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Industrial Technology
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Taiwan 5G and Beyond 5G Technology, Applications, and Industry Development

Pang-An Ting

ITRI/ICL

2021.10.26

Agenda

- ☞ ITU-R/3GPP B5G/6G Timeline
- ☞ Global B5G/6G Trend
- ☞ 5G Open RAN Opportunities and Taiwan Incubated Solution
- ☞ Taiwan Beyond 5G Initiatives

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2030 6G vision- Taiwan's viewpoint

Ubiquitous Intelligent Connection

- Multi-dimension coverage
- AI-native communication
- Intelligent & pervasive connected infrastructure

Cyber-Physical Converged Society

- Immersive Cyber-Physical interaction
- Digital Twin
- Multi-sensory internet

Source: MOEA 5G Office

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6G use cases

Fully autonomous unmanned vehicle

Real-time medical care

Mobile Telepresence Robots

Extreme Real Immersive experience

Ultra-precision public safety

Full-dimensional wireless coverage

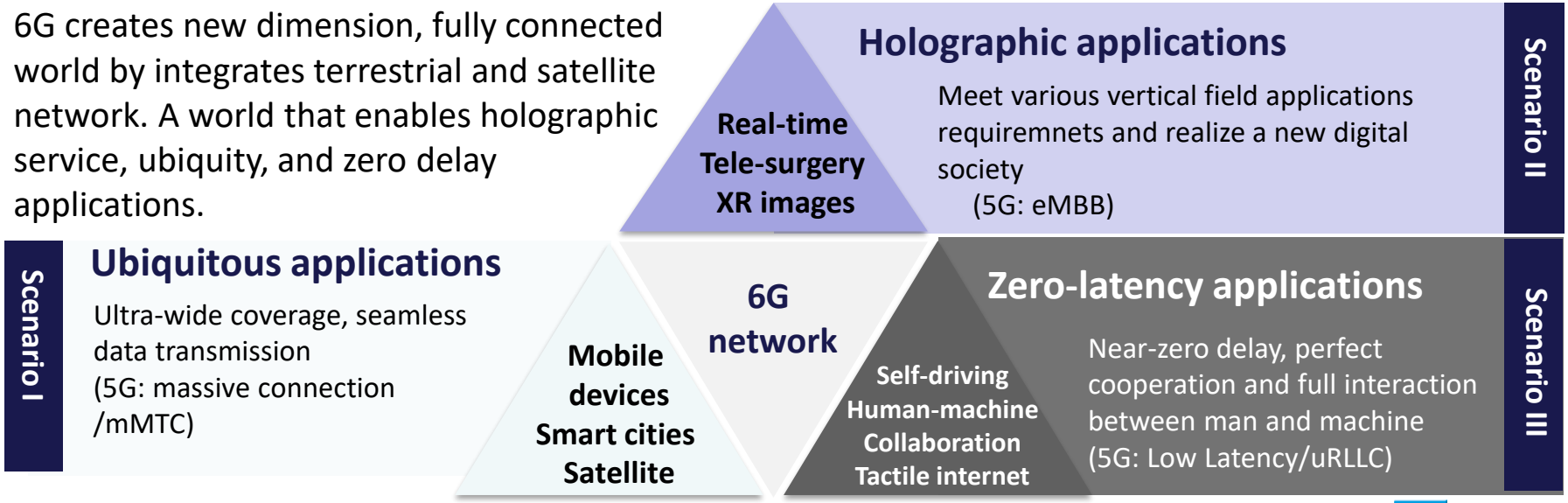
Multi-dimensional sensor big-data IoT

Zero-latency interactive AI

Ultra-precision 3D positioning sensing

6G Application Scenarios

6G creates new dimension, fully connected world by integrates terrestrial and satellite network. A world that enables holographic service, ubiquity, and zero delay applications.



Source: ITRI ITIS, 5G Office

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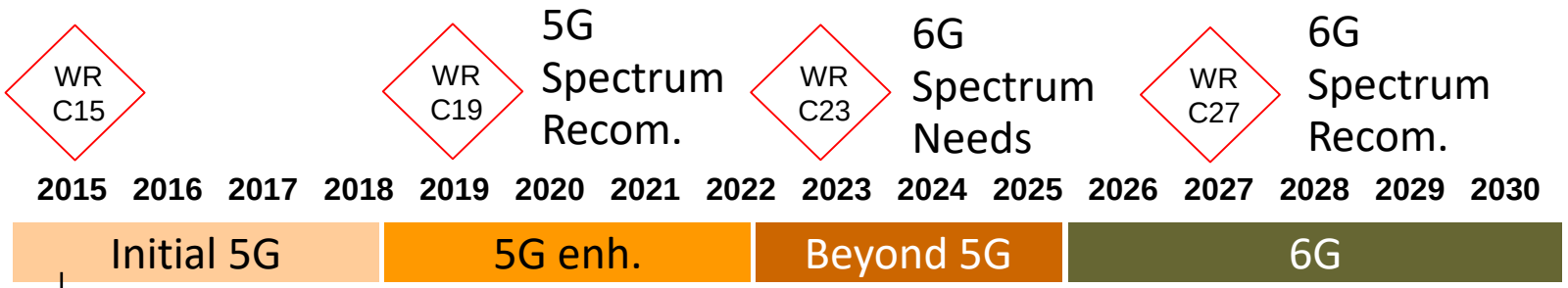
ITU-R/3GPP B5G-6G roadmap

6G standardization kickoff in around 2025-2026, 6G commercial network in 2030



ITU

IMT 2020 Vision

Key requirements for 3 major 5G usage scenarios: eMBB, uRLLC and mmTC

Future Technology Trends

the evolution of IMT through advances in technology and spectrally-efficient *techniques, and their deployment.*

Vision towards 2030

define the use cases, key capabilities, system characteristics and timelines on standardization and commercialization of 6G

3GPP

Source: ITRI ITIS, 3GPP, MIC

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GLOBAL B5G/6G TREND

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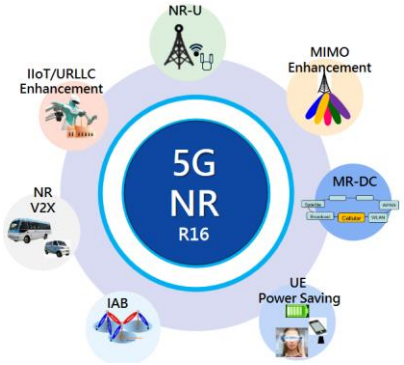
3GPP migrates towards 5G-Advanced

R15 *Extreme mobile broadband*

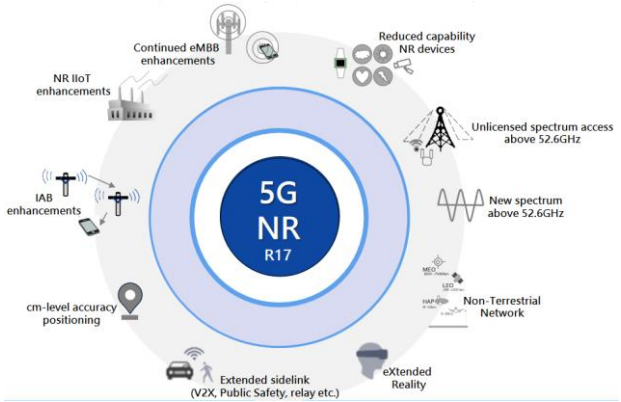
Initial 5G: Flexibility & Forward Compatible

5G NSA 5G SA

R16 *Augmented for Industrial IoT foundation*



Extended 5G: vertical domain expansion



R17 *Augmented for IoT capabilities & segments reqts*

5G-baseline: Continuing evolution and Accelerating 5G expansion

R18 *Augmented for Wider ecosystem expansion*

5G-Advanced: expansion towards energy, transportation, manufacturing, media and medical

2017 2018 2019 2020 2021 2022 2023

R15->R17 keep pushing broadband enhancement and ecosystem expansion

Source: Nokia, 3GPP, MIC

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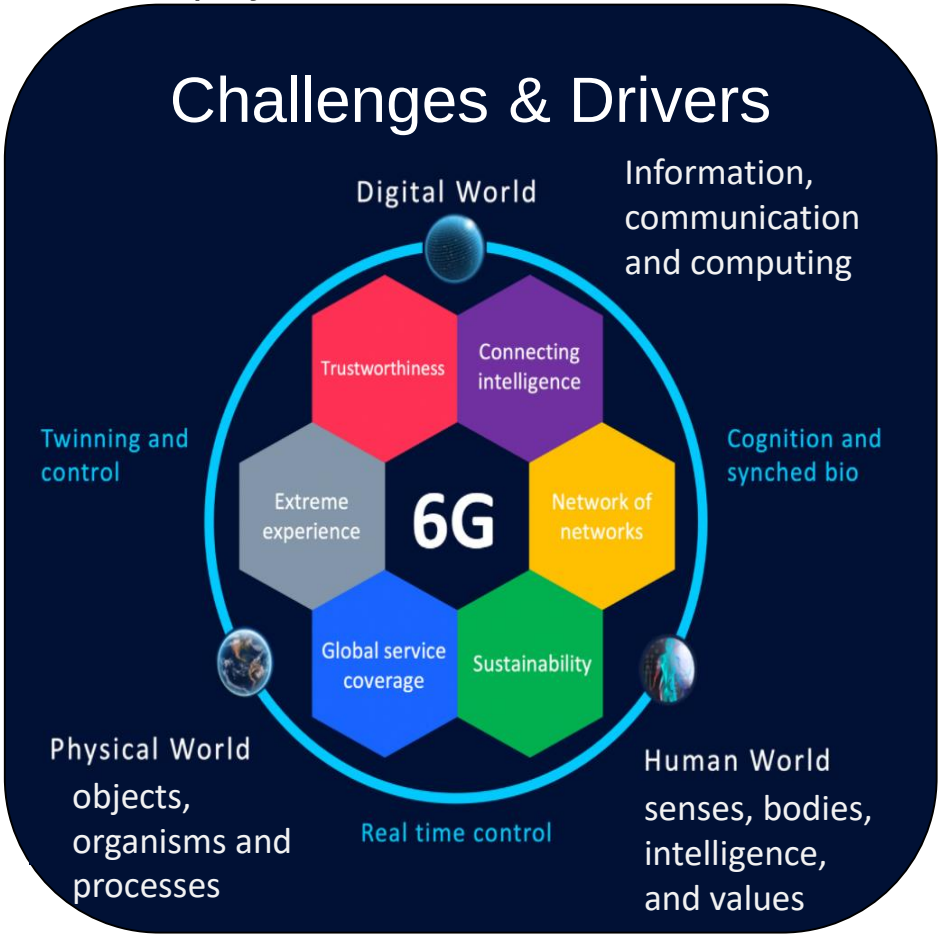
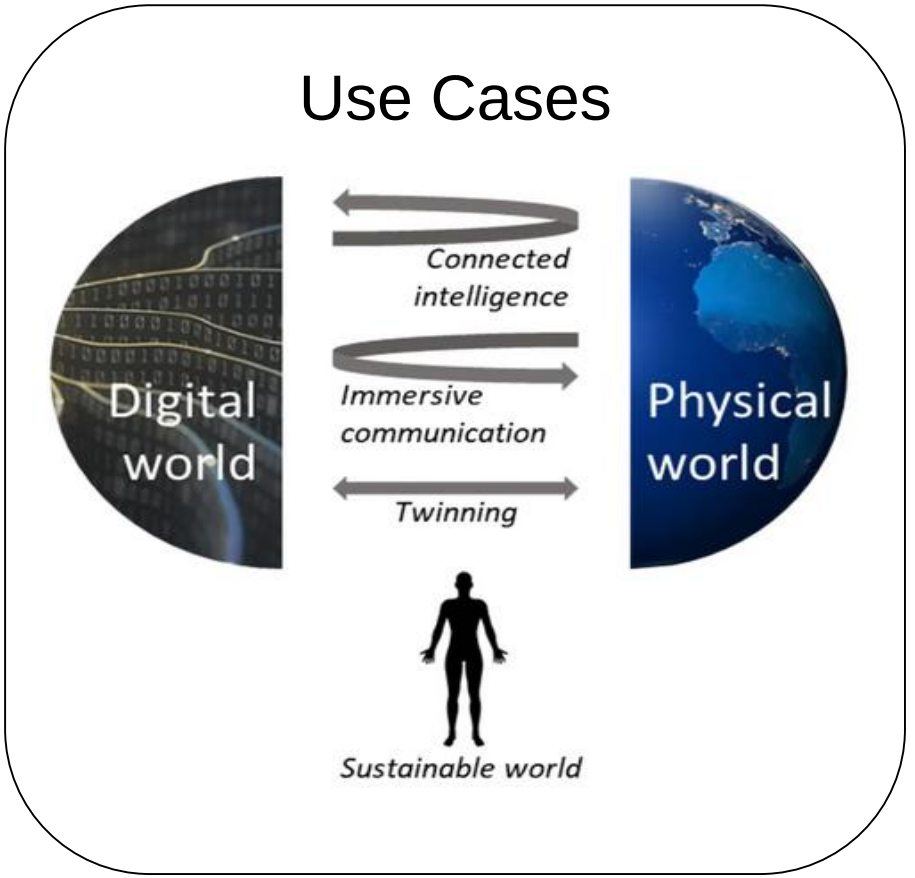
Nokia leads EU 6G Flagship Hexa-X project

- A collaborative initiative to frame 6G research agenda and lay groundwork for a long-term European investment in future wireless network technology
- 2.5 years project @ EU Horizon 2020 ICT-52 program
- 25 players from industries and academia





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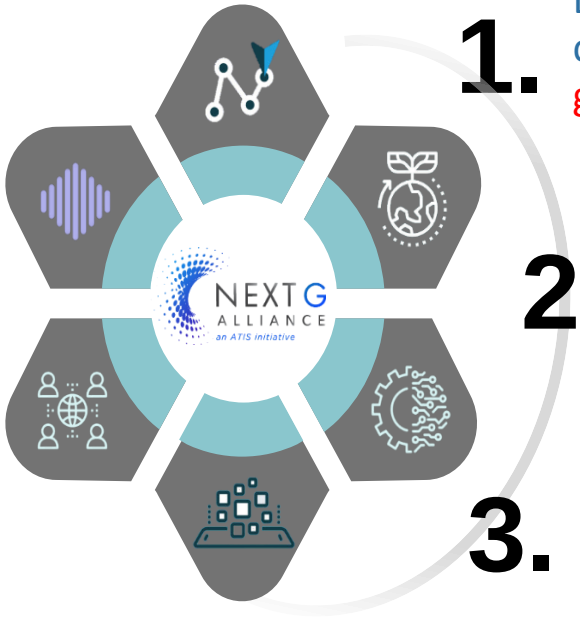
USA Next G Alliance

To advance North American mobile technology leadership



1. Next G National Agenda

Development of a 6G national roadmap that addresses the changing competitive landscape and positions North America as the global leader for Next G technologies

2. Strategic Model for Success

Align the North American technology industry on a core set of priorities that will steer leadership for 6G and beyond to influence government policies and funding

3. Market Leadership

Identify and define the early steps and strategies leading to rapid commercialization and adoption of Next G technologies across new domestic and global markets and business sectors

40

Founding and Full Members

26

Contributing Members

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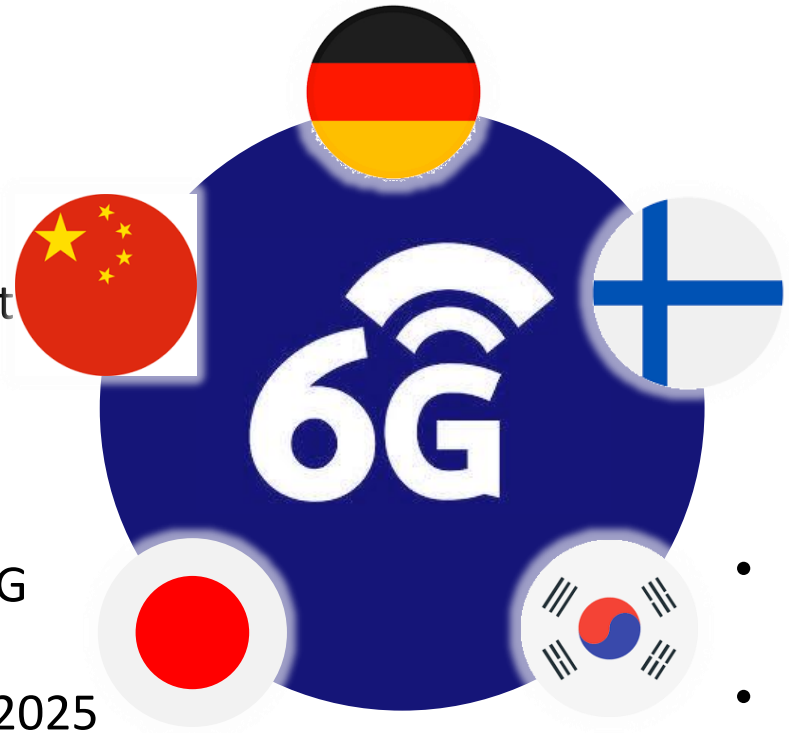
6G initiatives in other areas

- Provide $833M funding for 6G researches till 2025

- IMT-2030(6G) Promotion Group established in 2019
- 6G selected as a top priority in most recent "five-year plan"



- Invest €250M to support 6G flagship project for 8 years from 2019

- Earmark $450M for 6G development in 2020
- 6G showcases at the 2025 Osaka World Expo event

- Launch 6G pilot trail in 2026
- Invest $194M for five years from 2021

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Potential 6G technologies

THz/sub-THz communications and artificial intelligence (AI) Everywhere are 6G potential technologies mostly endorsed by leading manufacturers

6 technical indicators (KPIs)		Ultra coverage	Ultra data rate	Ultra energy saving	Ultra-low latency	Ultra reliable	Ultra precision
Technology		Satellite comm.	THz Comm.	Green Comm.	Massive beamforming	AI	Cm positioning
Equipment Vendors	Ericsson	●	●	●		●	
	Nokia	●	●	●		●	●
	Huawei	●	●		●	●	●
	ZTE	●	●		●	●	●
	Samsung	●	●		●	●	
Operators	CMCC		●	●	●	●	●
	NTT DoCoMo	●	●	●	●	●	●

Source: ITRI ITIS

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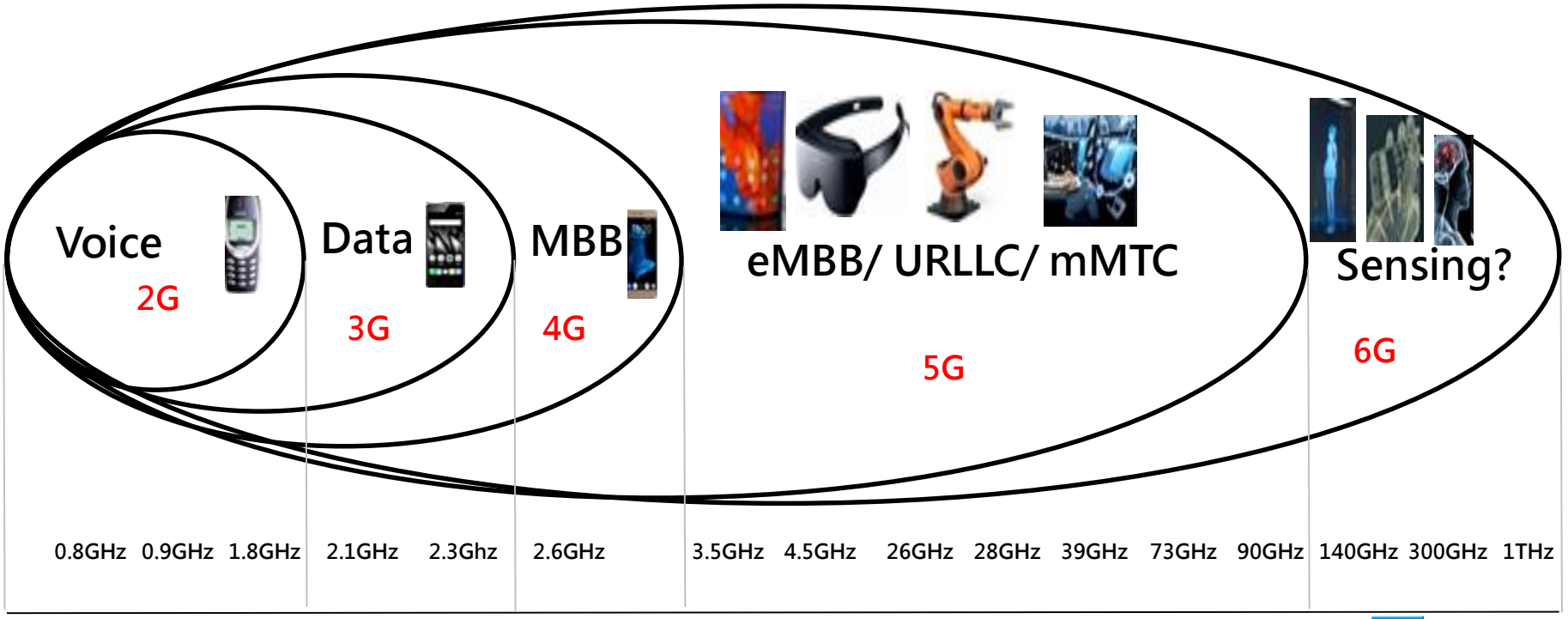
6G spectrum moves towards THz

- 5G is incapable to support ultra-high data rate services like tactile network & hologram
- 6G shall employ higher frequency bands (90GHz~1THz) for future immersive services
- Sub-THz communication is currently the key technology in global B5G/6G R&D spectrum
- Initially, the focus will be on sub-terahertz 100-300 GHz, then gradually move towards THz

Dominant applications and spectrum requirements of various Mobile Generations



Source: ITRI IEK

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6G KPIs - potential technical indicators

- 6G will dramatically improve ability to meet key performance indicators (KPIs) sustaining better future life
- 6G will bring unmanned vehicles, these technical scenarios put forward higher demand for location services

KPI	5G	6G
Peak date rate	20 Gbps	1,000 Gbps
Experienced data rate	0.1 Gbps	20 Gbps
Area traffic capacity	10 Mbps/m^2	10,000 Mbps/m^2
Mobility	500 km/h	1,000 km/h
Reliability	1-10^-5	1-10^-7
Latency	> 1ms	> 0.5ms
Connection density	100^6 / km^2	1,000^7 / km^2
Battery	10 years	20 years
Positioning	> 10 m	cm

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OPEN RAN OPPORTUNITY & TAIWAN INCUBATED SOLUTION

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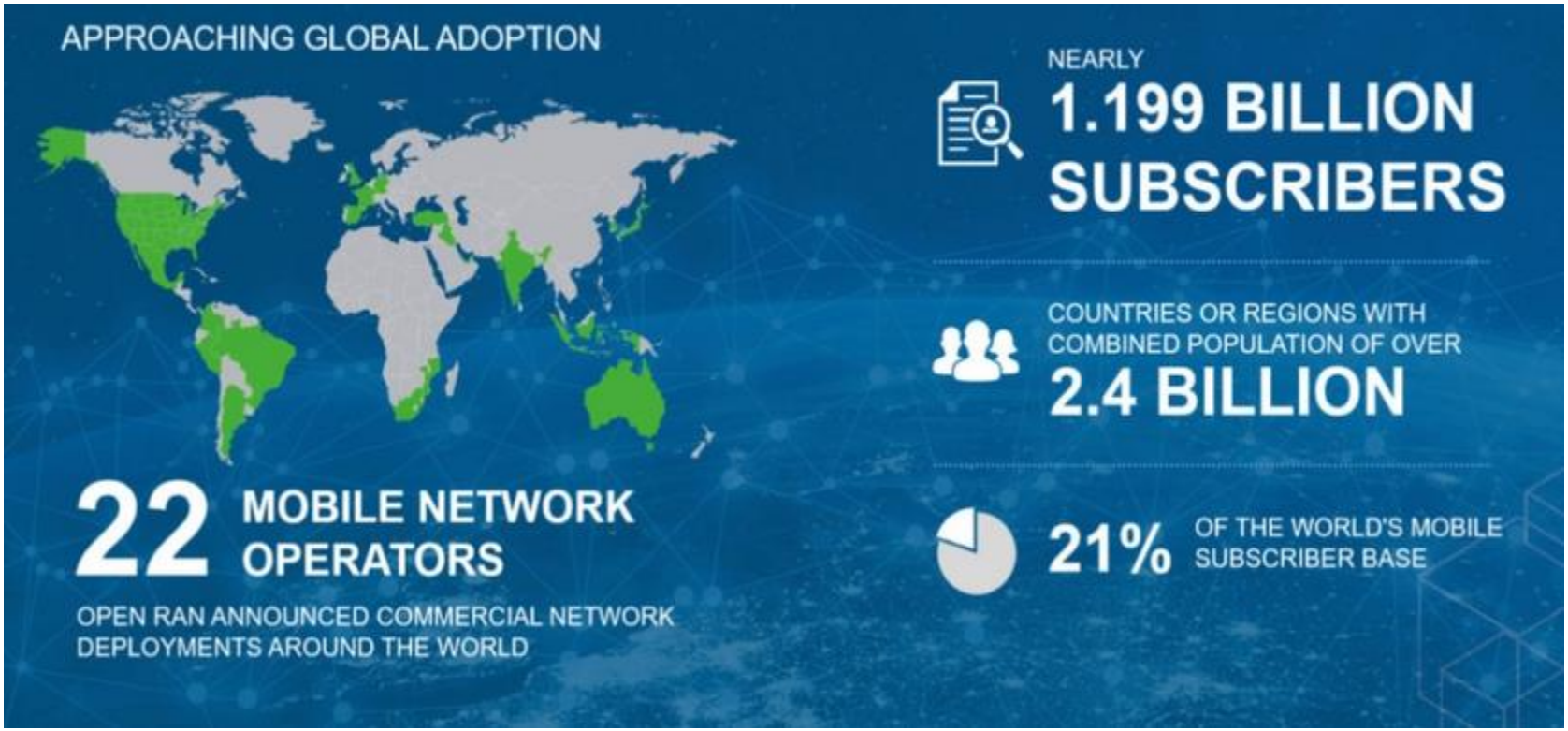
Open RAN by the numbers

- Numerous major MNOs conducted Open RAN trials for service feasibility
- Open RAN SW vendors (e.g. Mavenir, Altiostar, Parallel Wireless) uplifted role playing as solution integrator to enlarge market impact
- Traditional TEMs keep stepping in Open RAN



Source: iGR white paper "OPEN RAN Integration: Run with it "

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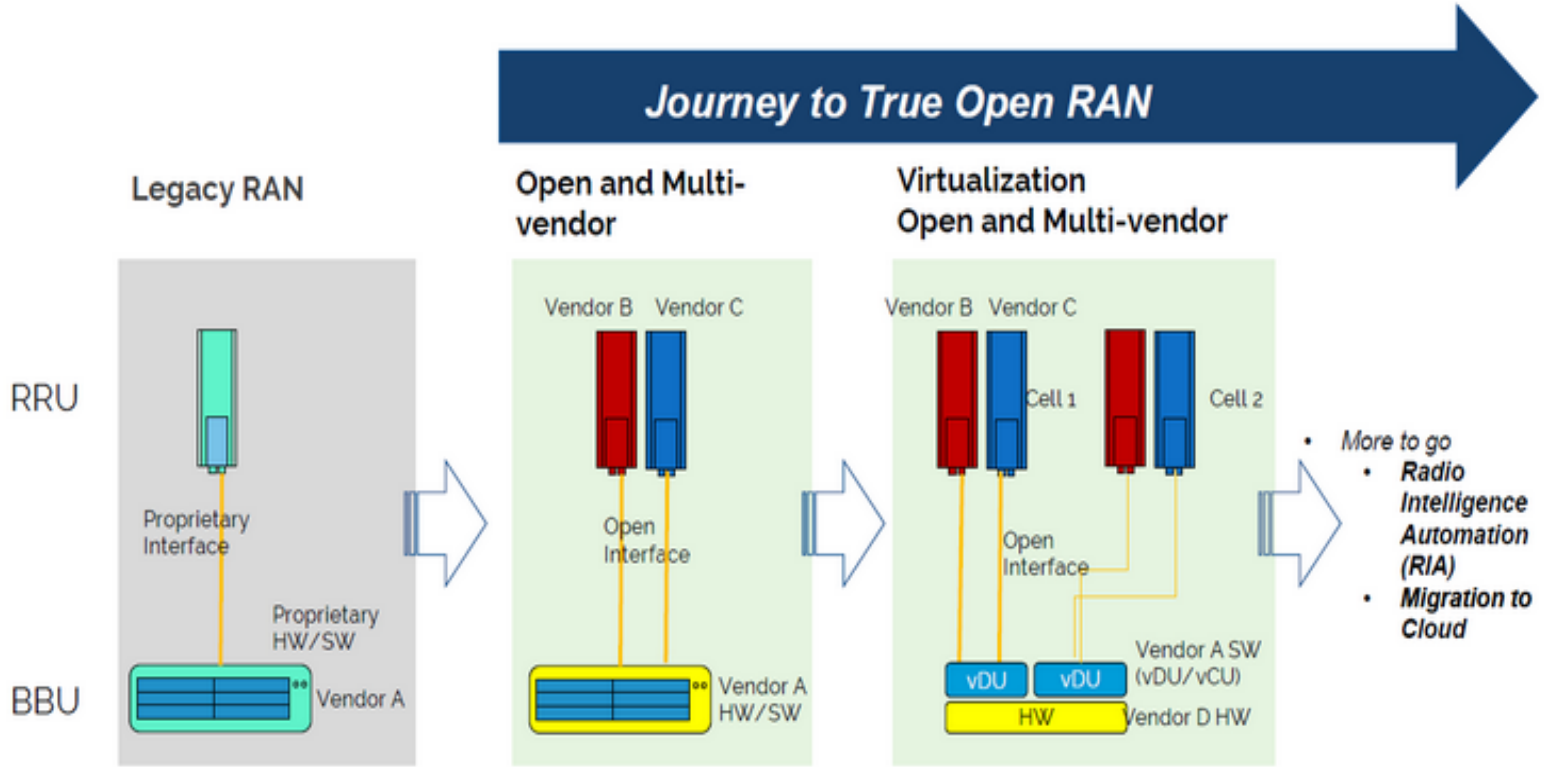
WHY Open RAN?

Brings RAN Architecture towards Disaggregation and Multi-Vendor



Source: comba Technology

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Open RAN is highly endorsed worldwide

Governments

Congress in 2020.11 approving $750 million funding to develop Open RAN technologies

NEC

UK's 5G supply chain diversification strategy (backed by an initial £250 million)

- Accelerate open interface solutions
- establish a SmartRAN Open Network Interoperability Centre (SONIC) for IOT
- NEC has participated UK 5G Open RAN trial program with the NeutrORAN testbed

Earmark €2 billion for Open RAN R&D

Industry (MNOs, TEM,…)

T-Mobile orange vodafone Telefónica

The 'ORAN G4' jointly commit in 2021.1 to Open RAN deployment as part of their 5G plans

- Encourage a competitive European OPEN RAN ecosystem
- Press for government funding to support European Open RAN startups and broader ecosystem

Open RAN POLICY COALITION

58 members consists of key Eco-system stakeholders

to promote policies that will advance the adoption of open and interoperable solutions in the RAN as a means to create innovation, spur competition and expand the supply chain for advanced wireless technologies including 5G

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Taiwan government sponsored 5G R&D projects

Research Institute
5G gNB, 5G Lite Core

Research Institute
5G enterprise solution

MIT 5G enterprise system solution

5G Open RAN
- 3GPP 5G RAN unit
- OA&M, MEC & Field Trials

B5G advanced RAN system R&D program

(2020-2023)

Annual 277M NTD

RU Analog Front End, RU system, DU, CU, 5G Core, 3GPP Standardization

5G+ system & application Trial program

(2020-2023)

Annual 480M to 187M NTD

Mobile Edge Computing, NFVI, 5G Competitive Drone, AI assisted 5G applications, 5G Localization, smart manufacturing & medicare

5G testbed & trial program for Culture innovation

(2021-2024)

Annual 160M NTD

Stadium As A Platform ecosystem, 2 fields: National Theater & Concert Hall, Kaohsiung Exhibition Center

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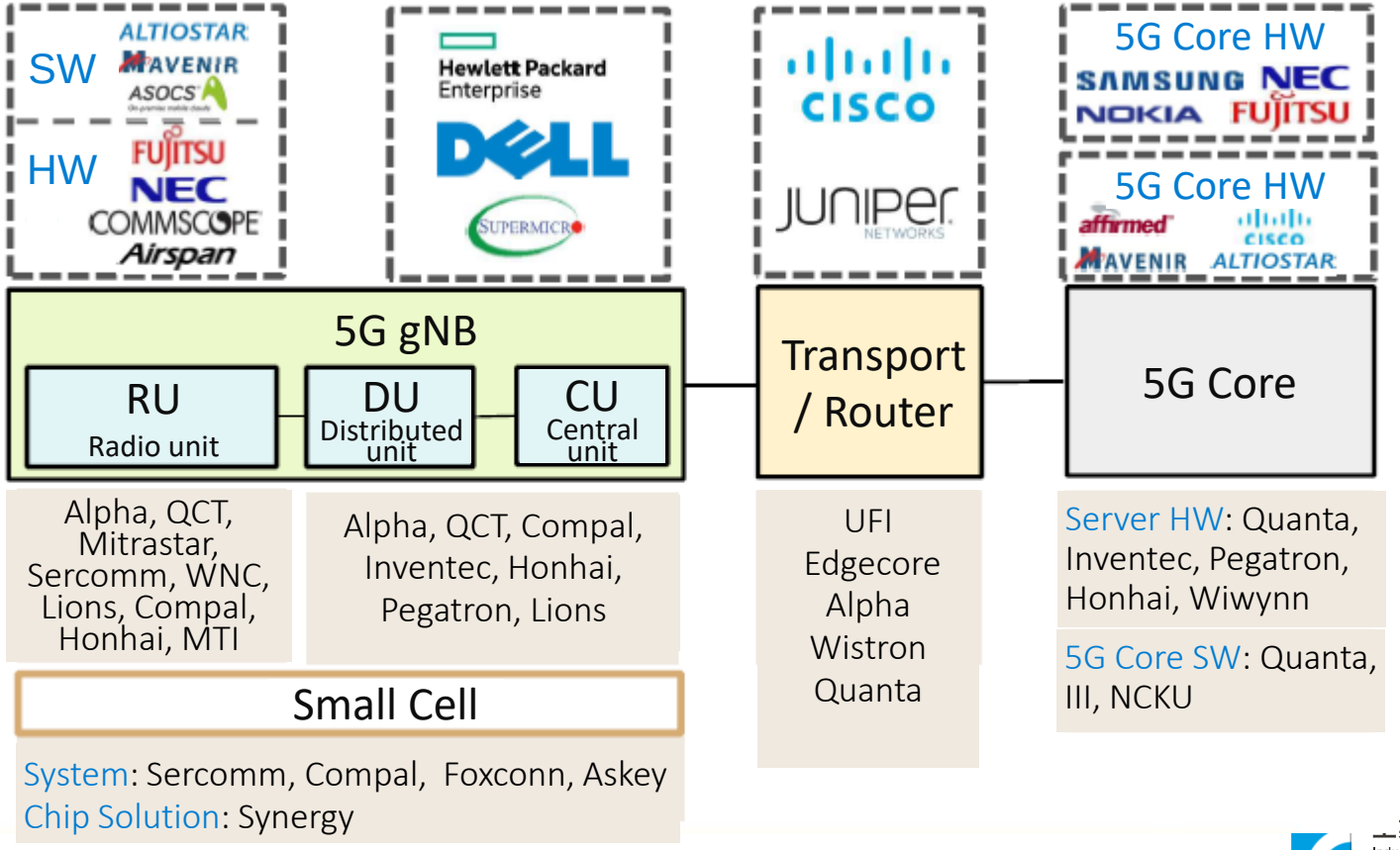
Taiwan engages in global Open RAN ecosystem

- Taiwan established strong foundation in ICT ODM/OEM and white-box servers
- Taiwan has strengthened Open RAN S/W capabilities to come out O-RAN based system solution



5G enterprise trials conducted in Taiwan

Category	cases	SI	Bands(Hz)	RU	DU	CU	Server	Core
Manufacturing	Quanta FAB (IT)	QCT	4.8-4.9G	QCT				
	Inventec FAB (IT)	Wavein	3.7-3.8G	Wavein	Inventec		Dell/Inventec	Microsoft /Affirmed
	CHPT FAB (Semicom)	CHT	3.42-3.51G	Nokia			-	Nokia
	Delta FAB (CT)	FETnet	3.34-3.42G	Ericsson			-	Ericsson
	ASE FAB (Semicom)	CHT	28G	Sercomm (smallcell)			-	Ericsson
Performance & Exhibition	National Theater & Concert Hall	CHT	3.5G, 28G	Nokia			HP/Delta	Nokia
	Kaohsiung Exhibition Center	FHNet	3.5G, 4.8G, 28G	Honhai	Honhai/HTC		Dell	Honhai
Medical	Tri-Service General Hospital	Transnet	4.8-4.9G	Alpha				III
	TPE City Hospital	FHNet	3.7-3.8G	MTI	Honhai		Dell	Honhai
Entertainment	Kaohsiung HTC ViveLand	HTC	4.8-4.9G	Alpha	HTC		QCT	III

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TAIWAN BEYOND 5G INITIATIVES

- RIS (Reconfigurable Intelligent Surface) PoC
- 6G Open Platform PoC
- AI-Native Communication System
- Ultra-high Frequency Power Amplifier
- LEO Communication

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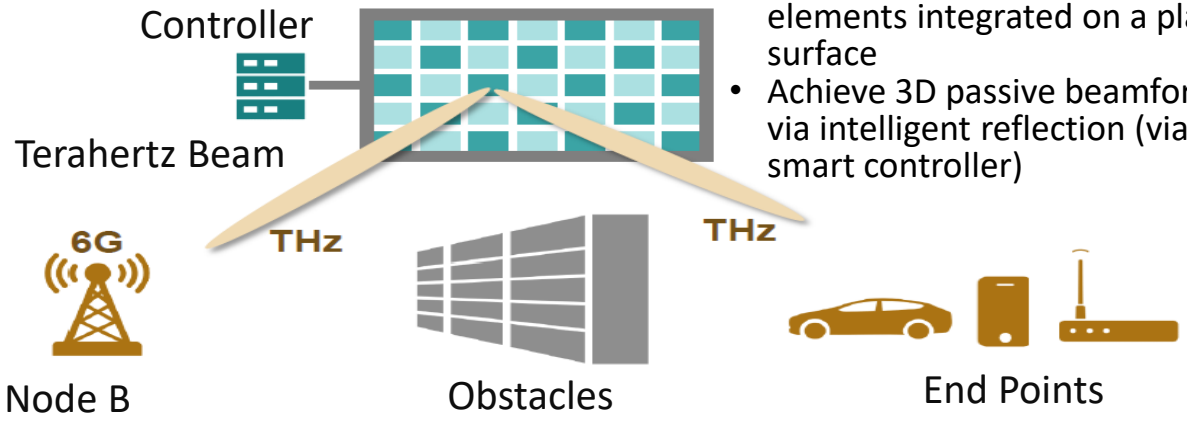
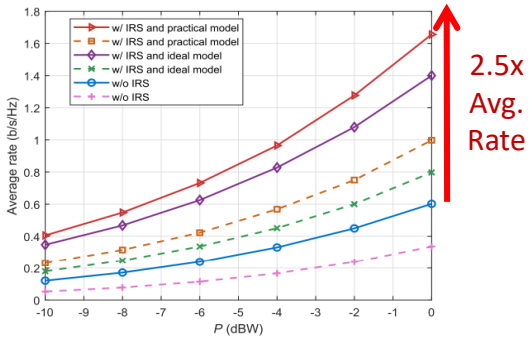
RIS for B5G/6G system



- Massive low-cost reflecting elements integrated on a planar surface
- Achieve 3D passive beamforming via intelligent reflection (via a smart controller)



An RIS-aided OFDM Communication System.

- RIS (Reconfigurable Intelligent Surface) or IRS (Intelligent Reflective Surface) is regarded as a revolution technology to improve wireless spectrum and energy efficiency
- Advantages
  - Enhancing coverage in communications systems
  - Enhancing network transmission rate
  - Enabling customization of radio propagation environments
- Challenges
  - IRS hardware design and implementation
  - Joint active and passive beamforming design for more general setups
  - Performance analysis under hardware/channel imperfections
  - Channel acquisition in IRS-aided wireless networks
  - IRS deployment, autonomous operation via machine learning

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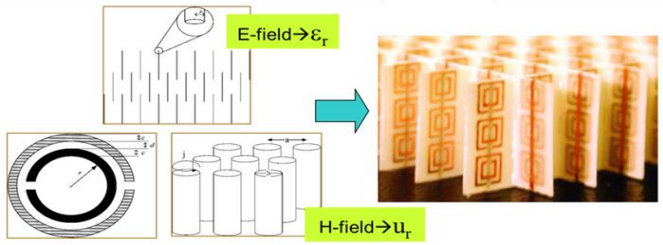
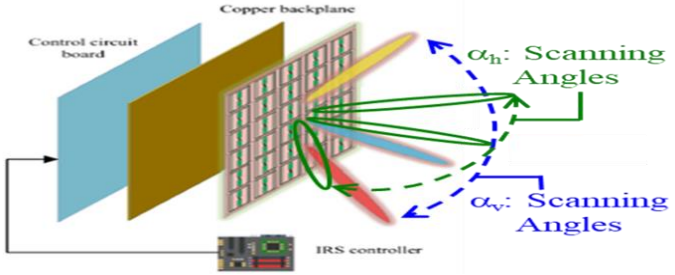
Wide-Scanning RIS PoC

Develop a specific reflection-type metamaterial surface

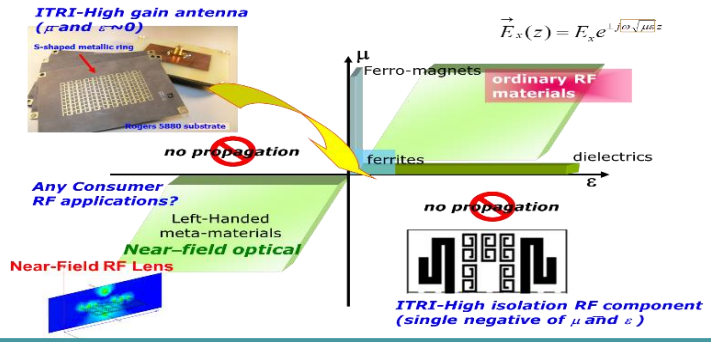
RIS module design

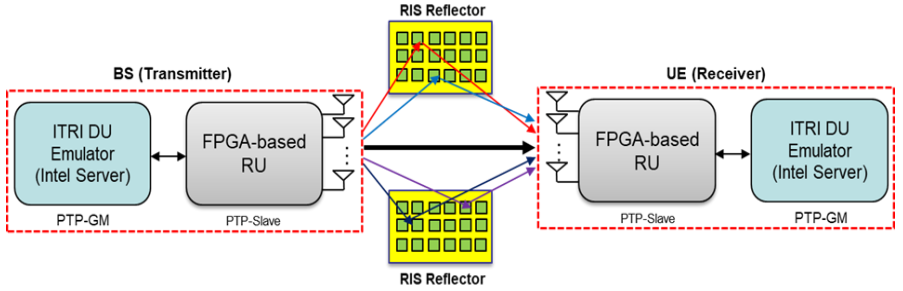
RIS System PoC





Metamaterial theory shows that negative e_r and m_r could be successfully created by properly designing artificial periodical structures *1





*1 Source: R. A. Shelby ,D. R. Smith and S. Schultz, “Experimental Verification of a Negative Index of Refraction”, Science, 2001

2022

- 6G RIS system level simulator
  - RIS network deployment topology formation
  - RIS simulation model & FR3 Channel Modeling
- RIS Design & SLS
  - RIS Prototype Design and Verification
  - Performance Simulation for RIS-oriented System
  - Probing RIS-related Parameters

2023

- Sub-THz system level simulator
  - Sub-THz channel modeling
  - High density RIS deployment
  - Huge multi-path transmission and channel interference
- RIS System Emulation
  - Wide-Scanning RIS and Controlling Module Design
  - Emulation with RIS-based PoC
  - RIS-oriented Demo System

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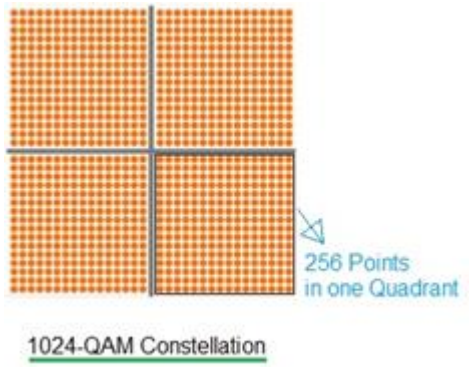
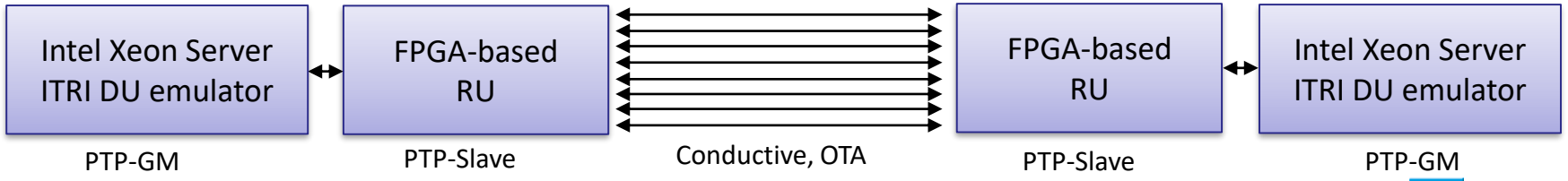
6G Open RAN exploration & PoC

- 6G open platform PoC test environment
  - x86 Commercial Off-The-Shelf (COTS) Architecture
  - Support O-RAN 7-2x Intra-PHY splitting
- Intel Xeon server based DU emulator + 100GbE NIC
  - 5G-extended PHY signal generation, detection
  - Real time 100GbE high speed front-haul
  - Compliant to O-RAN interface
- FPGA-based, high bandwidth, high layer number RU
  - Carrier Frequency: FR1/FR3 7GHz~14GHz, FR1@FY111, FR3@ FY112
  - Support 8T8R, 1024QAM, EVM < 1.8%
  - 200MHz bandwidth@FY111, 400MHz @FY112

4x-5x PHY Throughput @ FY111
8x-10x PHY Throughput @ FY112





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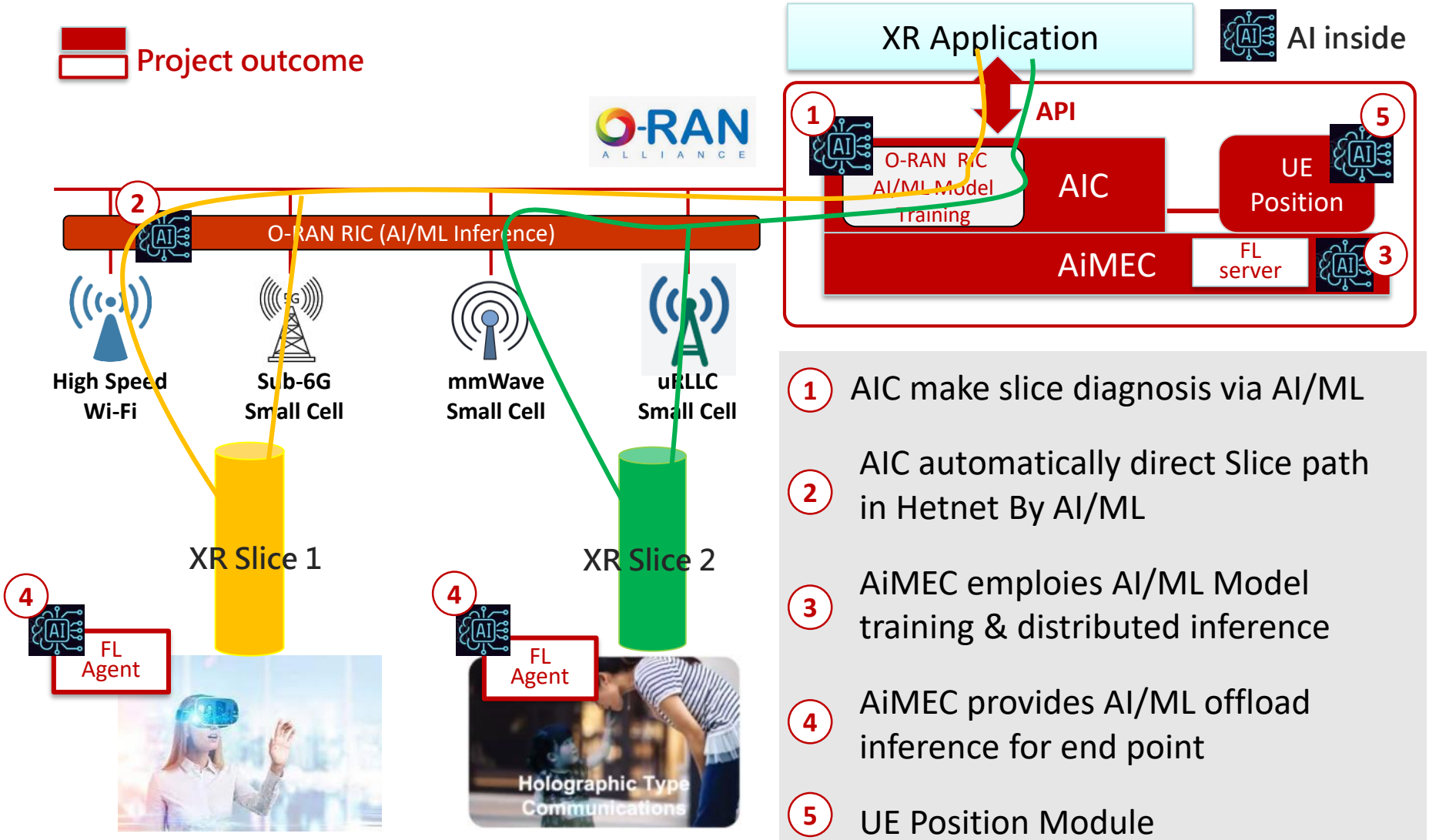
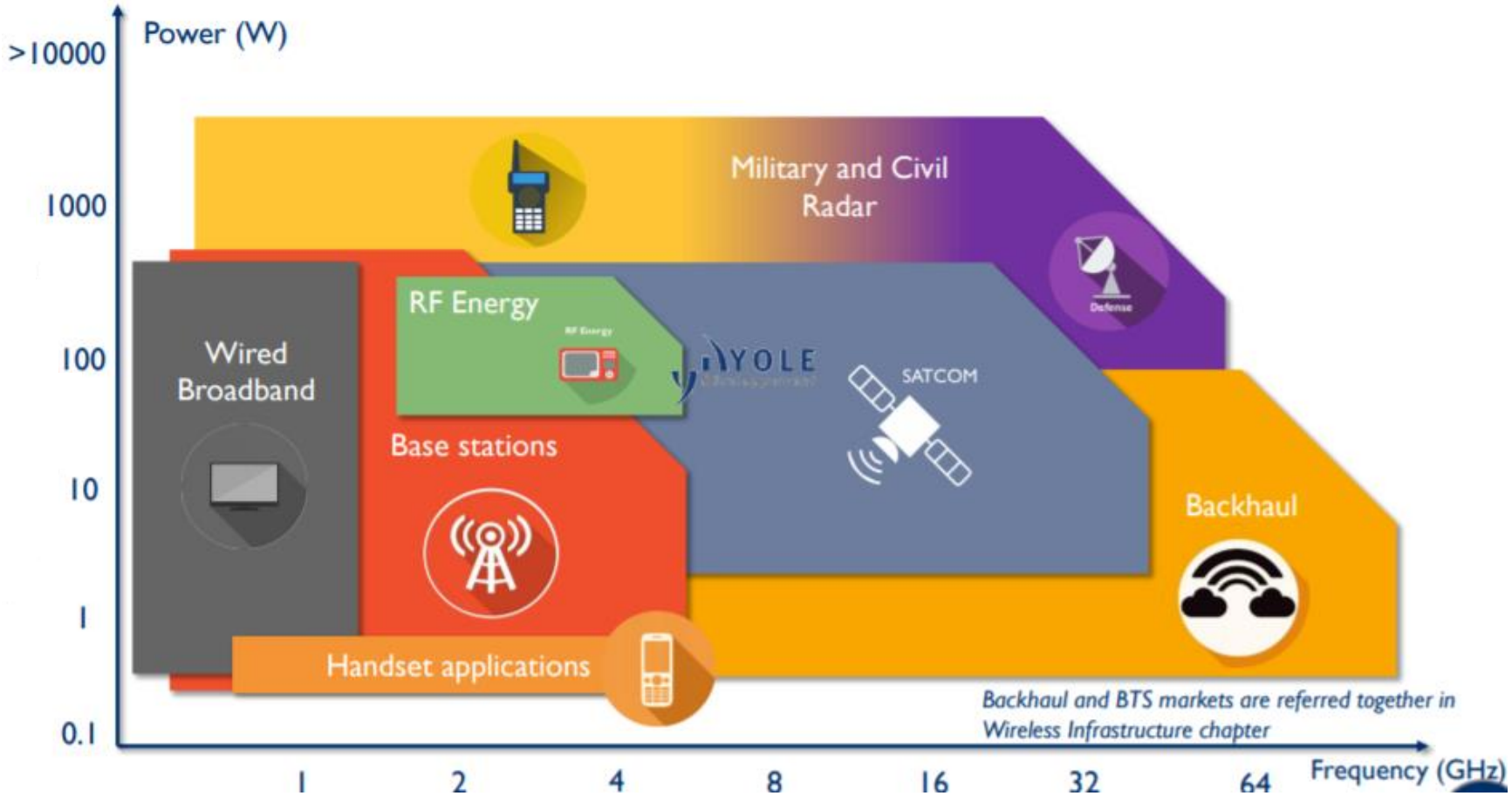
Planning for AI-Native Communication System



1. AIC make slice diagnosis via AI/ML
2. AIC automatically direct Slice path in Hetnet By AI/ML
3. AiMEC emploies AI/ML Model training & distributed inference
4. AiMEC provides AI/ML offload inference for end point
5. UE Position Module

RF GaN Market Segmentation

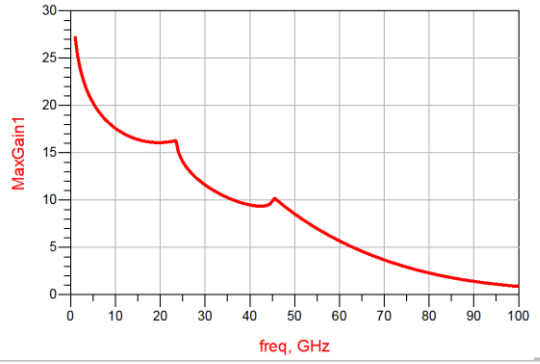
- GaN presence in RF market is more focused on high power, high frequency market.



UHF PA Key challenges & innovative breakthrough

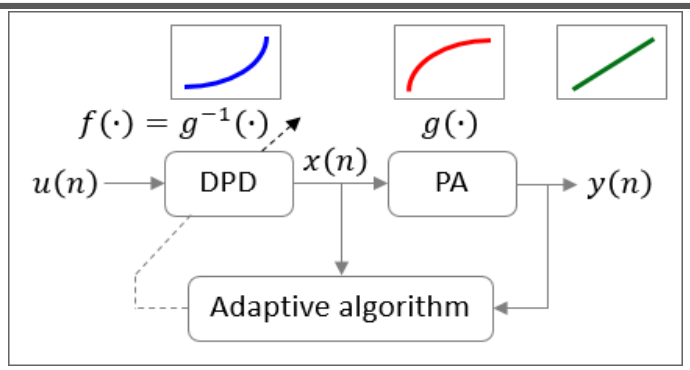
H-Freq. H-Power PA

PA gain drops dramatically along higher bands



1GHz BW DPD

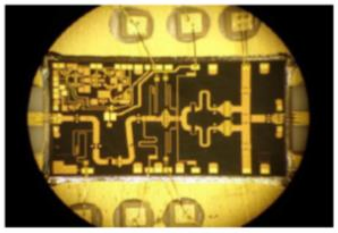
Ultra sampling rate & deep memory effect



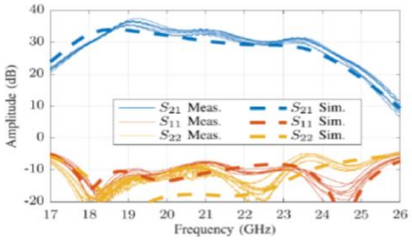
Breakthroughs

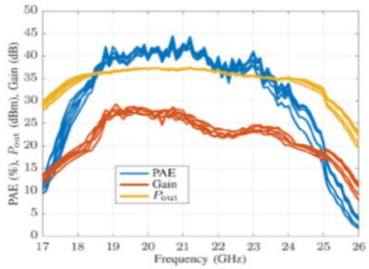
- Utilize GaN process advantages in UHG
- Employ multi-layer PA arch. to improve gain and output power
- Invent low sampling DPD technology to mitigate AD/DA sampling effect
- Low complexity DPD algorithm to mitigate memory effect

Example: K-band 4W GaN Power Amplifier



- Process: 0.25um GaN
- Topology: Direct-combining
- Frequency: 18.5-24 GHz
- Gain: 25dB
- P_{sat}: 35dBm, 40% PAE





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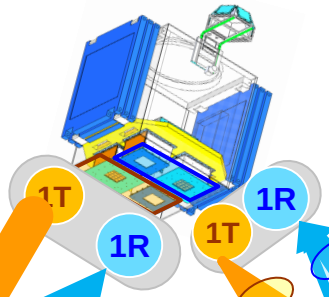
Ka band Feeder Link & Access Link

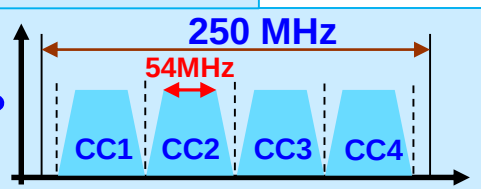
Network Architecture

Feeder Link

- ✓ Beam separated in space ➔ same band as access link used;
- ✓ Symmetric feeder and access traffic ➔ same data rate as access link planned

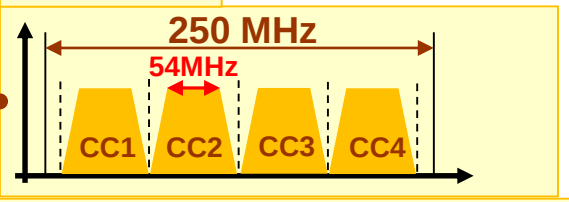


UL: Payload Rx **Ka-band (27.5-30 GHz)**



UL: total average 600Mbps (each CC 150Mbps)

DL: Payload Tx **Ka-band (17.7-20.2 GHz)**

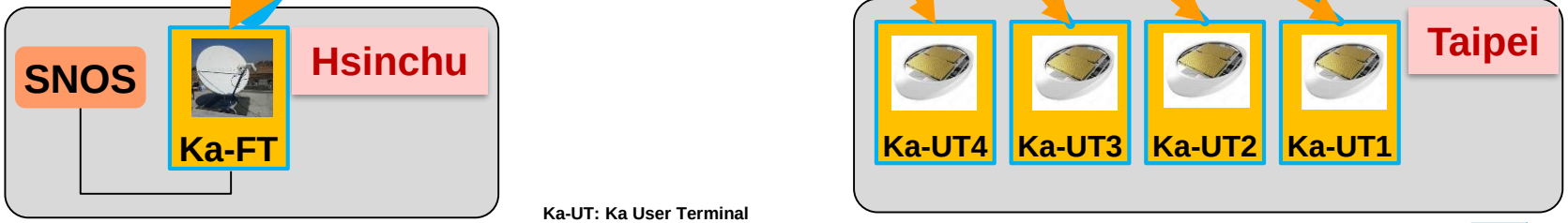


DL: total average 600Mbps (each CC 150Mbps)

Access Link

CC4 CC3 CC2 CC1

CC4 CC3 CC2 CC1



Larger Antenna (Dish) + Larger Modem

Ka-UT: Ka User Terminal
Ka-FT: Ka Feeder Terminal
SNOS: satellite network operating system
CC: Component Carrier

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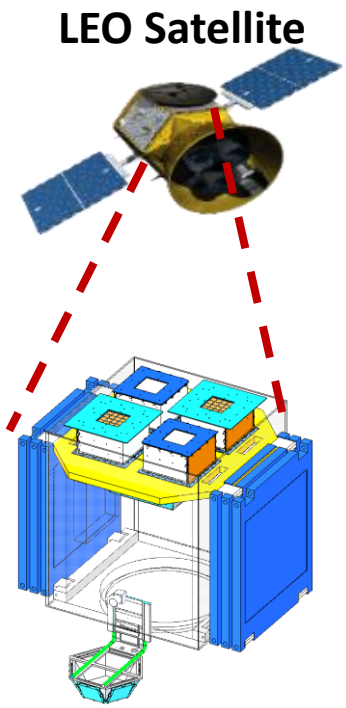
Ka band Feeder Link & Access Link
Payload (PL) Specification

- PL 2T2R: In payload, 1T1R for feeder link and 1T1R for access link
  - Both 1T1R in Ka-band (Feeder link and Access link) has the same PL specification as follows



(1) Per TX specification

Higher TX EIRP reduces ground terminal's requirement, ex: antenna aperture size. It also benefits MSS services, i.e. no EPFD limit.

Parameter	Telesat	Kuiper	SpaceX	ITRI	
Frequency	18.5	18.5	13.5	18.5	GHz
Bandwidth	0.25	NA	0.25	0.25*	GHz
EIRP	36	43.1	36.7	47.5 (0^o) 44.5 (52.5^o)	dBW
Power	NA	NA	NA	<500	W
Weight	NA	NA	NA	< 16	Kg
Data Rate	558.7	NA	674.3	ave.: 600 peak: 800	Mbps

*Power/Weight contains digital processing units

(2) Per RX specification

Parameter	Telesat	Kuiper	SpaceX	ITRI	
Frequency	28.5	28.5	28.5	28.5	GHz
Bandwidth	2.1	NA	0.5	0.25*	GHz
Rx antenna gain	31.8	40.7	40.9	39 (0^o), 36 (52.5^o)	dBi
Power	NA	NA	NA	<250	W
Weight	NA	NA	NA	<14	Kg
Data Rate	NA	NA	NA	ave.: 600 peak: 800	Mbps

*Power/Weight contains digital processing units

*ITRI build18/28GHz IC for lower power consumption

*: includes channelization and guard band (total effective bandwidth is 216MHz)

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Ka band Feeder Link & Access Link

User Terminal (Ka-UT) & Feeder Terminal (Ka-FT) Specification

- Ka-UT (Access link) uses 1CC for UL & 1 CC or 2 CC for DL
  - For TX specification in Ka-UT, 1CC is considered
  - For RX specification in Ka-UT, 2CC is considered

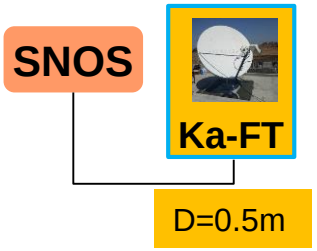
(1) Per TX specification

Parameter	SpaceX	ITRI	
Frequency	14.25	28.5	GHz
Bandwidth	NA	0.0625*	GHz
EIRP	38.2	43.5 (peak)	dBW
Data Rate	NA	ave.: 150 peak: 200	Mbps

(2) Per RX specification

Parameter	SpaceX	ITRI	
Frequency	11.8	18.5	GHz
Bandwidth	NA	0.125**	GHz
Rx antenna gain	33.2	32 (peak)	dBi
Data Rate	NA	ave.: 300 peak: 400	Mbps

- Ka-FT connects with SNOS for supporting network operation
- Ka-FT (Feeder link) uses 4CC for UL & 4CC for DL
  - Dish antenna for Ka-FT TX/RX with 4CC are outsourcing
  - Modem for Ka-FT TX/RX with 4CC are developed by ITRI



Dish antenna outsourcing

(1) Per TX specification

Parameter	SpaceX	ITRI	
Frequency	NA	28.5	GHz
Bandwidth	NA	0.25***	GHz
EIRP	NA	48 (peak)	dBW
Data Rate	NA	ave.: 600 peak: 800	Mbps

(2) Per RX specification

Parameter	SpaceX	ITRI	
Frequency	NA	18.5	GHz
Bandwidth	NA	0.25***	GHz
Rx antenna gain	NA	37 (peak)	dBi
Data Rate	NA	ave.: 600 peak: 800	Mbps

*: includes channelization and guard band (total effective bandwidth is 54MHz)
**: includes channelization and guard band (total effective bandwidth is 108MHz)
***: includes channelization and guard band (total effective bandwidth is 216MHz)

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Summary

- 5G-Advanced specification (i.e. 3GPP R18) is expected to be launched in the middle of 2022. The 6G research project is expected to be launched in 2023 and may starts 6G technical specifications in 2025.
- Taiwan has strong Open-RAN ecosystem and also dedicate our R&D to embrace the open-architecture evolution, we have established strong leadership in base station, network management system and mmWave/UHF frontend and array antenna module technology.
- For 6G exploration and proof of concept projects, initially Taiwan will focus on the research for Reconfigurable Intelligent Surfaces (RIS), open platform for 6G computing, AI-Native network management, UHF power amplifiers and LEO communication.

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