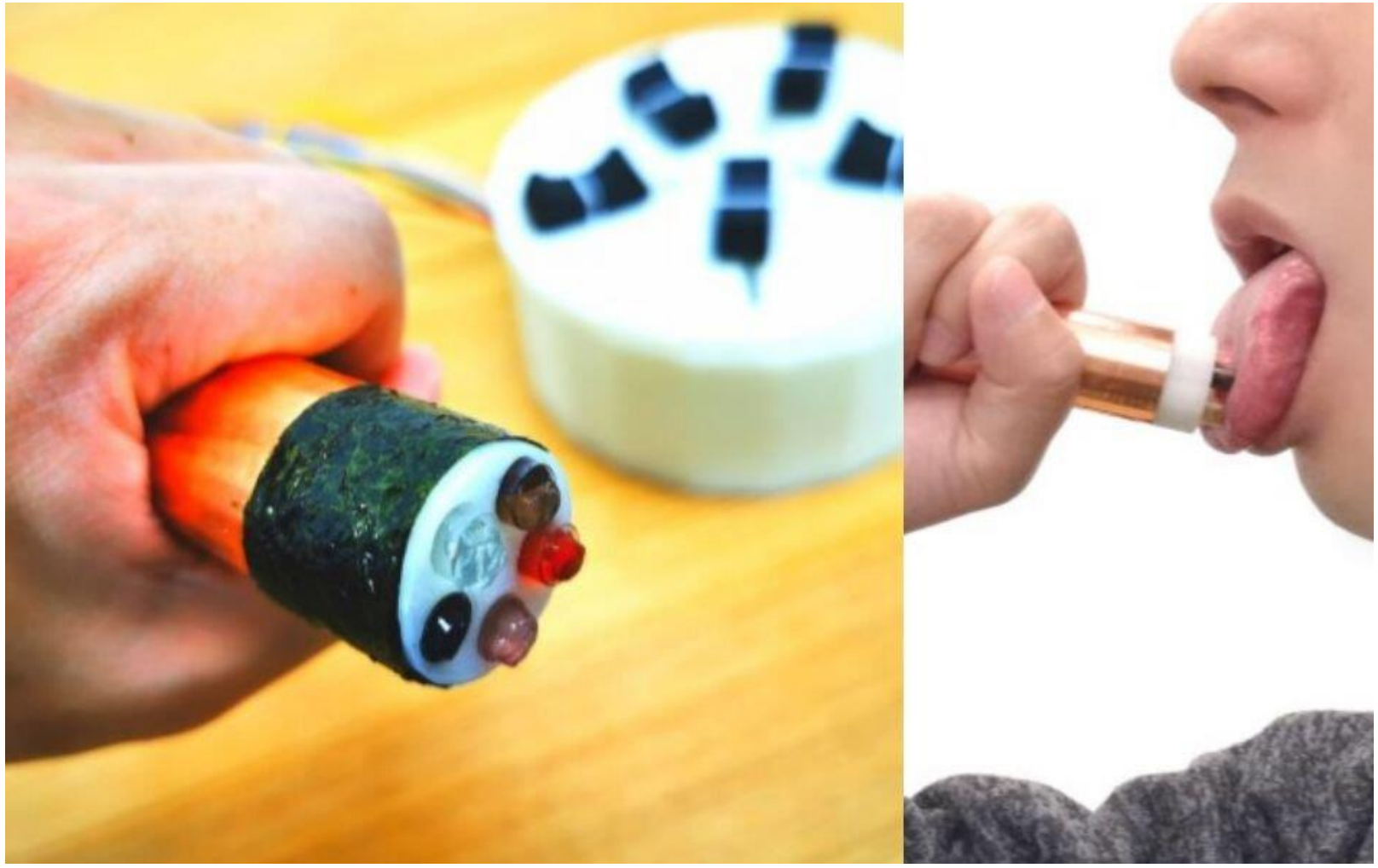

Pictures source: Fashnerd

# Ericsson’s 2030 Trends: Internet of Senses




Watch the ‘Internet of senses’ video here

# “Lickable Screen" device



Source: TechXplore

# ‘Zero-Energy’ or ‘Extreme-low power’ Devices


Figure 3-4. Extreme-low power consumption and cost reduction

Picture Source: NTT Docomo 6G Whitepaper


WE ARE ONE
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DPD DRONE
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KNIGHTSCOPE


MARKETS
VED
LLOY
KAZ
MRW
TSCO
IMT
XTA
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FTSE 100 GAINERS/FALLERS


TRAVEL
JOURNEY HOME
Bakerloo
Central
Circle
District
H'Smith & City
Jubilee
Metropolitan
Northern
Piccadilly
Victoria
Waterloo & City
Overground
DLR


BostonDynamics


FedEx
FedEx
prime

# Background Material

- Corning: A Day Made of Glass Video Series (link)
- Ericsson: A Social Web of Things (link)
- The 3G4G Blog: 5G eXtended Reality (5G-XR) in 5G System (5GS) (link)
- GSMA: The activities of GSMA on 5G and Cloud AR/VR (link)

# Further Reading

- University of Oulu: 6G vision for 2030 (video link)
- EE Times: Have Wearables Found Their True Killer App?, Nitin Dahad, April 2018 (link)
  - Cambridge Wireless: Scenarios for smart devices in 2025, David Wood, March 2018 (link)(summary on 3G4G blog)
- BBC - CES 2020: Nreal's mixed reality glasses win over sceptics (link)
- Nokia Bell Labs: Communications in the 6G Era Whitepaper, Sep 2020 (link)
- Free 6G Training: One XR Device to Rule Them All!, Dec 2020 (link)
- Qualcomm: Extended Reality (link)
- Cognitive Times: Smart Shirts & Clothes Could Help Save Lives with Health Monitoring (link)
- iDB: Future AirPods could track your heart rate and body temperature via built-in sensors (link)
- IEEE Spectrum: Your Earbuds Will Become Your Most Powerful Health Monitor (link)
- IEEE Spectrum: Treating Tinnitus Through the…Tongue? (link)
- Elsevier – Nano Energy: Battery-free short-range self-powered wireless sensor network (SS-WSN) using TENG based direct sensory transmission (TDST) mechanism, Nov 2019 (link)
- NTT Docomo white paper: 5G Evolution and 6G, January 2020 (link)
- Ericsson: Ever-present intelligent communication - A research outlook towards 6G, Nov 2020 (link)

# 6G Mobile Wireless Communications

## Vision, Roadmap, Technologies & Use Cases

*Part 9 - Course Summary & Conclusion*

@6Gtraining

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# Part 9 Video Link

# Course Outline: An Introduction to 6G Wireless

- Part 1: Introduction
- Part 2: 6G Vision
- Part 3: 6G Use Cases & Applications
- Part 4: 6G Timeline
- Part 5: 6G Requirements
- Part 6: 6G Groups
- Part 7: 6G Technologies
- Part 8: 6G Devices
- Part 9: Course Summary and Conclusion

# Part 1: Introduction

- What exactly is 6G?
- When is 6G coming?
- If 5G is being launched just now, why are we talking about 6G already?
- Who is standardising 6G?
- Will 6G be called 6G?

| | | | | | |
|---|---|---|---|---|---|
| **4G** | IMT-Advanced | LTE-Advanced | E-UTRAN | Evolved Packet Core (EPC) | Evolved Packet System (EPS) |
| **5G** | IMT-2020 | 5G | New Radio (NR) | 5G Core (5GC) | 5G System (5GS) |
| **6G** | IMT-2030 | 6G | ? | ? | ? |

Red text indicates that the names have not been confirmed.

# Part 2: 6G Vision

## NTT Docomo's 6G Vision

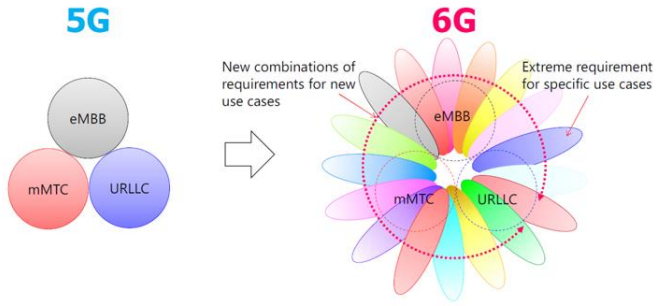
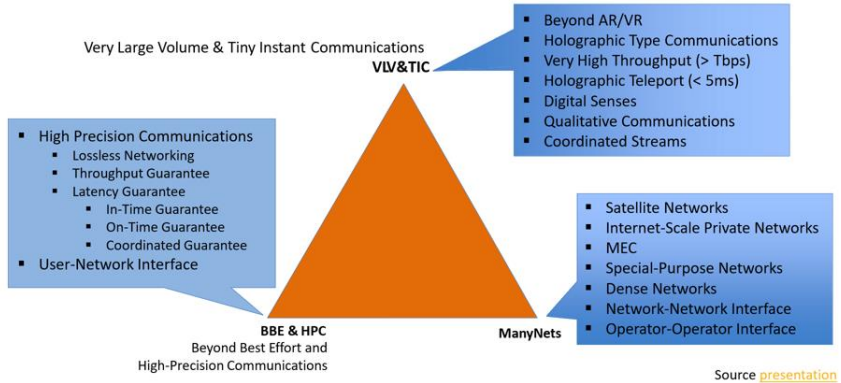



Figure 2-5. Image of technological development toward 6G

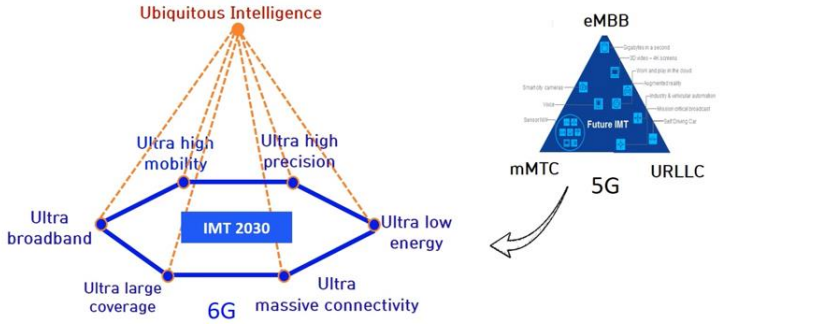
NTT Docomo 6G whitepaper

## ITU FG NET-2030 Vision



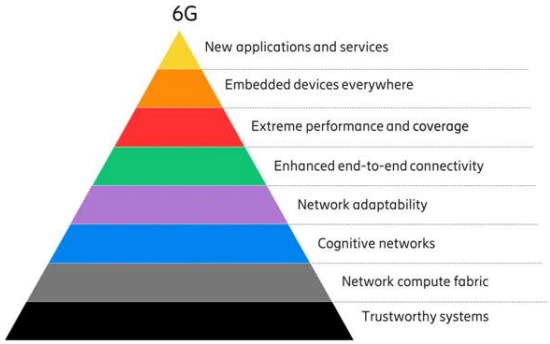

Source presentation

## ETRI: 6G Usage Elements and Scenarios




Source: ETRI, South Korea (link)

## Ericsson's 6G Vision




Source: Free 6G Training

# Part 3: 6G Use Cases & Applications

## XR will impact everyone and everything

| Transform how children learn and play | Tourists exploring historical sites | Families communicating | Working Professionals | Health and Fitness | People with disabilities |
|---|---|---|---|---|---|
|  |  |  |  |  |  |
| Children chasing virtual characters/immersive gaming, students using VR aids | Exploring historical sites through VR seeing them in their original state | Families bought together with life-like communication | Engineers collaborating on shared design to improve efficiency | Virtual trainers to motivate fitness groups | Experiences that might be impossible or unsafe for them in real life. They can run, ski, ride bikes, and climb mountains. |

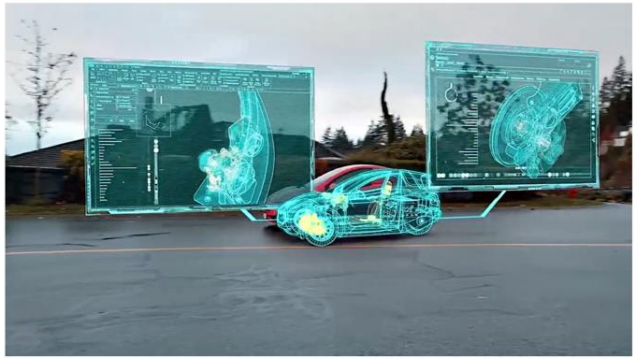


## Holoportation / 'Holographic Telepresence'


Holoportation example from movie Kingsman: The Secret Service (see video)



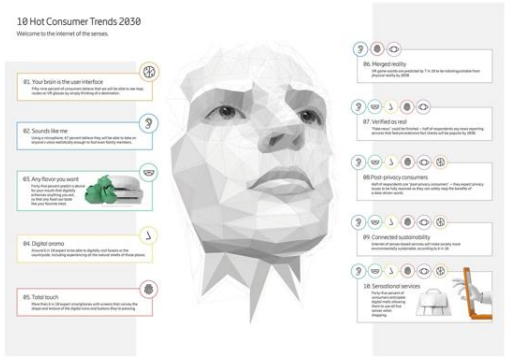
## Digital Twins



Source: Siemens

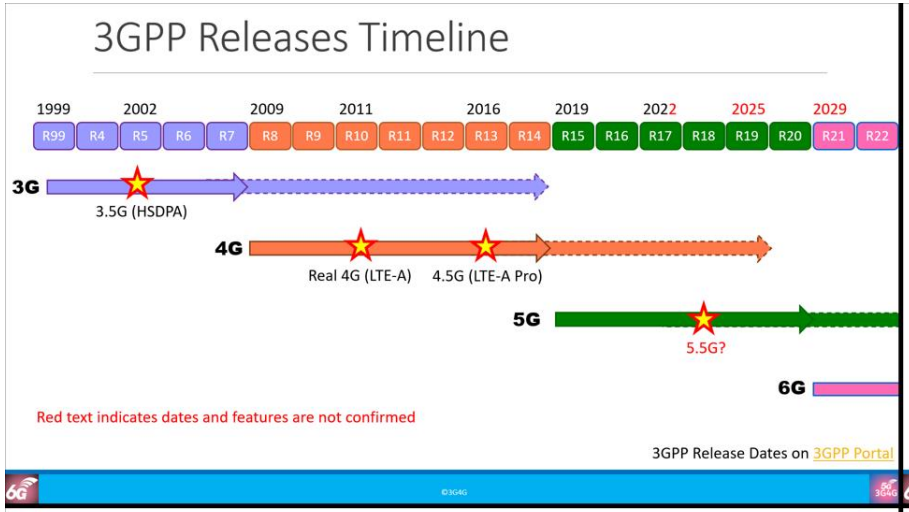


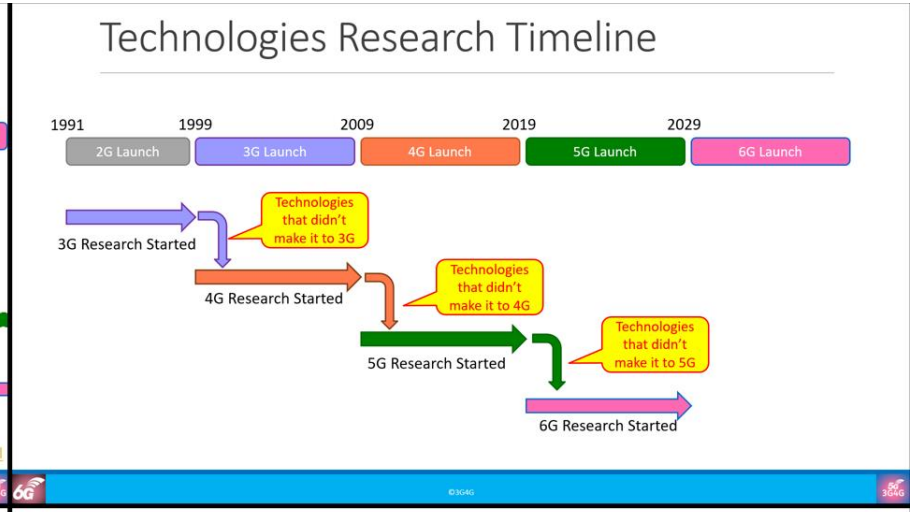
## Ericsson's 2030 Trends: Internet of Senses

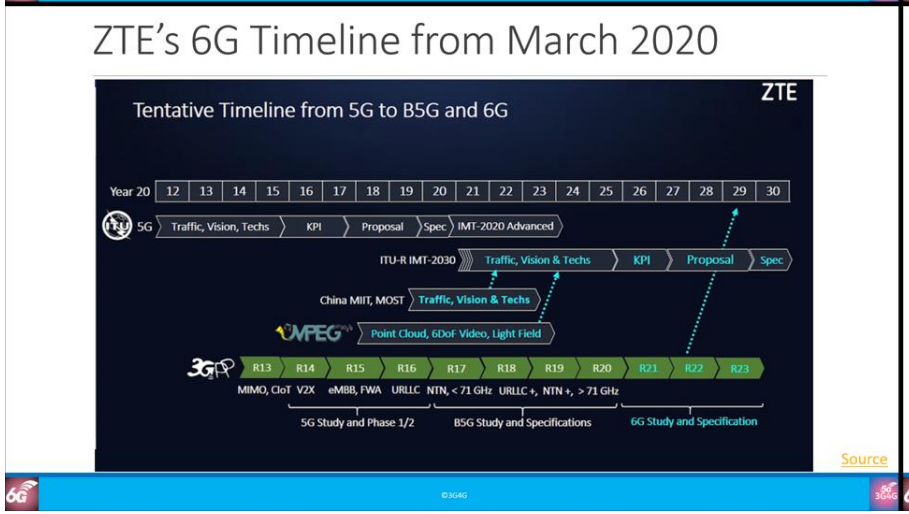


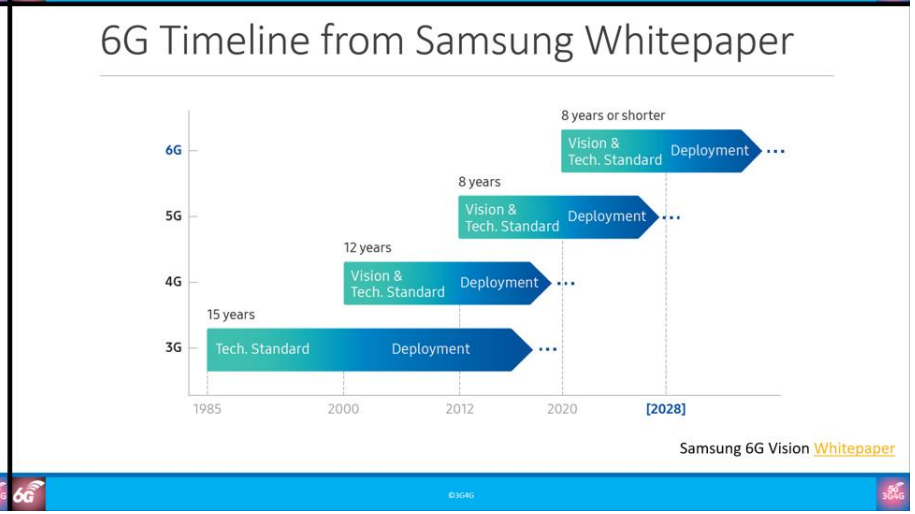

Watch the 'Internet of senses' video here

# Part 4: 6G Timeline



# Part 5: 6G Requirements

## NTT Docomo 6G Requirements

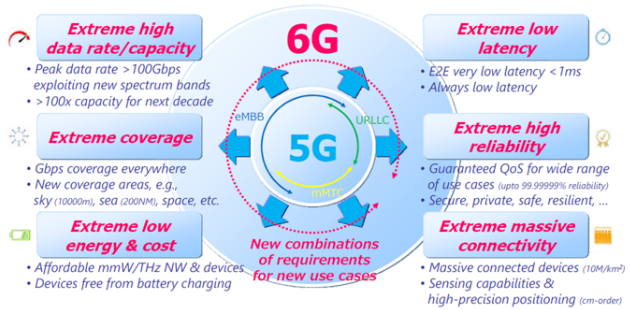



Figure 3-1. Requirements for 6G wireless technology

Source: NTT Docomo 6G Whitepaper, Jan 2020

## 6G Research Visions, 5G & 6G KPIs Comparison

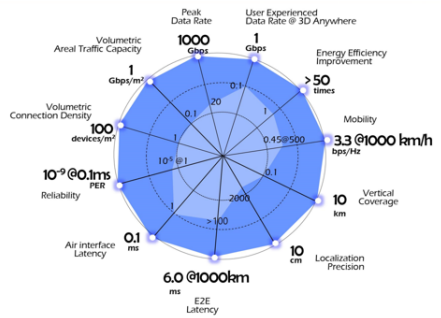
| KPI | 5G | 6G |
|---|---|---|
| Peak data rate | 20 Gb/s | 1 Tb/s |
| Experienced data rate | 0.1 Gb/s | 1 Gb/s |
| Peak spectral effciency | 30 b/s/Hz | 60 b/s/Hz |
| Experienced spectral effciency | 0.3 b/s/Hz | 3 b/s/Hz |
| Maximum bandwidth | 1 GHz | 100 GHz |
| Area traffic capacity | 10 Mb/s/m² | 1 Gb/s/m² |
| Connection density | $10^6$ devices/km² | $10^7$ devices/km² |
| Energy effciency | not specified | 1 Tb/J |
| Latency | 1 ms | 100 µs |
| Reliability | $1\text{-}10^{-5}$ | $1\text{-}10^{-9}$ |
| Jitter | not specified | 1 µs |
| Mobility | 500 km/h | 1000 km/h |

© 6G Flagship

Table 1: A comparison of 5G and 6G KPIs [4–6,9].

6G Research Visions: White Paper 10 on Broadband Connectivity in 6G

## ETRI: 6G KPIs




Source: ETRI, South Korea (link)

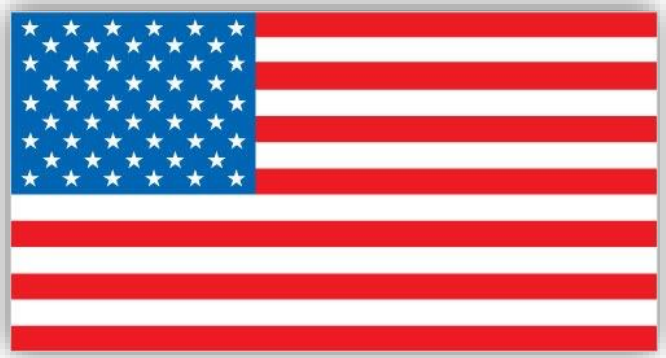
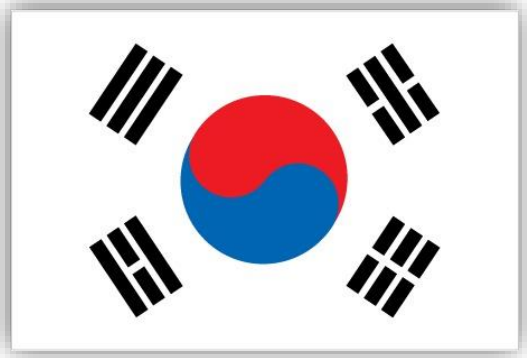
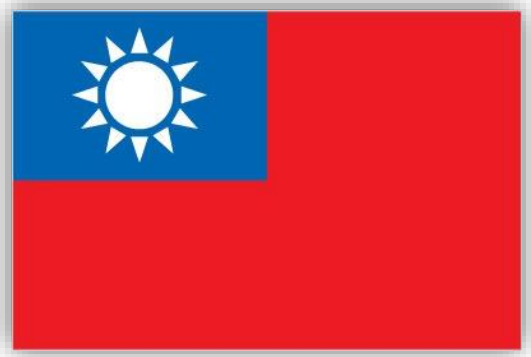
## Comparison* of different Technology Generations

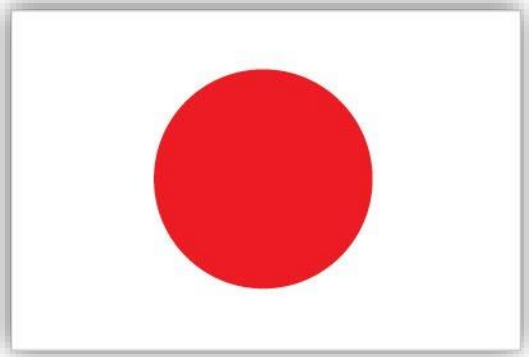
| | 2G | 3G (HSPA+) | 4G | 5G | 6G** |
|---|---|---|---|---|---|
| Year | 1990 | 2000 | 2010 | 2020 | 2030 |
| Max DL Speed (theoretical) | 473.6 Kbps | 42 Mbps | 3 Gbps | 20 Gbps | 1 Tbps |
| Avg DL Speed (practical) | 50 Kbps | 8 Mbps | 100 Mbps | 300 Mbps | 1 Gbps |
| Max UL Speed (theoretical) | 473.6 Kbps | 11.5 Mbps | 1.5 Gbps | 10 Gbps | 10 Gbps |
| Avg UL Speed (practical) | 50 Kbps | 2 Mbps | 50 Mbps | 100 Mbps | 1 Gbps |
| E2E Latency (practical) | 600 ms | 120 ms | 30 ms | 10 ms | 1 ms |
| Reliability | 99% | 99.9% | 99.99% | 99.999% | 99.99999% |
| Connection Density | N/a | N/a | $10^5$ devices/km² | $10^6$ devices/km² | $10^7$ devices/km² |
| Mobility | 150 km/h | 300 km/h | 350 km/h | 500 km/h | 1000 km/h |

* Approximate values to show comparisons. **Subject to change when standards process starts.

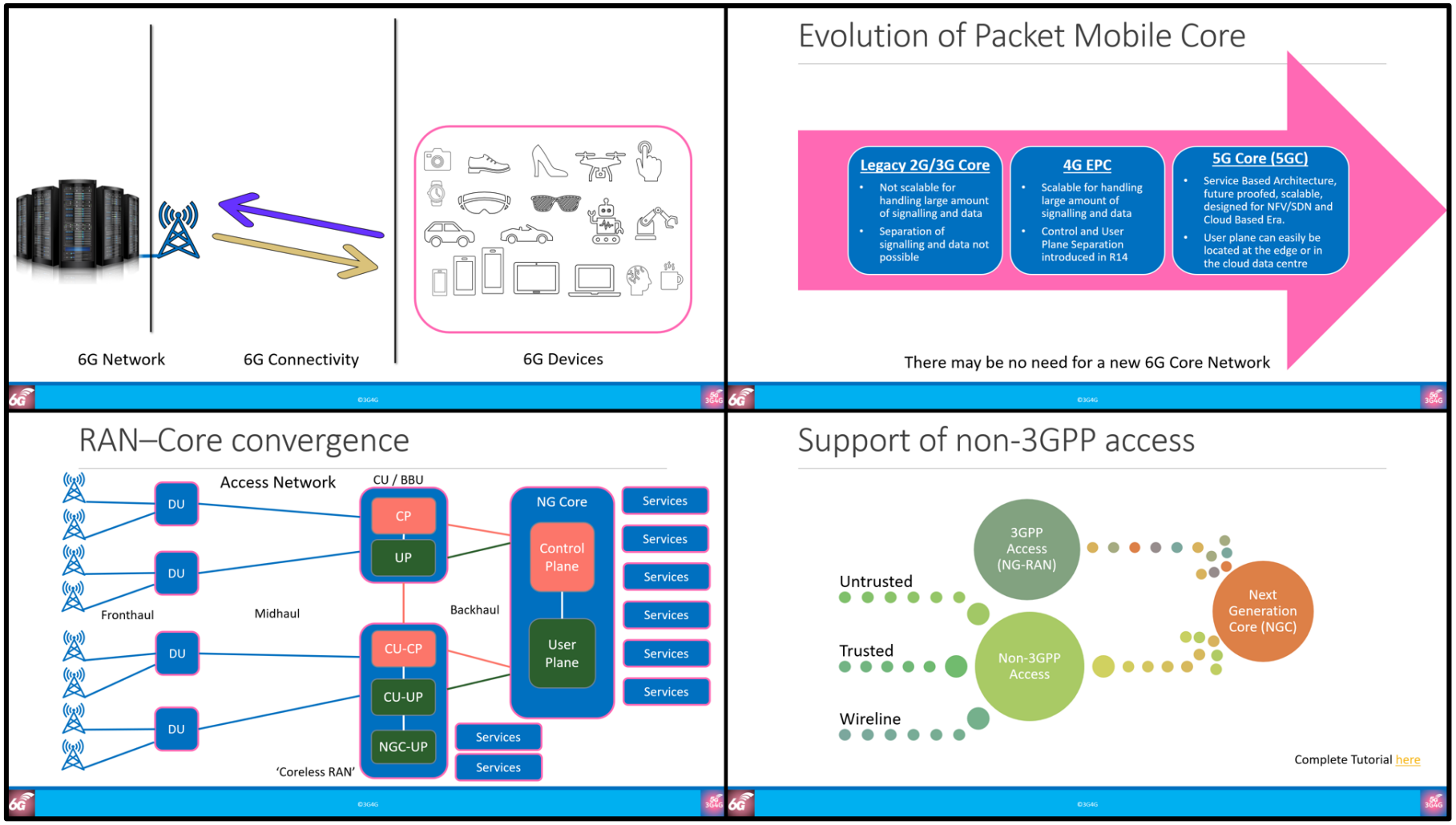
# Part 6: 6G Groups



# Part 7: 6G Technologies



# Part 7: 6G Technologies

## List of Probable 6G Technologies

| | | | |
|---|---|---|---|
| Spectrum | THz | mmWave | |
| Spectrum Sharing | | | |
| Antenna Technologies | OAM | RIS | Metamaterials |
| Evolution of Duplex | Half Duplex FDD | In-band Full Duplex (IBFD) | |
| Evolution of Network Topology | HAPS, Satellites, NTN | Wireless Wireline Convergence | |
| Comprehensive AI/ML | AI/ML Air Interface | AI/ML at Edge | AI/ML in RAN |
| Split Computing | | | |
| High Precision Network | | | |
| Communications & Sensing | | | |
| Extreme Connectivity/Networking | Extreme URLLC | | |
| Industrial IoT | Sub-Networks | | |
| Localization & Sensing | | | |
| Security & Trust | | | |
| Fully Service Based, Cloud Native Networking and RAN-Core Convergence | | | |
| Expanded integration of variable wireless technologies | | | |
| Open Platforms | | | |

Presentations on these topics coming soon

# Part 8: 6G Devices

## Example of Companion Devices

Smaller Companion Phones

Smart Watches and Fitness Trackers

XR Headsets

Smart Clothing

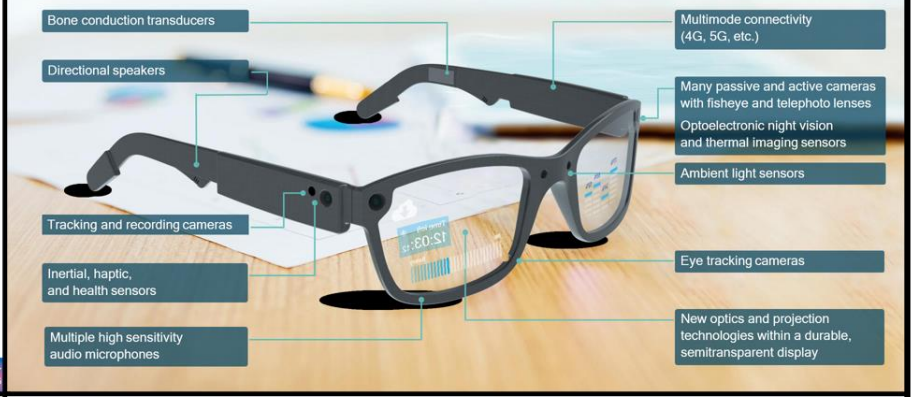
Electronic Skin Patches

Hearables



Source: Qualcomm

## A glimpse into the future — everyday AR glasses




## Wearable 360° Cameras

NEXX360

NEXX360 Details

See Linkflow

FITT360

FITT360 Details

## Wearables – TESLASUIT (link)


Teslasuit relies on 2.4GHz Wi-Fi for connectivity today. Could it be using 5G/6G in future?

# An Update from ITU

MyITU News Publications Events Membership English Log in

MyITU > News > 5G: IMT-2020 update

## Beyond 5G: What's next for IMT?

5G | NETWORK MANAGEMENT | POLICY AND REGULATION | STANDARDS

02/02/2021 | ITU News


The ITU Radiocommunication Sector (ITU-R) has recently published Recommendation ITU-R M.2150 titled 'Detailed specifications of the radio interfaces of IMT-2020'.

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Link

# Further Reading – Our Websites

- Free 6G Training (link)
- 3G4G: 6G and Beyond-5G Wireless Technology (link)

Not directly relevant to 6G but may be useful

- The 3G4G Blog (link)
- Telecoms Infrastructure Blog (link)
- Operator Watch Blog (link)
- Connectivity Technology Blog (link)
- 3G4G YouTube (link)
- Free 5G Training (link)

# Further Reading – 6G Whitepapers

- 6G Research Visions: White paper 1 on Key drivers and research challenges for 6G ubiquitous wireless intelligence, Sep 2019 (link)
- 6G Research Visions: White paper 2 on 6G Drivers and The UN SDGs, June 2020 (link)
- 6G Research Visions: White Paper 3 on Business of 6G, June 2020 (link)
- 6G Research Visions: White Paper 4 on Validation and Trials for Verticals towards 2030's, June 2020 (link)
- 6G Research Visions: White Paper 5 on Connectivity for Remote Areas, June 2020 (link)
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- 6G Research Visions: White Paper 7 on Machine Learning in 6G Wireless Communication Networks, June 2020 (link)
- 6G Research Visions: White Paper 8 on Edge Intelligence, June 2020 (link)
- 6G Research Visions: White Paper 9 on Research Challenges for Trust, Security and Privacy, June 2020 (link)
- 6G Research Visions: White Paper 10 on Broadband Connectivity in 6G, June 2020 (link)
- 6G Research Visions: White Paper 11 on Critical and Massive Machine Type Communication towards 6G, June 2020 (link)
- 6G Research Visions: White Paper 12 on Localization and Sensing, June 2020 (link)

# Further Reading – 6G Whitepapers

- ITU FG NET-2030: Focus Group on Technologies for Network 2030 (link)
- 5G Americas: Mobile Communications Beyond 2020 – The Evolution of 5G Towards Next G, Dec 2020 (link)
- NTT Docomo white paper: 5G Evolution and 6G, January 2020 (link)
- University of Surrey, 6GIC – 6G Wireless: A New Strategic Vision (link)
- Samsung 6G Vision Whitepaper, July 2020 (link)
- Nokia Bell Labs: Communications in the 6G Era Whitepaper, Sep 2020 (link)
- Ericsson: Ever-present intelligent communication - A research outlook towards 6G, Nov 2020 (link)
- University of Surrey, 6GIC – 6G Wireless: A New Strategic Vision (link)

# Further Reading – 6G Research Papers

- Z. Zhang et al., "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies," in IEEE Vehicular Technology Magazine, 28-41, Sept. 2019 (link)

- Virtual Reality Book by Steven M. LaValle (link)

# Further Reading – Others

- Free 6G Training: 6G Usage Elements and Scenarios (link)
- Free 6G Training: '6G Vision for 2030+' from 6th Generation Innovation Centre (6GIC) (link)
- Free 6G Training: Huawei talks about Beyond 5G, 5.5G and 6G (link)
- NTT announces new R&D projects of Digital Twin Computing, Nov 2020 (link)
- Free 6G Training: 6G may just make Teleportation a Reality (link)
- Ericsson: 10 Hot Consumer Trends 2030 (link)
- Enabling holographic media for future applications: Missing pieces and limitations in networks, SIGCOMM, Aug 2019 (link)
- Holographic Type Communication, Kiran Makhijani, Future Networks, Futurewei, Oct 2019 (link)

# Thank You

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