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5G to 6G: Vision and Drivers

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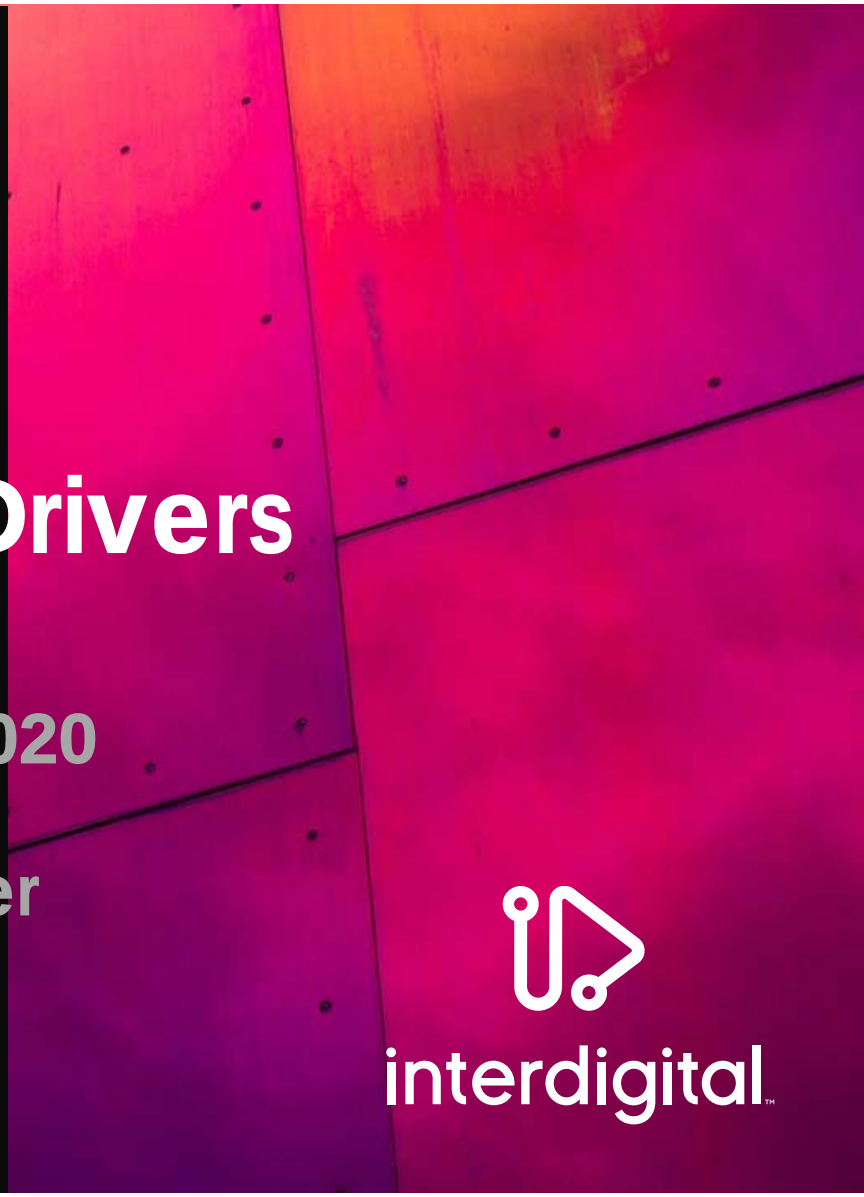

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InterDigital Introduction

A world-class R&D lab that drives InterDigital's technology development and is a respected participant in international standards & industry activities

5G Video Technology IoT

In Our Labs

- "2G-5G & Beyond" Wireless Standards
  - Also Internet & Mobile Edge Computing
- JV with Sony:
  - IoT Standards & Platforms
- Acquisition of research division of Technicolor:
  - Advanced Video Standards & Platforms
  - Immersive and Volumetric Video (3D, 360-degree, AR/VR)
  - Artificial Intelligence / Machine Learning

Why Talk about 6G Now?

- **The base 5G standards are now finalized and commercial systems are being rolled out:**
  - 5G standards are specified by 3GPP in R15/R16 (finalized in 2019/20)
  - Expect to have 200+ commercial 5G deployments by end of 2020

- **Academic and industry research is already underway for B5G/6G technologies:**
  - A mixture of evolutionary and revolutionary improvements over 5G
  - Expected time frame: starting in ~2020 (vision setting & applied research) and extending to ~2030 (6G trials)


Looking Further – Where are 6G Ideas Being Cooked?

- **H2020|5GPPP Phase 3 Focus is entirely on "B5G" Innovation targeting 3GPP R17++**
  - THz Cluster (6 coordinated projects) notable for its pioneering work in 100GHz+ system wide research
  - Also noteworthy is EU-US EMPOWER Technology Roadmapping initiative that will feed HEU* agenda
- **ITU-T Network 2030 is driving the vision for network architecture required for 6G**
- **In US, the Platform for Advanced Wireless Research (PAWR) is exploring 5G/B5G**
- **6GFLAGSHIP is a Finnish research partnership with focus on B5G/6G research**

*Horizon Europe is avoiding all generational nomenclature but will support continued B5G/6G research under a new "Smart Connectivity PPP" that will replace 5GPPP

So, What Do We Need to Get to a Next G?

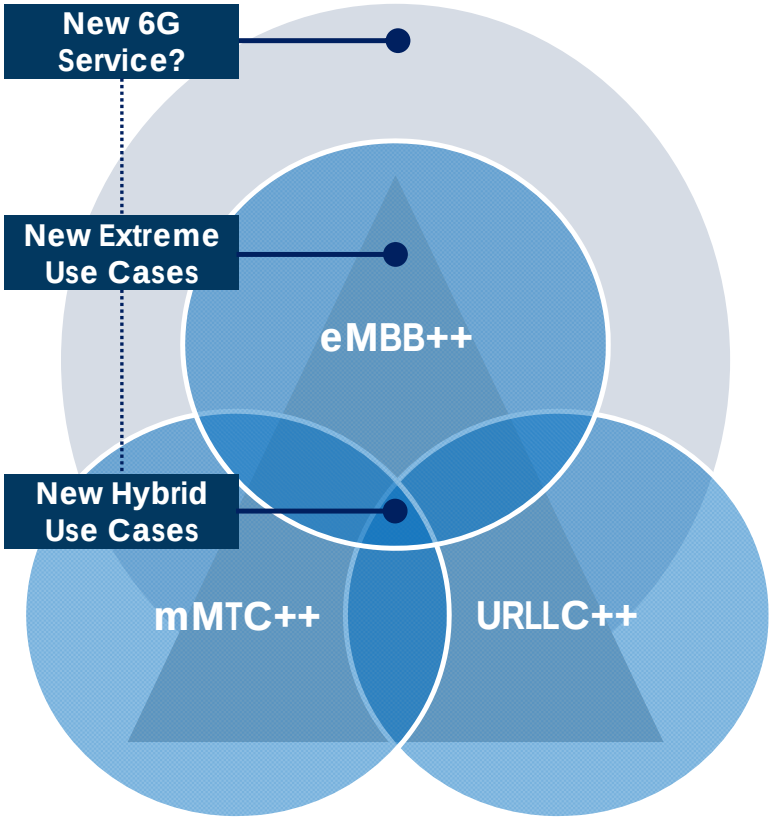
Every Gen. has Shaped up in the Same Way and 6G? will be No Different

2G	3G	4G	5G	6G
Voice	Voice	Voice	Voice	Voice
	Data	Data	Data	Data
		MBB	(e)MBB+	(e)MBB++
		MTC	(m)MTC+	(m)MTC++
			URLLC	URLLC+
				A New Service?

Key:
MBB = Mobile Broadband
MTC = Machine Type Communications
URLLC = Ultra-reliable and Low Latency Communications

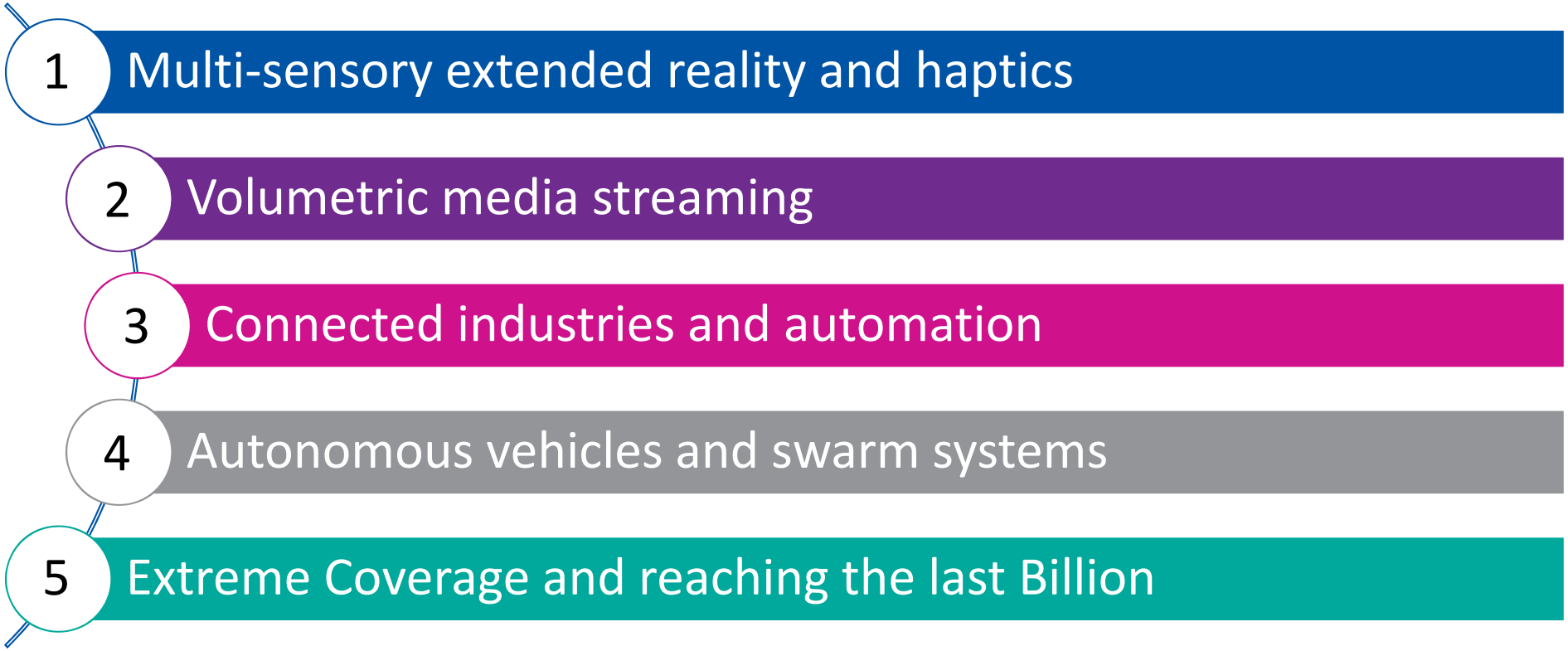
Something New, Something Broken & More(+) of the Same!

10,000 Feet: How We See the Future Emerging



- 6G will be required to reach a much wider set of use cases and market diversities
- 5G will NOT support extreme requirements of many of the use cases that it enables entry to
- New Service will emerge at the convergence of 'Physical & Virtual' but may not be so *new*
- The convergence of wireless, AI/ML and other tech will be the key to completing this vision
- 5G is a major step on this roadmap but we will probably need a 6G to see at a full scale

Extended Use Cases Conceal Long Roadmaps



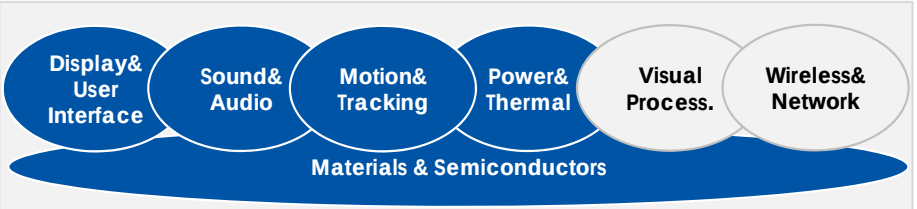
Case Study: Multi-Sensory–Extended Reality

What is the 6G significance of this use case?

Extended Reality (XR) describes the wide category of real-world to virtual-world interactions between humans and machines. It encompasses AR, VR and everything in between. XR is already transforming consumer experiences and many market verticals, from manufacturing and healthcare to education, gaming and retail…

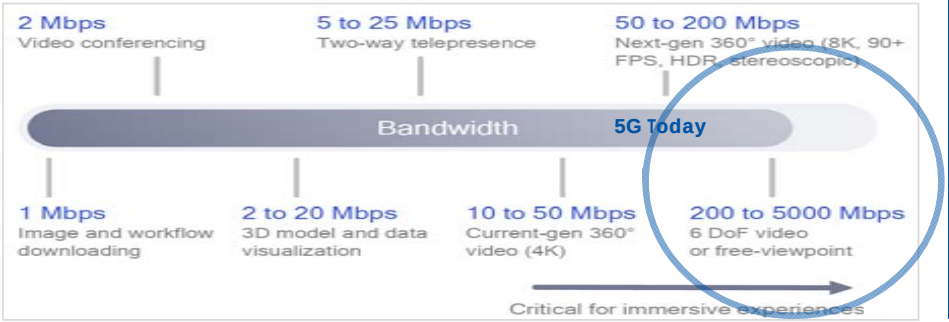
But it is still in very early stages and has 10+ years to run!

Other factors/roadmaps pertinent to this use case?



Many challenges on roadmap to Total Mobile Immersion

How will this use case challenge the 5G KPI?[1]



Takeaways (on how this will drive wireless)

- XR is the leading contender for the next mobile compute platform with "smartphone" like evolution potential
- Challenges on this roadmap are immense & incremental breakthroughs will lead to progressive product entries
- Wireless (& Video) has a critical enabling role but todays 5G **User Data Rate** will barely meet entry needs
- More, as this new category grows & applications expand **Connection Density** and **Latency** KPI will also be pushed

[1]ABI Research

Example: EMPOWER Project is Setting Wireless KPI Targets for 6G

Target KPI	5G	6G (Short Term)	6G (Medium Term)	6G (Long Term)
Spectrum	<52.6 GHz	<250 GHz	<500 GHz	<1000 GHz
Bandwidth	<0.5 GHz	<2.5 GHz	<5 GHz	<10 GHz
Peak Data Rate	DL: >20 Gbps UL: >10 Gbps	DL: >100 Gbps UL: >50 Gbps	DL: >200 Gbps UL: >100 Gbps	DL: >400 Gbps UL: >200 Gbps
User Data Rate	DL: >100 Mbps UL: >50 Mbps	DL: >500 Mbps UL: >250 Mbps	DL: >1 Gbps UL: >0.5 Gbps	DL: >2 Gbps UL: >1 Gbps
Peak Spectral Efficiency	DL: >30 bps/Hz UL: >15 bps/Hz	DL: >40 bps/Hz UL: >20 bps/Hz	DL: >50 bps/Hz UL: >25 bps/Hz	DL: >60 bps/Hz UL: >30 bps/Hz
Area Traffic Capacity	> 10 Mbps/sqm	>50 Mbps/sqm	>100 Mbps/sqm	>200 Mbps/sqm
Density	>1 device/sqm	>1.3 device/sqm	>1.7 device/sqm	>2 device/sqm
Reliability	URLLC: >5 nines	>6 nines	>7 nines	>9 nines
U-Plane Latency	URLLC: <1 ms	<0.5 ms	<0.2 ms	<0.1 ms
C-Plane Latency	<20 ms	<10 ms	<4 ms	<2 ms
Net. Energy Efficiency	Qualitative	>30 % gain	>70 % gain	>100% gain
Term. Energy Efficiency	Qualitative	>30 % gain	>70 % gain	>100% gain
Mobility	<500 Km/h	<500 Km/h	<500 Km/h	<1000 Km/h
Positioning accuracy	NA (<3 m)	<1 m	<30 cm	<10 cm

6G Use Case Impact on 5G KPI Heat Map

	User Data Rate	Latency		Reliability	Connection Density	Energy Efficiency	Positioning	Coverage Area Probability	Mobility
		C-Plane	U-Plane						
Multi-Sensory XR	20X				5X				
Volumetric Media	100X+					2X			
Connected Industry			10X	100X+	10X		100X		
Auto and Swarm		2X							
Extreme Coverage								~1	2X
Extreme Gaming									
Ultra Low Power IoT		2X			4X	4X			

5G Will be Challenged by these Extreme Uses Cases!

Key Technology Trends that Challenge 5G

- **Every wireless generation is charted on a catalogue of key trend lines. Some Fizzle, others over long term lead to break points that ultimately challenge the status quo…**
- **In this B5G/6G era there may be many but we highlight 3 with some potential:**
  - Push into new bands & sharing models
  - Fusion of Wireless & Networking with AI
  - Virtualization to Full Cloud Native Model

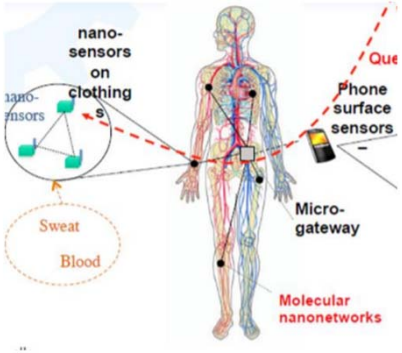
Key 6G Technology Trends

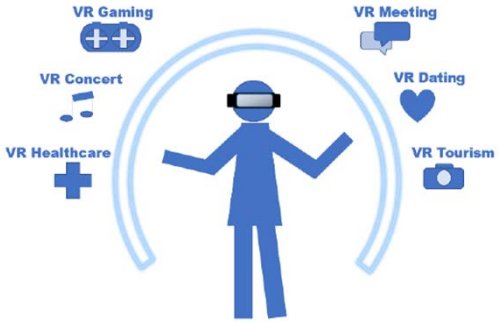
- New Radio Tech and Moves to Terahertz Band
- Wireless Fusions with AI/ML
- Extreme Cloud Native – Edge Computing
- Convergence of Terrestrial and Non Terrestrial Comms
- Emergence of Joint Communications, Sensing & Imaging
- MIMO Evolution Meets Metamaterial Intelligent Surfaces
- Innovation Enabled by Mass Availability of Small Data
- Self Sustaining, Energy optimized Network Design
- Trickle to a Stream of Quantum Methods & Technologies

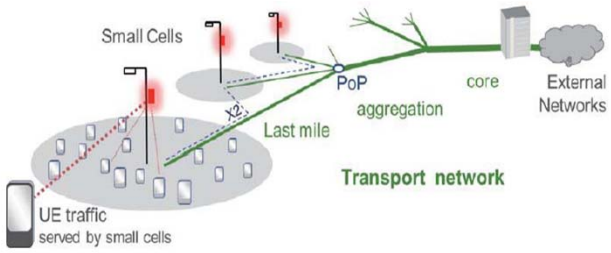
Move to Above Terahertz Communication

New link-level connectivity as backbone of future communication systems

Ultra-small form factors – miniature/biological communication networks
Ultra-high throughputs (Tbps scale) – true virtual presence and multimedia
Joint communications and sensing – high resolution environment mapping







Move to Above Terahertz Communication

- **Value Proposition for 6G:**
  - **Potential for significantly higher bandwidth (Tbps range) and antenna miniaturization**
- **Current State of the Art:**
  - **Mostly academia-lead *lab* demonstrations of photonic and/or electronic based transceivers in the range of 100GHz to 750GHz spectrum with data rates achieving between 10Gbps-100Gbps (distance dependent)**
  - **IEEE 802.15.3d was completed in 2017 as the first global standard of the technology between 250GHz-350GHz ranges**
- **Main Challenges:**
  - **The key challenge, aka *THz technology gap*, is on the design and implementation of low-power and compact THz devices (RF and baseband)**
- **Outlook:**
  - **Multiple public/state-funded large-scale collaborative projects (e.g., DARPA, EC H2020) aim at widely deployable commercial THz products within 5-10 year timescale**

Key 6G Technology Trends

New Radio Tech and Moves to Terahertz Band

Wireless Fusions with AI/ML

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Innovation Enabled by Mass Availability of Small Data

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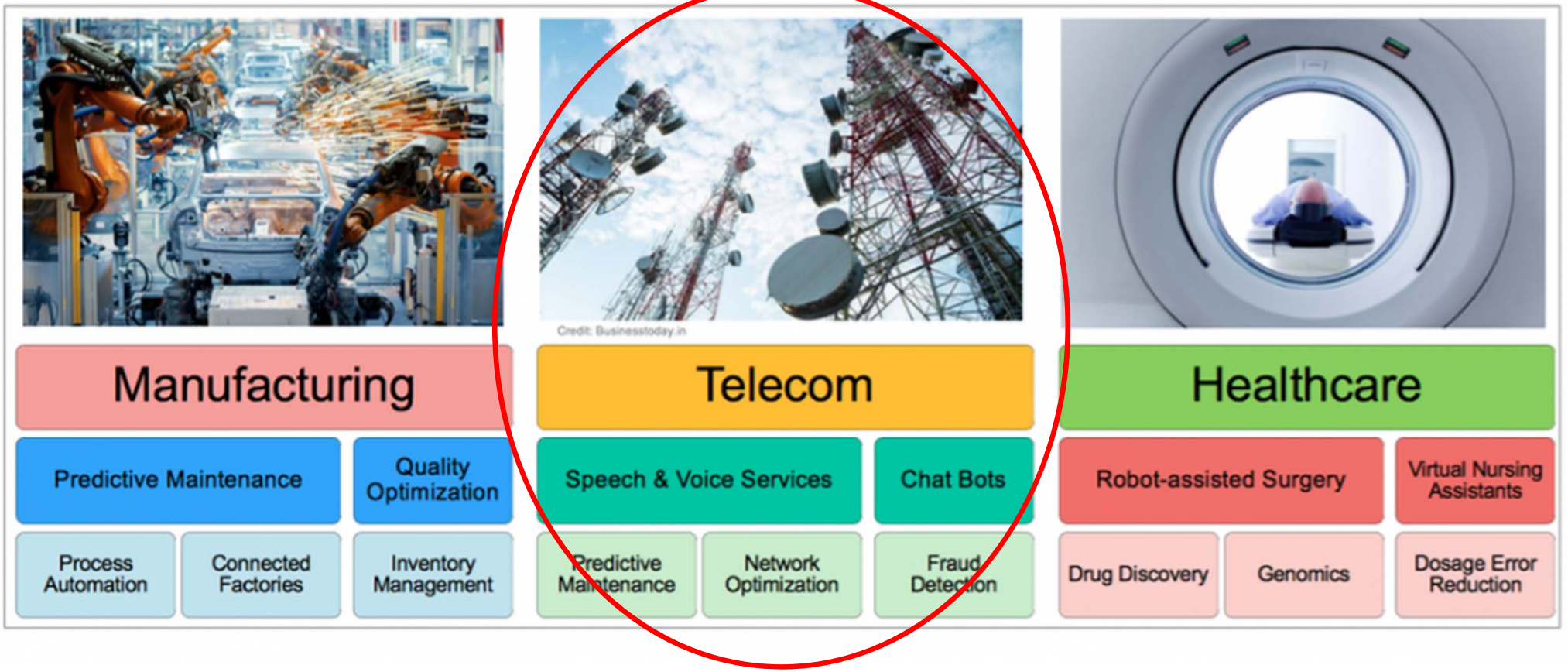
Wireless Fusion with AI/ML at Every Layer of Stack



https://blog.netapp.com/ai-across-industries-manufacturing-telecom-healthcare/

Wireless Fusion with AI/ML at Every Layer of Stack

- **Value Proposition for 6G:**
  - Use power of AI/ML to harness the vast amount of data available in 5G/6G systems to significantly improve system performance, network automation and user experience
- **Current State of the Art:**
  - AI/ML has already dramatically improved performance in the IT world (e.g., classify content in pictures; make recommendations for purchases, movies, songs, etc.)
  - Early research has started in using AI/ML for key 6G features: PHY processing, and network operation tasks (e.g., spectrum sharing, mobility management, network slicing optimization, transport protocol optimization, user QoE)
- **Main Challenges:**
  - Ensuring telecom grade reliability and accuracy for AI/ML features, and enable its pervasive integration into the operator's network operation
- **Outlook:**
  - AI/ML impacts to devices and network will be extensive and nearly impossible to forecast (e.g., similar in scale to changes when networks went from analog to digital)

Key 6G Technology Trends

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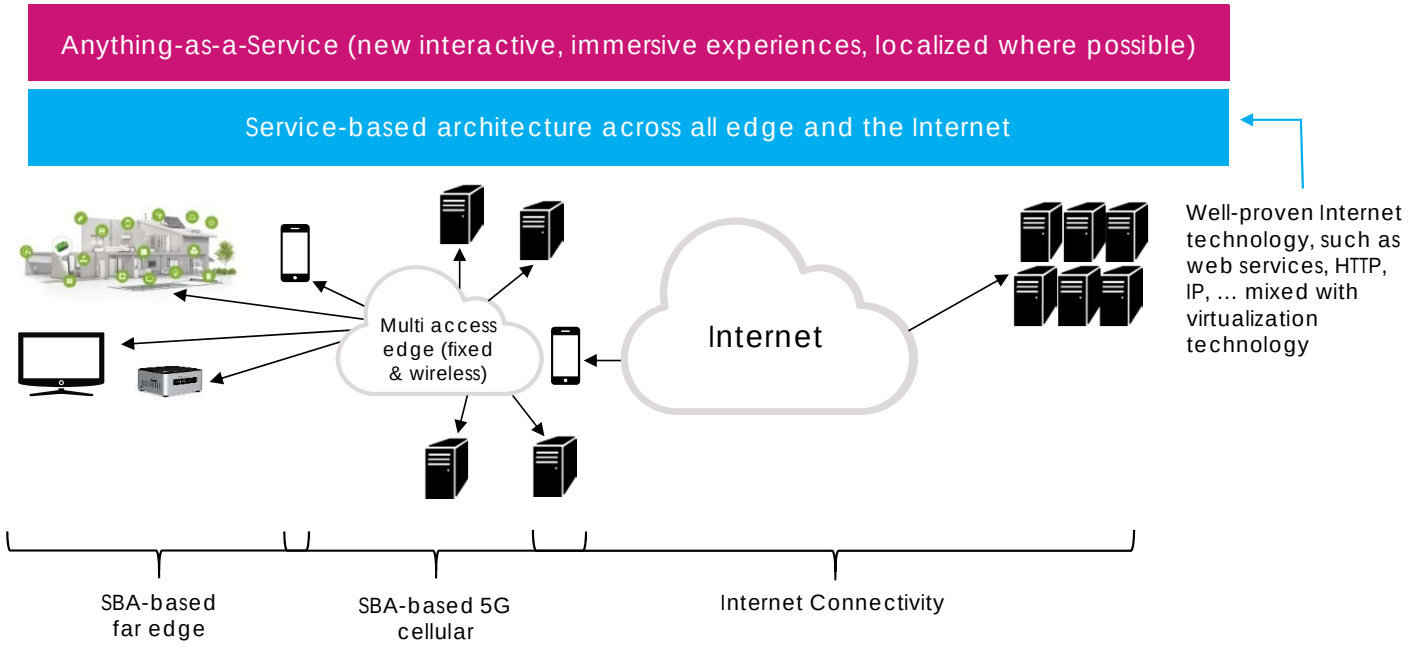
Extreme Cloud Native – Edge Computing

Providing Micro Services From Distant Cloud to the Far-Edge

Apply principles that made major Internet players successful to enable **new wireless experiences** by delivering a flexible, innovative **micro-service platform** that is integrated across the distant cloud over mobile **networks** to far **edge devices**.



Extreme Cloud Native – Edge Computing

- **Value Proposition for 6G:**
  - **6G can reap the benefits of the full distribution of applications in the form of collaborating micro-services that are dynamically executed in the most appropriate data center available**
- **Current State of the Art:**
  - **Cloud-native Service Based Architecture (SBA) is currently limited to 5G control plane (in 3GPP R16)**
  - **Support for edge computing and all-LAN connectivity to terminals being studied for 3GPP R17**
- **Main Challenges:**
  - **Adopt flexible Web scale architecture that (1) spans the Core Network, RAN, Edge down to the Devices and (2) includes both the control and user plane**
- **Outlook:**
  - **Unification beyond mobile core and edge networks lead to a common edge/access architecture for wireless and fixed network that is fully cloud-native and backward-compatible to existing devices**
  - **Other forums such as ITU-T Network2030 are also driving this vision of cloud-native for 2030**

A Few of the 6G EU Projects InterDigital is Involved in

https://www.advancedwireless.eu/

https://epic-h2020.eu/

http://5growth.eu/

https://5g-dive.eu/

(Keywords: B5G Roadmap, Above 150GHz, Wireless AI Fusion, Edge AI, 3D Wireless, Extreme Verticals, etc.)

Working with >50 Diverse Partners (Traditional + Non-Traditional) Exploring 6G Challenges and New Requirements

A Few Closing Thoughts

- **5G is now being commercially deployed and from here we enter the "Beyond IMT2020" era and this evolution will likely span the next ten years**
  - The emerging use cases for B5G/6G may seem quite familiar but hide a truth that 5G may only open the door to these roadmaps
  - Extreme requirements will continue to push evolution of wireless well beyond 5G and in time will enable a new service experience

- **The B5G push is now starting and will require fundamental rethinking of all aspects for future 6G systems:**
  - HW (e.g., miniaturized Tera Hz baseband and RF)
  - SW (e.g., AI operating in all layers from PHY processing to network control)
  - Networks (e.g., cloud native approach extending to user plane and edge/devices)

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Appendix: Detailed Technology Trend Analysis

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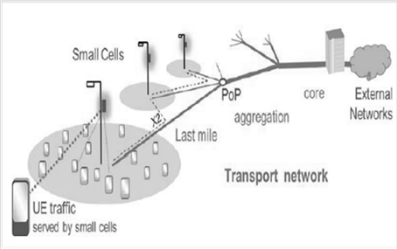
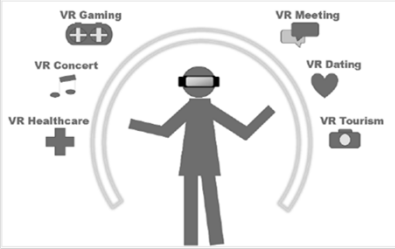
#1: Push into New Spectrum & Sharing Models

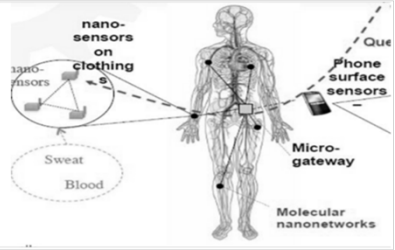


Next Generation Infrastructure



Ultra High Throughputs for XR

Joint Communications & Sensing



Ultra Small Form Factors & Apps

Technology Roadmap

Shorter Term (in IEEE & 3GPP Now or Soon):

- **72GHz-100GHz:** Mature precommercial TX tech. with applications in NGI, XR & JCS. Throughputs in excess of 50Gbps forecast

Mid Term:

- **100GHz-300GHz:** Lab grade reference designs & testbeds. Future applications in NGI, XR & JCS. Throughputs in excess of 100Gbps

Longer Term:

- **300GHz Plus:** Still mostly academic with experimental TX designs & testbeds. Focus of ultra small form factor research

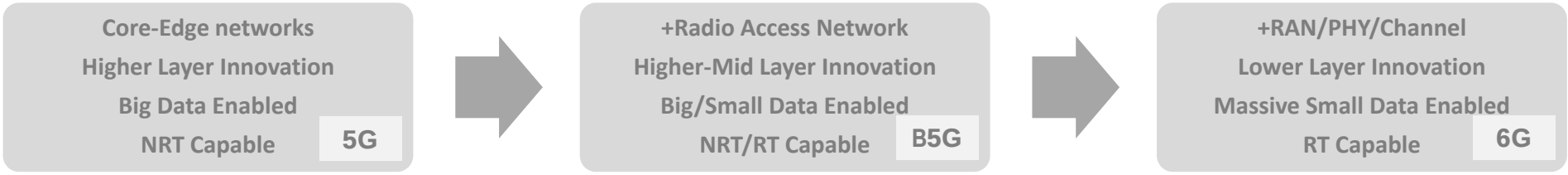
Potential for this Trend Line to "Break" 5G

HIGH: Fundamental problems begin to appear with digital design and OFDM methods at above 100GHz. This has to do with limitations in underlying physics/electronics (e.g. power & dark silicon issues), as well as a slowing of Moore's law

IMPACT: ***New Waveform Emergence*** and a reengineering of many baseband blocks in 5G in the direction of a new hybrid analog-digital design. New technologies may include: Device & RF aware new waveforms, low complexity encoder/decoder designs & efficient ultra massive MIMO techniques

#2: Fusion of Wireless & Networking with AI/ML

Expected expanding scope and emphasis of Wireless-AI/ML fusion over time



Technology Roadmap

Shorter Term: Research hype cycle continues…

- ***Exploring every permutation*** but lead industrial research area continues in Core/Edge Network orchestration/optimization + SON/RRM/MDT

Mid Term: Migration to greater real time controls

- Enabled by standards dev, AI/ML will use small data and migrate towards the middle layers of the stack. Support for near-real time emerging

Longer Term: Deep applications in all layers

- Massive small data-based AI/ML embedded in **All** protocol stack **Layers** and **All** network **nodes**. Fully distributed AI with lifelong learning

Potential for this Trend Line to "Break" 5G

HIGH: Intuitively, making nodes progressively more intelligent than they have ever been before will have an impact on future interface designs perhaps to a point that will challenge traditional principles e.g. AI/ML based solutions may replace conventional model-based Layer 1 design as we move towards 6G

IMPACT: ***New approaches to protocol design*** may result in a transition from hand crafted, specialized protocol solutions to black box ML soln. Long-time cycle standardization moves to short cycle ML model & training-based standardization

#3: Virtualization to Cloud Native Computing

Technology Roadmap

Shorter Term:

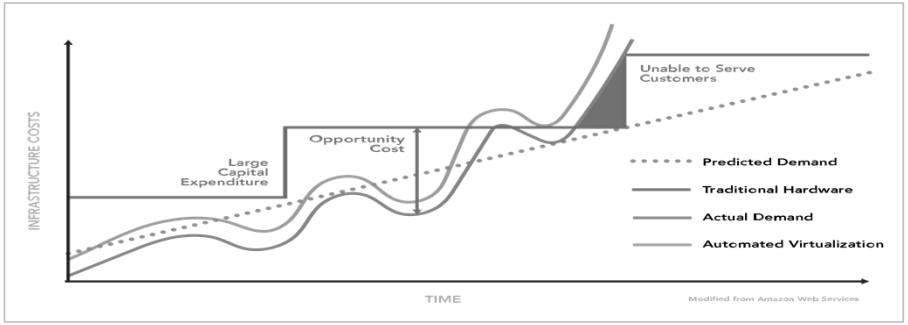
- Continued enhancements in the core and edge to support ever tighter integration and increasing opening of Network Functions to 3rd Party players
- RAN level slicing, Network exposure & Analytics

Mid Term:

- Evolution to a pervasive distributed open edge with Network Functions beginning to look more like application services, with increasing blurring of the lines between Public & Telco/Edge clouds

Longer Term:

- Extreme Cloud-Edge convergence to a huge distributed computing fabric, consuming Core, RAN & Device, progressive decomposition of Network functions into a new on-demand, orchestrated, AI/ML enabled, AaaS model



Potential for this Trend Line to "Break" 5G

HIGH: This roadmap trend is particularly disruptive in terms of factors above and beyond technology and simply, even if the technology challenges are overcome, commercial factors and complex business relationships may limit and push the roadmap evolution into the scope of only 6G

IMPACT: Emergence of new Device and Telco models as we have known them for decades, completing the journey of Telecom to IT and the emergence of new Telco App. Developer industry all innovating over common Restful API