5G 테스트베드 기술 교육 (v2.1)

2022년 3월
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I. 5G EN-DC Architecture

EN-DC stands for 'E-UTRAN New Radio – Dual Connectivity'

- 5G 기술 발전과 EN-DC 아키텍처
- 5G 네트워크 구성 기술 요소

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I. 5G EN-DC ARCHITECTURE

❖ Open Software. Commodity Hardware. Cloud-Native Architecture. (FreedomFi)

- Radio agnostic network core. Tested with most small cells. Single appliance aggregates up to 3 radios.
- Support for 4G LTE, 5G or Wi-Fi in a single appliance.
- Software based and open source. Buy our pre-tested appliance or contact us to deploy on a platform of your choice.

FREEDOMFI

Source: https://freedomfi.com/?fbclid=IwAR3NgJn4nbX-8NdVeSKrE5wPtQp-XdMaMmqlKrPEpEoxkWuvGQv2h5pplyA

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I. 5G EN-DC ARCHITECTURE

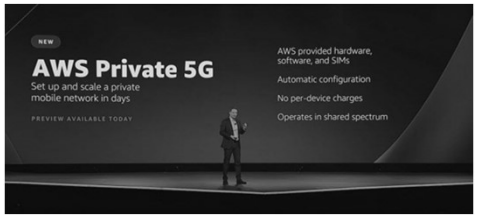
❖ AWS Private 5G 서비스 (2022)

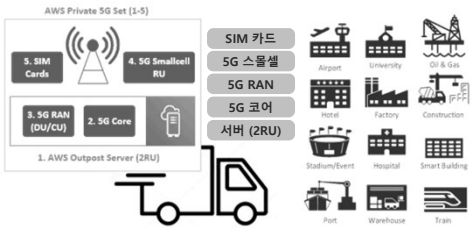
- **AWS가 신청 기업으로 AWS Private 5G망 세트를 배송 (3개의 선택 옵션 제공)**

1) 5G망 Full Set를 기업내에 설치
2) 5G 코어 UPF는 기업내, Control Plane(AMF, SMF,...)은 AWS 클라우드(Region 또는 Local Zone)
3) 기업내에는 RU만 두고 나머지는 모두 AWS 클라우드에 두는 경우.

5G 소프트웨어를 AWS outpost/Local zone/Region에 올려 테스트한 기술 파트너 벤더

- Ericsson,
- Nokia,
- Cisco,
- Mavenir,
- Altiostar,
- Samsung,
- Athonet,
- Celona,
- Druid,
- JMA Wireless 등





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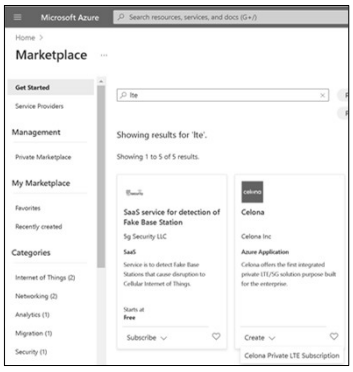
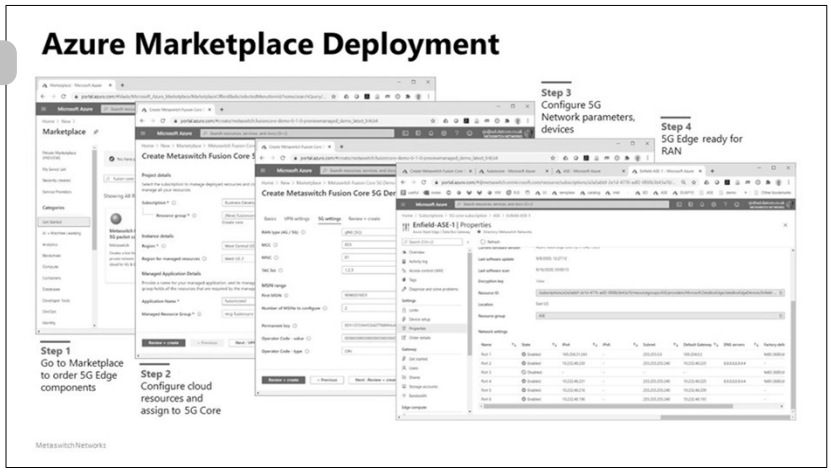
I. 5G EN-DC ARCHITECTURE

❖ Fusion Core - 5G Packet Core @ Azure Marketplace

Azure 마켓플레이스에서 5G or LTE코어 다운로드 적용





Source: https://azuremarketplace.microsoft.com/ko-kr/marketplace/apps/metaswitch.fusioncore_0-1-0?tab=Overview

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I. 5G EN-DC ARCHITECTURE

❖ **Microsoft claims it's making progress assembling a more expansive telco cloud stack for operators six months after it inhaled AT&T's Network Cloud technology via acquisition.**

- **Azure for Operators, now combined with the crown jewels of AT&T's seven-year effort in SDN and network virtualization, includes more than 60 cloud-native network functions (CNF) and virtual network functions (VNF) from 15 vendors, Microsoft's VP of 5G strategy Shawn Hakl explained in a blog post.**
- **AT&T in selling its technology to Microsoft also announced plans to move its 5G network core, workloads, and services to Microsoft's Azure for Operators platform.**

AT&T의 통신사를 위한 Telco Cloud Stack 제공

Matt Kapko | Senior Editor, January 7, 2022 8:00 PM

Source: https://www.sdxcentral.com/articles/news/microsoft-teases-5g-cloud-core-progress-post-att-deal/2022/01/

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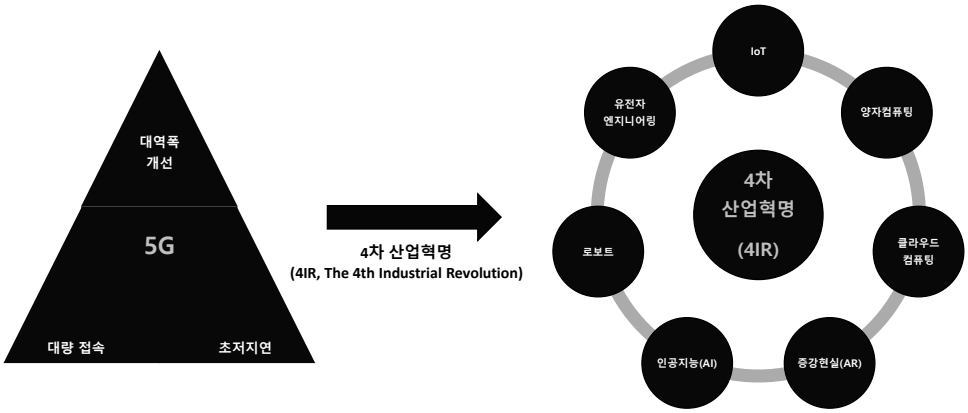
I. 5G EN-DC ARCHITECTURE

❖ 5G Enablers 4IR

• Steam (1차 산업혁명)→ Assembly Line (2차 산업혁명) → Digital (3차 산업혁명) --> 4IR



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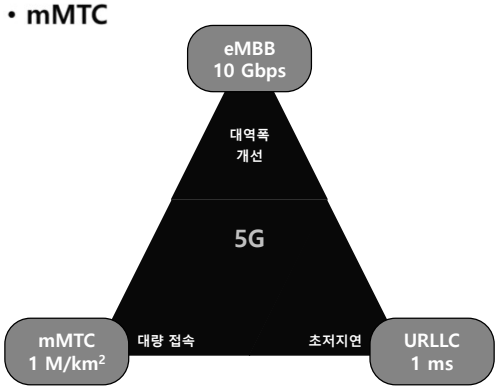
I. 5G EN-DC ARCHITECTURE

❖ 5G Enablers 4IR

- eMBB
- URLLC
- mMTC



Generation	Maximum Download Speed	Typical Download Speed
2G	100 to 300 Kbps	<100 to 100 Kbps
3G	0.3 to 42 Mbps	0.1 to 8 Mbps
4G	150 to 979 Mbps	15 to 90 Mbps
5G	1 to 10 Gbps	150 to 200 Mbps
6G*	8 Tbps	Unknown

*not defined nor deployed; this is estimated data download speed.

eMBB (enhanced Mobile Broadband)**; URLLC** (Ultra Reliable Low Latency Communications)**; mMTC** (massive Machine Type Communications)

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I. 5G EN-DC ARCHITECTURE

❖ 5G 네트워크 설계의 발전 방향 고려

무선 스펙트럼:
무선 토폴로지와 셀사이트 관리의 효과와 효율을 위한 투자

클라우드 인프라:
모듈화와 가상 네트워크 기능 지원

AI/ML:
네트워크 복잡성을 관리하고, 필요시 행동을 취함

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I. 5G EN-DC ARCHITECTURE

❖ Enabling 5G Enabled Digital Transformation (출처: Capgemini)

We drive **Intelligent Industry** across the business...

- Consultative services
- Systems integration & verification of network and applications
- Deployment services
- Maintenance & operations
- Monitor performance & adherence to KPIs

IT

INFORMATION TECHNOLOGY
Enterprise IT services
정보

- Application development and integration
- Data architecture and rationalisation
- IT integration services
- Cloud and edge deployment services
- DevOps maintenance and updates
- Third party partner management

OT

OPERATIONAL TECHNOLOGY
Industry business solutions
산업

- Business case and plan
- Operational req. definition
- Operational scenarios vetting and verification
- Operational design
- Enterprise app. modernisation

NT

NETWORK TECHNOLOGY
Communications solutions, Comms ER&D
통신

- Network req. definition
- Functional, non-functional requirements verification
- Traditional NEP, CSP R&D
- Comms aware apps design
- Network & operations design
- Network operations services

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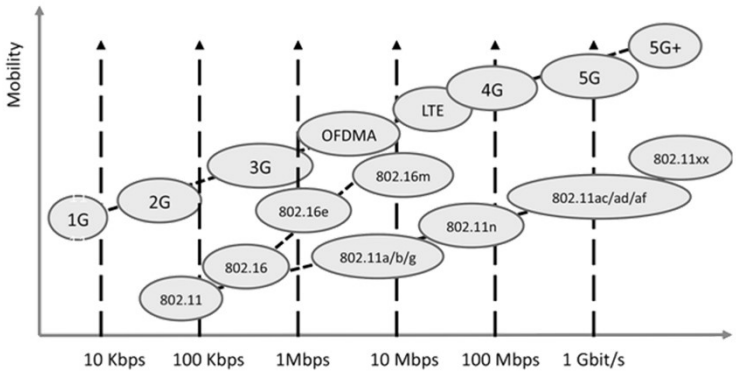
I. 5G EN-DC ARCHITECTURE

❖ 무선 네트워크의 발전 (Wi-Fi 와 5G)

- **The different generations of wireless networks**



Source: Software Networks (Virtualization, SDN, 5G and Security), by ISTE Press Ltd and John Wiley & Sons, Inc. 2020

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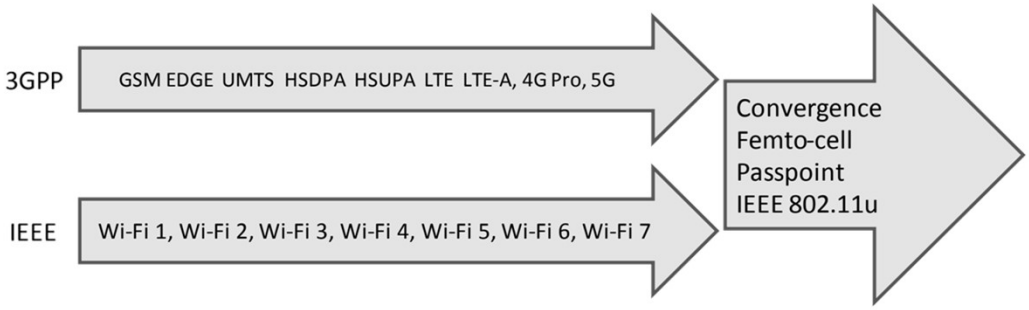
I. 5G EN-DC ARCHITECTURE

❖ 무선 기술 융합 (Wi-Fi 와 5G)

- The two major wireless solutions and their convergence
- 이기종 네트워크간 심리스 핸드오버 기술 표준화
- 노트북이나 스마트폰 등 통신 기기들이 무선랜 등에 연결 할 수 있는 IEEE 802.11의 기술 표준



Source: Software Networks (Virtualization, SDN, 5G and Security), by ISTE Press Ltd and John Wiley & Sons, Inc. 2020

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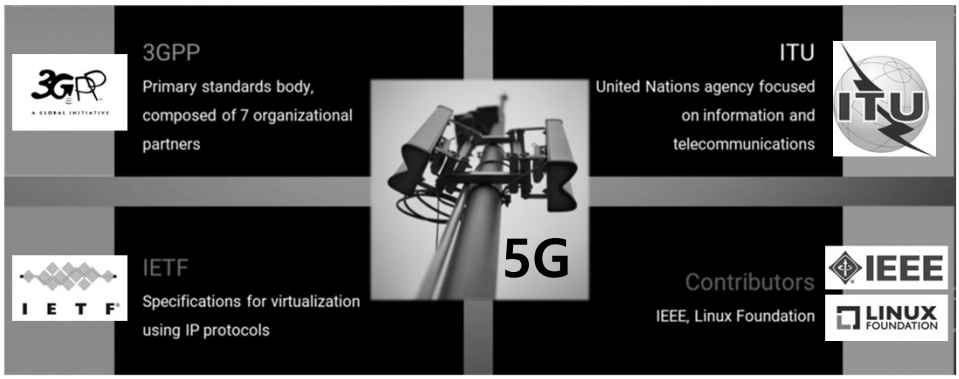
I. 5G EN-DC ARCHITECTURE

❖ 5G 무선 표준 기관

- 3GPP
- ITU
- IETF
- IEEE
- 리눅스 재단
- 기타



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I. 5G EN-DC ARCHITECTURE

❖ ITU (International Telecommunications Union): UN 산하 기관

• 5G 표준 준비: IMT-2000

Capability	Description	Target Value	Usage scenario
Downlink peak data rate	Minimum maximum data rate technology must support	20 Gbps	eMBB
Uplink peak data rate	Minimum maximum data rate technology must support	10 Gbps	eMBB
User experienced downlink data rate	Data rate in dense urban test environment 95% of time	100 Mbps	eMBB
User experienced uplink data rate	Data rate in dense urban test environment 95% of time	50 Mbps	eMBB
Latency	Radio network contribution to packet travel time	4 ms	eMBB
Latency	Radio network contribution to packet travel time	1 ms	URLLC
Mobility	Maximum speed for handoff and QoS requirements	500 km/h	eMBB/URLLC
Connection density	Total number of devices per unit area	1,000,000 devices/km2	mMTC
Energy efficiency	Data sent/received per unit energy consumption (by device or network)	Equal to 4G	eMBB
Area traffic capacity	Total traffic across coverage area	10 Mbps/m2	eMBB

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I. 5G EN-DC ARCHITECTURE

❖ 5G 무선 표준 기관

• 이동통신 기술의 진화와 세대별 특징 / 명칭

마케팅 용어	ITU 용어	3GPP 용어	RAN 용어	Core 용어	시스템 이름
3G	IMP-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**	**EPC** (Evolved Packet Core)	**EPS** (Evolved Packet System)
5G	**IMT-2020**	**5G**	**NR** (New Radio)	**5GC (5G Core)**	**5GS** (5G System)
6G	**IMT-2030**	**6G**	-	-	-

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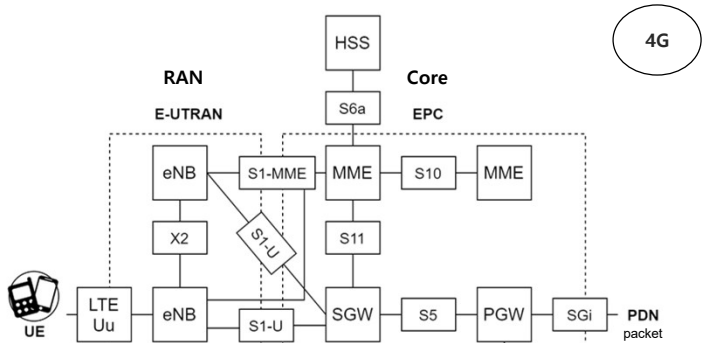
I. 5G EN-DC ARCHITECTURE

❖ LTE 아키텍처

- E-UTRAN: LTE 무선접속망 (RAN)
- EPC: LTE 코어망
- EPS: Evolved Packet System
  EPS = E-UTRAN + EPC (+UE)



- ✓ UE (User Equipment)
- ✓ eNB (Evolved Node B)
- ✓ S-GW (Serving Gateway)
- ✓ P-GW (PDN Gateway)
- ✓ MME (Mobility Management Entity)
- ✓ HSS (Home Subscriber Server)
- ✓ PCRF (Policy and Charging Rule Function)
- ✓ PDN (Packet Data Network)

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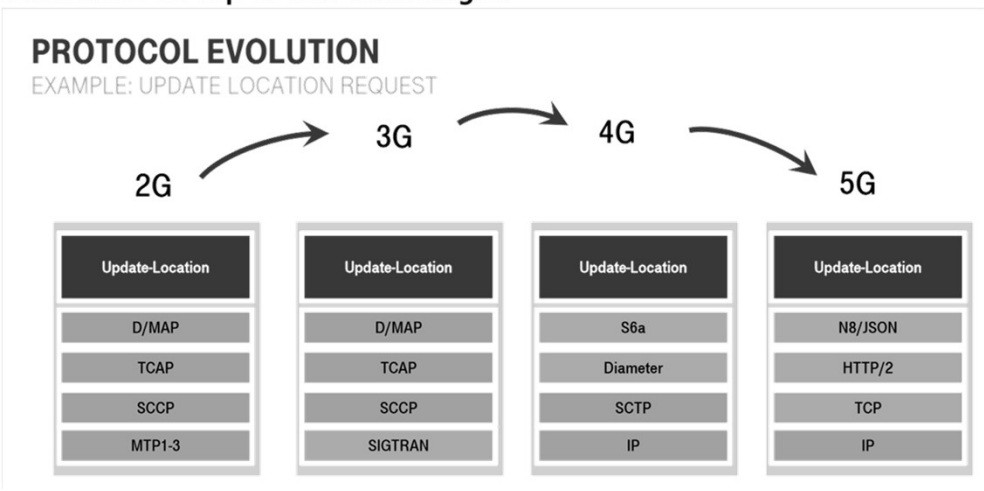
I. 5G EN-DC ARCHITECTURE

❖ 5G Core procedures run on top of web technologies



Source: https://devopedia.org/5g-service-based-architecture#further-reading

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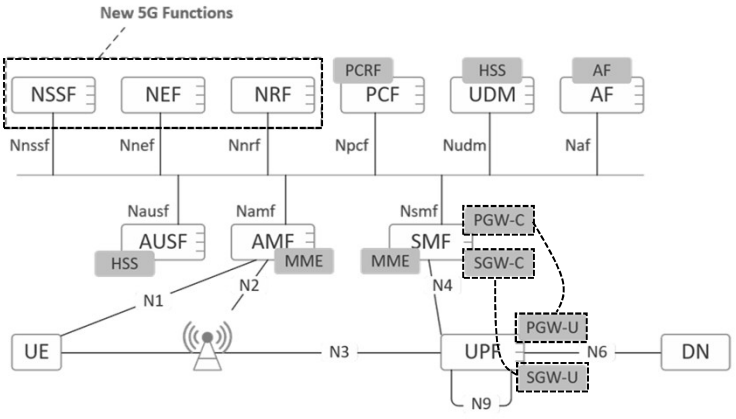
I. 5G EN-DC ARCHITECTURE

❖ 4G EPC functions mapped to 5G core network functions

• Main functions in 5G SBA

AUSF	Authentication Server Function
AMF	Access and Mobility Managment Function
AF	Application Function
DN	Data Networks
SMF	Session Management Function
NEF	Network Exposure Function
NSSF	Network Slice Selection Function
NRF	Network Repository Function
PCF	Policy Control Function
UPF	User PLane Function
(R)AN	(Radio) Access Network



Source: Mastering Service Mesh, Anjali Khatri, Vikram Khatri, 2020 Packt Publishing

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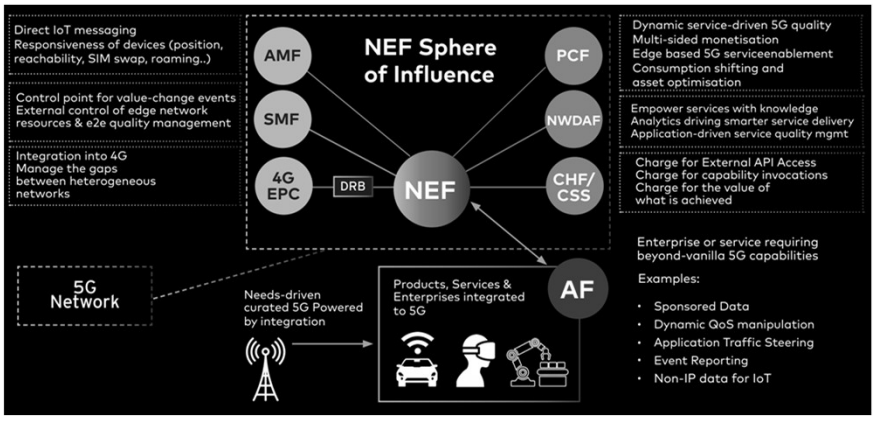
I. 5G EN-DC ARCHITECTURE

❖ NEF (예)

• Amdocs의 NEF (Network Exposure Function)



NEF Amdocs Network Exposure Function

Source: Amdocs

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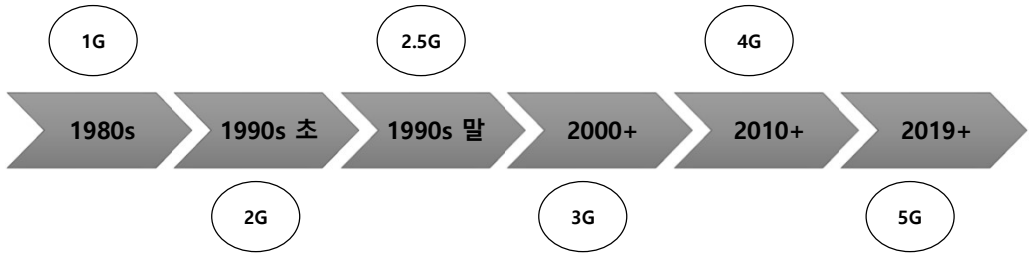
I. 5G EN-DC ARCHITECTURE

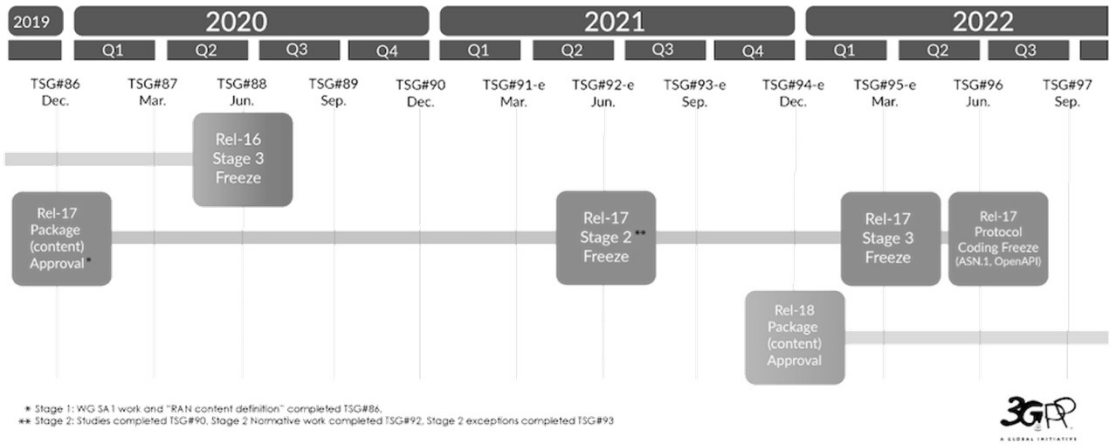
❖ 모바일 기술 발전과 3GPP

3GPP(3rd Generation Partnership Project): 이동통신 관련 단체들 간의 공동 연구 프로젝트로 국제전기통신연합(ITU)의 IMT-2000 프로젝트의 범위 내에서 - 전 세계적으로 적용 가능한 - 3세대 이동통신 시스템 규격의 작성을 목적으로 하고 있다. 3GPP 규격은 진보된 GSM 규격에 기반을 두고 있으며, 무선(radio)과 코어 네트워크(core network), 서비스 구조(service architecture)를 모두 표준화 범위에 포함시키고 있다.



I. 5G EN-DC ARCHITECTURE

❖ 3GPP 표준



Source: https://on5g.es/en/the-3gpp-sets-the-priorities-for-5g-advanced-with-specifications-expected-to-be-approved-in-2024/

I. 5G EN-DC ARCHITECTURE

❖ **Releases 15 와 16** (Phase 1, Phase 2)

	Release 15	Release 16

NR – New Radio
Non Standalone (NSA)
Standalone (SA)
	• NR- New Radio
	  • NR NSA ,5G Radio to work with **LTE** core
	  • NR SA, 5G Radio to work with **5G** core
		Radio
		NR in unlicensed band
		Industrial IOT
		Accurate NR positioning
		NR for integrated Access and Backhaul (IAB)

	• Massive MTC and Internet of things	5G Core
	• Vehicle to everything communication (V2x)	Enhanced SBA (eSBA)
	• Mission Critical (MC) internetworking with legacy systems	특화망 Private networks
	• WLAN unlicensed spectrum use	유/무선 Wireless/Wireline (Cable/BNG) Convergence + Access Steering
	• Slicing- logical and end to end networks	Time Sensitive Network (TSN)
	• API Exposure – 3rd Party access to 5G services	Cellular IoT (NB-IOT, CatM)
SBA	• Service Based Architecture (SBA)	Slice Management
	• Further LTE improvements	Network Analytics
	• Mobile communication system for Railways	V2x Phase 3: Platooning extended sensors, automated driving, remote driving
	• MEC	URLLC enhancements

과기정통부는 5G특화망을 '이음(e-Um) 5G'라는 새 이름으로 부를 계획

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I. 5G EN-DC ARCHITECTURE

❖ **Release 17**

	Release 17	
NR MIMO	• NR MIMO	• NR Sidelink relay
Sidelink	• NR Sidelink enhancement	• RAN Slicing Enh. for small data
	• 52.6 - 71 GHz with existing waveform	• SON / Minimization of drive tests (MDT) enh. NR Quality of Experience
	• Dynamic Spectrum Sharing (DSS) enh. Industrial IoT / URLLC enh.	• eNB architecture evolution, LTE C-plane / U-plane split
	• Study - IoT over Non-Terrestrial Networks (NTN) NR over Non-Terrestrial Networks (NTN)	• Satellite components in the 5G architecture
	• NR Positioning enh.	• Non-Public Networks enh.
	• Low complexity NR devices Power saving	• Network Automation for 5G - phase 2 Edge Computing in 5GC
	• NR Coverage enh.	• Proximity based Services in 5GS
	• Study - NR eXtended Reality (XR) NB-IoT and LTE-MTC enh.	• Network Slicing Phase 2
	• 5G Multicast broadcast Multi-Radio DCCA enh.	• Enh. V2x Services
Multi SIM	• Multi SIM Integrated Access and Backhaul (IAB) enh.	• Advanced Interactive Services
	• Unmanned Aerial Systems	• Access Traffic Steering, Switch and Splitting support in the 5G system architecture
	• 5GC Location Services	• 5G LAN-type services
	• Multimedia Priority Service (MPS)	• User Plane Function (UPF) enh. for control and 5G Service Based Architecture (SBA)
	• 5G LAN-type services	
	• 5G Wireless and Wireline Convergence	

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I. 5G EN-DC ARCHITECTURE

❖ 3GPP 표준

- Rel 18
- 5G Advanced

Source: Image courtesy of Qualcomm Technologies, Inc.

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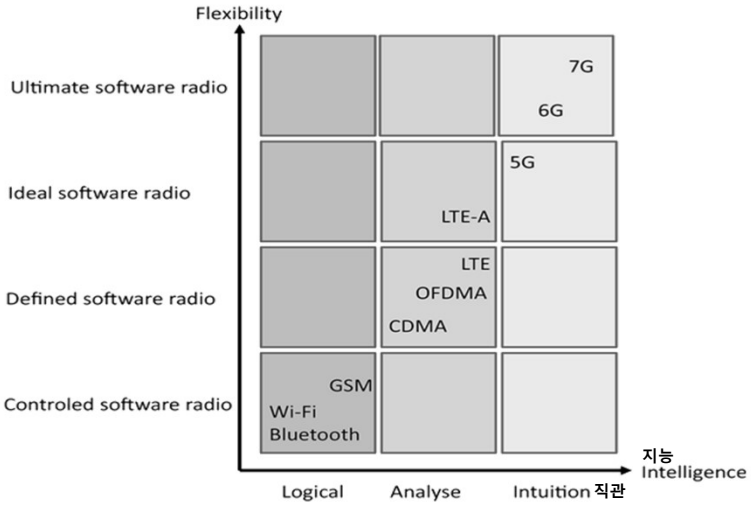
I. 5G EN-DC ARCHITECTURE

❖ 모바일 네트워크 기술의 발전



Source: Software Networks (Virtualization, SDN, 5G and Security), by ISTE Press Ltd and John Wiley & Sons, Inc. 2020

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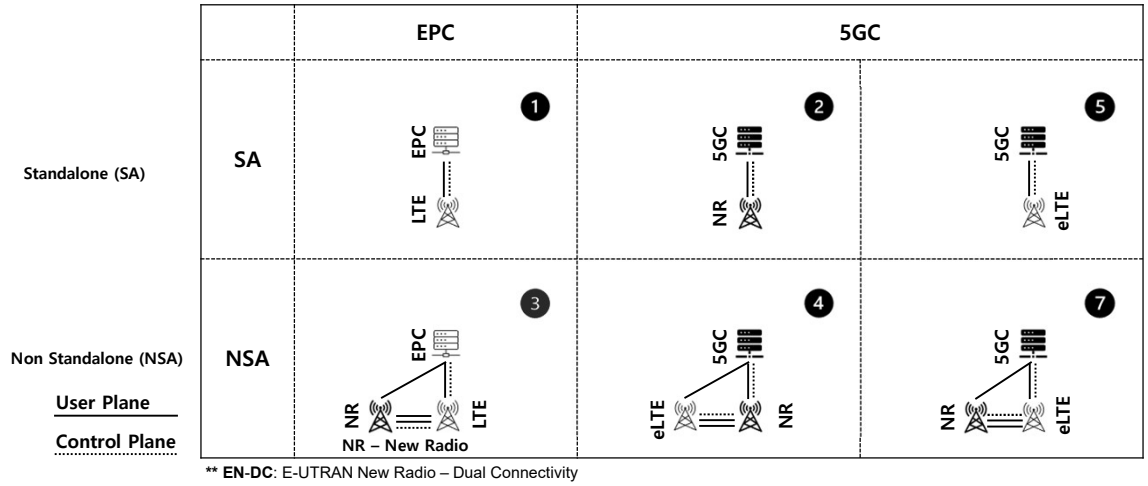
I. 5G EN-DC ARCHITECTURE

❖ 적용 옵션 (Deployment options)



** **EN-DC**: E-UTRAN New Radio – Dual Connectivity

I. 5G EN-DC ARCHITECTURE

❖ 5G 표준과 Market의 Radio 환경 변화/발전

주파수	Sub 6GHz		Above 6GHz		
대역 / 통산사	<3GHz	3~5 GHz	6~24 GHz	24~30 GHz	30~40 GHz
SKT		3.6~3.7 GHz (100MHz)		28.1~29.0 GHz (800MHz)	
KT		3.5~3.6 GHz (100MHz)		26.5~27.3 GHz (800MHz)	
LGU+		3.42~3.5 GHz (80MHz)		27.3~28.1 GHz (800MHz)	

동시 지원 가능
- 5G NR (100MHz) 1.5 Gbps
- 4G LTE (145MHz) 1.2 Gbps

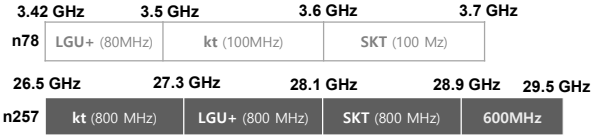
- Frequency range 1 (FR1): 410–7125 MHz.
- Frequency range 2 (FR2): 24.25–52.6 GHz.

I. 5G EN-DC ARCHITECTURE

- FR1: n78 (3.3GHz~3.8GHz)
- FR2: n257 (26.5GHz~29.5GHz)

Frequency range	Carrier bandwidth (MHz)
FR1	5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100
FR2	50, 100, 200, 400

NR Band	Uplink and Downlink Range (MHz)	Duplex Mode	Main Region(s)
n257	26,500–29,500	TDD	Asia, Americas (global)
n258	24,250–27,500	TDD	Europe, Asia (global)
n259	37,000–40,000	TDD	US (global)



	NR Band	Uplink Range (MHz)	Downlink Range (MHz)	Duplex Mode	Main Region(s)
B1	n1	1920–1980	2110–2170	FDD	Europe, Asia
	n2	1850–1910	1930–1990	FDD	Americas (Asia)
B3	n3	1710–1785	1805–1880	FDD	Europe, Asia (Americas)
B5	n5	824–849	869–894	FDD	Americas, Asia
B7	n7	2500–2570	2620–2690	FDD	Europe, Asia
	n8	880–915	925–960	FDD	Europe, Asia
	n20	832–862	791–821	FDD	Europe
	n28	703–748	758–803	FDD	Asia/Pacific
	n38	2570–2620	2570–2620	TDD	Europe
	n41	2496–2690	2496–2690	TDD	US, China
	n50	1432–1517	1432–1517	TDD	
	n51	1427–1432	1427–1432	TDD	
	n66	1710–1780	2110–2200	FDD	Americas
	n70	1695–1710	1995–2020	FDD	
	n71	663–698	617–652	FDD	Americas
	n74	1427–1470	1475–1518	FDD	Japan
	n75	N/A	1432–1517	SDL	Europe
	n76	N/A	1427–1432	SDL	Europe
	n77	3300–4200	3300–4200	TDD	Europe, Asia
	n78	3300–3800	3300–3800	TDD	Europe, Asia
	n79	4400–5500	4400–5500	TDD	Asia
	n80	1710–1785	N/A	SUL	
	n81	880–915	N/A	SUL	
	n82	832–862	N/A	SUL	
	n83	703–748	N/A	SUL	
	n84	1920–1980	N/A	SUL	

re-farming carriers from LTE to NR
DSS(Dynamic spectrum sharing)

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I. 5G EN-DC ARCHITECTURE

- 기술 비교: Private LTE vs WiFi vs 5G (VMware 예)

		Private LTE	Wi-Fi 6	5G
환경	Environment	• All environments • Mines • Construction Site • Sites where Public LTE does not exist	• Office environments • Homes • Shopping Malls • Transportation Hubs	• All environments including industrial environments 산업 환경을 위한 모든 환경
가용성	Availability	• Available now	• Wi-Fi 6 certification finalized in Q3 2019	• Rel 16 to be finalized in June 2020 • Commercial availability 2021 현재 사용 가능
속도	Speed	• Up to 1 Gbps	• Up to 9.6 Gbps	• Up to 10 Gbps 최대 10 Gbps
밀도	Density	• 100,000 connections per KM	• Designed for densely digitally populated homes and offices	• 1M connections per KM 제곱킬로미터당 1M
모빌리티	Mobility	• Roaming from private to public LTE networks	• Designed for fixed locations	• Roaming from private to public LTE networks Private Public 로밍
지연/신뢰성	Latency and Reliability	• 40-50 milliseconds	• >100 milliseconds but may not be able to guarantee low latency as load increases	• Ultrareliable low latency • Sub millisecond latency • 99.9999% reliability 초저지연, 99.9999% 신뢰
주파수 범위	Frequency Ranges	• Licensed and unlicensed spectrum • CBRS (3.5 GHz) in US	• 2.4 Ghz and 5 Ghz	• Licensed and unlicensed spectrum • 600 MHz to mmWave (24-29 Ghz and 37-43 Ghz) 면허/비면허 mmWAVE

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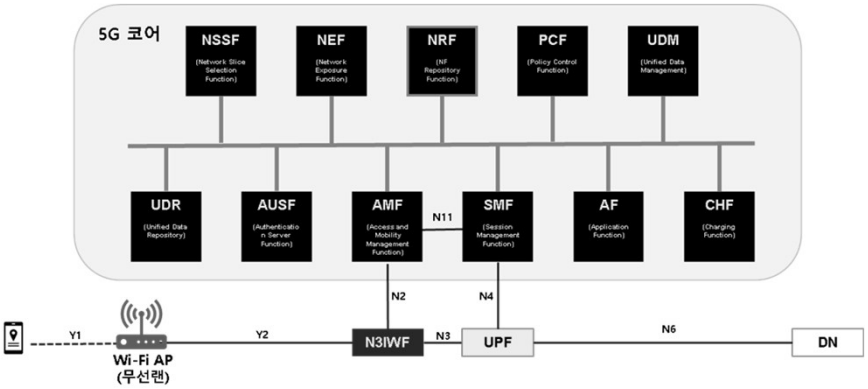
I. 5G EN-DC ARCHITECTURE

❖ non-3GPP

• **Architecture of untrusted non-3GPP access using Wi-Fi network**

○ **N3IWF:** Non-3GPP Interworking Function



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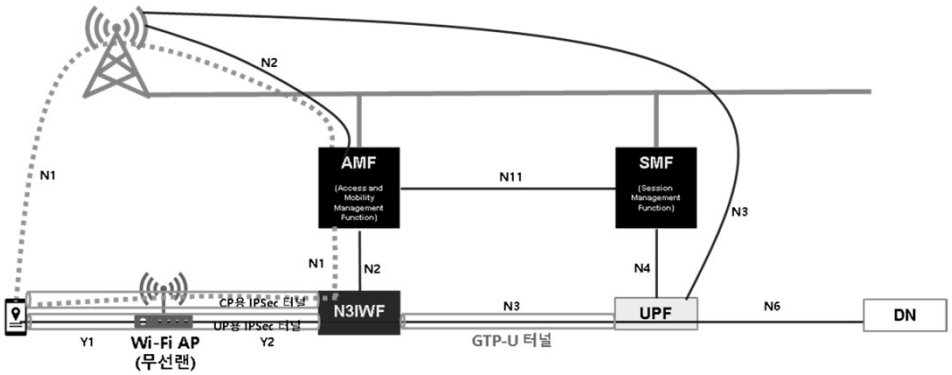
I. 5G EN-DC ARCHITECTURE

❖ non-3GPP

• **Architecture of untrusted non-3GPP access using Wi-Fi network**

○ CP용 IPSec 터널, UP용 IPSec 터널, GTP-U 터널



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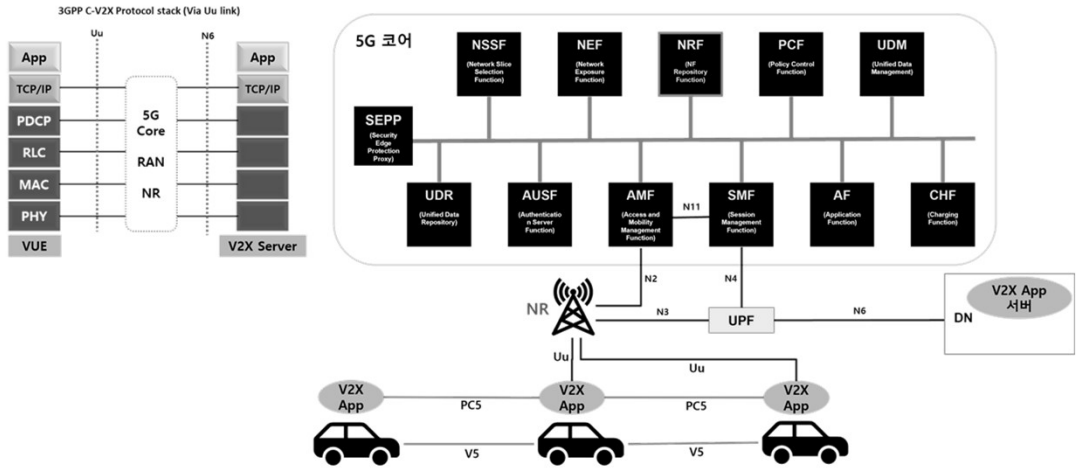
I. 5G EN-DC ARCHITECTURE

❖ 5G-V2X 아키텍처



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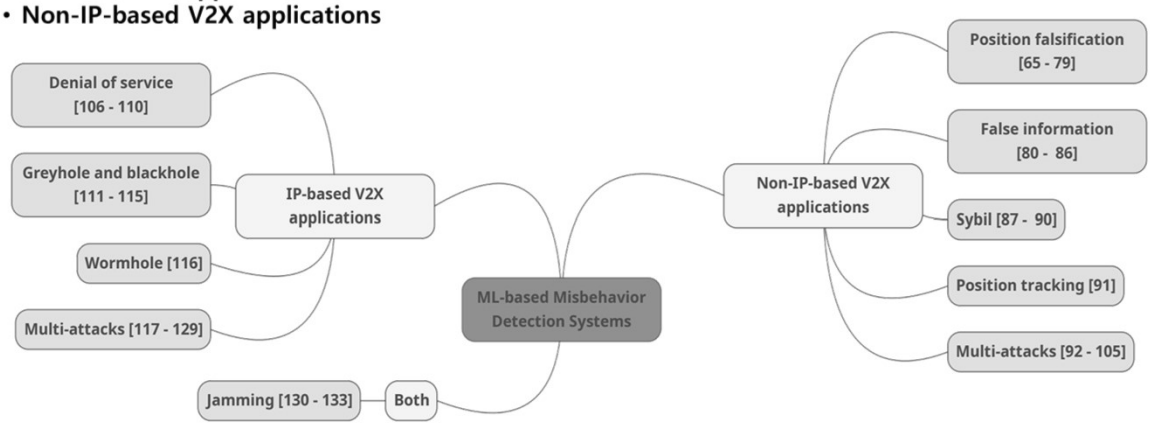
I. 5G EN-DC ARCHITECTURE

❖ Taxonomy of ML-based Misbehavior Detection Systems

- IP-based V2X applications
- Non-IP-based V2X applications



Source: A Survey on Machine Learning-base Misbehavior Detection Systems for 5G and Beyond Vehicular Network, Abdelwahab Boualouache, Member, IEEE and Thomas Engel, Member, IEEE

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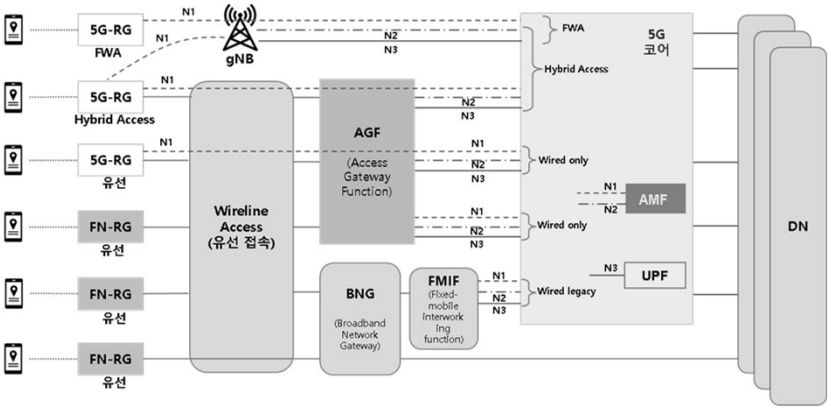
I. 5G EN-DC ARCHITECTURE

❖ **FMC(Fixed Mobile Convergence)**

- **5G RG** (Residential Gateway)
- **FN RG** (Fixed Network Residential Gateway)



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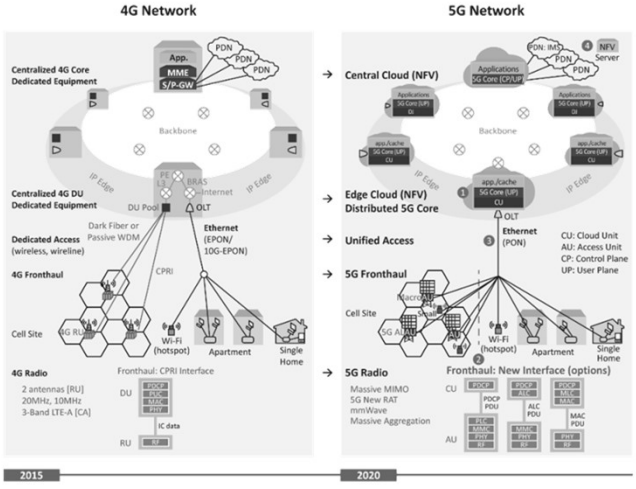
I. 5G EN-DC ARCHITECTURE

❖ **From 4G to 5G**



Source: Software Networks (Virtualization, SDN, 5G and Security), by ISTE Press Ltd and John Wiley & Sons, Inc. 2020

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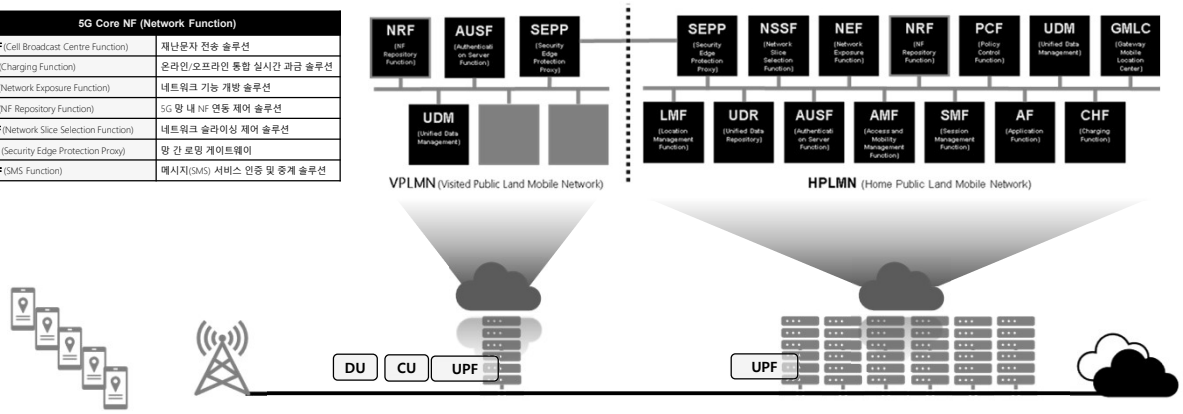
I. 5G EN-DC ARCHITECTURE

❖ 5G Core의 클라우드화

• 5G Core와 RAN

5G Core NF (Network Function)	
CBCF (Cell Broadcast Centre Function)	재난문자 전송 솔루션
CHF (Charging Function)	온라인/오프라인 통합 실시간 과금 솔루션
NEF (Network Exposure Function)	네트워크 기능 개방 솔루션
NRF (NF Repository Function)	5G 망 내 NF 연동 제어 솔루션
NSSF (Network Slice Selection Function)	네트워크 슬라이싱 제어 솔루션
SEPP (Security Edge Protection Proxy)	망 간 로밍 게이트웨이
SMSF (SMS Function)	메시지(SMS) 서비스 인증 및 중계 솔루션



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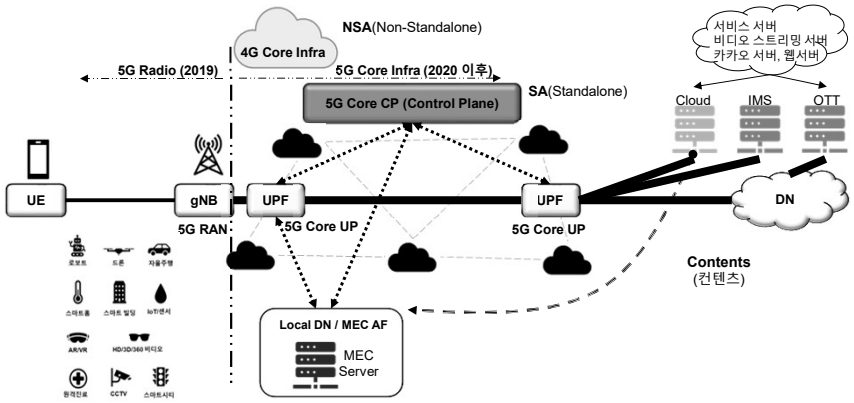
I. 5G EN-DC ARCHITECTURE

❖ 에지의 데이터센터 기술 도입: 국사의 데이터센터화 기지국 확대 고려

❖ 5G는 4G EPC 코어 공유로 서비스 시작: 5G 코어 적용 확대 중

❖ MEC는 Eco-system 확대 영역: API 제공 및 B2B 등의 모델 확대



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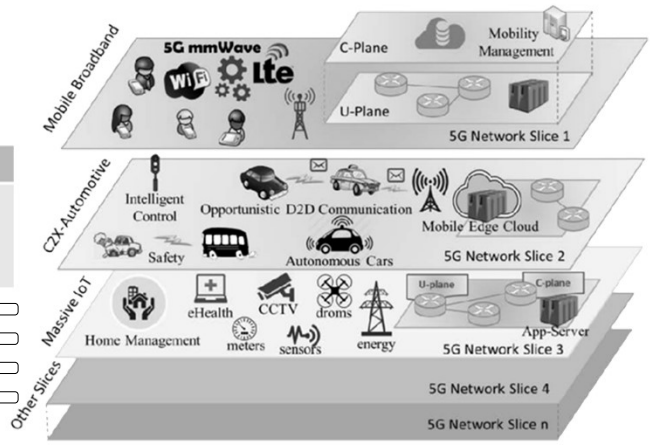
I. 5G EN-DC ARCHITECTURE

❖ Basic slicing of 5G core network

- Mobile Broadband (5G/LTE/WiFi)
- V2X or C-V2X
- mIoT
- 기타

Release 15 - 2019	Release 16 - 2020	Release 17 -2022
• First NR ("New Radio") release. • 5G Vehicle-to-x service • Service Based Architecture (SBA)	• The 5G System - Phase 2 • Industrial IoT • URLLC enhancements • 5G efficiency including Dynamic Spectrum Sharing (DSS)	• Support for non-terrestrial networks • Unmanned Aerial Systems • RAN Slicing • Edge Computing

- 비지상네트워크 지원
- 무인 항공 시스템
- RAN 슬라이싱
- 에지 컴퓨팅



Source: Software Networks (Virtualization, SDN, 5G and Security), by ISTE Press Ltd and John Wiley & Sons, Inc. 2020

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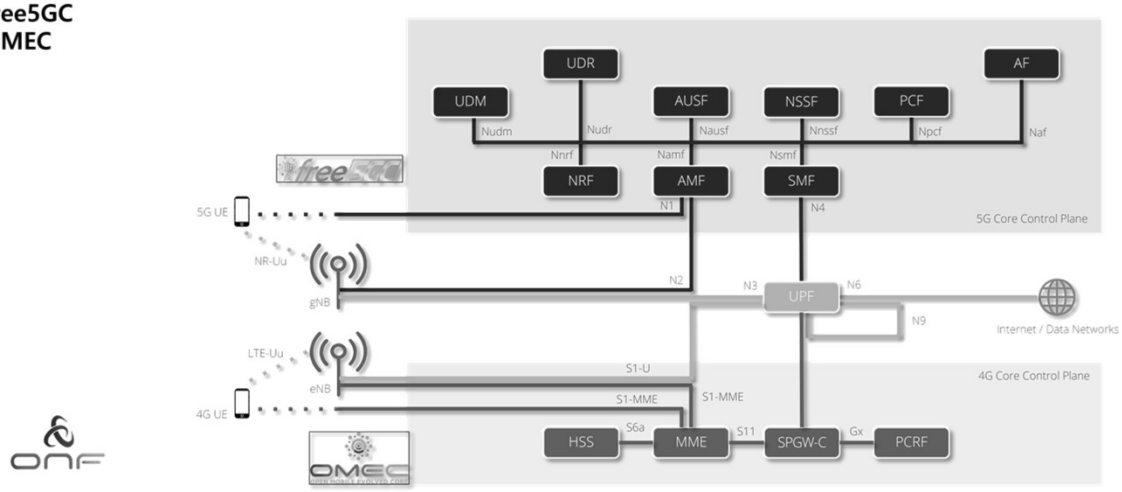
I. 5G EN-DC ARCHITECTURE

❖ SD-Core supports 5G SA, 5G NSA (option 3x) and LTE

- free5GC
- OMEC



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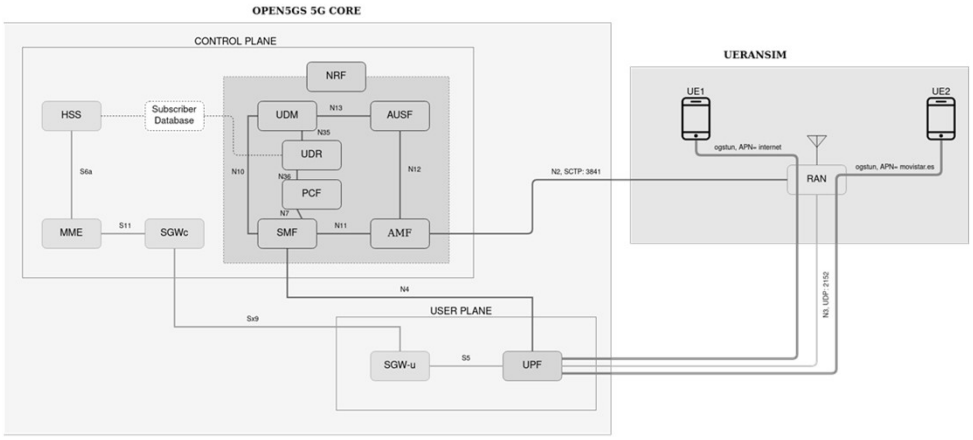
I. 5G EN-DC ARCHITECTURE

❖ **Configuration of different AMBR**(Aggregate Maximum Bit Rate) **per slice**

• **Architecture of the Network for the test**



Source: VIRTUALIZED CELLULAR NETWOKS WITH NATIVE CLOUD FUNCTIONS, Iria Míguez González

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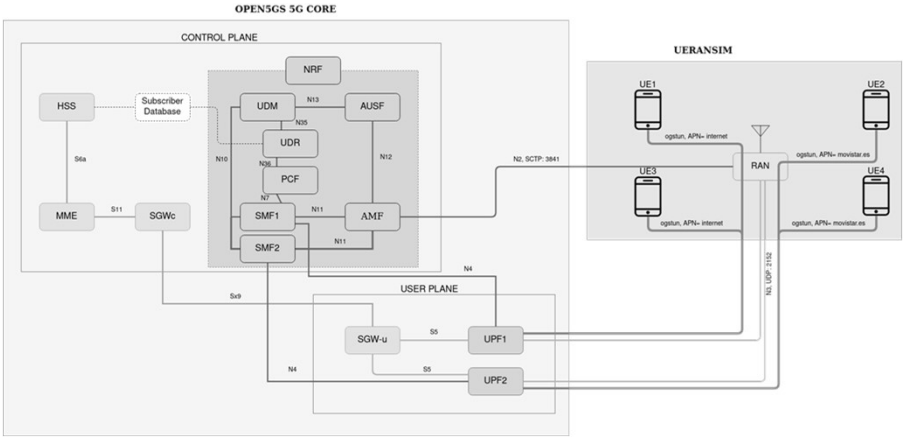
I. 5G EN-DC ARCHITECTURE

❖ **Selection of UPF and SMF by slice**

• **iperf Slicing Test Architecture**



Source: VIRTUALIZED CELLULAR NETWOKS WITH NATIVE CLOUD FUNCTIONS, Iria Míguez González

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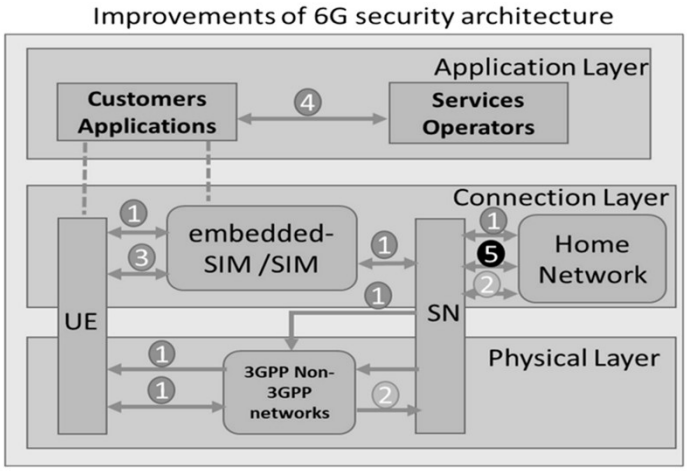
I. 5G EN-DC ARCHITECTURE

❖ Security Requirements and Challenges of 6G Technologies

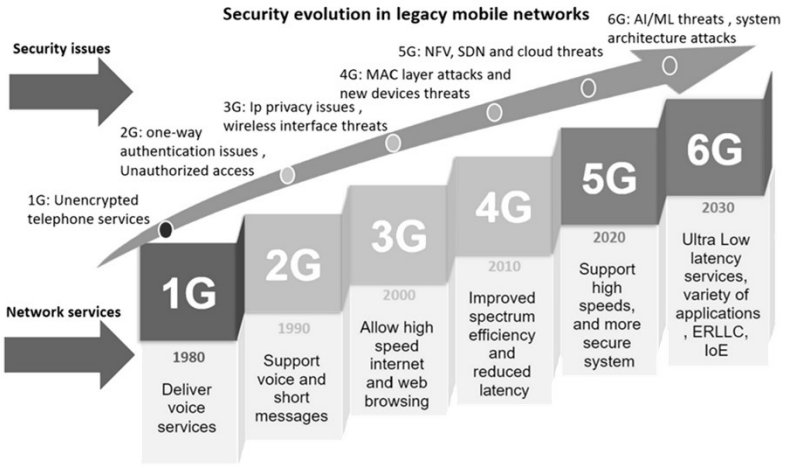


Source: 'Security Requirements and Challenges of 6G Technologies and Applications' Shimaa A. Abdel Hakeem , Hanan H. Hussein and HyungWon Kim, mdpi

I. 5G EN-DC ARCHITECTURE

❖ The security evolution of mobile communications from 1G to the predicted future 6G

- 4G: MAC layer / new devices
- 5G: NFV / SDN / Cloud



Source: 'Security Requirements and Challenges of 6G Technologies and Applications' Shimaa A. Abdel Hakeem , Hanan H. Hussein and HyungWon Kim, mdpi

II. 엔터프라이즈 Use Case

- 국내외 엔터프라이즈 Use Case
- 엔터프라이즈 오프소스 생태계

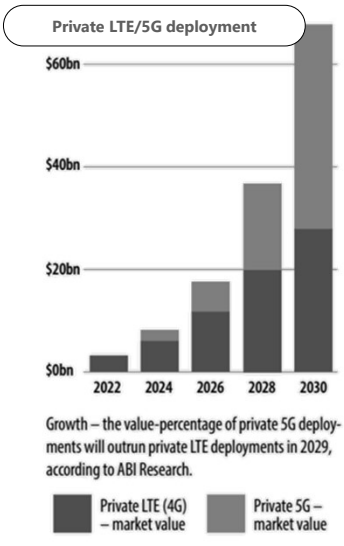
II. 엔터프라이즈 USE CASE

- Private 5G
- Private LTE/5G

INDUSTRY	SITES	SIZE
Industrial & manufacturing	10,710,000	IM+
Warehouses	3,300,000	
Hospitals & labs	263,000	100K+
Water utilities	140,000	
Mining	54,000	10K+
Transport venues & ports	50,000	
Power generation	47,600	
Military bases	10,000	
Oil & gas	8,000	1K+
TOTAL	14,582,600	

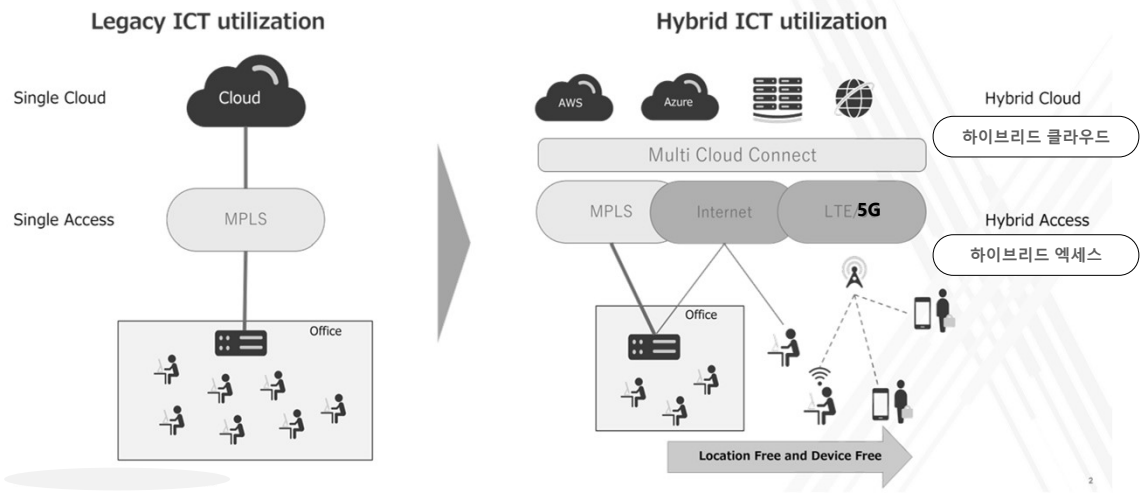
Potential venues for private 5G

Source: Nokia



II. 엔터프라이즈 USE CASE

❖ **Enterprise Network Transitions (예: NTT Communications Corporation)**



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II. 엔터프라이즈 USE CASE

❖ **ABI Research: VMware and Red Hat Come Out on Top in ABI Research's 5G Telco Cloud Native Platforms Competitive Ranking.**

- **Market Leaders:** VMware, Red Hat 엔터프라이즈 제조사의 5G를 위한 클라우드 네이티브 플랫폼 제공
- **Mainstream:** Nokia, ZTE, Canonical, Huawei, Google, Ericsson, Wind River
- **Followers:** AWS, Microsoft Azure

ABI Research, New York, New York - March 01, 2022
Source: https://www.abiresearch.com/press/vmware-and-red-hat-come-out-on-top-in-abi-researchs-5g-telco-cloud-native-platforms-competitive-ranking/?utm_source=Cision

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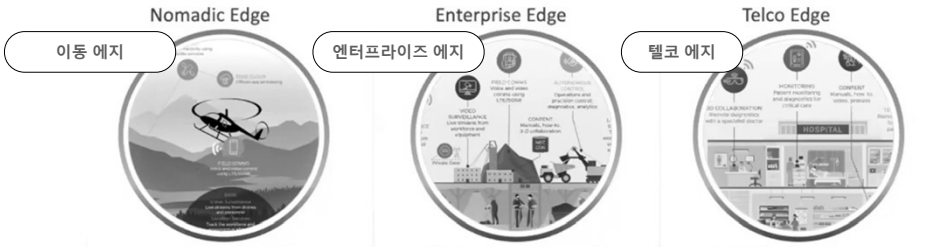
II. 엔터프라이즈 USE CASE

❖ 엔터프라이즈 제조사의 Private 5G Network 적용 모델: VMware (예)



	Coverage & safety	Ultra low latency & security	Reliability & performance
Deployment	Backpack, Cellular on Wheels	Customer On-Premise	Distributed CSP Clouds
Use Cases	First Responders, Rural Capacity, Drones, Events, Popup Retail	Smart Factory, AR/VR, Health, AGV, Mining, Robotics, Asset Tracking	Smart City, Smart Home, Ambulance, Environment/Energy, Logistics
Geography	20 + sq. miles	1 + sq. miles	100 + sq. miles
Connectivity	< 80ms | 1 Gbps | < 500 attach	< 10ms | 10+Gbps | < 10K attach	< 20ms | 200+ Gbps | M+ attach
Services	Location, Voice, Video	Location, Voice, Video, MEC, AI/ML	Location, Video, MEC, CDN
Spectrum	Shared, Unlicensed	Shared, Licensed	Licensed

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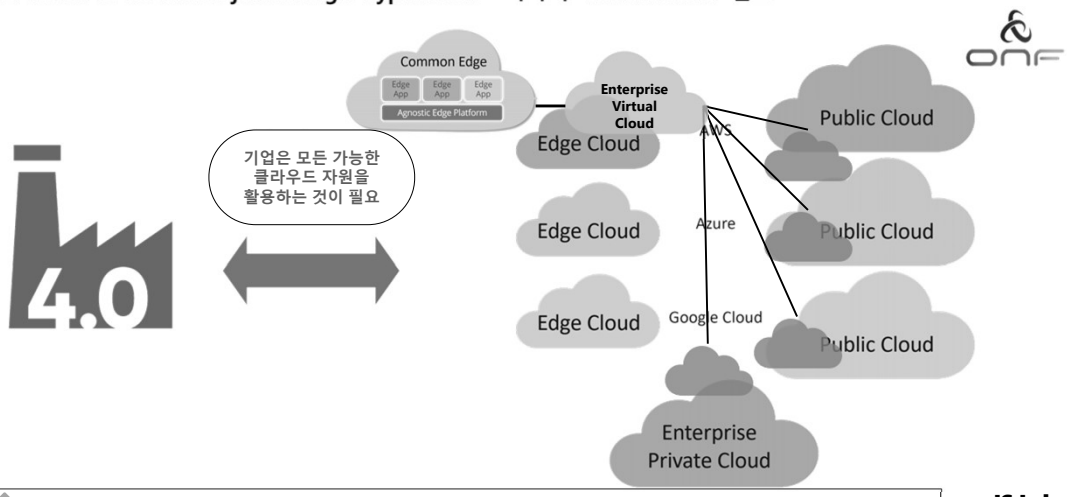
II. 엔터프라이즈 USE CASE

❖ 멀티클라우드는 뉴노멀 (ONF: Enterprise Multi-Cloud is the New Normal)

- Can't afford to be tied to just a single hyperscaler – 하나의 'Virtual Cloud' 필요



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II. 엔터프라이즈 USE CASE

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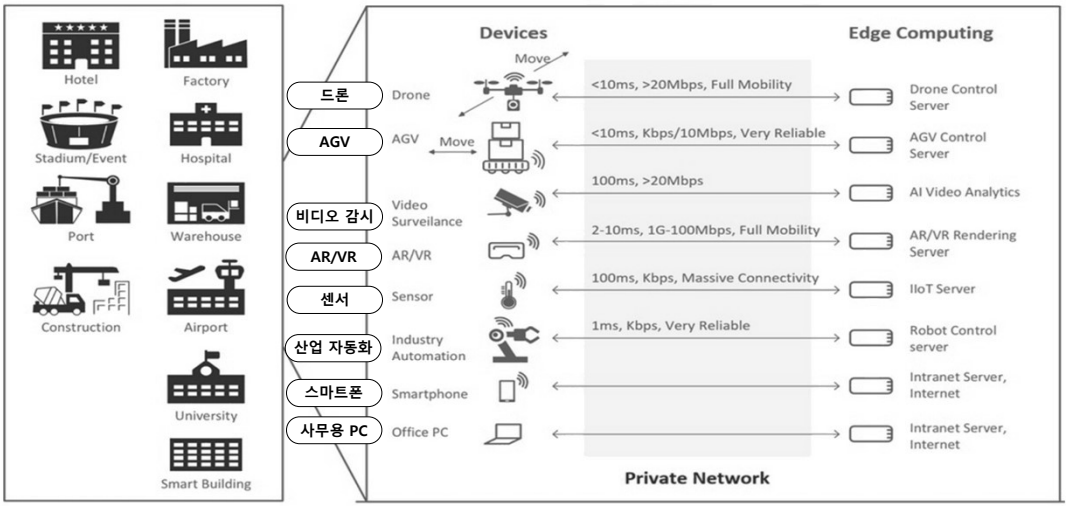
❖ Industry Digital Transformation and requirements for the communication connection



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II. 엔터프라이즈 USE CASE

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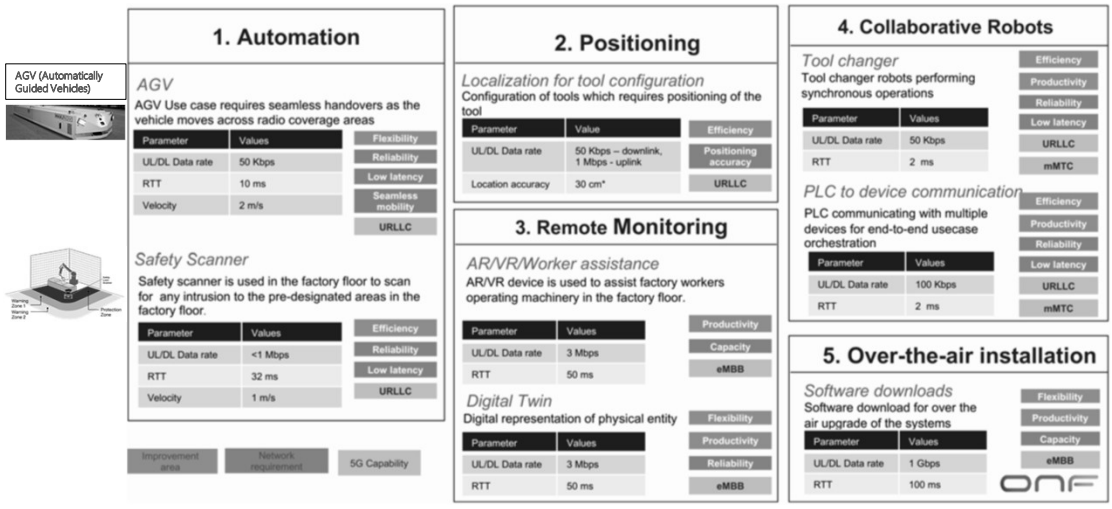
❖ Common Use Cases in Manufacturing (예: ONF)



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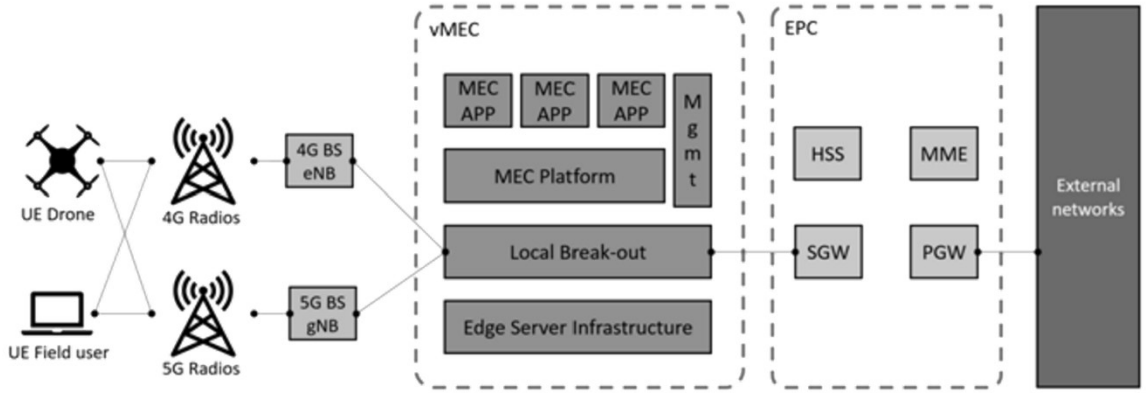
II. 엔터프라이즈 USE CASE

❖ 5GTN MEC deployment in NSA mode



Source: Report on infrastructure-level enablers for 5G!Drones, European Union's Horizon 2020 research and innovation programme under grant agreement No 857031.

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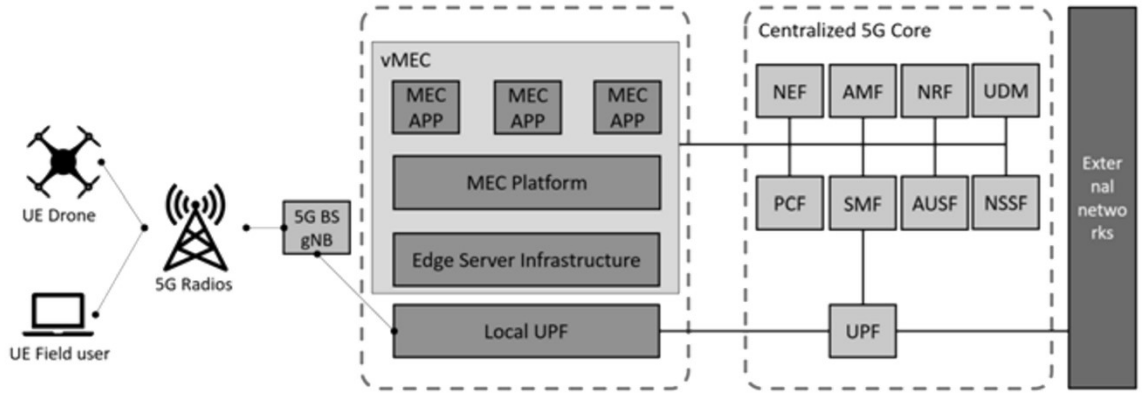
II. 엔터프라이즈 USE CASE

❖ 5GTN MEC deployment in SA mode



Source: Report on infrastructure-level enablers for 5G!Drones, European Union's Horizon 2020 research and innovation programme under grant agreement No 857031.

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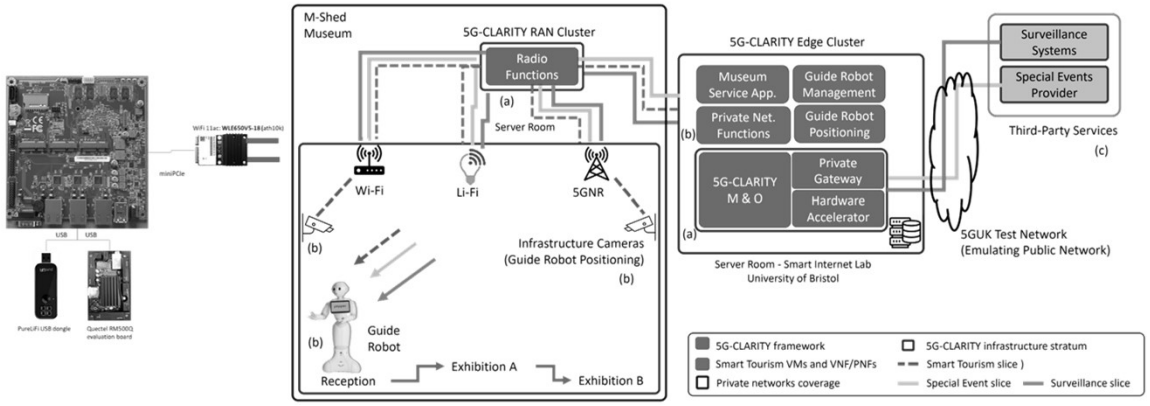
II. 엔터프라이즈 USE CASE

❖ 5G-CLARITY proposed architecture

- UC1 framework, components and service slices overview
- 5G-CLARITY CPE preliminary design



Source: 5G-CLARITY [H2020-871428], Mir Ghoraishi(GIGASYS)

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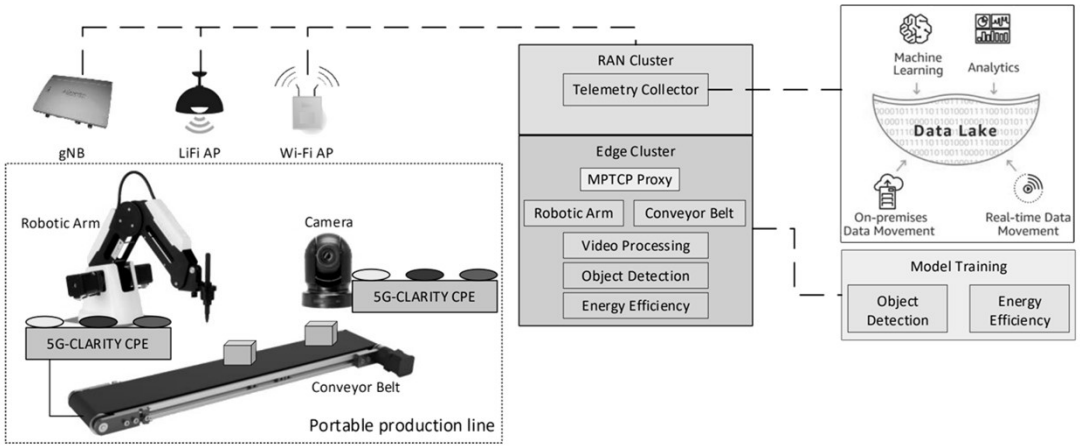
II. 엔터프라이즈 USE CASE

❖ Production line testbed and its integration to 5G-CLARITY system architecture



Source: 5G-CLARITY [H2020-871428], Mir Ghoraishi(GIGASYS)

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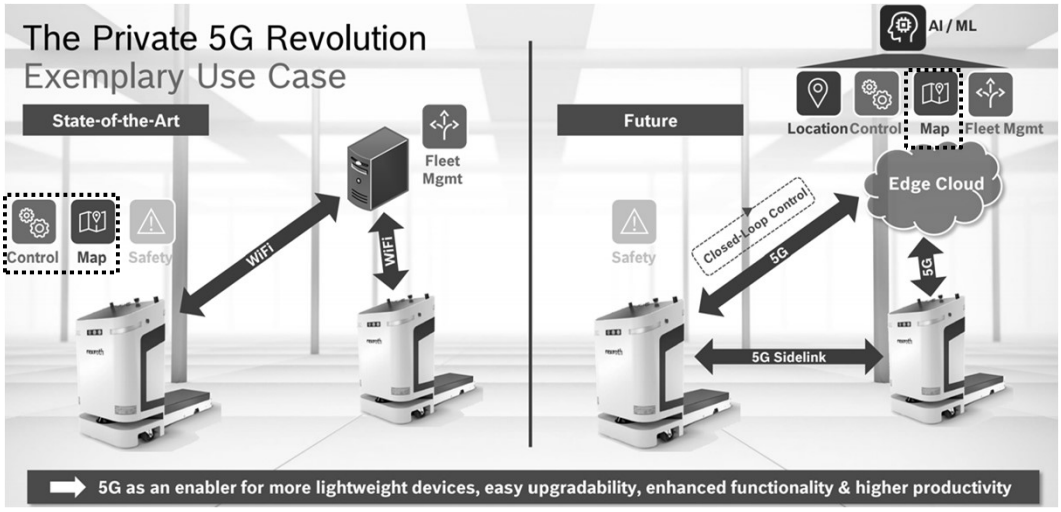
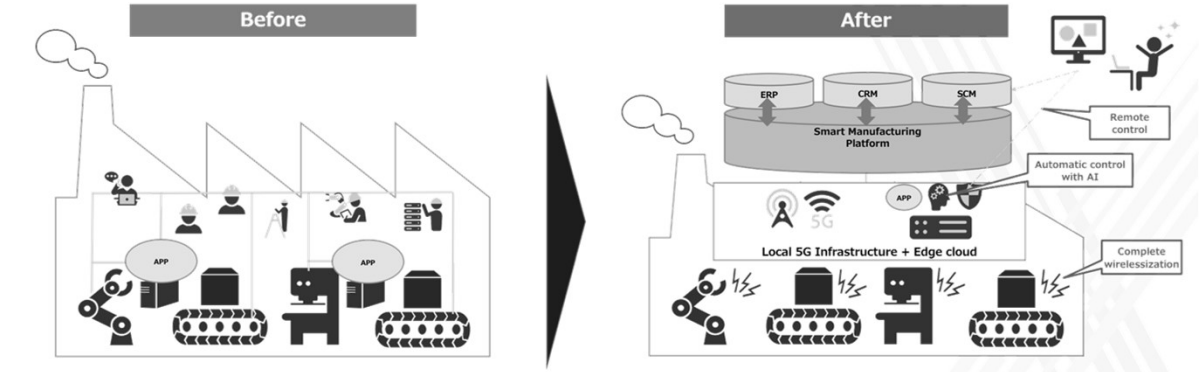
II. 엔터프라이즈 USE CASE

❖ **Private 5G (예: Bosch)**



II. 엔터프라이즈 USE CASE

❖ **OT Network Transitions** (예: NTT Communications Corporation)



- Laying wired NWs for collecting operational facility data in a factory is a challenge.
- Managing disparate legacy applications is difficult.
- Employees basically need work onsite.

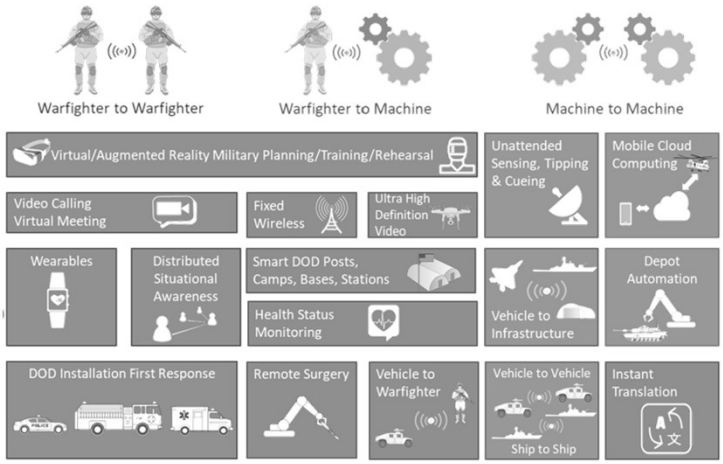
- Highly reliable and high-quality data collection are realized by using **wireless technology** such as Local 5G.
  - Moreover, **remote control** of production machines and transportation devices such as AGV can be expected.
- **Centralized application management** is enabled by introducing the edge cloud
  - Moreover, it facilitates the adoption of **AI solutions.**
- Integration of OT and IT will accelerate **unmanned factory.**

II. 엔터프라이즈 USE CASE

❖ **5G Use Cases for DoD** (Department of Defense)

- **Enterprise private 5G networks for National applications are very similar to commercial networks**
- **Most military-related tasks are "behind the lines"**
- **More challenges in forward-deployed use cases**
- **Opportunities to both use 5G as writ, as well as contribute ideas to future standards**

DoD에서 Private 5G 기술이 필요



II. 엔터프라이즈 USE CASE

❖ **5G Use Cases for DoD** (Department of Defense)

- **Military vehicles and equipment**
- **Military vehicular networking includes both manned and unmanned vehicles**
- **Largely mirrors civilians needs – but infrastructure may not always be available**
- **Need to be able to**
  - Collect data in real time and data analytics
  - Automated repair
  - Tool and equipment tracking
  - Provide remote engineering support and connect maintenance personnel

low SWaPC(Size, Weight, and Power, and Cost)

Storage

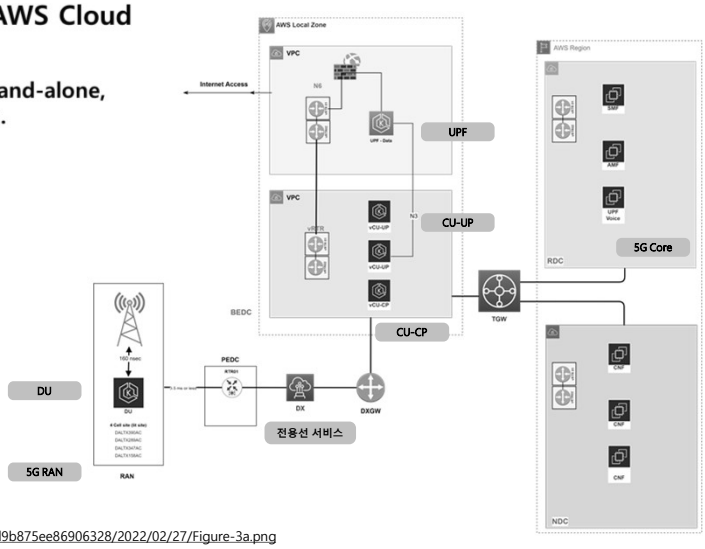
Stock readiness

Maintenance

II. 엔터프라이즈 USE CASE

❖ Deploying DISH's 5G Network in AWS Cloud

- AWS의 RAN 연계
- DISH Network is deploying the first stand-alone, cloud-native, autonomous 5G network.



Source: https://d2908q01vomqb2.cloudfront.net/c5b76da3e608d34edb07244cd9b875ee86906328/2022/02/27/Figure-3a.png

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II. 엔터프라이즈 USE CASE

❖ Microsoft Extends Enterprise Chops to Operators.

- Microsoft, as part of its deal with AT&T, also gained roughly 100 engineers from the operator. The enlarged team is now working to build AT&T's Network Cloud technology into Microsoft's standard hybrid-cloud product and a telco-centric platform for AT&T and other operators to deploy.

MS 하이브리드 클라우드 제품의 AT&T를 위한 플래랫폼 제동

- The combination of AT&T and Microsoft's efforts in this space is unique because it marks "the first time that a tier-one operator has embraced commercial hybrid cloud technology to run mobility network workloads," wrote Hakl, a former longtime Verizon executive.
- Microsoft's 5G strategy links the private Azure Edge Zones service it announced in 2020, Azure IoT Central, virtualized evolved packet core (vEPC) software it gained by acquiring Affirmed Networks, and CNFs it brought on board when it acquired Metaswitch Networks.

MS의 통신장비 제조사 인수

Matt Kapko | Senior Editor, March 3, 2022 10:00 PM
Source: https://www.sdxcentral.com/articles/news/aws-ceo-twists-cloud-giant-all-over-telco-systems/2022/03/

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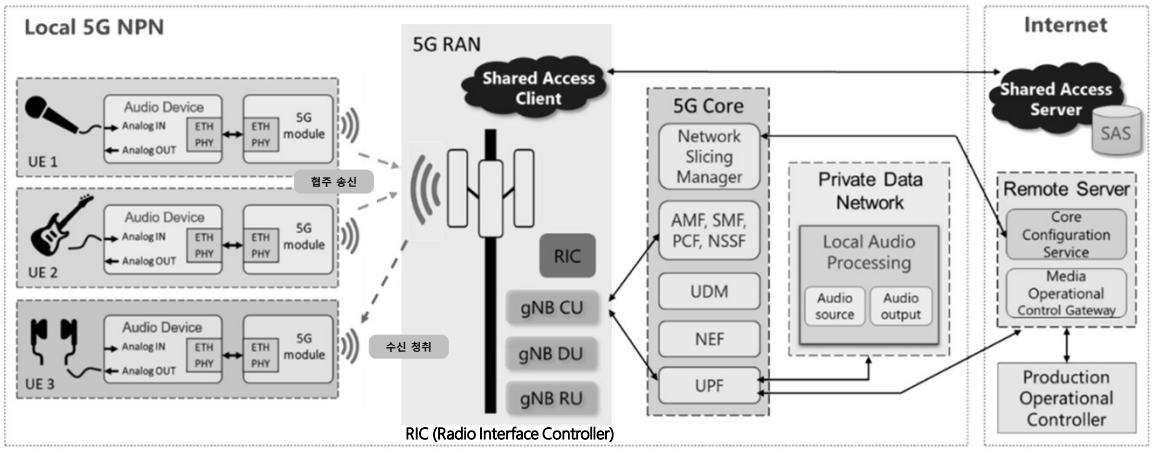
II. 엔터프라이즈 USE CASE

❖ **Architecture of the live audio production use case (UC1)**



Source: 5GPPP Architecture Working Group, 5G Architecture White Paper

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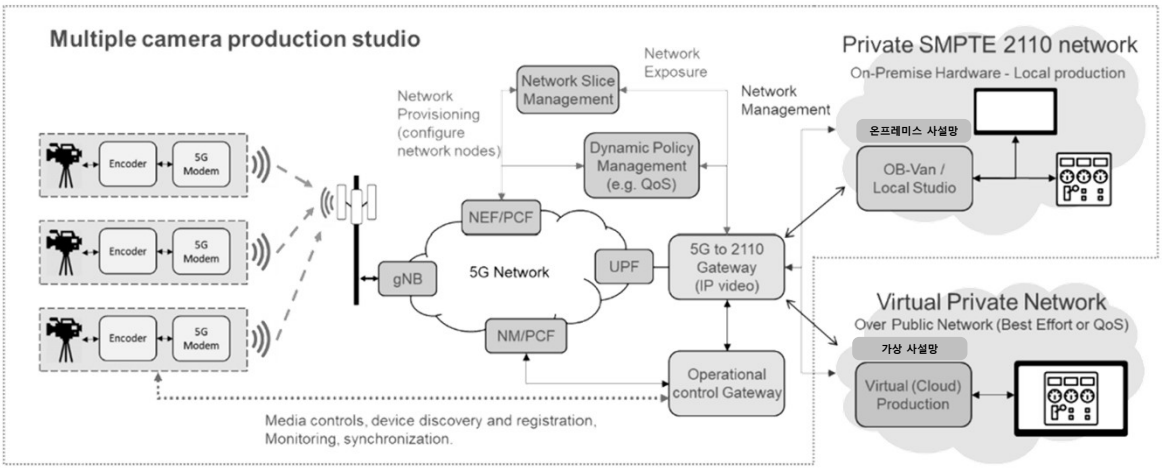
II. 엔터프라이즈 USE CASE

❖ **Architecture of the multiple camera wireless studio use case** (Private 5G)



Source: 5GPPP Architecture Working Group, 5G Architecture White Paper

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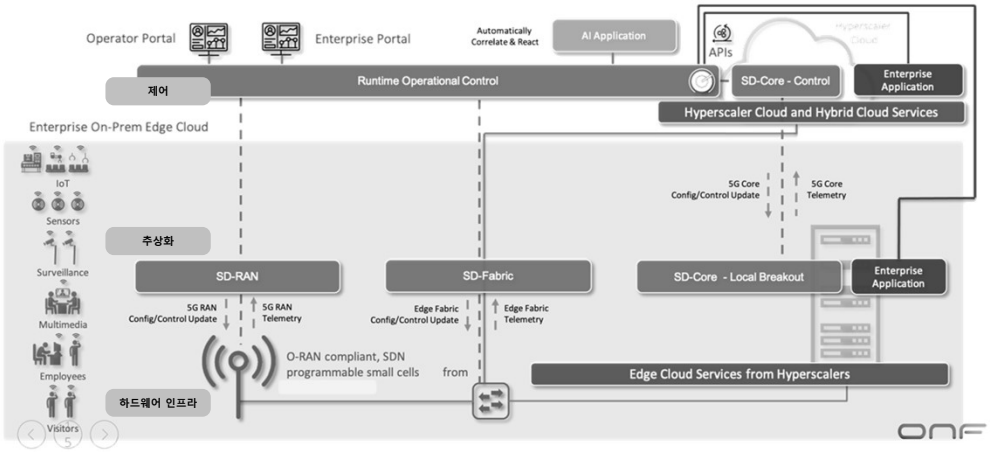
II. 엔터프라이즈 USE CASE

❖ **Aether: 엔터프라이즈의 DT을 위한 5G 커넥티드 에지 플랫폼 오픈소스**

Aether

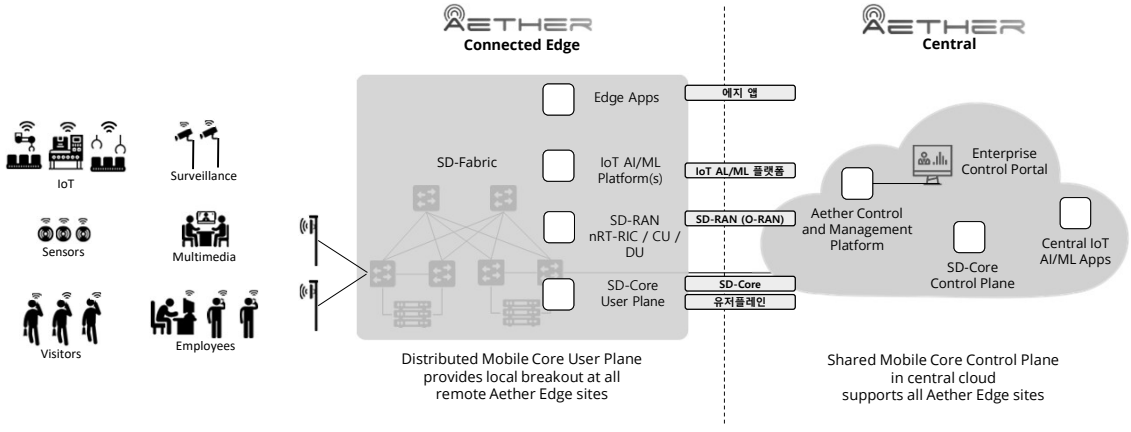


Source: https://opennetworking.org/wp-content/uploads/2020/12/Spotlight-OPs-1.pdf

65

II. 엔터프라이즈 USE CASE

❖ **Aether: 5G/LTE Private Edge Cloud**



Source: https://opennetworking.org/sd-fabric/

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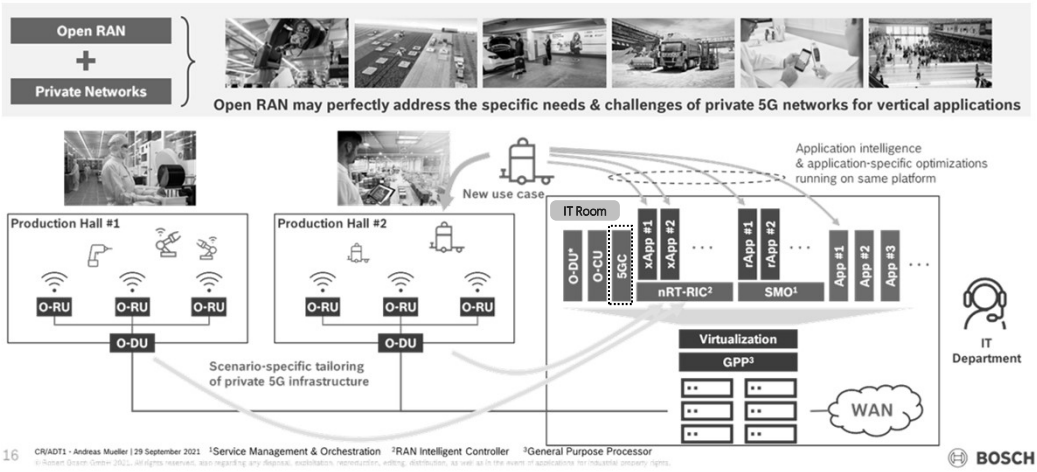
II. 엔터프라이즈 USE CASE

❖ **Private 5G & Open RAN (예): Bosch**



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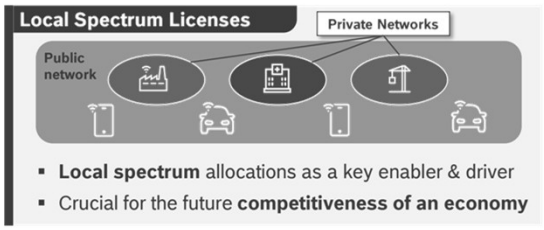
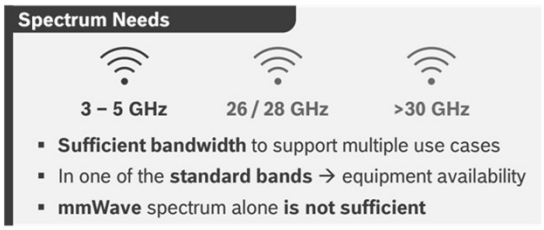
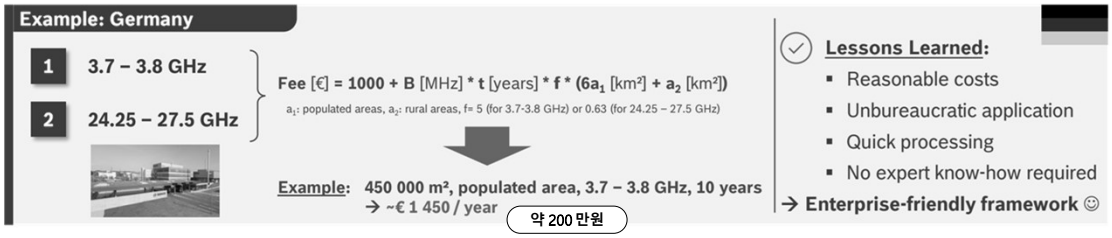
II. 엔터프라이즈 USE CASE

❖ **Local Spectrum as a Key Enabler** (예: Bosch)







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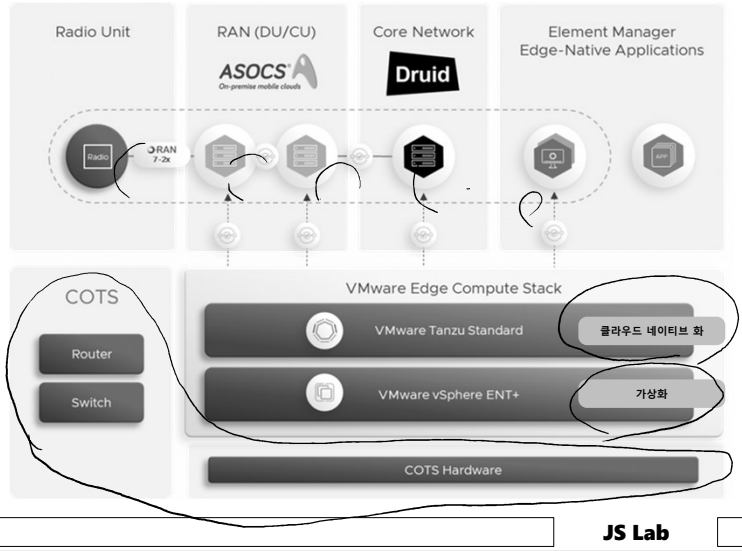
II. 엔터프라이즈 USE CASE

❖ **Private 5G at the Enterprise Edge** (예: VMware)



Source: https://blogs.vmware.com/telco/private-5g/

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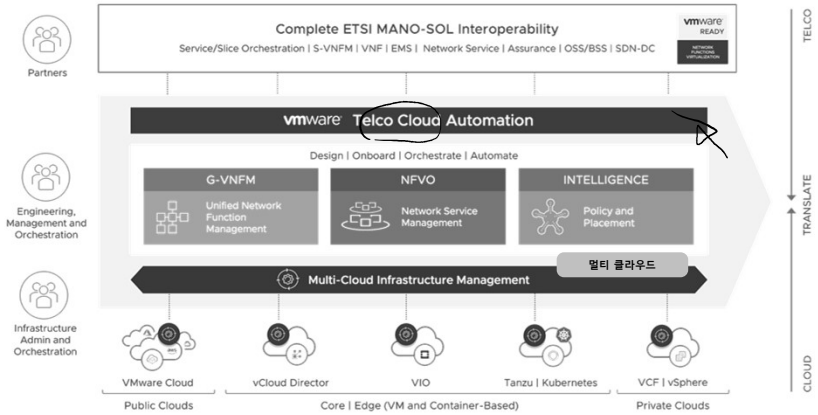
II. 엔터프라이즈 USE CASE

❖ 오픈소스 수용 제조사의 Telco Cloud 정책 (VMware 예)

- 오픈스택(OpenStack), 쿠버네티스(Kubernetes) 수용 자동화
- 오픈소스 기반 파트너 생태계 형성



Source: https://blogs.vmware.com/telco/introducing-telco-cloud-automation/

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II. 엔터프라이즈 USE CASE

❖ **Red Hat OpenShift as a 5G NFV platform**

5G RAN

Source: Red Hat

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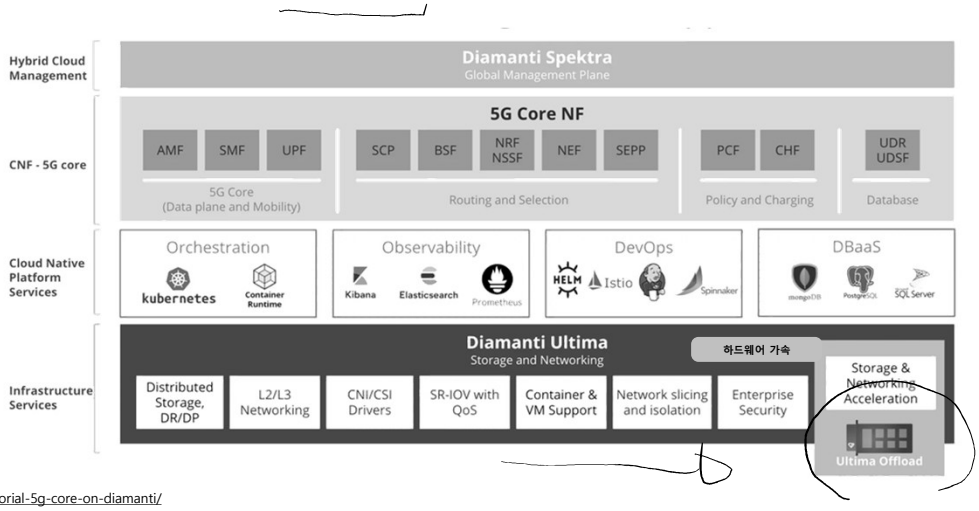
II. 엔터프라이즈 USE CASE

❖ **Full Stack for running 5G core** (예: Diamanti)



Source: https://diamanti.com/tutorial-5g-core-on-diamanti/

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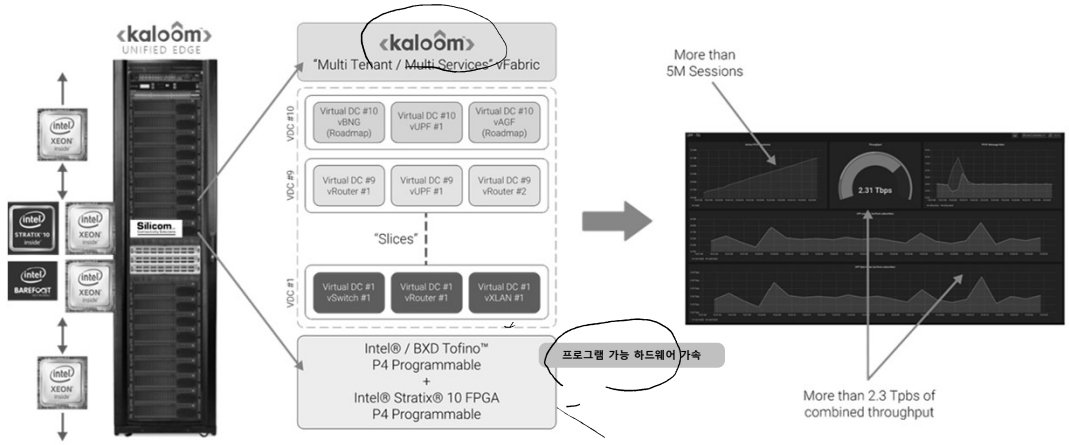
II. 엔터프라이즈 USE CASE

❖ **Data Plane 가속 (예): 엣지를 위한 컨테이너 플랫폼의 P4 사용**



Source: https://www.kaloom.com/partners/intel/fpga

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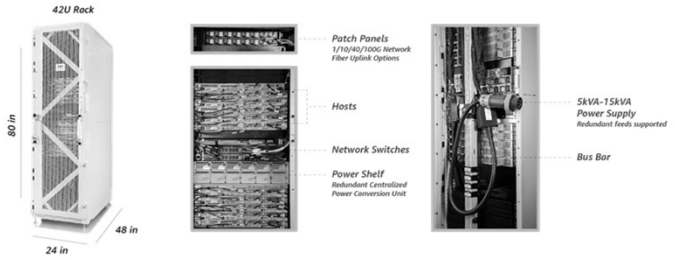
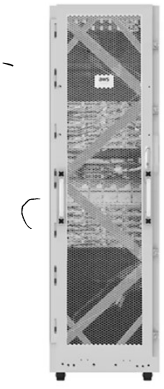
II. 엔터프라이즈 USE CASE

❖**Outposts 실행 가능 AWS 서비스**(AWS Native 또는 VMware 모드 제공)

- **컴퓨트: Amazon EC2, Amazon ECS, Amazon EKS**
- **스토리지: Amazon EBS**
- **데이터베이스: Amazon RDS (Preview)**
- **분석: Amazon EMR**





Source: https://aws.amazon.com/ko/outposts/specs/

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III. 5G Access Network 구조

- NR 과 Access Network
- Access Network 기술 과 기기

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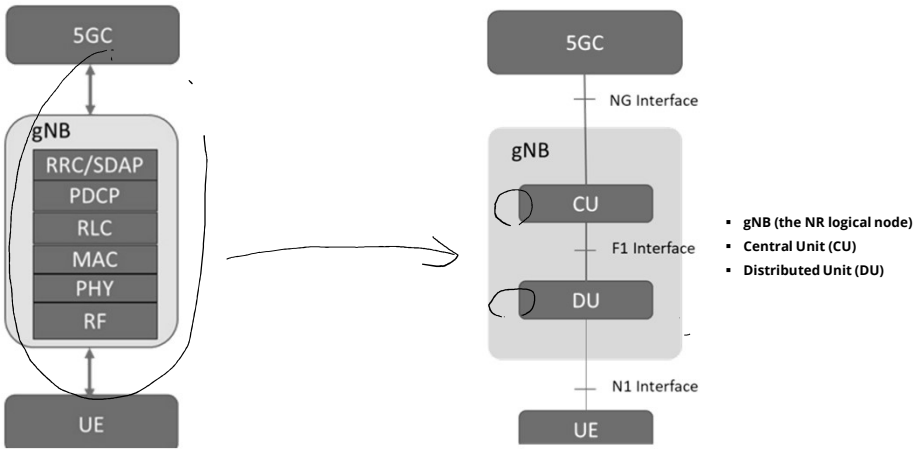
III. 5G ACCESS NETWORK 구조

❖ RAN 구조의 변화 (New C-RAN/Fronthaul)



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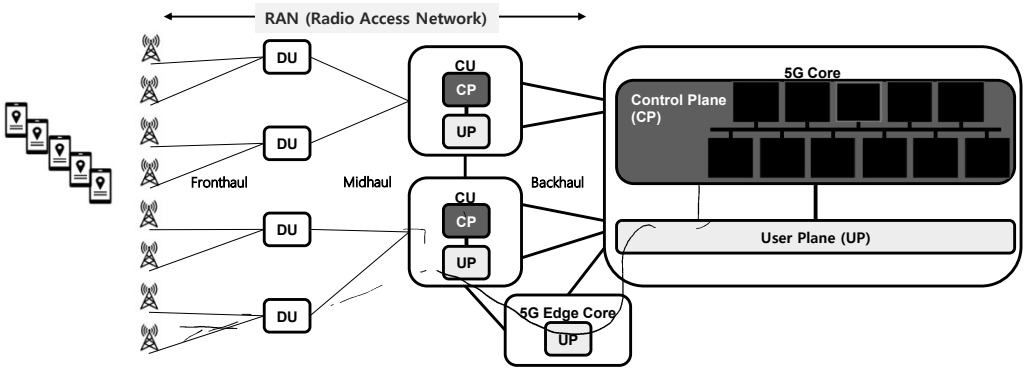
III. 5G ACCESS NETWORK 구조

❖ 5G Network Architecture

- **Open Systems Interconnection Layer.**
  - **CU** (Centralized Unit) / **DU** (Distributed Unit)
  - **UP** (User Plane) / **CP** (Control Plane)



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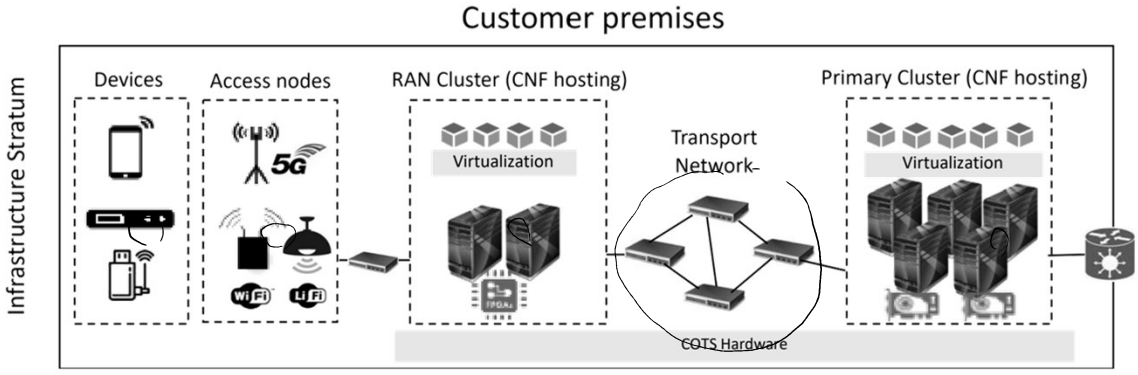
III. 5G ACCESS NETWORK 구조

❖ 인프라 계층 (Infrastructure stratum)



Source: 5GPPP Architecture Working Group, 5G Architecture White Paper

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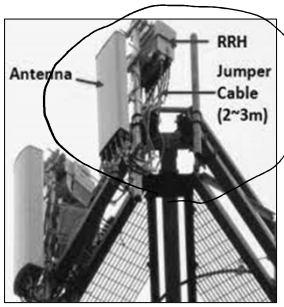
III. 5G ACCESS NETWORK 구조

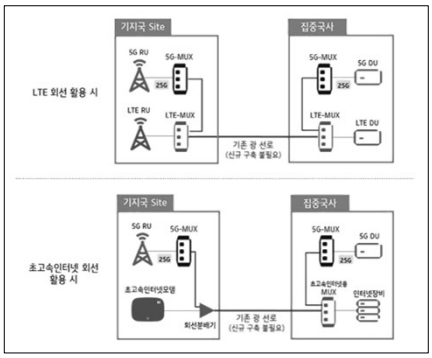
❖ 5G RAN 기기

- RRH(Remote Radio Head): RU를 외장형으로 구성
- 통신부품
- MUX
- 중계기



www.netmanias.com

KT가 5G 네트워크 '5G MUX'와 25G 광모듈 도입 구축/시험

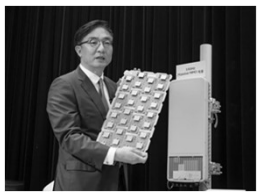


Source: 테크데일리(TechDaily) (http://www.techdaily.co.kr)

III. 5G ACCESS NETWORK 구조

❖ 5G RAN 기기

- RRH(Remote Radio Head): RU를 외장형으로 구성
- 통신부품
  - RF 필터
  - 안테나
  - 광트랜스퍼
  - RRH 케이스
- MUX: 프론트홀(RU-DU) 연결
- 중계기
  - 광중계기 (DAS: Distributed Antenna System)
  - RF 중계기 (ICS: Interference Cancellation System)
- DU (Distributed Unit)
- CU (Centralized Unit)



Kim Young-ki, head of Samsung Electronics' network business division, shows the firm's 5G network gear in a press conference at the tech firm's headquarters in Suwon, Gyeonggi Province, July 13. / Courtesy of Samsung Electronics

- 중계기 기업 (기타)
  - 에프알텍
  - CS
  - 기산텔레콤 등

5G 주요 업체 List

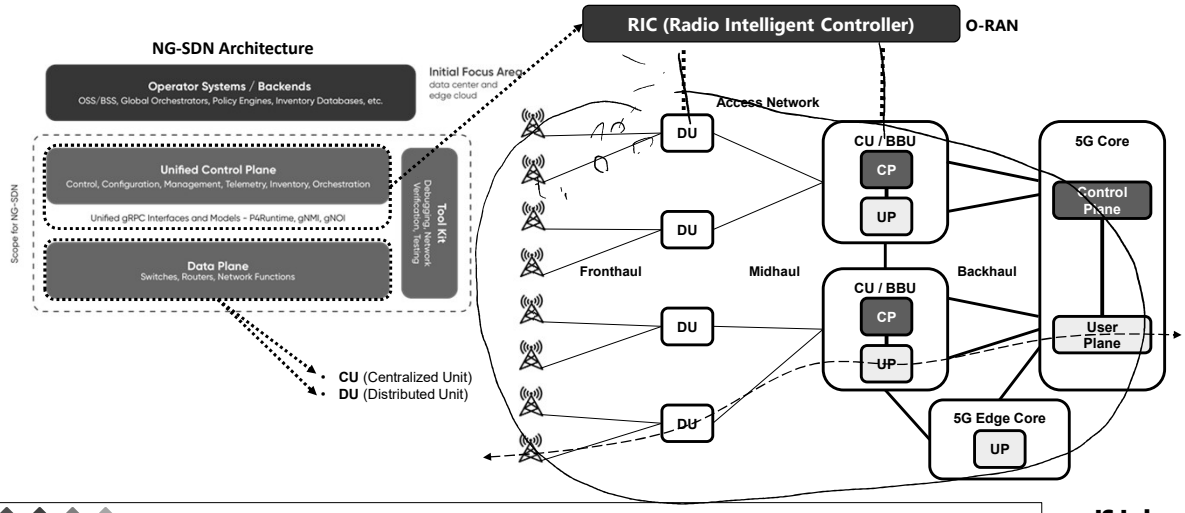
	주요 제품 및 사업	주요 기업
무선통신장비	안테나, RRH, RF부품	케이엠더블유, 에이스테크
	광트랜시버	오이솔루션
	프론트홀 장비	에치에프알, 쏠리드
	중계기	에치에프알, 쏠리드
	기지국 장비 케이스	서진시스템
	GaN트랜지스터	RFHIC
유선네트워크장비	FTTX, 스위치 장비	유비쿼스, 다산네트웍스, 에치에프알, 머큐리
	광트랜시버	오이솔루션
시험인증	인증	에이치시티

자료: 신한금융투자

Source: https://m.blog.naver.com/PostView.naver?isHttpsRedirect=true&blogId=atlasstock&logNo=221559939410

III. 5G ACCESS NETWORK 구조

❖ O-RAN과 '프론트홀/미드홀/백홀'



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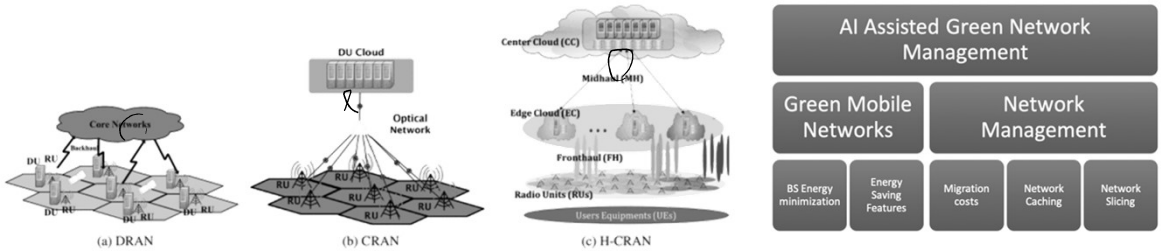
III. 5G ACCESS NETWORK 구조

❖ Data Driven AI Assisted Green Network Design and Management

- DRAN
- CRAN
- H-CRAN



Source: http://kth.diva-portal.org/smash/get/diva2:1626735/FULLTEXT01.pdf?fbclid=IwAR1F1GlV3bU_YONZzxElLtb4kp_Y7t70VczSb_0abIVqJZxt2ErbJ60UuAg

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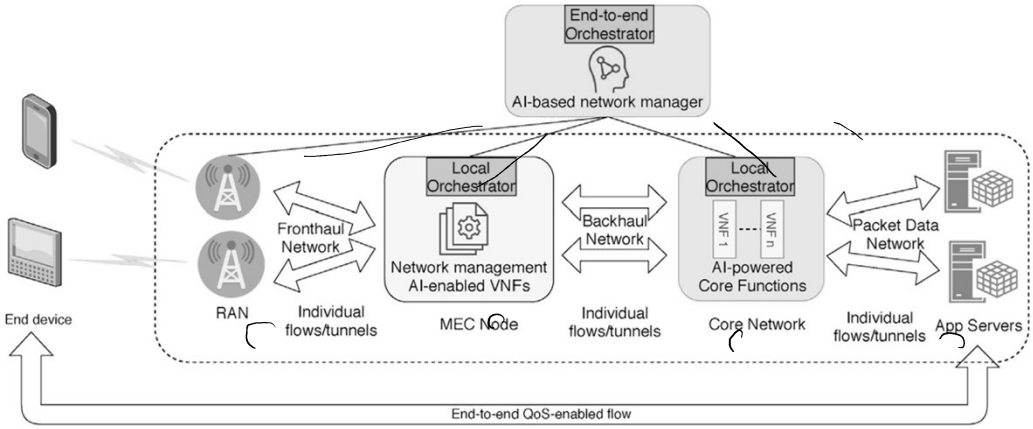
III. 5G ACCESS NETWORK 구조

❖ Overall Zero-touch Network and Service Management (ZSM) vision.



Source: Machine learning-based zero-touch network and service management, Jorge Gallego-Madrid,, Ramon Sanchez-Iborra, Pedro M. Ruiz, Antonio F. Skarmeta

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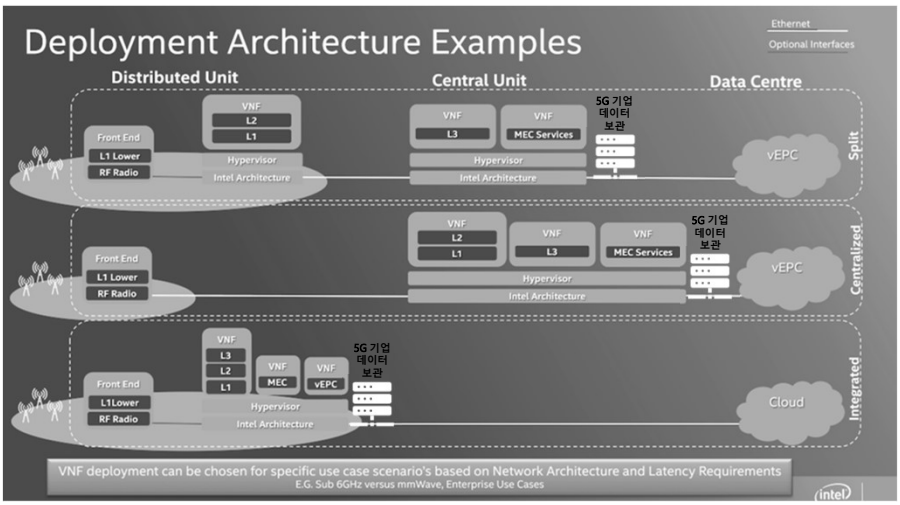
III. 5G ACCESS NETWORK 구조

❖ 5G RAN 구성 (예): 인텔의 FlexRAN

분할(Split)

중앙집중(Centralized)

통합(Integrated)



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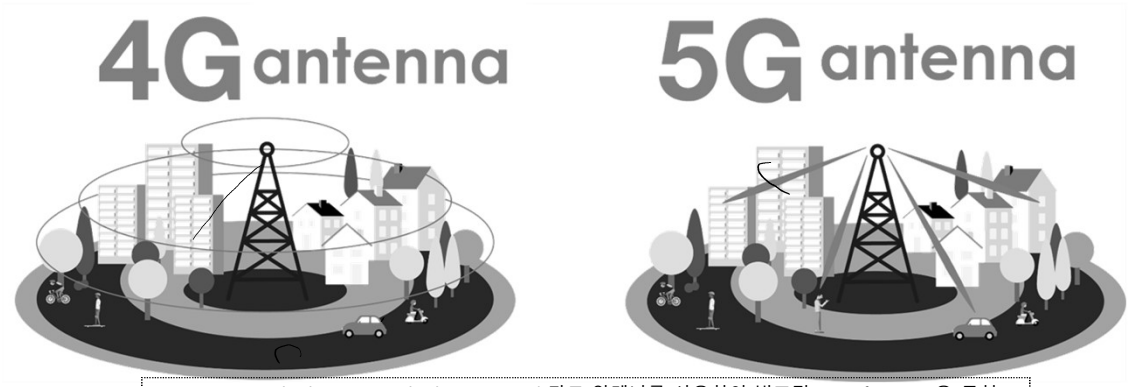
III. 5G ACCESS NETWORK 구조

❖ 5G는 더 큰 대역폭의 스펙트럼을 사용

❖ 5G 안테나는 빔포밍 기술을 이용하여 동일 주파수를 반복 사용하며 무선 대역폭을 확대



- MIMO (Multiple Input Multiple Output) 스마트 안테나를 사용하여 빔포밍(Beamforming)을 구현

Source: https://radio-waves.orange.com/en/radio-networks-and-antennas/5g/

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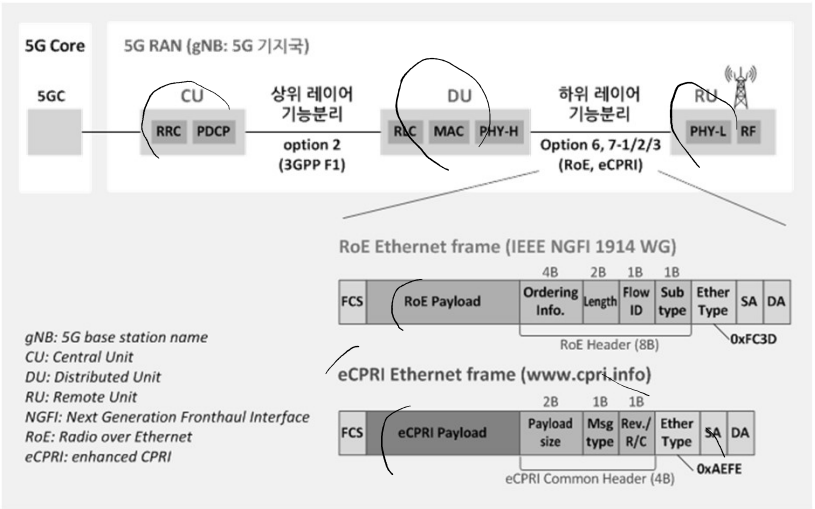
III. 5G ACCESS NETWORK 구조

❖ 5G Access Network의 Multiple-Split 구조 (Two-Level Fronthaul)



Source: 넷매니아즈

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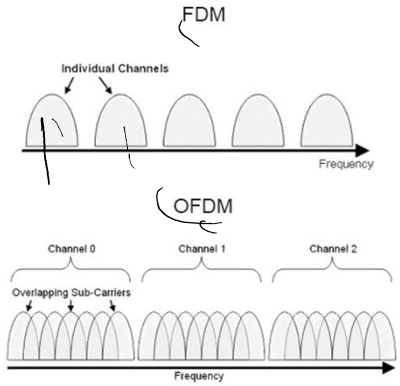
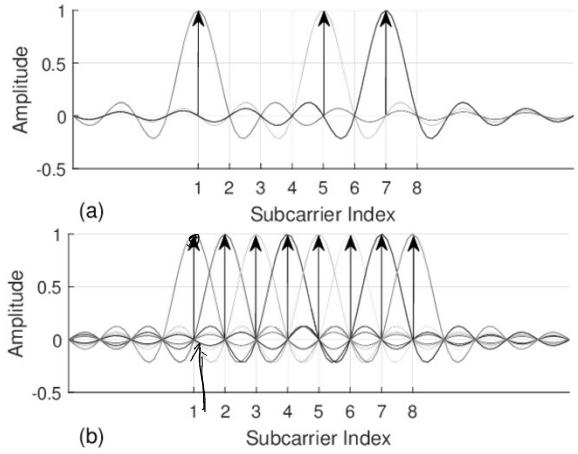
III. 5G ACCESS NETWORK 구조

- ❖ **Waveforms and Mixed-Numerology**
- ❖ **Spectrum of OFDM signals with , depicted by the dashed line.**





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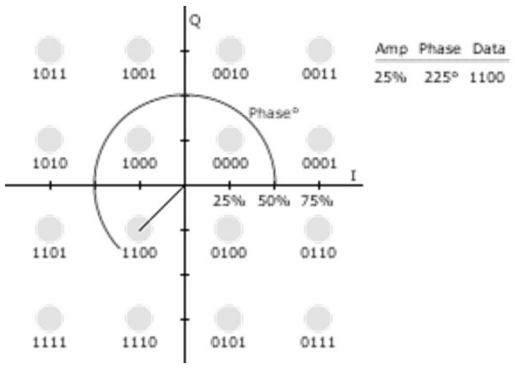
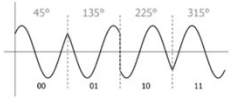
III. 5G ACCESS NETWORK 구조

- ❖ **OFDM: Orthogonal Frequency Division Multiplexing**
- ❖ **QAM은 signal space(신호 공간) 개념과 복소평면을 사용 constellation 표현**

16-QAM의 constellation (예)





64-QAM의 constellation (예)

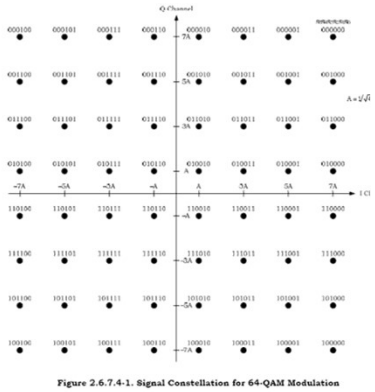


Figure 2.6.7.4-1. Signal Constellation for 64-QAM Modulation

Source: https://namu.wiki/w/%EB%B3%80%EC%A1%B0(%ED%86%B5%EC%8B%A0)

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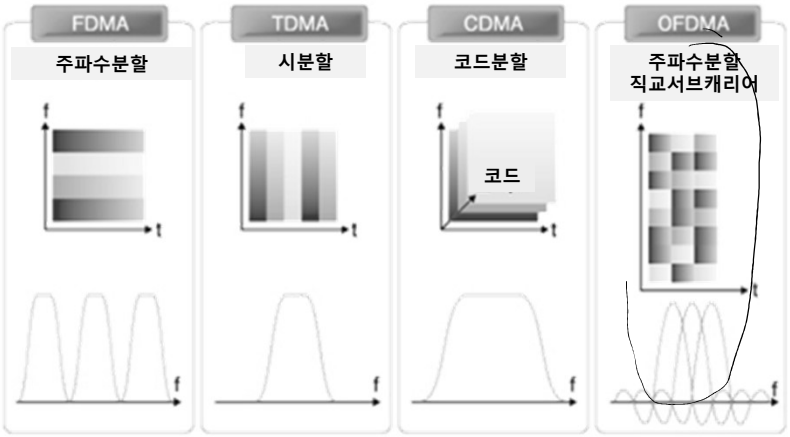
III. 5G ACCESS NETWORK 구조

❖ FDMA, TDMA, CDMA, OFDMA



Source: https://www.atmarkit.co.jp/ait/articles/1005/13/news092.html

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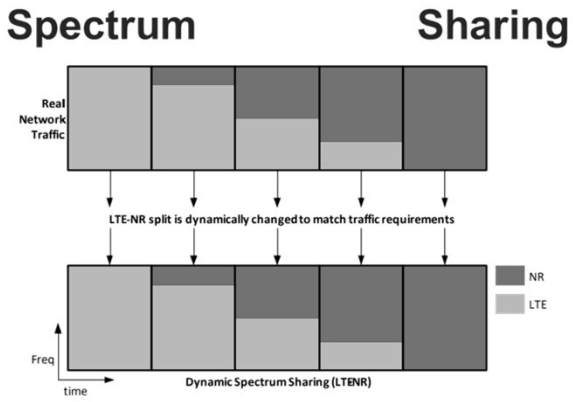
III. 5G ACCESS NETWORK 구조

❖ Dynamic Spectrum Sharing

Dynamic

"**Dynamic**" is the key

- The split between LTE and NR can be changed at any time
- **Advantages**: Can adapt to traffic demands; rollout is possible with a software upgrade
- **Disadvantages**: Scheduling complexity



KEYSIGHT TECHNOLOGIES

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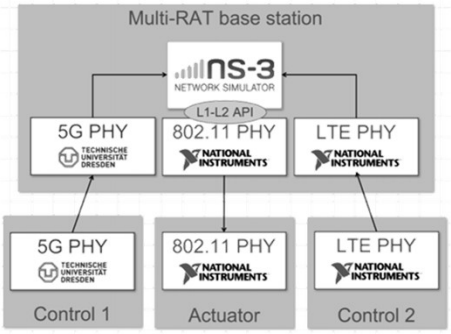
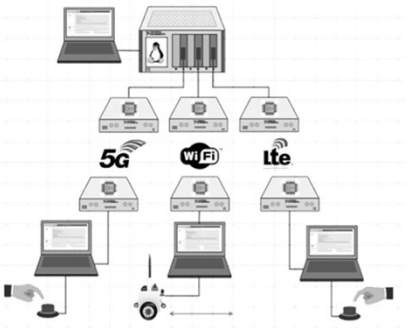
III. 5G ACCESS NETWORK 구조

❖ 무선 계층의 추상화로 다양한 무선 기술 수용

- WiFi등의 비면허 무선 기술을 5G에 수용
- Multi-RAT (Radio Access Technology)
- SDR (Software Defined Radio, 소프트웨어 정의 라디오)





Source: https://www.netmanias.com/ko/?m=view&id=oneshot&no=14450

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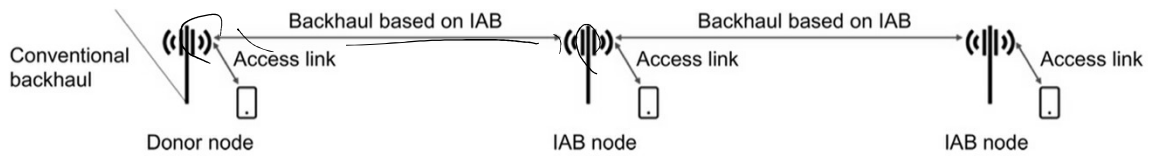
III. 5G ACCESS NETWORK 구조

❖ Integrated Access and Backhaul

- WiFi등의 비면허 무선 기술을 5G에 수용
- Multi-RAT (Radio Access Technology)
- SDR (Software Defined Radio, 소프트웨어 정의 라디오)



Source: The Next Generation Wireless Access Technology Second, Edition Erik Dahlman Stefan Parkvall Johan Sköld

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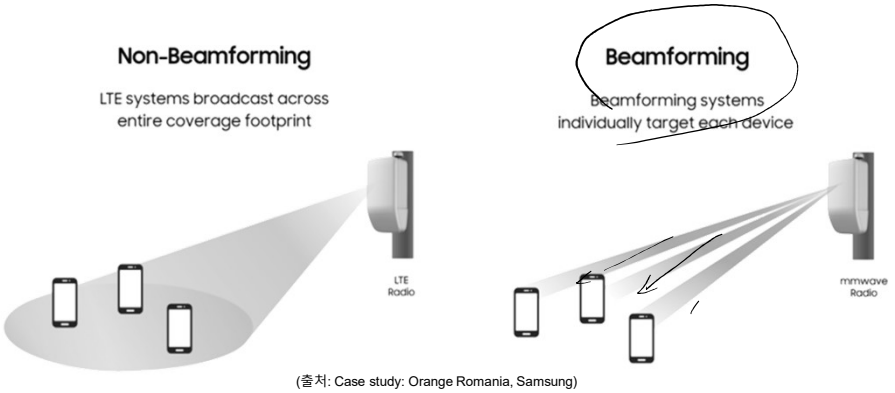
III. 5G ACCESS NETWORK 구조

❖ 기존 안테나와 Beamforming 비교

❖ 빔포밍은 동일 주파수를 재사용하며 지향성으로 고속도 지원



(출처: Case study: Orange Romania, Samsung)

빔포밍(Beamforming): 빔 스티어링은 모든 방사 요소에서 입력 신호의 위상을 변경함으로써 달성하며, 위상변조를 통해 신호가 특정 수신기를 대상으로 할 수 있음

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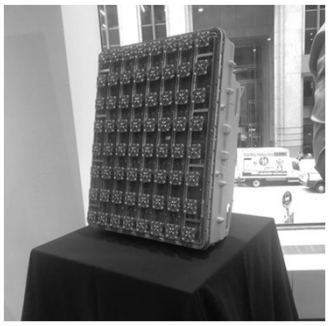
III. 5G ACCESS NETWORK 구조

❖ Massive MIMO (예)

64 TX + 64 RX 5G MU-MIMO antenna suitable for Massive MIMO, (Credit: Ericsson)

Aurora CMM.100.A 5-6GHz C-Band Massive MIMO Phased Array



Massive MIMO has traditionally been used in TDD bands. (Bevin Fletcher/FierceWireless)

Source: https://medium.com/5g-nr/massive-mimo-75f775ead2e9
Source: https://www.fiercewireless.com/tech/t-mobile-exec-says-massive-mimo-can-be-used-tdd-and-fdd-bands

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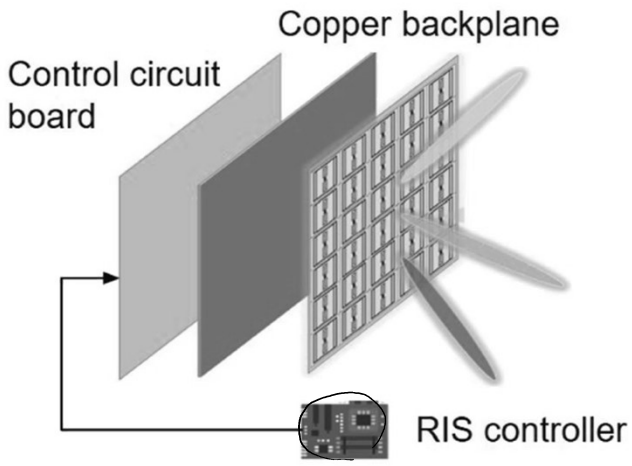
III. 5G ACCESS NETWORK 구조

❖ O-RAN의 RIC(RAN Intelligent Controller) 제어



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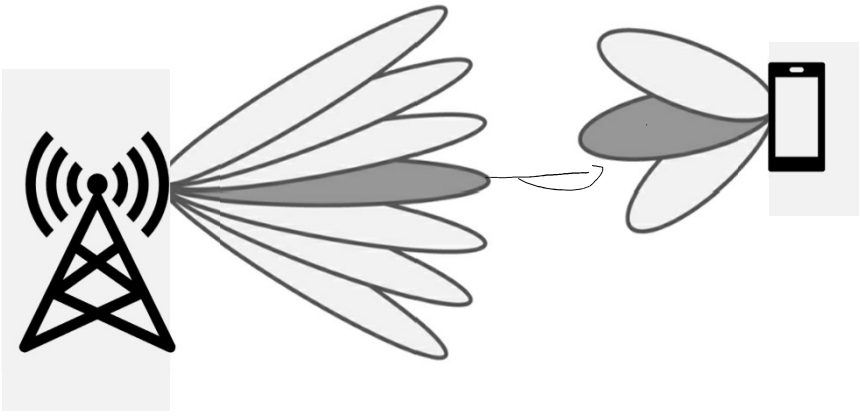
III. 5G ACCESS NETWORK 구조

❖ Downlink

❖ Uplink



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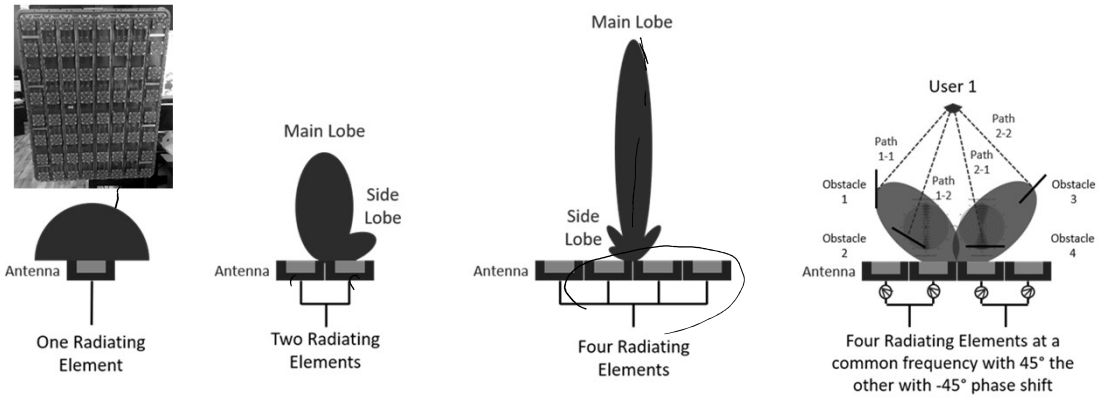
III. 5G ACCESS NETWORK 구조

❖ 빔포밍 (What is 5G beamforming?)

• 무선의 위상제어(Beam steering): 위상변화를 수신자 목표로 지향성 무선 신호를 송신



Source: https://www.metaswitch.com/knowledge-center/reference/what-is-beamforming-beam-steering-and-beam-switching-with-massive-mimo

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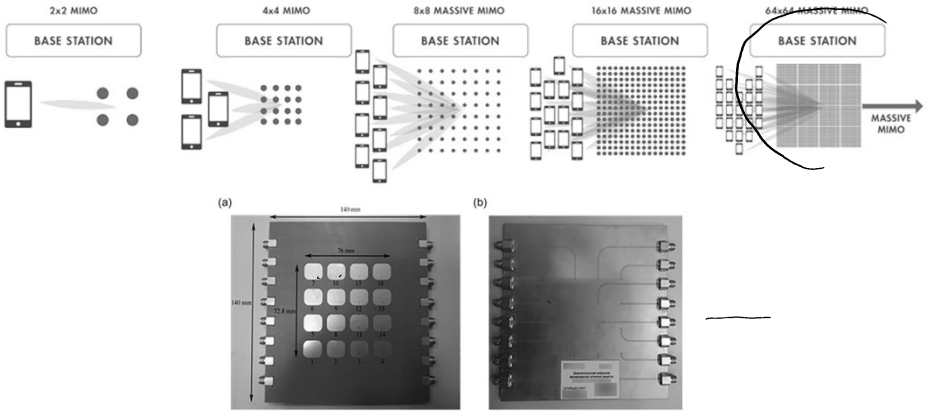
III. 5G ACCESS NETWORK 구조

❖ Massive MIMO: 일반 주파수를 동시에 여러 방향으로 전송

❖ 동일 주파수 중복 사용



Source: https://www.dolcera.com/web/blog/massive-mimo-a-boost-for-next-gen-5g-wireless-communication/

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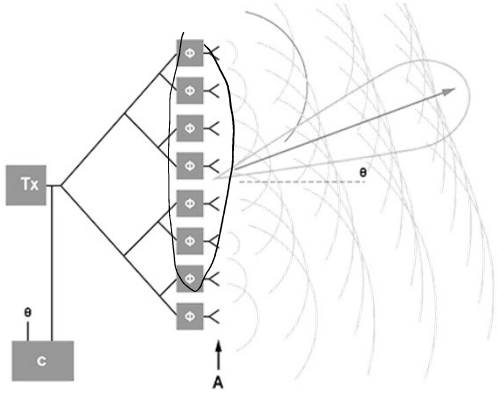
III. 5G ACCESS NETWORK 구조

❖ 5G beamforming

• Phased array antenna systems enable beamforming and steering



(Source: Analog Devices)

Source: https://www.avnet.com/wps/portal/abacus/solutions/markets/communications/5g-solutions/5g-beamforming/

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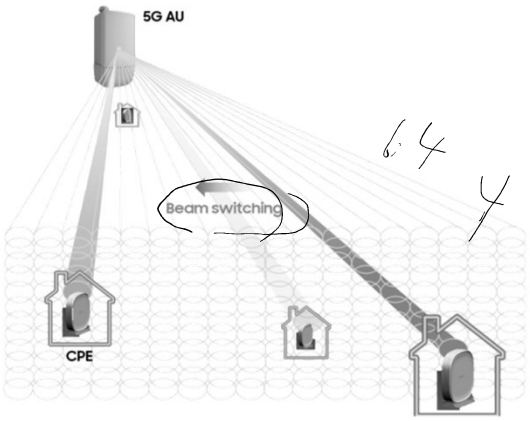
III. 5G ACCESS NETWORK 구조

❖ **빔스위칭 (Beam switching):** 무선 시스템은 범위 제한을 극복하기 위해 이들 대상 중 몇 개를 동시에 대상으로 할 수 있으며, 전체적으로 무선 에너지에 초점을 맞추며, 전체 그리드를 커버하기 위해 스케줄링 알고리즘에 따라 빔이 각 장치 사이를 빠르게 전환



Source: Case study: Orange Romania, Samsung

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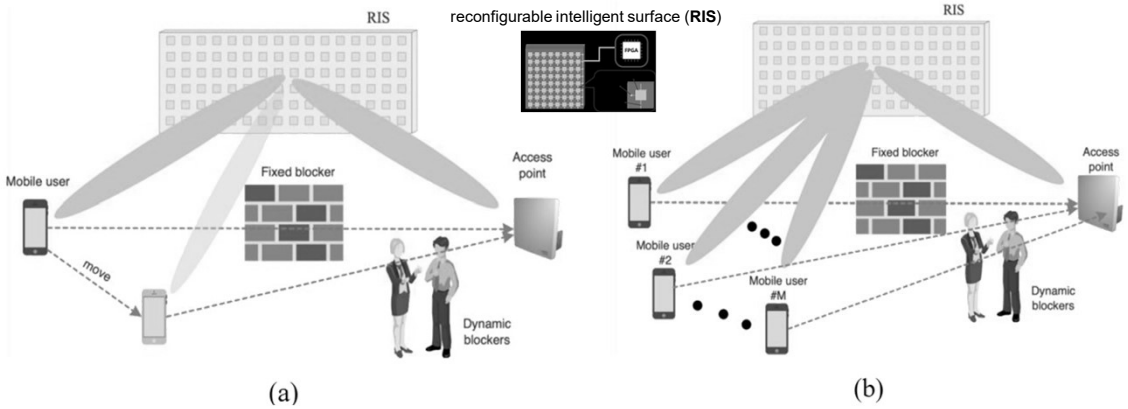
III. 5G ACCESS NETWORK 구조

❖ (a) RIS-assisted beamforming, and (b) RIS-assisted broadcasting



Source: 5GPPP Architecture Working Group, 5G Architecture White Paper

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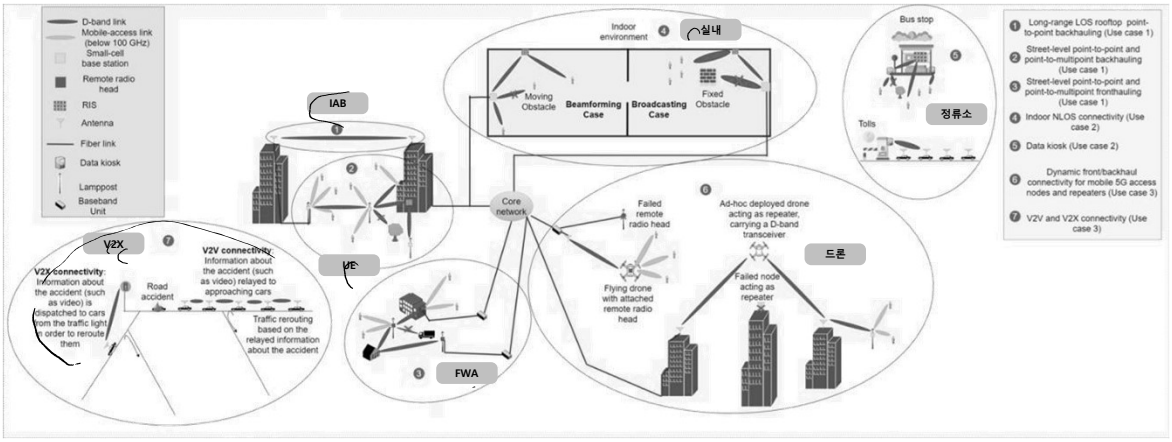
III. 5G ACCESS NETWORK 구조

❖ Reconfigurable surfaces deployment scenarios



Source: 5GPPP Architecture Working Group, 5G Architecture White Paper

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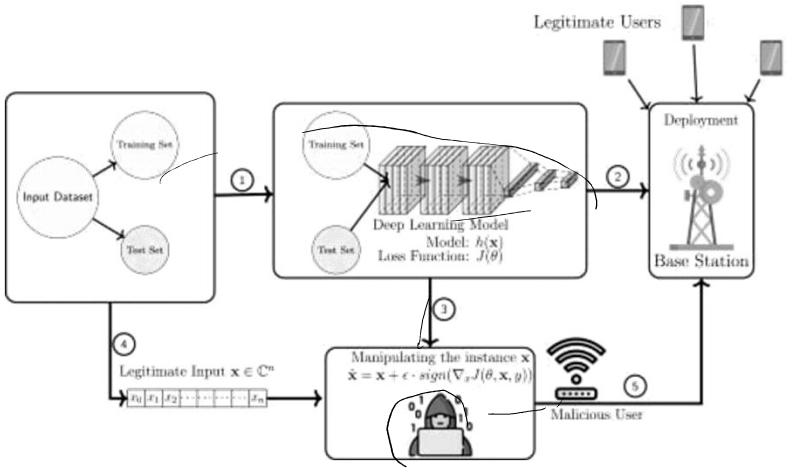
III. 5G ACCESS NETWORK 구조

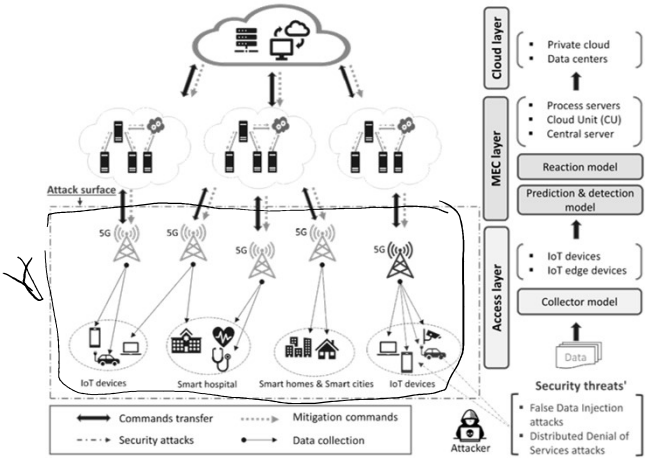
❖ **Security concerns on machine learning solutions for 6G networks in mmWave beam prediction**



Source: https://www.sciencedirect.com/science/article/pii/S1874490722000155?fbclid=IwAR3pITAJqU92g4ByHS7FsCond6Xih9DdKIbmqXjuubDRtXb2tko8kPSX-4E

III. 5G ACCESS NETWORK 구조

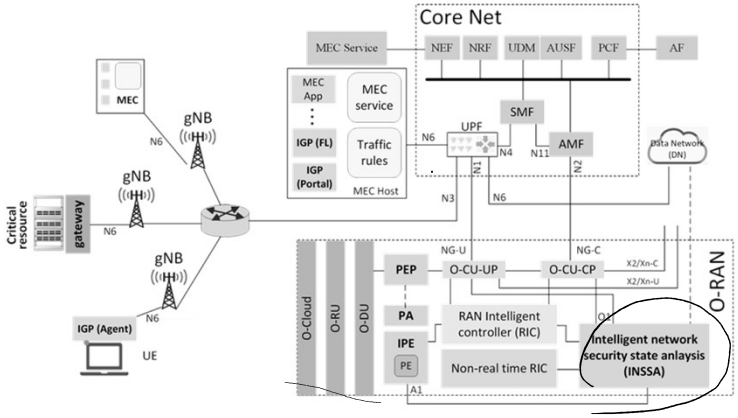
❖ **Prediction and Detection of FDIA and DDoS Attacks in 5G Enabled IoT**



Source: https://arxiv.org/pdf/2201.11368.pdf?fbclid=IwAR2Ac8ltnbsCloAZkAXCLAXxFQdVGiX7xTlPlvj217yM7k8cUuhUz8GV0Cg

III. 5G ACCESS NETWORK 구조

❖ Intelligent Zero Trust Architecture(iZTA) for 5G/6G Networks: Principles, Challenges, and the Role of Machine Learning in the context of O-RAN



Source: https://arxiv.org/pdf/2201.11368.pdf?fbclid=IwAR2Ac8ltnbsCloAZkAXCLAXxFQdVGiX7xTlPlvj217yM7k8cUuhUz8GV0Cg

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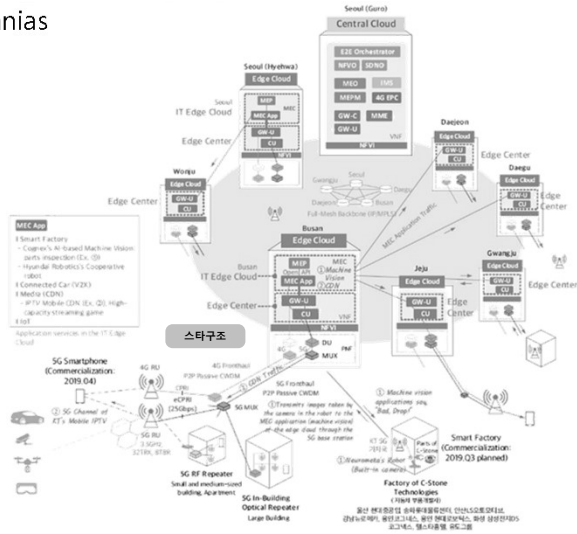
III. 5G ACCESS NETWORK 구조

❖ **현재 통신사업자의 망 구성 (KT)** – by Netmanias

kt 5G VS SKT 5GX



Source: https://www.netmanias.com/ko/?m=view&id=oneshot&no=14450

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III. 5G ACCESS NETWORK 구조

❖ **현재 통신사업자의 망 구성 (SKT)** – by Netmanias

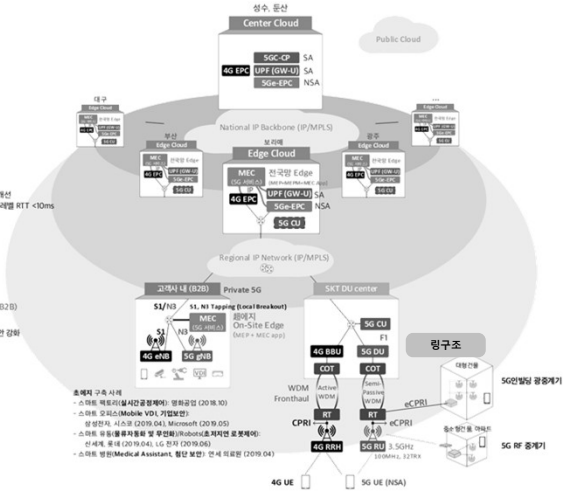
kt 5G vs SKT 5GX

센터 클라우드

2019. 07.18 발표 에지 클라우드 12개
(위치: 교환국)
5GX Edge (전국망 Edge, B2C)
- Distributed Edge라고도 함
- 이동형 단말에 전국 망 서비스
- 대용량 데이터 초저지연 전송, 고객 품질 개선
- 단말과 에지간 망 RTT delay ~ 3ms, 응용레벨 RTT <10ms
- 사례: VR, AR, Streaming, V2N
- Public Cloud와도 연동

2019. 08.13 발표 5GX 超Edge (On-Site Edge, B2B)
- 고객 부지 내 저지연/보안 인감 서비스
- 기업, 공공 데이터의 실시간 전처리 및 보안 강화
- Public Cloud와도

셀사이트



Source: https://www.netmanias.com/ko/?m=view&id=oneshot&no=14450

IV. 기업을 위한 5G 특화망

이음(e-Um) 5G

- **5G 특화망 기술**
- **제조사 솔루션**
- **설계 및 구축**

james@jslab.kr

IV. 기업을 위한 5G 특화망

❖ 비즈니스(예): 네이버클라우드, 국내 첫 5G 특화망 사업자 등록…통신망 직접 구축

- 네이버 2사옥에 구축된 5G로 자율주행 로봇 서비스
- 네이버랩스 개발 로봇 자율주행 용도 5G 구축

2021년 12월 28일 과기정통부는 5G특화망을 '이음(e-Um) 5G'라는 새 이름으로 부를 계획이라고 밝혔다.

과기정통부는 한국방송통신전파진흥원과 함께 2021년 11월29일부터 12월17일까지 5G특화망 새 이름 공모전을 진행한 결과 총 3천300여건이 제출됐고 관련 전문가로 구성된 심사위원회를 거쳐 6개의 당선 명칭을 선정

Source: https://zdnet.co.kr/view/?no=20211228110405

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IV. 기업을 위한 5G 특화망

❖ 비즈니스(예): LG CNS가 5G 특화망을 신청하고 스마트팩토리에 5G를 결합해 디지털 전환 사업을 추진

5G 특화망과 5G 이동통신망 비교

	5G 특화망	5G 이동통신망
서비스 범위	생산 기지, 건물 등	전국
서비스 기업	LG CNS 등 수요기업, 기관	이동통신사업자
서비스 대상	수요기업, 기관, 기업 고객(B2B)	이동통신 가입 소비자(B2C)
주요 활용처	스마트팩토리, 원격제어 등 다양	음성, 데이터 중심
주파수 대역	4.7GHz, 28GHz	3.5GHz, 28GHz

Source: https://www.inews24.com/view/1456796

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IV. 기업을 위한 5G 특화망

❖ 비즈니스(예): LG유플러스는 6일 네트워크 인프라 개선에 활용할 미래 클라우드 기술을 확보하기 위해 아마존웹서비스 코리아와의 네트워크 클라우드 기술 개발

- 5G 네트워크 인프라에 클라우드 기술 도입
- DX 기술을 활용한 네트워크 품질 향상 방안 연구
- AWS의 미래기술의 선제적 실증 등 협력

Source: https://n.news.naver.com/article/014/0004798468?cds=news_my&fbclid=IwAR1NgYO-AXNBk8yzprzyN3IS8684BzLRaHD12b8c9AhWUIY7c5aczEC5D7I

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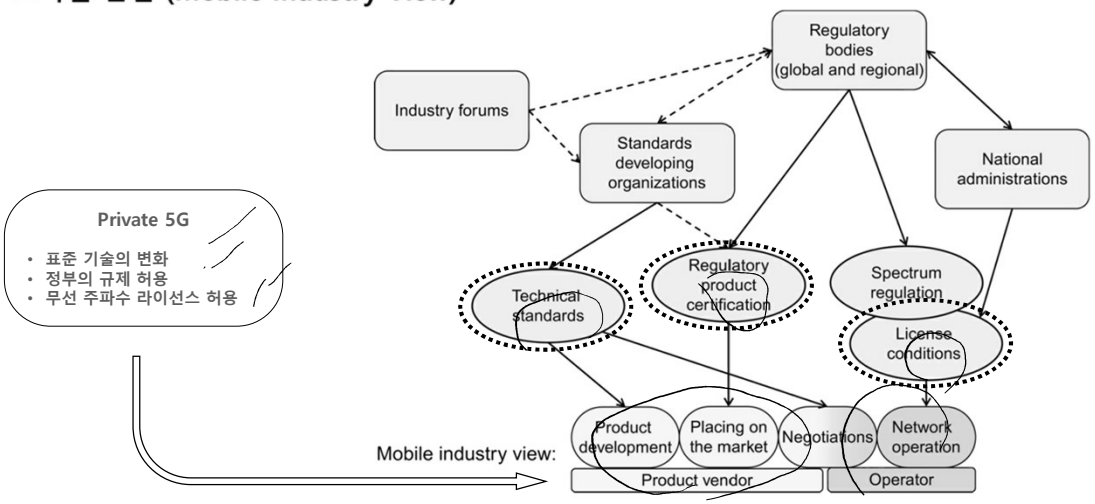
IV. 기업을 위한 5G 특화망

❖ 모바일 산업 (Mobile Industry View)



Source: The Next Generation Wireless Access Technology Second, Edition Erik Dahlman Stefan Parkvall Johan Sköld

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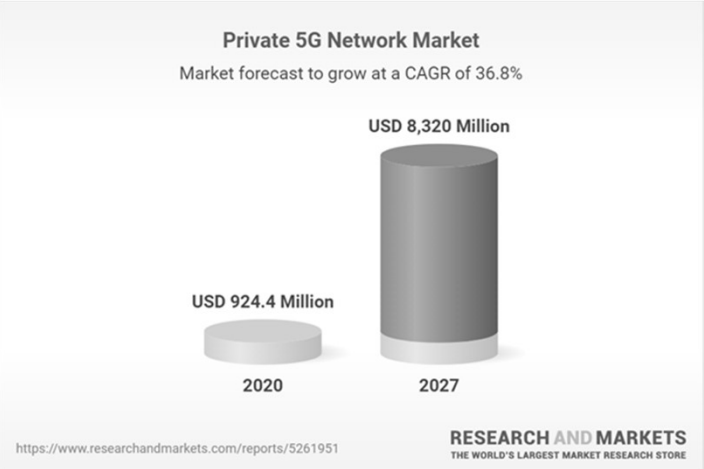
IV. 기업을 위한 5G 특화망

❖ Private 5G Network Market

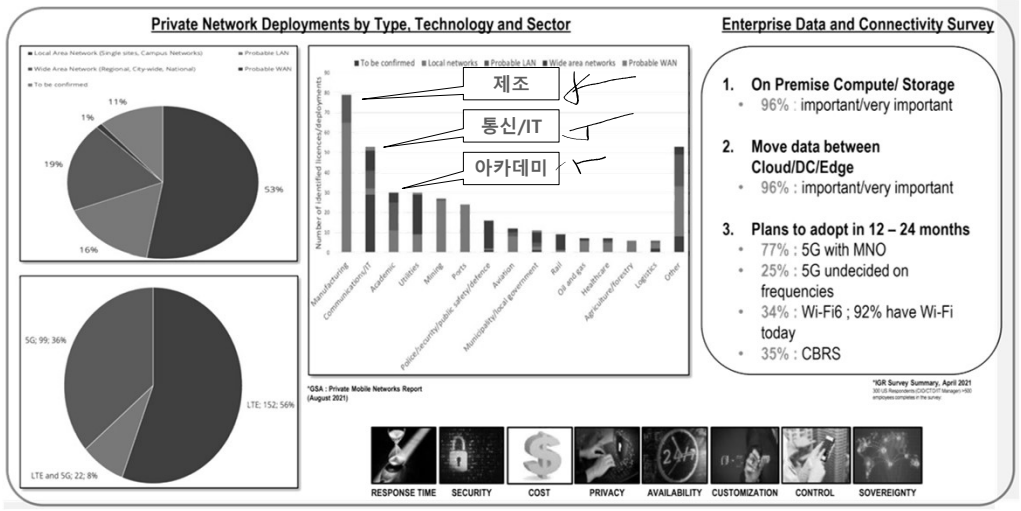
• CAGR 36.8% 성장 전망



Source: https://www.researchandmarkets.com/reports/5261951/private-5g-network-market-share-size-trends

IV. 기업을 위한 5G 특화망

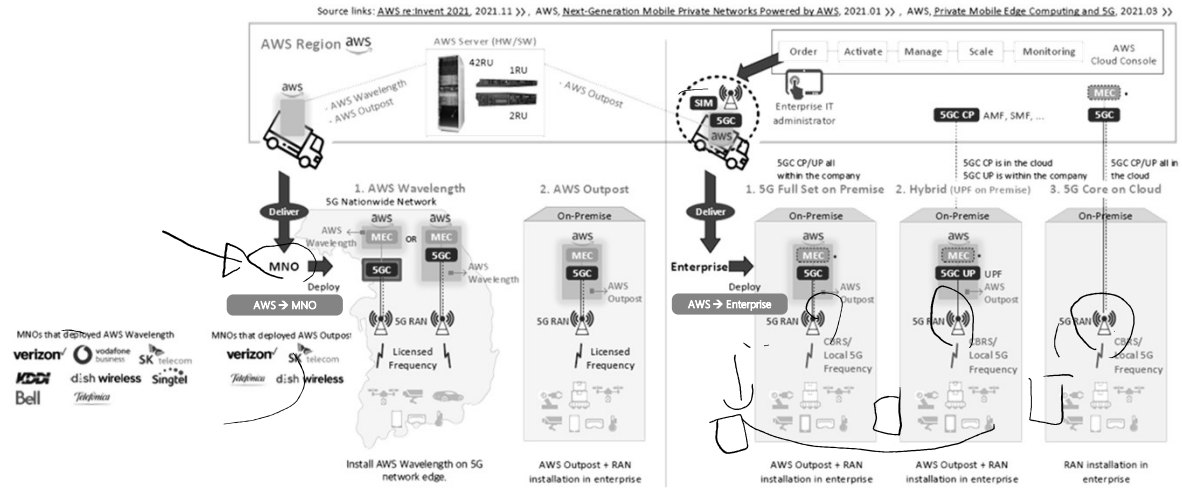
❖ Private Networks의 기회 (예: Intel)



MNO는 Mobile Network Operator로 통신망을 통해 독자적인 이동통신서비스를 제공하는 사업자

IV. 기업을 위한 5G 특화망

❖ **AWS Private 5G for enterprises and AWS Wavelength for mobile operators**



Source: https://www.netmanias.com/en/?m=view&id=oneshot&no=15352

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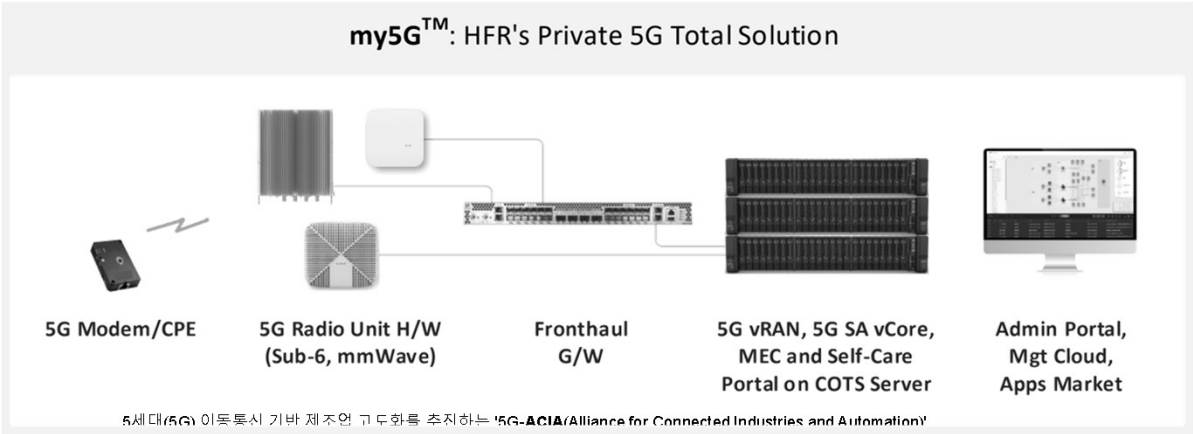
IV. 기업을 위한 5G 특화망

❖ **HFR's my5GR™ Solution: Private 5G Total Solution**



Source: https://www.netmanias.com/en/?m=view&id=blog&no=15161

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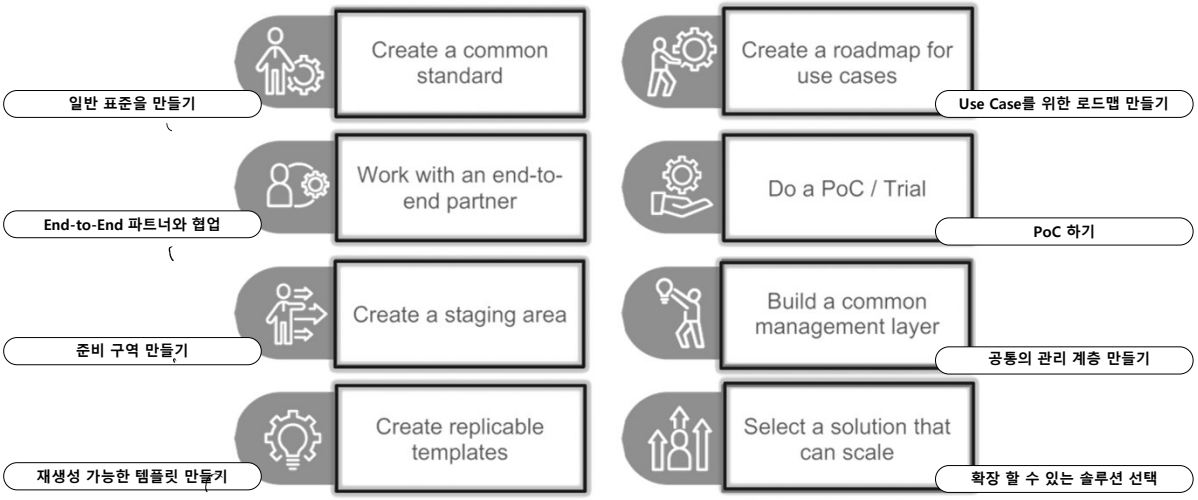
IV. 기업을 위한 5G 특화망

❖ 엔터프라이즈를 위한 가이드라인 (Guidelines for enterprises) 예: ONF



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IV. 기업을 위한 5G 특화망

❖ 커스터마이제이션/제어/비용 (예: GSMA Intelligence, GSMA IoT Programme)

Groupe Speciale Mobile Association (GSMA)

Public network	Public network with SLAs	Public network with slicing	Public network with local infrastructure	Private network (operator spectrum)	Private network (non-operator spectrum)
• Efficient use of infrastructure and spectrum • Mobile edge computing within public network	• Operator expertise and spectrum portfolio • Superior customer support and SLAs	• Dedicated and customised network resources • Higher data isolation, security and privacy	• Dedicated network equipment • Choices regarding localisation of data/control • On-site mobile edge computing	• Isolated network • Managed service or leasing of spectrum • Customised design, operations and deployment	• Direct responsibility for spectrum access and usage • Independent design, operation, procurement and radio plan

Less customisation
Less control
Lower cost

커스터마이제이션/제어/비용 고려

More customisation
More control
Higher cost

Global System for Mobile Communications

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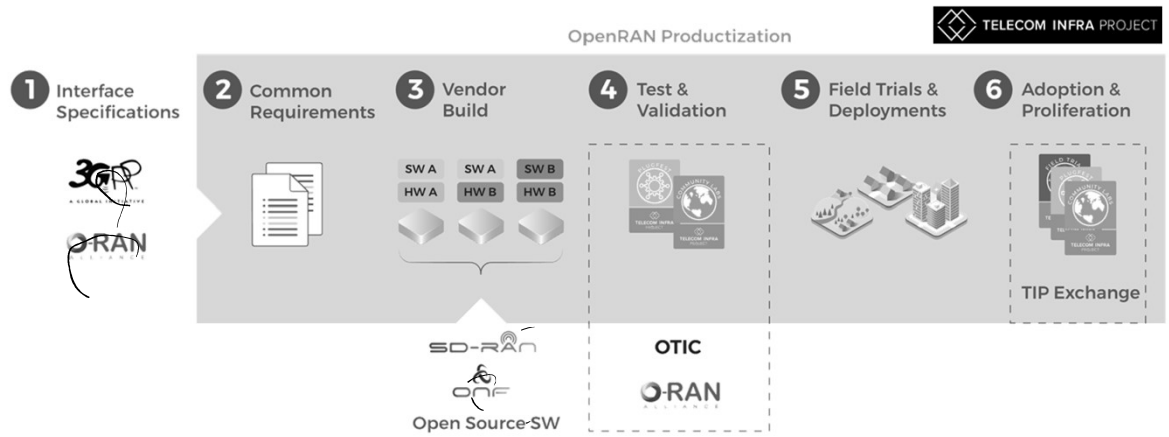
IV. 기업을 위한 5G 특화망

❖ **OpenRAN and Industry Collaboration**



Source: https://telecominfraproject.com/openran/

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IV. 기업을 위한 5G 특화망

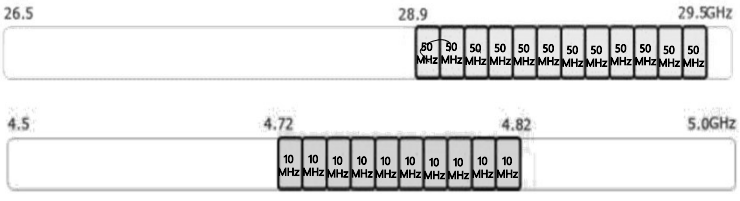
❖ **28㎓대역은 600㎒폭(28.9~29.5㎓)을 50㎒폭 12개 블록으로 나누어 수요기업의 신청에 따라 적정 대역폭을 공급**

❖ **6㎓이하(Sub-6㎓) 대역은 업계의 수요를 고려해 일부 지역에서만 사용하고 있는 기존 무선국 등과 주파수를 공동 사용하는 방식으로 4.7㎓ 대역 100㎒폭(4.72~4.82㎓)을 확보하였으며, 10㎒폭 10개 구역(블록)으로 나누어 수요기업의 신청에 따라 적정 대역폭을 공급**

< 5G 특화망 주파수 대역 표준현황 >

대 역	부반송파 간격	지원 대역폭(㎒)
4.7㎓(n79)	30㎑	40, 50, 60, 80, 100
28㎓(n257)	120㎑	50, 100, 200, 400

※ 3GPP 38.101-1 Table 5.3.5-1 Channel Bandwidths for Each NR band('21.10월 기준)



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IV. 기업을 위한 5G 특화망

- ❖ 특화망 사업자가 기간통신사업자로 등록하여 28㎓ 대역을 이용해 이동통신서비스를 제공하는 경우 가입자 당 적용되는 서비스 단가를 현행 분기당 2,000원에서 200원으로 1/10 감경된 단가를 적용
- ❖ 자가망 시설자에 대해서도 28㎓ 대역에 대한 전파사용료를 현행 기준 대비 대폭 감경하고, 교육·연구 목적의 비영리법인에 대해서는 전파사용료를 면제

할당대가 산정식

$$\text{할당대가} = \text{기준금액} \times (5a_1 + a_2 + 1) \times \text{이용기간} \times \text{대역폭}$$

1) 기준금액 : 4.7㎓대역 (100,000원/10㎒폭), 28㎓대역 (50,000원/50㎒폭)

2) 면적(a_1, a_2) : 대도시 지역(a_1), 대도시 외의 지역(a_2) (단위: ㎢, 연면적 기준)

3) 이용기간 : 주파수의 총 이용기간(단위: 년)

4) 대 역 폭 : 할당신청 블록수(신청단위 기준) ※ 신청단위: (4.7㎓대역) 10㎒, (28㎓대역) 50㎒

Source: https://www.netmanias.com/ko/?m=view&id=blog&no=15133

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IV. 기업을 위한 5G 특화망

❖ 주요국의 사설 5G 주파수 할당 현황 (Sub-6 and mmWave)

국가	정부기관	주파수 범위	대역폭	주파수 상용화 시점
독일	BNetzA	3.7 - 3.8 GHz	100MHz	2019.11.21 면허신청개시
		24.25 - 27.5 GHz	3.25GHz	2021.01.01 면허신청개시
영국	Ofcom	3.8 - 4.2 GHz	400MHz	2019.12.09 면허신청개시
		24.25 - 26.5 GHz	2.25GHz	2019.12.09 면허신청개시
일본	MIC (총무성)	4.6 - 4.9 GHz	300MHz	2020.12.18 면허신청개시
		28.2 - 28.3 GHz	100MHz	2019.12.24 면허신청개시
		28.3 - 29.1 GHz	800MHz	2020.12.18 면허신청개시
미국	FCC	3.55 - 3.7 GHz (CBRS)	150 MHz	2020.08.25 PAL 경매 완료
한국	과기정통부	4.71 ~ 4.82 GHz	100MHz	2021
		28.9 - 29.5 GHz	600MHz	2021

Source: https://www.netmanias.com/ko/private-5g/

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IV. 기업을 위한 5G 특화망

❖ 사설 5G망 확보를 위한 기업의 선택지

	1. 기업이 **이통사 사설 5G 서비스를 이용하는 경우** (NTT Docomo, KDDI, Softbank, Rakuten)	2. 기업이 **로컬 5G망 직접 구축/운영하는 경우**	3. 기업이 **로컬 5G 서비스 사업자의 서비스를 이용하는 경우** (NTT Com, NEC, Fujitsu 등)
주파수	Sub-6, mmWave ☺ 3.7GHz, 4.5GHz, 28GHz	Sub-6, mmWave ☺ 4.6-4.9GHz, 28.2-29.1GHz	Sub-6, mmWave ☺ 4.6-4.9GHz, 28.2-29.1GHz
eMBB, uRLLC, mMTC	○ ☺	○ ☺	○ ☺
통신요금	유료 (데이터량 기반) ☹	무료 (와이파이처럼) ☺	무료 (와이파이처럼) ☺
Full Control	△	○ ☺	△
Network Slicing	△	○ ☺	△
전파사용료 납부	불필요 ☺	필요 ☹	필요 ☹
주파수 면허 취득	불필요 ☺	필요 (절차가 까다로움) ☹	**면허 취득 대행** ☺
설계 및 구축 지식	전문지식 필요 없음 ☺	전문지식 필요함 ☹	**매니지드 서비스** ☺
설비투자	불필요 ☺	큼 (5G RAN/Core 등 구매) ☹	**월정액 구독 서비스** ☺
운용부하	작음 ☺	전문지식 필요함 ☹	**매니지드 서비스** ☺

국내 사업자

Source: https://www.netmanias.com/ko/?m=view&id=blog&no=15054

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IV. 기업을 위한 5G 특화망

❖ 특화망 기획

1. 사업 계획서 작성
2. 사업의 타당성 확인
3. 제안요청서 작성
4. 시스템 벤더사 선정

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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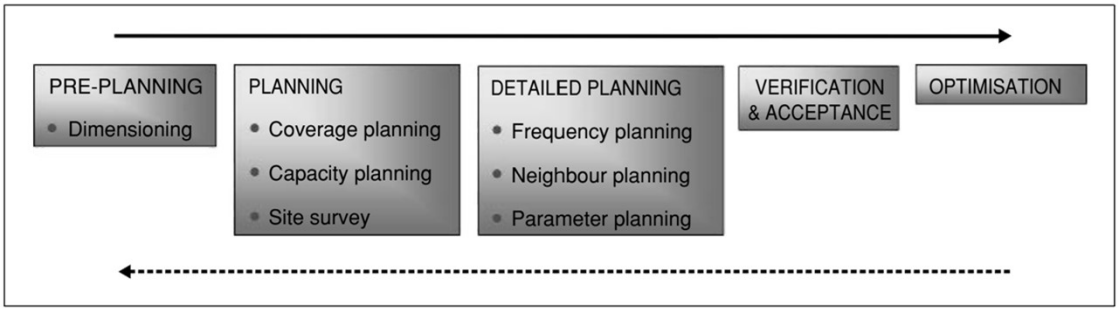
IV. 기업을 위한 5G 특화망

❖ Network planning process steps (제조사 예)

1. 사전 계획 (규모 조사)
2. 기술 계획 (커버리지, 용량, 실사)
3. 상세 계획 (주파수, 주변 환경, 파라메터)
4. 검증 (검수)
5. 최적화



Source: ADVANCED CELLULAR NETWORK PLANNING AND OPTIMISATION, Ajay R Mishra, Nokia Networks

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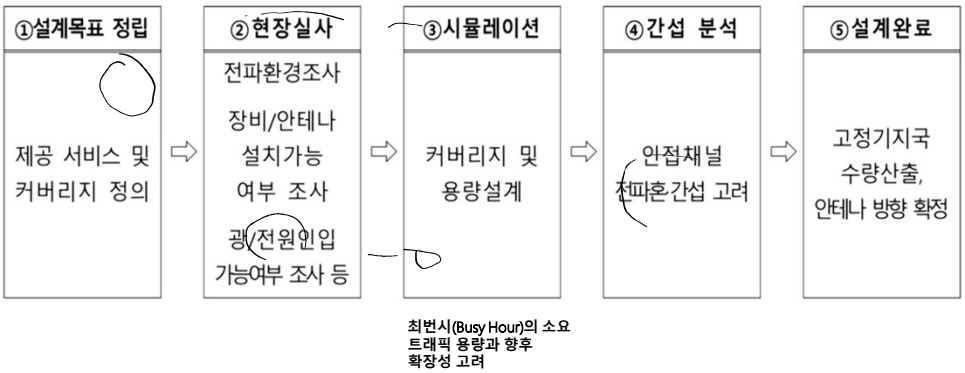
IV. 기업을 위한 5G 특화망

❖ 5G 특화망 네트워크 설계 절차(예시)



Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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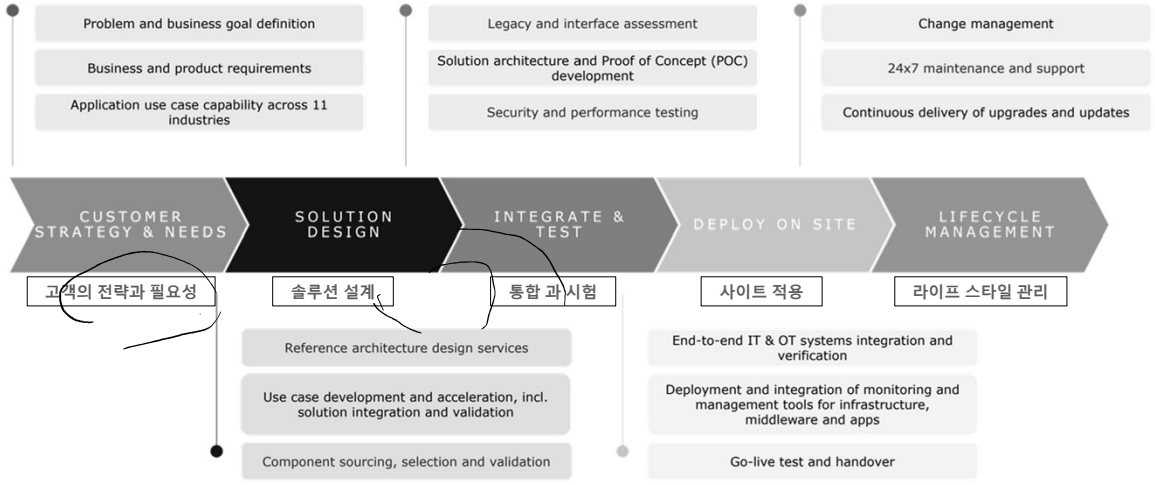
IV. 기업을 위한 5G 특화망

❖ 사업 진행 (예): 5G Enabled Digital Transformation Engagement (출처: Capgemini)



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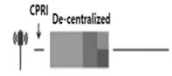
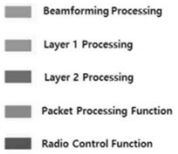
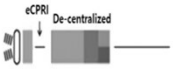
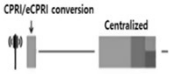
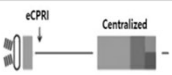
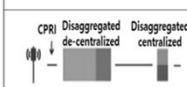
IV. 기업을 위한 5G 특화망

❖ 5G NR 기지국 구축가능 모델

- 기지국 이중화
- 전송망 이중화
- 예비전원 확보
- QoS 보장방안
- 간섭회피 방안
- 성능 강화 확장성

모델 예시	구분	특장점	비고
	분산형 CU/DU	무선 백홀 부담 경감	
	다중 안테나 기능 분리	대용량 데이터 전송의 부담 경감	
	집중형 기지국에 전통적인 RU 사용	무선자원 효율화, mMTC 적합	
	집중형 기지국	무선자원 효율화	
	분산형 DU와 집중형 CU	무선자원 효율화와 대용량 데이터 전송 지원	

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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IV. 기업을 위한 5G 특화망

❖ 5G코어망 구성방식 비교

구 분	데이터 관리	유지보수 인력	비용절감	보 안	정기 사용료	QoS보장	서비스 지연 최소화
5G코어 독립구축	◎	◎	△	◎	◎	◎	◎
5G코어 일부공유 (CP한정)	○	△	○	○	○	○	◎
5G코어 전부공유	△	△	◎	△	△	○	△

※ ◎ : 매우우수 또는 매우필요, ○ : 우수 또는 필요 , △ : 보통

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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IV. 기업을 위한 5G 특화망

❖ 특화망 도입 시 고려해야 할 보안 인증제도

대 상	인 증	담당부처·기관	관계법률
방화벽, IPS, DDOS대응장비, 접근통제 등 20종 보안제품·솔루션	CC인증	과기부, ITSCC	국가정보화법
국제CC인증 제품 및 L3이상 네트워크 장비, 가상화(SDN) 제품 (국가·지자체·공공기관 한)	보안적합성검증	국정원, 국가보안기술연구소	전자정부법
암호화모듈 (국가·지자체·공공기관 한)	KCMVP	국정원, 국가보안기술연구소	전자정부법

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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IV. 기업을 위한 5G 특화망

❖ 무선 서비스 주요 통계지표(예시)

주요 통계지표	설 명
호 접속(RRC) 성공률	접속을 시도하여, 성공한 호의 비율
지연시간(Latency)	5G 특화망 시스템에서의 데이터 전송 지연시간
패킷 손실율(Packet Loss)	단말-서버간의 데이터 송수신시 수신되지 못한 데이터양의 비율
전송속도(Throughput)	단말-서버 구간의 데이터 송·수신 속도
SINR (Signal to Interference Noise Ratio)	트래픽 채널의 신호대 잡음비
BLER(Block Error Rate)	순방향(Downlink), 역방향(Uplink)의 Block Error Rate

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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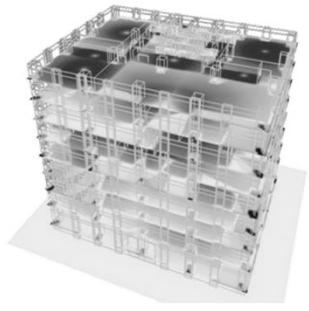
IV. 기업을 위한 5G 특화망

❖ 특화망 설계 도구 (예)

https://www.gapwireless.com/manufacturers/consultix/attachment/3d-heatmap/

- **기지국 수량 산출**
- **특화망 설계** (예: 전문 엔지니어링 용역업자에게 발주)
- **시뮬레이션 툴(iBwave) 사용 커버리지 설계와 현장실사를 통해 사업장 내 전파환경조사**
- **장비제원을 고려한 기지국의 치국위치를 최종결정**
- **설치에 필요한 접지, 트레이 등의 선로확보 등 정보통신공사 전반에 관한 설계도서를 작성·산출**



Source: https://ibwave.com/ibwave-design/

https://www.gapwireless.com/manufacturers/consultix/attachment/3d-heatmap/

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IV. 기업을 위한 5G 특화망

❖ 특화망 설계 (예)

- 장비제원(출력 등) 고려: 필요 기지국 수, 장비형태 산출
- 환경
  - 전고높이
  - LOS

DAS Passive Antenna

도면에 따른 4.7㎓ 안테나 소요량 산출 예시

Universal Mode	Region	Country	Operator
OFF	APAC	Republic of Korea	Enterprise
Measurement Unit	**Traffic Model**	**Traffic Growth Analysis**	**Complexity**
Meters	Enterprise	OFF	Few Walls
Macro Level	**No Of Floors**	**Indoor System(s)**	**Band Type**
Low	1	RDS 50	Single Band
Primary Band	**Simulation Type**	**Band 1, Tech 1 Indoor System**	**Band 1, Tech 1 Technology**
Band 1	Downlink + Uplink	RDS 50	NR
Band 1, Tech 1 Carrier Frequency	**Band 1, Tech 1 TDD SubFrames**	**Band 1, Tech 1 MIMO Mode**	**Band 1, Tech 1 Downlink Bandwidth (MHz)**
B79(4700 MHz)	6	4T4R	40
Band 1, Tech 1 Output Power per Antenna (dBm)	**Band 1: External Antennas Enabled**	**Enable NLS Radio Dot Positioning Simulation**	**Modeling**
24.0	OFF	OFF	Dominance
Dominance (dB)	**Number of Nodes Deployment**	**Floor Material**	**Max Coverage Per Node (m^2)**
4.0000	OFF	Heavy Concrete	1500.0000
Max Cable Length (m)	**Target Coverage (%)**	**Cell Border Shifting**	**VoLTE Capacity Simulation**
150.0000	95.00	OFF	OFF
Integrated Indoor Modelling	**Integrated Micro Modelling**	**Uplink Traffic Volume Per Subscriber (GB/Month/Sub)**	**Downlink Traffic Volume Per Subscriber (GB/Month/Sub)**
OFF	OFF	1.2000	2.3000
Gigabit LTE Feature Selection	**Carrier Aggregation**	**CRS Gain**	**Combined Cell**
OFF	OFF	OFF	OFF
Lean Carrier	**256 QAM (Downlink)**		
OFF	ON		

Number Of Floors	Floor Height (m)	Ceiling Height (m)	User Height (m)	No. Users / Floor	Floor Area (m^2)	Aoi Area (m^2)
1	4.00	2.80	1.50	40	6048.00	6048.00

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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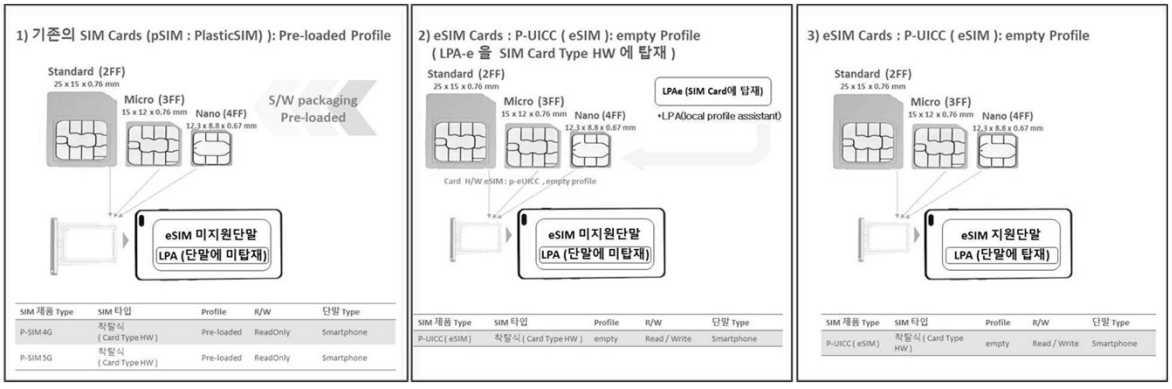
IV. 기업을 위한 5G 특화망

❖ SIM/eSIM 제품 종류

1) 기존 SIM
2) eSIM (eSIM 미지원 단말, eSIM 지원 단말)



Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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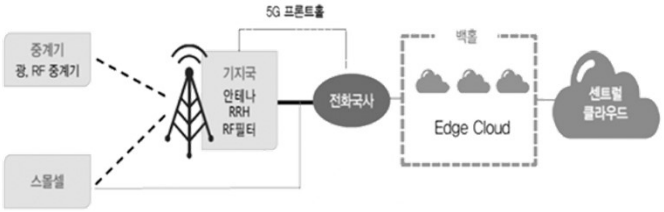
IV. 기업을 위한 5G 특화망

❖ 5G 네트워크 구조와 제조사

- 5G 코어(Access Network) 부문은 토탈 솔루션을 보유한 대기업 중심으로 시장이 형성
- 중소기업은 스몰셀 장비 등 작은 시장에서 활동

분류	스몰셀	안테나	중계기/DAS	매크로 기지국
주요 기업	콘텔라 주니 이노와이어리스 유니캐스트 유캐스트	담스테크 선우커뮤니케이션즈 에이스테크(글로벌 5위)	에이스테크놀로지 기산텔레콤 솔리드	삼성 유캐스트(LTE) (外)에릭슨 (外)화웨이 (外)노키아



Source: https://m.blog.naver.com/drryuhk/221898589988

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IV. 기업을 위한 5G 특화망

❖ 통신장비 제조사 HUCOM Wireless (예)

- Qualcomm 사의 최신 Chipset 인 X55 5G 전용 Chipset.(SDX55-0_최상위 버전 사용)
- 적용대상 : Robot / Smart Factory / Router / CCTV 등 관련 협력업체 적용 개발 중.
- 5G Sub 6 Module SKT & LG U+ 인증 완료. (2020년 10월)
- mmWave Module LG U+ 인증 완료 / SKT 인증 진행 중.

5GNR Multimode
(Gen 2)

3GPP Rel 15 modem
+ Standalone Multimode modem
+ All RAT–2G to 5G-NR & GPS
+ SA and NSA Sub-6
+ NSA mmWave
+ Sub-6GHz 5G FDD and TDD
+ 5G core network Opt. 3 and 2
+ 4G: 20-layer DL/ 2CA UL
+ HPUE Support for 4G and sub-6 5G
+ High Power mmW Support (45+ dBm)
+ PC5 Support
+ mmWave CPE with QTM527

Sub 6 Module

mmWave Module

Model		HM-900
5G NR	5G NR	3GPP Release 15 NSA/SA
	Sub-6G	N77 / N78 / N79
	mmWave	N257/N258/N260/N261(Option)
LTE	LTE-FDD	Band 1/3/5/7/8
DL 4*4 MIMO		Band 1/3/5/7/8
WCDMA		Band 1
Interface		PCIE 3.1 , USB3.1
Module interface		M.2

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IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 콘텔라

• 5G vCore, CU/DU

제품 사양 5G (v)Core & 5G CU/DU

5G (v)Core

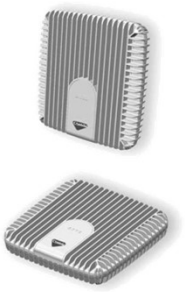
최대 수용 가입자수	200,000
동시 수용 가입자 수	20,000
인터페이스	1G, 10G or 25G Optic
Throughput	UL 20Gbps, DL 20Gbps, 25G Network, Non-QoS 기준
제공기능	AMF/SMF/UDM(with AUSF)/PCF/UPF/EMS/DB
형태 및 사이즈	범용 HW, 용량에 따른 HW 변경 가능
사용 HW 스펙	DL 380 G10
기반 Platform, SW	Docker Container
기타	20 CU 연동, Network Slice

5G CU/DU

Device Type	(CU/DU)
3GPP Standard	3GPP 5G NR Rel15
Frequency Band	4.7GHz (4.72 - 4.82GHz)
Duplex Mode	TDD
Network Architecture	SA
Data Throughput	DL: 3, UL: 0.8
Modulation(Max)	256 QAM
MAX Bandwidth	100MHz
SCS	30kHz
TTI duration(ms)	0.5
Active UEs	32('22), 64(~'23)
Network Interface	N2, N3, Netconf, ORAN(7-2x)
Fronthaul Interface	eCPRI (ORAN 7-2x)
Synchronous	GPS, IEEE1588, SynE

제품 사양 mmWave Small Cell

Device Type	Integrated Type (All-In-One)
3GPP Standard	3GPP 5G NR Rel15
Frequency Band	28GHz (26.5 – 29.5 GHz)
Duplex Mode	TDD
Network Architecture	SA
Data Throughput	DL: 1.6 Gbps, UL: 0.75 Gbps
Modulation(Max)	256QAM
MAX Bandwidth	400MHz
SCS	120kHz
MIMO	2x2
Antenna(Tx/Rx)	128T128R
TTI duration(ms)	0.125
Active UEs	16('22), 32('23)
No. of Cell	1Cell
Network Interface	N2, N3, Netconf
Fronthaul Interface	eCPRI (ORAN 7-2x)
Synchronous	GPS, IEEE1588, SyncE
Radio Conformance	3GPP TS38.104, 3GPP TS38.141-2



Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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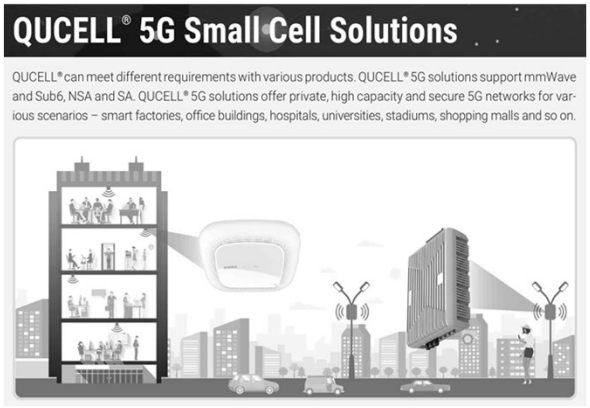
IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 이노와이어리스

• 5G Small Cell Solutions



Item	QUCELL® 5G mmWave All-in-One Type (CU+DU+RU)	QUCELL® 5G Sub6 All-in-One Type (CU+DU+RU)
Type		
Frequency	5G mmWave NR	5G Sub 6 NR
Transmit Power	48dBm (EIRP)	30dBm (EIRP)
Bandwidth	Max. 400 MHz	Max. 100MHz
RF Antenna	Internal-128 Tx / 128 Rx (64dual-pole)	Internal-2 Tx / 2 Rx
Synchronization	IEEE1588v2 / GPS	IEEE1588v2 / GPS
Interface	Backhaul · 10Gbps Ethernet x 1 port · SFP+ (for optical) x 1 port (Option) Management · 1Gbps Ethernet x 1 port	Backhaul · 2.5Gbps Ethernet x 1 port · SFP+ (for optical) x 1 port (Option) Management · 1Gbps Ethernet x 1 port
Power Input	AC-DC adapter	AC-DC adapter
Size	285 X 285 X 60 (W x H x D, mm)	240 x 240 x 55 (W x H x D, mm)
IP Grade	IP30	IP30
Mount Type	Wall Mount	Ceiling Mount (optional. Wall Mount)

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 유캐스트

• mmWave Small Cell, Sub6GHz Small Cell

EUCAST

- CU (Central Unit) / DU (Digital Unit) / RU (Radio Unit) integrated
- Standard : 3GPP Release 15
- 5G NR NSA
- EN-DC
- Sync. : GPS or IEEE1588v2

ITEM	Specification	Remark
Frequency (Band)	28GHz (n257) : 26.5~29.5GHz	
Maximum Tx Power	EIRP 50dBm (64QAM)	
Bandwidth	800MHz (2*400MHz or 8*100MHz)	
Modulation	QPSK/16QAM/64QAM	
Antenna	128T/128R	MIMO 2x2
Backhaul	10Gbps SFP+	802.3 10GBase-X
Power	AC adaptor : AC 100~240V, 50/60Hz DC 12V	Using AC/DC adaptor
Power Consumption	<75W	
Size (mm)	275(W) x 275(D) x 50(H)	
Weight	3.5 Kg	
Temperature	-5 ~ +40°C	
Installation	Wall Mount	

- CU / DU / RU integrated
- Standard : 3GPP Release 15
- 5G NR SA
- Max 128 connected, 64 active users
- Sync. : GPS or IEEE1588v2

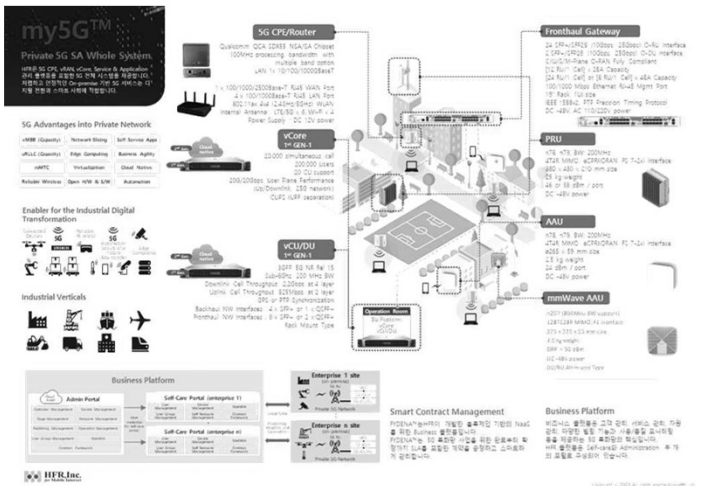
ITEM	Specification	Remark
Frequency (Band)	Sub 6GHz	n78, n79, and etc.
Maximum Tx Power	EIRP 50dBm (64QAM)	
Bandwidth	100MHz	
Modulation	QPSK/16QAM/64QAM/256QAM	
Antenna	2T/2R	MIMO 2x2
Backhaul	2.5Gbps NBase-T Ethernet	802.3 10GBase-X
Power	AC adaptor : AC 100~240V, 50/60Hz DC 12V	Using AC/DC adaptor,
Power Consumption	<25W	
Size (mm)	200(W) x 200(D) x 62(H)	
Weight	2.5 Kg	
Temperature	-5 ~ +40°C	
Installation	Wall Mount, Ceiling	

Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

IV. 기업을 위한 5G 특화망

❖ 5G 특화망 솔루션 (예): 에치에프알

- vCore, vCU/DU, CPE
- Fronthaul Gateway
- PRU
- AAU
- mmWave AAU



Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

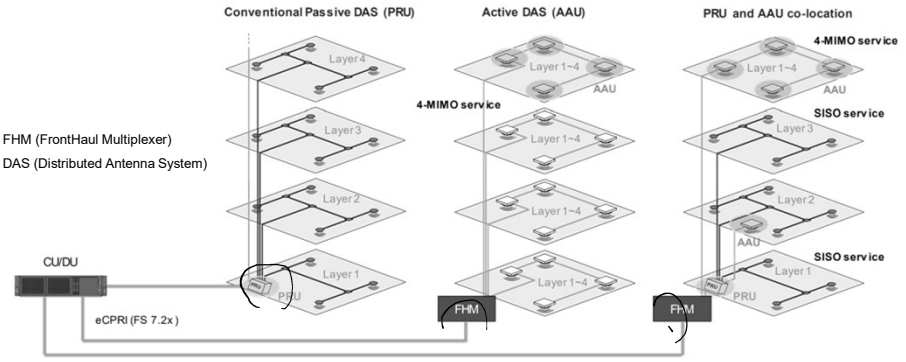
IV. 기업을 위한 5G 특화망

❖ 5G 특화망 솔루션 구축(예): 에치에프알 CU/DU & O-RU

인빌딩 분산 전개 예시

망 구성 별 소요 Throughput 검토

- 인빌딩 Radio Unit 분산은 Capacity와 Coverage를 고려하여 효율적인 구조 선택
- HFR 장비는 ORAN 7.2x 인터페이스 지원, 고객사 Radio 장비와 IOT 및 수용 가능
- FHM 장비는 Shared 셀 (단일 셀) 기능 지원, 간섭을 회피하면서 서비스 5G 서비 coverage 확장 가능



Source: www.hfrnet.com

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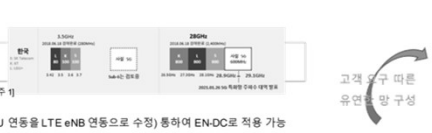
IV. 기업을 위한 5G 특화망

❖ 통신장비 제조사 HFR 5G NR RAN 솔루션 (예)

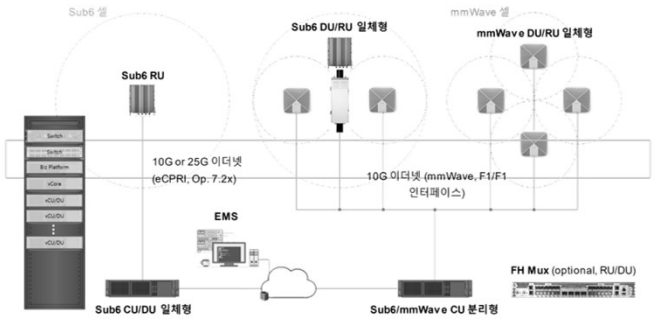
서비스 위한 셀 구성

- Sub6 single 셀
- mmWave single 셀
- NR-DC dual 셀 (Sub6 + mmWave) (주 1)

[주 1] NR-DC 용 mmWave 제품은 SW 변경 (CU 연동을 LTE eNB 연동으로 수정) 통하여 EN-DC로 적용 가능



고객 요구 따른 유연한 망 구성



제품 구성 형태

- CU/DU 제품
  - ① Sub6 CU/DU 일체형 (실내형)
  - ② Sub6 CU/DU 일체형 (실외형)
  - ③ Sub6 DU 분리형 (실외형)
  - ④ Sub6 CU 분리형 (실내형)
  - ⑤ mmWave+Sub6 CU 분리형 (실내형, F1/F2 인터페이스)
- RU 제품
  - ① Sub6 대출력 O-RU
  - ② Sub6 소출력 O-RU
  - ③ mmWave DU/RU 일체형 (실내형)
- FH Multiplexer (Optional)
  - ① RU-DU 연결을 위한 게이트웨이

Source: https://www.hfrnet.com/front/main/mainPage

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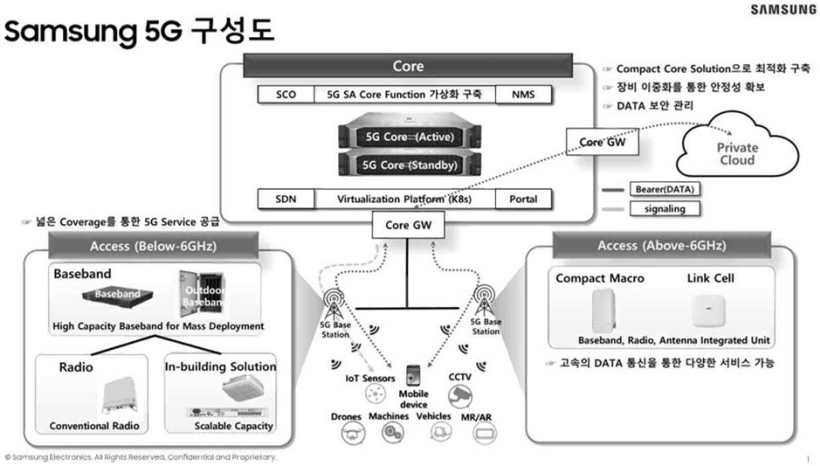
IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 삼성

• Core, Access



Source: 5G 특화망 가이드라인 , 과기정통부/KCA (2021. 10.)

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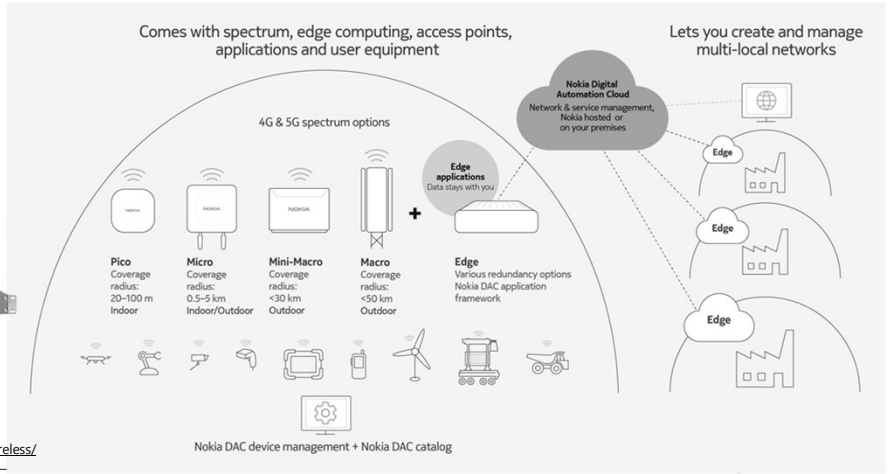
IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 노키아(Nokia)

• An end-to-end platform that makes private wireless networking and automation easy



Source: https://www.dac.nokia.com/private-wireless/

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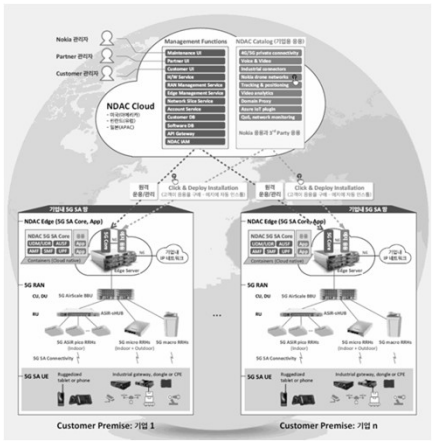
IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 노키아(Nokia)

• **Nokia Private Wireless Solution**

1. Nokia Digital Automation Cloud (DAC), Plug and Play
2. Nokia Modular Private Wireless (MPW)



Source: https://www.netmanias.com/ko/private-5g/vendors/1550/

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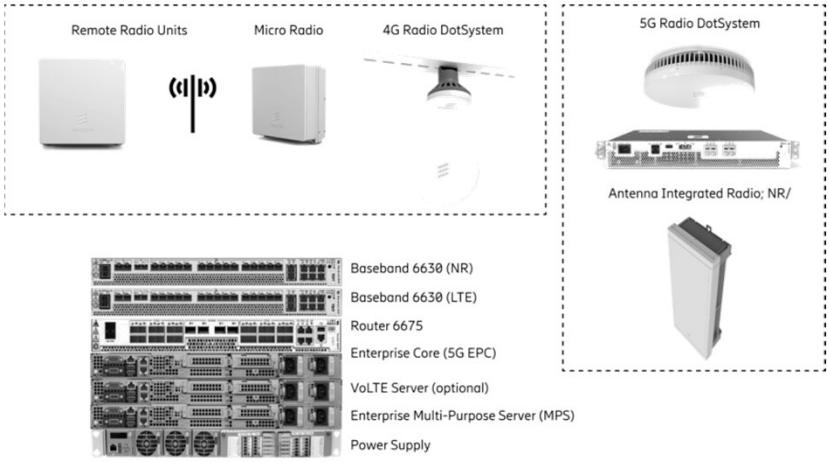
IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 에릭슨(Ericsson)

• **Private Networks**



Source: https://www.ericsson.com/en/portfolio/iot-and-new-business/dedicated-networks/private-networks

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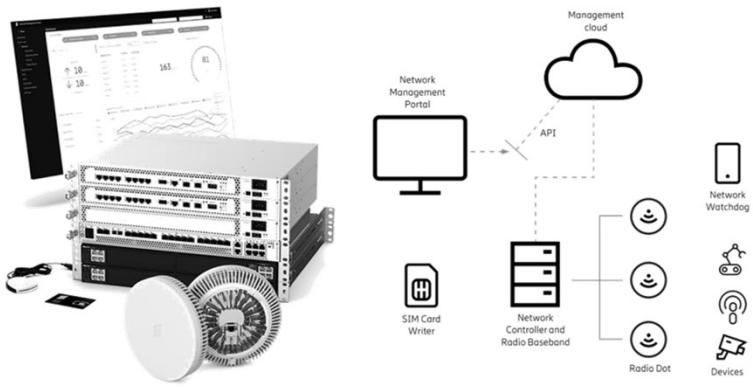
IV. 기업을 위한 5G 특화망

❖ 벤더별 특화망 솔루션 (예): 에릭슨(Ericsson)

• Private Networks

Ericsson: Dedicated Networks 5G SA Trial Kit (Industry Connect with Radio Dot)



Radio Dot (Antenna), Indoor RU (IRU), Baseband, CU, 5G SA Core
Ericsson Management Cloud, Network Management Portal, SIM Card Writer

Source: https://www.netmanias.com/ko/private-5g/vendors/1549/

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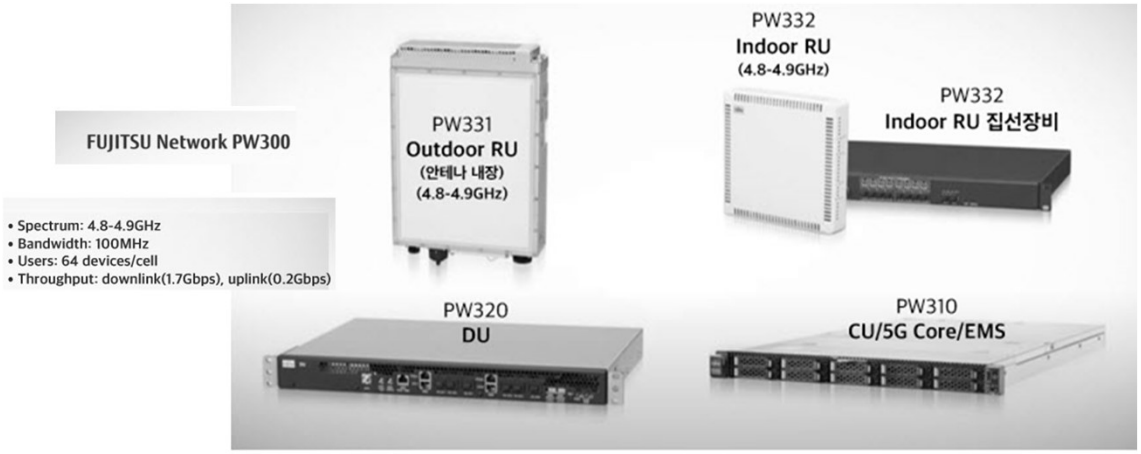
IV. 기업을 위한 5G 특화망

❖ Fujitsu의 Private 5G 장비



Source: https://www.netmanias.com/ko/private-5g/vendors/1549/

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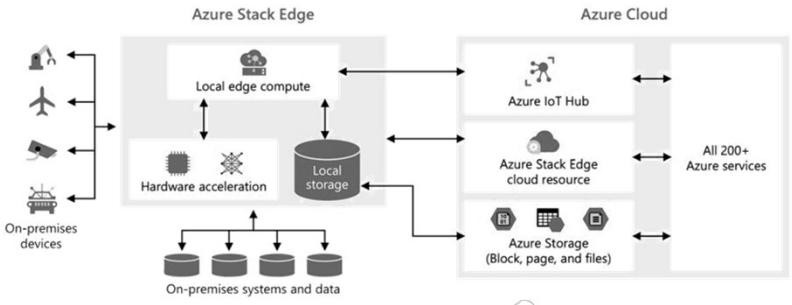
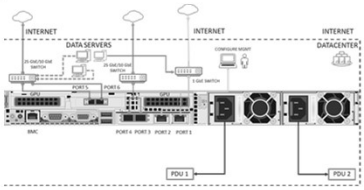
IV. 기업을 위한 5G 특화망

❖ **Azure Stack Edge**





Radio 가상화 분야 제조사 인수

AT&T 사업 인수

Source: https://docs.microsoft.com/ko-kr/azure/databox-online/azure-stack-edge-gpu-deploy-install

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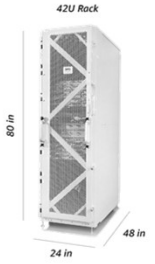
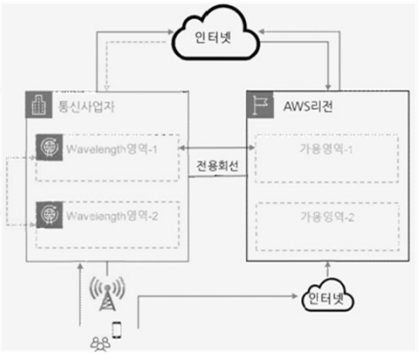
IV. 기업을 위한 5G 특화망

❖ **AWS Outpost Wavelength: 통신사업자 내에 구축된 AWS 인프라 서비스**

- Wavelength는 통신사 내에 설치된 가용영역
- 일반 가용 영역과 다르게, Wavelength 영역 사용하기 위해서는 사용 신청(Opt-in) 과정이 필요
- AWS 서비스 중에 제한된 일부 서비스만 사용 가능
- 서비스는 인터넷을 통해서 직접 접근이 불가하며, 통신사 망을 통해서만 서비스 가능
- Wavelength 영역 간에는 통신이 불가





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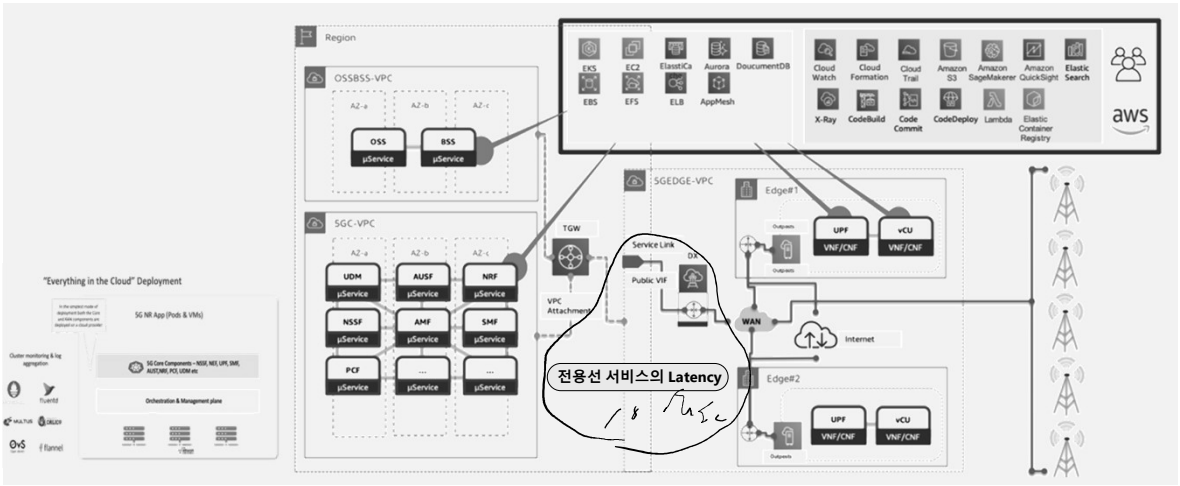
IV. 기업을 위한 5G 특화망

❖ **Reference Architecture "The Everything in the Cloud" Pattern** (예: VMware)



Source: https://www.vamsitalkstech.com/5g/5g-reference-architecture-1-the-everything-in-the-cloud-pattern/

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V. 5G 테스트베드 구성 및 활용

- 국내 5G 테스트베드 소개
- 5G 독립망 구성
- 5G 테스트베드 레퍼런스

V. 5G 테스트베드 구성 및 활용

❖ Quectel 5G @ MS Azure

• Quectel RM500-GL 5G 모뎀을 사용하여 5G 또는 LTE를 통해 Azure Percept DK 연결

Source: https://docs.microsoft.com/ko-kr/azure/azure-percept/connect-over-cellular-usb-quectel

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V. 5G 테스트베드 구성 및 활용

❖ Fusion Core - 5G Packet Core @ Azure Marketplace

리눅스 가상머신에 다운로드/설치 (Download and install Azure command line on a Linux VM)

•Get kubernetes config using the Azure Command Line tool (az cli)

```
az aks get-credentials --resource-group <RESOURCE GROUP> --name <CLUSTER_NAME> --overwrite-existing
```

•Get the public IP and port number for the GUI

```
kubectl get svc --all-namespaces -o wide --field-selector="metadata.name=emcoui-gui“
```

•On a browser, access the IP address of the GUI

```
http://<EXTERNAL-IP>:9080
```

k slicing, SON, analytics) will be proprietary.

to access the GUI for AMCOP

Source: https://azuremarketplace.microsoft.com/ko-kr/marketplace/apps/aarnanetworksinc1595980852623.amcop001?tab=Overview

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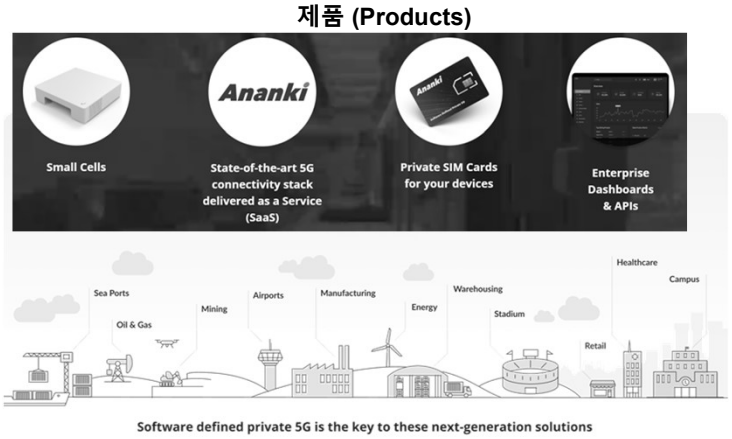
V. 5G 테스트베드 구성 및 활용

❖ 비즈니스(예): Ananki의 소프트웨어 정의 Private Enterprise 5G+ (Powering Industry 4.0 Innovations)



Source: https://ananki.io/

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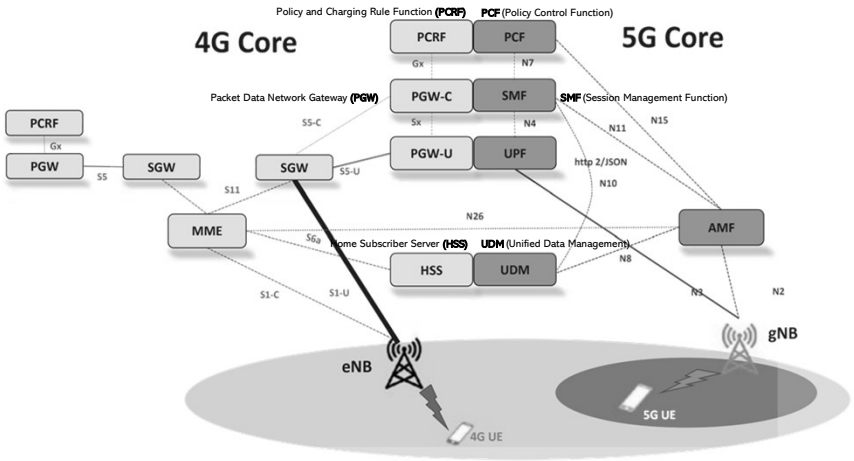
V. 5G 테스트베드 구성 및 활용

❖ 오픈소스 5G Core (예): 'Open5GS'

- NSA (4G Core)
- SA (5G Core)



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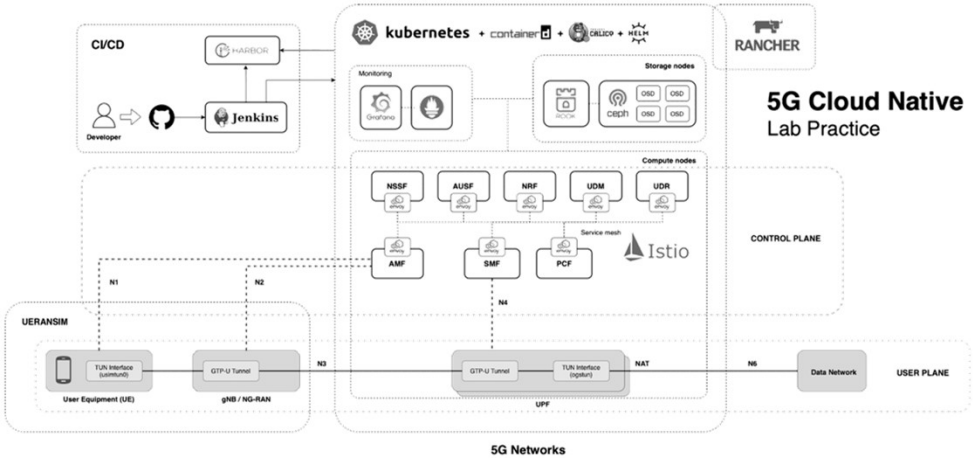
V. 5G 테스트베드 구성 및 활용

❖ 5G Cloud Native Simulation with Open5GS



Source: https://assyafii.com/docs/5g-cloud-native-simulation-with-open5gs/

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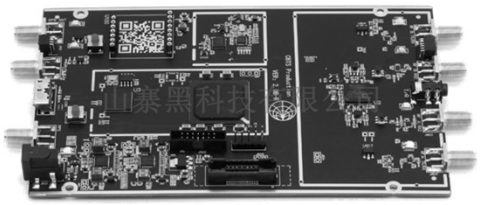
V. 5G 테스트베드 구성 및 활용

❖ RAN 가상화 사용 가능한 Dual Channel Transceiver(예)

• Dual Channel Transceiver 70MHz – 6GHz SDR Software Defined Radio USB3.0 Compatible with ettus USRP B210

Open Hardware



•First fully integrated, two-channel USRP device with continuous RF coverage from 70 MHz – 6 GHz ,
•Full duplex, MIMO (2 Tx & 2 Rx) operation with up to 56 MHz of real-time bandwidth (61.44MS/s quadrature)
•Fast and convenient SuperSpeed USB 3.0 connectivity
•GNURadio and OpenBTS support through the open-source USRP Hardware Driver™ (UHD)
•Open and reconfigurable Spartan 6 XC6SLX150 FPGA (for advanced users)
•Early access prototyping platform for the Analog Devices AD9361 RFIC, a fully integrated direct conversion transceiver with mixed signal baseband

Source: https://www.aliexpress.com/item/4000365720818.html

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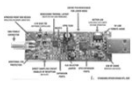
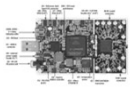
V. 5G 테스트베드 구성 및 활용

❖ **Comparisons for Open SDR**

	HackRF One	Ettus B200	Ettus B210	BladeRF x40	RTL-SDR	LimeSDR
Frequency Range	1MHz-6GHz	70MHz-6GHz	70MHz-6GHz	300MHz-3.8GHz	22MHz-2.2GHz	100kHz-3.8GHz
RF Bandwidth	20MHz	61.44MHz	61.44MHz	40MHz	3.2MHz	61.44MHz
Sample Depth	8 bits	12 bits	12 bits	12 bits	8 bits	12 bits
Sample Rate	20MSPS	61.44MSPS	61.44MSPS	40MSPS	3.2MSPS	61.44MSPS (Limited by USB 3.0 data rate)
Transmitter Channels	1	1	2	1	0	2
Receivers	1	1	2	1	1	2
Duplex	Half	Full	Full	Full	N/A	Full
Interface	USB 2.0	USB 3.0	USB 3.0	USB 3.0	USB 2.0	USB 3.0
Programmable Logic Gates	64 macrocell CPLD	75k	100k	40k (115k avail)	N/A	40k
Chipset	MAX5864, MAX2837, RFFC5072	AD9364	AD9361	LMS6002M	RTL2832U	LMS7002M
Open Source	Full	Schematic, Firmware	Schematic, Firmware	Schematic, Firmware	No	Full
Oscillator Precision	+/-20ppm	+/-2ppm	+/-2ppm	+/-1ppm	?	+/-1ppm initial, +/-4ppm stable
Transmit Power	-10dBm+ (15dBm @ 2.4GHz)	10dBm+	10dBm+	6dBm	N/A	0 to 10dBm (depending on frequency)
Price						





BladeRF Not stable



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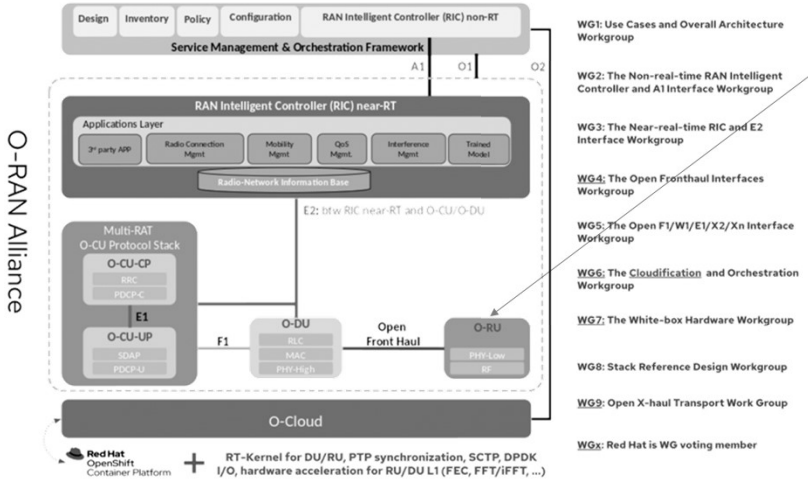
V. 5G 테스트베드 구성 및 활용

❖ **AI/ML @ O-RAN**



YANG models that help manage the radio units feature more than 6,000 parameters, with less than 3% of them mandatory, and network vendors also implement custom protocols.

Source: https://www.redhat.com/en/blog/open-ran-and-o-ran-brief?fbclid=IwAR0V6fivK9xv2LEkXNTvjBeOSRVYB0cej4Q_zV6teY2Oh_GrVWmWDMS07js

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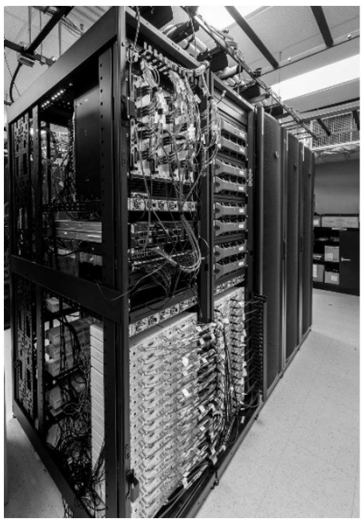
V. 5G 테스트베드 구성 및 활용

❖ **AI/ML @ O-RAN**

- **O-RAN 구성**
- **256 software-defined radios**
- **25.6 GHz of emulated bandwidth, 52 TB/s RF data**
- **21 racks of radios, 171 high-performance servers w/ CPUs, GPUs**
- **Massive computing capabilities (CPU, GPU, FPGA):**
  - > 900 TB of storage
  - 320 FPGAs
  - 18 10G switches
  - 19 clock distribution systems
  - 52 TB/s of digital RF data

Institute for the Wireless Internet of Things at Northeastern



V. 5G 테스트베드 구성 및 활용

❖ **RIC**

- **Near-RT RIC**
- **Non-Real time RIC**

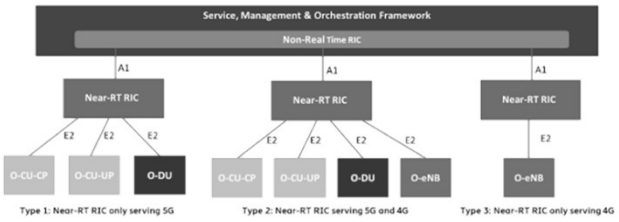


Figure 5: Centralized Near-RT RIC Serving 4G and 5G Simultaneously

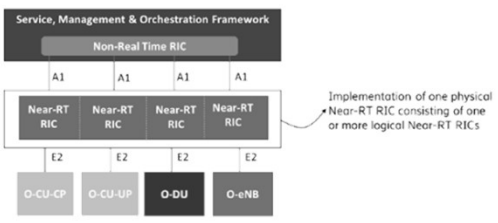
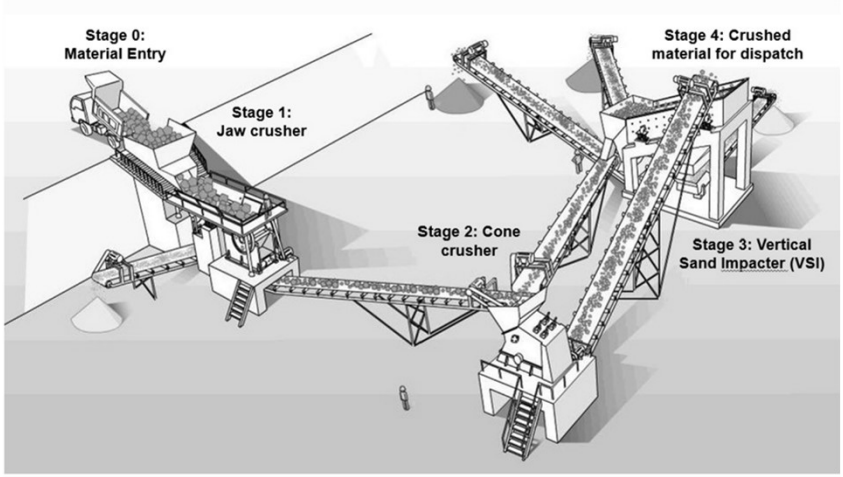


Figure 6: Distributed Near-RT RIC

Source: https://www.redhat.com/en/blog/open-ran-and-o-ran-brief?fbclid=IwAR0V6fivK9xv2LEkXNTvjBeOSRVYB0cej4Q_zV6teY2Oh_GrVWmWDMS07js

V. 5G 테스트베드 구성 및 활용

❖ **Stone Crushing Plant at GS Lab**



Source: Lab Setup at GS Lab: https://youtu.be/_fOU3a4brPY , Stone Crushing Plant at GS Lab: https://youtu.be/YWRlXqR0Xnc

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V. 5G 테스트베드 구성 및 활용

❖ **오픈 프레임워크와 프로젝트**

모바일 (Mobile)					
프레임워크	집중분야	상태	라이선스	Main 맴버	커뮤니티 지원
O-RAN	Virtualized, intelligent RAN	가능	Apache v2.0, O-RAN software license v1.0	O-RAN Alliance w/telecom operators	No
COMAC	Agile service delivery at the edge	가능	Apache v2.0	ONF	Mailing list
SD-RAN	CU/DU control and user planes	개발중		ONF	N/A
Aether	5G/LTE,Edge-Cloud-as-a-Service(ECaaS)	개발중		ONF	N/A
Magma	CN Orchestration	가능	BSD	페이스북	Mailing list/forum
OpenRAN	Programmable, disaggregated RAN w/open interfaces	소스 비공개		TIP	No
Radio Edge Cloud	O-RAN RIC automated configuration/integration testing blueprint	가능	Apache v2.0	Akraino	No
Aerial	SDK for GPU-accelerated 5G vRAN	Early access	proprietary	NVIDIA	N/A

슬라이싱 (Slicing)					
프레임워크	집중분야	상태	라이선스	Main 맴버	커뮤니티 지원
5G-EmPOWER	Centralized controller for heterogeneous RAN	가능	Apache v2.0	FBK (in the framework of multiple EU projects)	N/A
FlexRAN	Real-time controller for software-defined RAN	가능	MIT License	Mosaic5G Consortium	Mailing list

에지 (Edge)					
프레임워크	집중분야	상태	라이선스	Main 맴버	커뮤니티 지원
CORD (Central Office Re-architected as a Datacenter)	Data center for network edge	가능	Apache v2.0	ONF, AT&T, Google, Telefonica	Mailing list
LL-MEC	Low-latency MEC and network slicing	가능	Apache v2.0	Mosaic5G Consortium	Mailing list
LightEdge	MEC services	가능	Apache v2.0	FBK (in the framework of multiple EU projects)	N/A

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V. 5G 테스트베드 구성 및 활용

❖ RAN 소프트웨어 설치 가능한 SDR

SDR	TX/RX channels	Frequency range	Instantaneous bandwidth (up to)	RAN software	Target
bladeRF	1	[300 MHz, 3.8 GHz]	28 MHz	OAI, srsLTE	DAS node, small cell
bladeRF 2.0 micro	2	[47 MHz, 6 GHz]	56 MHz	OAI, srsLTE	DAS node, small cell
Iris	2	[50 MHz, 3.8 GHz]	56 MHz	OAI	DAS node, small cell, cell tower
LimeSDR	4 TX, 6 RX	[100 kHz, 3.8 GHz]	61.44 MHz	OAI, srsLTE	DAS node, small cell
USRP B205mini-i	1	[70 MHz, 6 GHz]	56 MHz	srsLTE	DAS node
USRP B210	2	[70 MHz, 6 GHz]	56 MHz	OAI, srsLTE	DAS node, small cell
USRP N310	4	[10 MHz, 6 GHz]	100 MHz	OAI	DAS node, small cell, cell tower, rooftop
USRP X310	Up to 2	[DC, 6 GHz]	160 MHz	OAI, srsLTE	DAS node, small cell, cell tower

출처: Survey paper, Computer Networks 182 (2020) 107516, Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead☆
Leonardo Bonati ∗, Michele Polese, Salvatore D'Oro, Stefano Basagni, Tommaso Melodia, Institute for the Wireless Internet of Things, Northeastern University, Boston, MA 02115, USA

bladeRF 2.0 micro xA4

Iris V2.1 Transponder Stack

LimeSDR

USRP

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V. 5G 테스트베드 구성 및 활용

❖ 서비스 기본 요구 기능

- 서버 가상화
- 스토리지 가상화
- 네트워크 가상화
- 데이터 관리
- 가용성
- 확장성
- 개방성
- 사용자 포탈
- 관리자 포탈
- 백업/복구

openstack.

서버 가상화	VM 생성 및 관리
	VM Thin Provisioning
	VM Export/Import
	VM 템플릿
	VM 가용존 지정
	VM MAC 주소 지정
	VM 스케줄링
	VM 메타데이터 조회
스토리지 가상화	블록 스토리지 생성 및 관리
	멀티 블록 스토리지 지원
	블록 스토리지 리사이징
	오브젝트 스토리지 생성 및 관리
네트워크 가상화	네트워크 분산 처리
	프라이빗 네트워크 생성 및 관리
	퍼블릭 네트워크 생성 및 관리
	가상 네트워크 영역별 테넌트 분리
데이터 관리	데이터 중복 제거
	데이터 압축
	데이터 리빌드
	데이터 재분배
	데이터 복제
	데이터 저장 방식
가용성	라이브 마이그레이션
	컨트롤러 삼중화
확장성	단일 서버 지원
	무중단 서버 확장
	다양한 타입의 서버 확장
개방성	오픈 아키텍처 지원
	멀티 하이퍼바이저 지원
사용자 포탈	VM 관리
	VM 볼륨 관리
	VM 볼륨 스냅샷 관리
	VM 템플릿 관리
	보안그룹 관리
관리자 포탈	통합 관리자 포탈 제공
	통합 모니터링 대시보드 제공
	하드웨어 모니터링
	오픈 API 제공
	가상, 물리 네트워크 관리를 위한 프로토 콜 제공(OVS sflow, 가상 Tap 등)
백업/복구	VM 백업 및 복구
	블록 스토리지 백업 및 복구

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V. 5G 테스트베드 구성 및 활용

❖ 서비스 확장 요구 기능

- 스토리지 가상화
- 네트워크 가상화
- 부하분산
- 가용성
- GPU 가상화
- 컨테이너 관리
- 재해복구
- 백업/복구
- 기타 (하이브리드 클라우드 등)

openstack.

스토리지 가상화	파일 스토리지 생성 및 관리
	파일 스토리지 리사이징
네트워크 가상화	언더레이 네트워크와 연동 가능
부하분산	다양한 프로토콜을 통한 부하 분산
	서버 상태 검사
	세션 유지
	다양한 부하 분산 알고리즘
가용성	서버 이베큐에이션
GPU 가상화	그래픽 가속 지원
컨테이너 관리	다중 사용자 지원
	클러스터 템플릿 관리
	컨테이너 클러스터 관리
	컨테이너 클러스터 사이즈 변경
	컨테이너 클러스터 모니터링
	다양한 컨테이너 엔진 지원
재해복구	분산 백업
	다양한 백업 방식 지원
	압축 백업
	암호화 백업
	스케줄링 자동 복구
백업/복구	파일 스토리지 백업 및 복구
	볼륨 백업 예약

V. 5G 테스트베드 구성 및 활용

❖ OpenStack* EPA (Enhanced Platform Awareness)

- 적용 기능별 성능 개선 분석(Feature Breakdown and Analysis)
- EPA Features Covered
  - ✓ Host CPU feature request (20~40%)
  - ✓ PCI passthrough (~8%)
  - ✓ HugePages* support (10~20%)
  - ✓ NUMA awareness (~10%)
  - ✓ IO based NUMA scheduling (~25%)
  - ✓ CPU pinning (10~20%)
  - ✓ CPU threading policies (~50%)
  - ✓ OVS-DPDK, neutron (~900%)

openstack.

Feature Name	First OpenStack* Release	Description	Benefit	Performance Data
Host CPU feature request	Icehouse*	Expose host CPU features to OpenStack managed guests	Guest can directly use CPU features instead of emulated CPU features	~20% to ~40% improvement in guest computation
PCI passthrough	Havana*	Provide direct access to a physical or virtual PCI device	Avoid the latencies introduced by hypervisor and virtual switching layers	~8% improvement in network throughput
HugePages* support	Kilo*	Use memory pages larger than the standard size	Fewer memory translations requiring fewer cycles	~10% to ~20% improvement in memory access speed
NUMA awareness	Juno*	Ensures virtual CPUs (vCPU)s executing processes and the memory used by these processes are on the same NUMA node	Ensures all memory accesses are local to the node and thus do not consume the limited cross-node memory bandwidth, adding latency to memory	~10% improvement in guest processing
IO based NUMA scheduling	Kilo*	Creates an affinity that associates a VM with the same NUMA nodes as the PCI device passed into the VM	Delivers optimal performance when assigning PCI device to a guest	~25% improvement in network throughput for smaller packets
CPU pinning	Kilo	Supports the pinning of VMs to physical processors	Avoids scheduling mechanism moving the guest virtual CPUs to other host physical CPU cores, improving performance and determinism	~10 % to ~20% improvement in guest processing
CPU threading policies	Mitaka*	Provides control over how guests can use the host hyper thread siblings	More fine-grained deployment of guests on HT-enabled systems	Up to ~50% improvement in guest processing
OVS-DPDK, neutron	Liberty*	An industry standard virtual switch accelerated by DPDK	Accelerated virtual switching	~900% throughput improvement

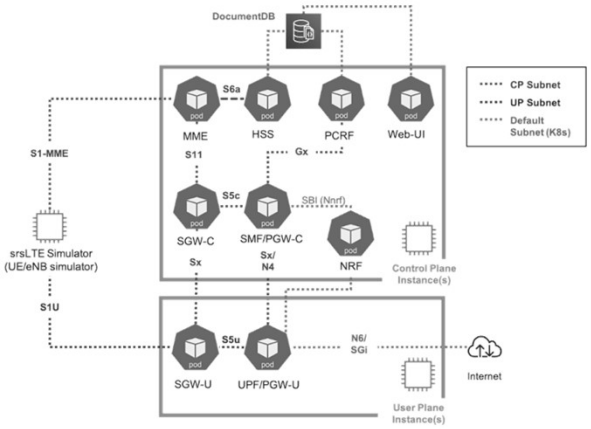
EPA 적용시 네트워크와 CPU 처리등의 10% 이상 성능 개선 기대

Source: https://software.intel.com/content/www/us/en/develop/articles/openstack-epa-feature-breakdown-and-analysis.html

V. 5G 테스트베드 구성 및 활용

❖ Mobile core network implementation on Amazon Elastic Kubernetes Service

Network Function	Role
MME	Mobility Management Entity
HSS	Home Subscriber Server
PCRF	Policy and Charging Rules Function
SGW-c	Serving Gateway Control Plane
SGW-u	Serving Gateway User Plane
SMF+PGW-c	Session Management Function + PDN Gateway Control Plane
UPF+PGW-u	User Plane Function + PDN Gateway User Plane
NRF	Network Repository Function (it is only for NF registration of 5G functions)
Web-UI	GUI to configure subscriber and its profile for HSS/PCRF



Source: https://aws.amazon.com/blogs/opensource/open-source-mobile-core-network-implementation-on-amazon-elastic-kubernetes-service/

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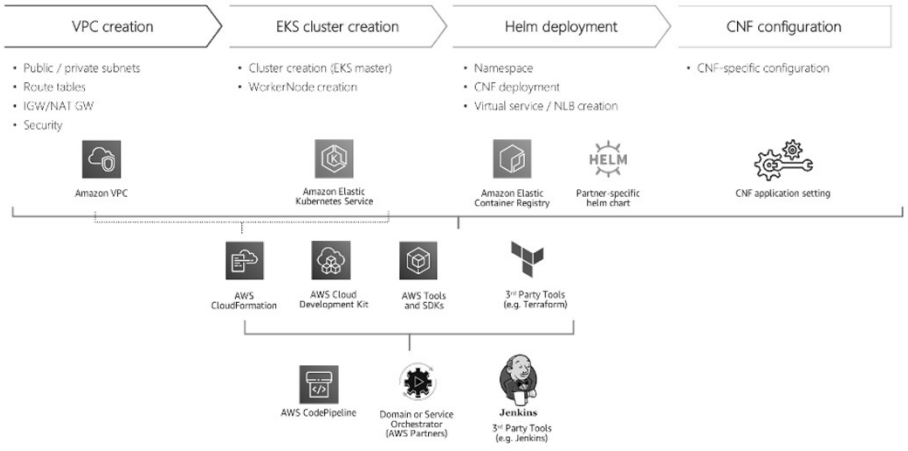
V. 5G 테스트베드 구성 및 활용

❖ Mobile core network implementation on Amazon Elastic Kubernetes Service



Source: https://aws.amazon.com/blogs/opensource/open-source-mobile-core-network-implementation-on-amazon-elastic-kubernetes-service/

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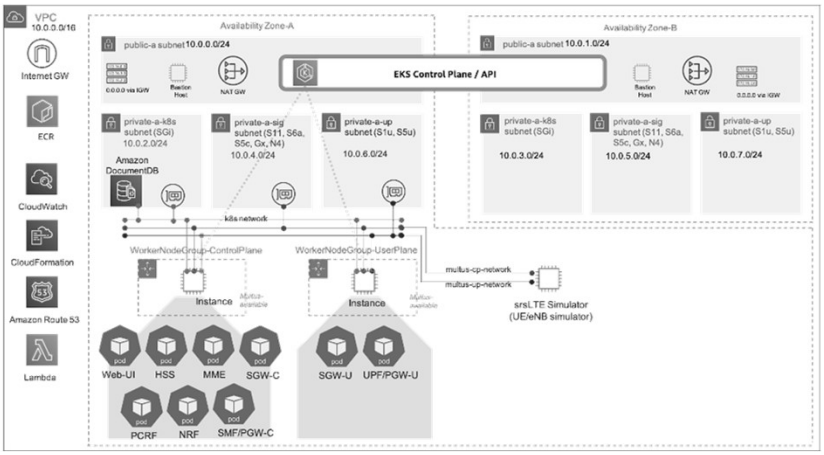
V. 5G 테스트베드 구성 및 활용

❖ Mobile core network implementation on Amazon Elastic Kubernetes Service

Time to complete	About 45-60 minutes
Cost to complete (estimated)	$489 (for a month, on-demand instance cost based)
Learning level	Advanced (300)
Services used	AWS CloudFormation, Amazon Elastic Kubernetes Service, Amazon DocumentDB, AWS Lambda, Amazon CloudWatch



Source: https://aws.amazon.com/blogs/opensource/open-source-mobile-core-network-implementation-on-amazon-elastic-kubernetes-service/

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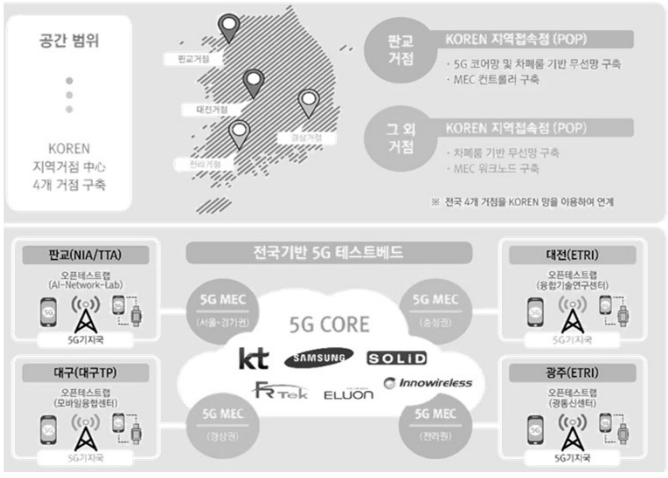
V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds

*20년부터 중소·벤처기업 등이 실제 5G망 환경에서 융합서비스·인프라·디바이스를 자유롭게 개발·시험·검증할 수 있도록 전국 4개 거점을 중심으로 5G 테스트베드를 구축·운영하고 있습니다.



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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds

• 5G 오픈테스트랩 개요

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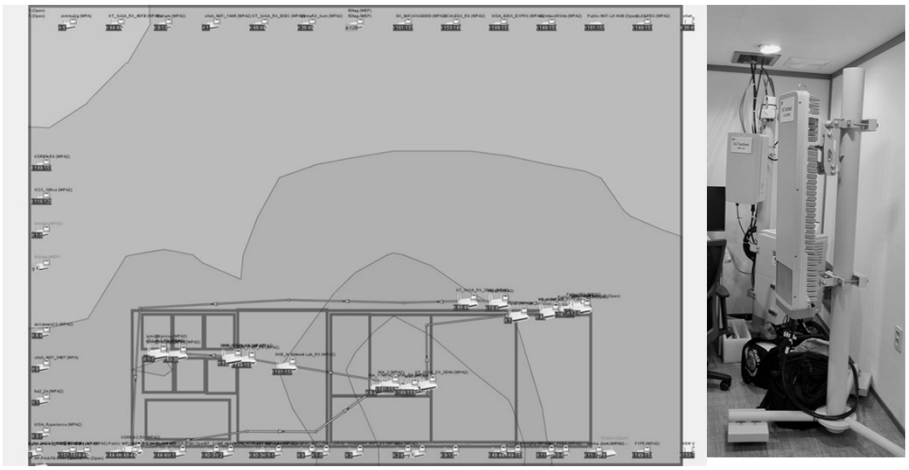
V. 5G 테스트베드 구성 및 활용

❖ Shield Room at 5G Test Lab

• Heatmap (벽에 대한 차폐 정도 등의 물리 정보 고려 탐지 위치 조정 필요)



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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G 테스트베드 사업 내용

❶ 전국 5G 시험망을 기반으로 5G 테스트센터(판교)와 ❷ 4개 거점(판교, 대전, 광주, 대구) 오픈테스트랩을 통하여 MEC 기반 5G 융합서비스와 ❸ 5G 국가망 및 관련 단말·디바이스·장비의 기능·성능, 상호 호환성 등을 시험합니다.

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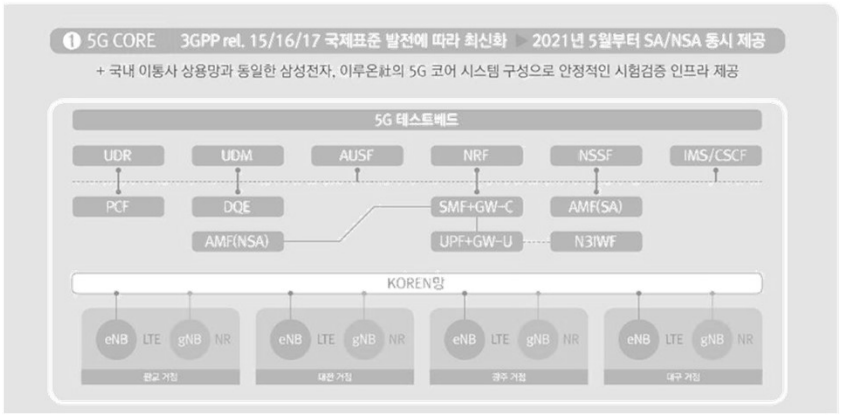
V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds

• 5G Core

세계 최초 가상화 기술 국제 표준에 기반한 5G 테스트베드는 2023년까지 KOREN을 기반으로 1개 센터와 4개 거점에 국제표준/기술규격에 따라 단계별로 구축·운영됩니다.
산·학·연이 활용할 수 있도록 코어, MEC, 3.5GHz/28GHz 기지국 5G 오케스트레이션 등을 지원 예정입니다.



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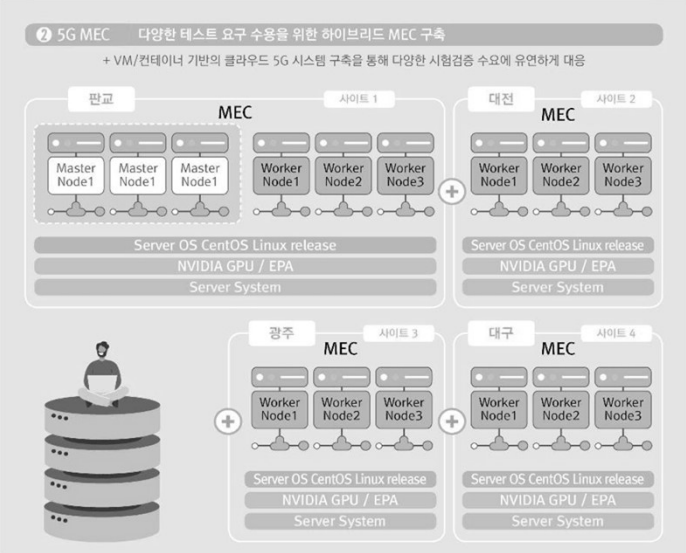
V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds

• 5G MEC



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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds

• 5G RAN

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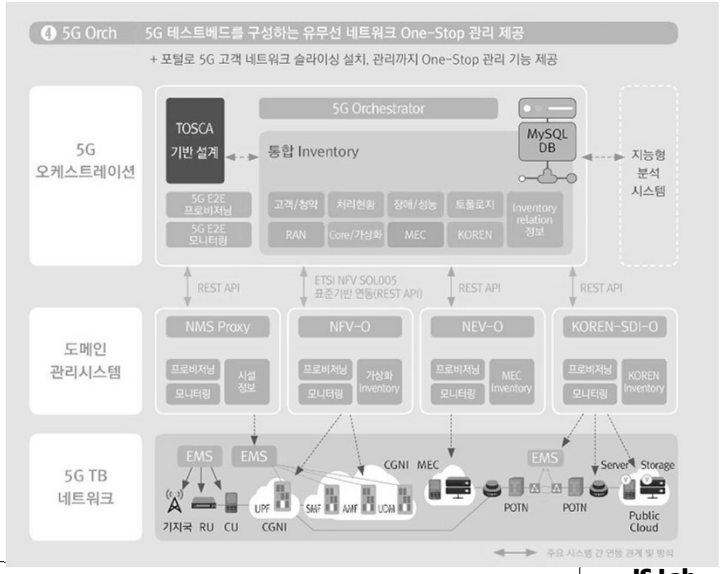
V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
- 5G 오케스트레이션



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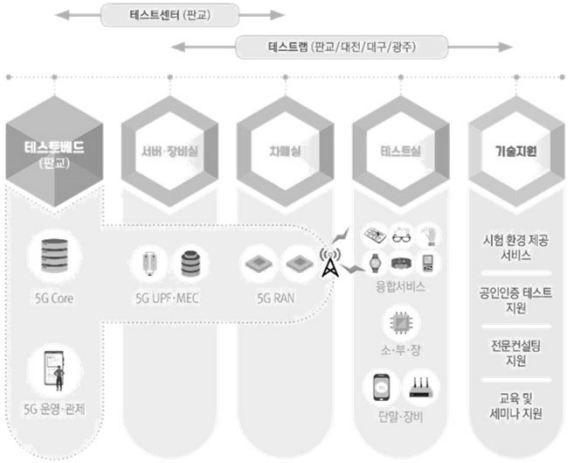
V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
- 5G 오픈테스트랩 서비스 개요

5G 오픈테스트랩은 전국 4개 거점에서 ❶ 시험 환경 제공 서비스, ❷ 공인인증 테스트 지원, ❸ 전문컨설팅 지원, ❹ 교육 및 세미나 지원 등을 제공합니다. 이를 통해 맞춤형 시험검증, 기술개발 고도화, 사업화 전략 컨설팅 등 목적에 따라 다양한 방식으로 5G 오픈테스트랩 인프라 및 서비스를 이용할 수 있습니다.



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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
- 5G 오픈테스트랩 시험환경 제공 서비스

1.
시험 환경
제공 서비스

Open test lab
Support service
for 5G

5G 오픈테스트랩은 5G 환경에서 서비스, 기술 등을 테스트할 수 있는 전용 공간입니다.
전용공간에서 5G 단말 성능 측정 장비 및 솔루션, 전자파 차폐룸, Fronthaul 회선 서비스 환경 등을 구축해 5G 테스트 환경을 제공합니다.

- 5G 시험용 단말, 5G 통신 모듈, 5G 단말 제어, 계측장비 등 기술개발 시 필요 장비 구비
- 5G 관련 고가 장비 공동활용 등 기관 간 연계 추진

- 판교 거점 : 5G 코어망 구축, MEC 컨트롤러 설치
- 대전/대구/광주 거점 : DU , MEC 워커노드 구축

- 시험사무공간, WIFI, 프린터 구비
- 회의실, 세미나룸, PC 기반 실습 교육장 구성

- 차폐룸 LTE 1.8GHz, 5G 3.5GHz, 5G 28GHz(AU) 구축
- 대구 거점 : 5G 및 Private 5G 망 시험 검증 LAB 추가 구축

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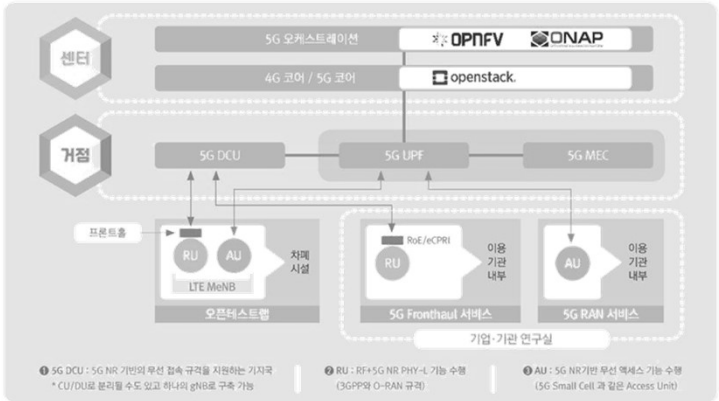
V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
- 5G 오픈테스트랩 시험환경 제공 서비스

전용공간뿐만 아니라 국가연구개발망(KOREN)과 연계한 5G 전용회선(25M 이상) 서비스를 제공하여
테스트랩을 방문하지 않으시더라도 소속 기업과 기관의 연구실에서 5G 단말, 디바이스, 장비 등 시험검증을 지원합니다.



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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
• 공인인증 테스트 지원

2.
공인인증
테스트 지원

Open test lab
Support service
for 5G

오픈테스트랩은 중소벤처기업의 MEC 기반 5G 융합서비스와 관련 단말, 디바이스, 장비 등의 시험개발을 지원하고 있으며 특히, 5G SA 시스템 기반의 시험검증, 특화망 및 O-RAN 활용 시험검증, 5G 정부업무망 통신장비 시험검증 환경 등을 제공합니다. 또한, 시험검증 결과를 바탕으로 공인인증기관의 시험성적서(Tested, Verified, Operated)를 발급하여 제공 중입니다.

1. **신 청** : 5G 오픈테스트랩에 인증시험 신청
2. **일정협의** : 시험일정 협의
3. 시험진행
4. **시험결과 보고** : 시험결과 업로드
5. 시험결과 검토
6. 인 증 : 시험성적서 발급

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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
• 공인인증 테스트 지원

5G 특화망 활용 기지국 장비 시험개발 지원

주요 시험 시나리오

5G CN	5G 특화망용 코어망 연동 현장시험
5G 서비스	5G 특화망용 종단 간 단말·융합서비스 시험
5G RAN	5G 특화망용 28GHz 장비(AU/RU/DU) 시험

5G 정부업무망 시험 지원

❶ 5G 국가망에 적용되는 5G 단말, 스몰셀 장비, 인빌딩 중계기 등 통신장비 시험개발 지원
❷ 5G 국가망 관련 융합서비스 시험개발 지원

망 연동 테스트 지원

통신사업자 단말기 등의 통신사 망 연동 시험 지원
※ 이동통신사, 공인인증기관이 공동으로 시험 항목 및 절차 마련

5G 개방형 규격인 Open RAN 지원

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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
• 컨설팅 지원

5G 모듈 활용 기술지원

- 보유 5G 모듈 (Sub-6 NSA/SA)
  - Quectel 5G RM500Q-GL 모듈 및 평가보드
  - Waveshare 8200EA-M2 5G HAT 평가보드
  - SIMCOM SIM8200EA-M2 모듈 및 평가보드
  - HUCOM HM-900 모뎀 (구매예정)
- 삼성, 애플, LG 5G 단말 보유
- 5G 단말 분석 툴 (구매예정)

5G 프론트홀 광송수신 모듈 기술지원

- 5G 프론트홀 (DU-RU) 광송수신 모듈 망연동 시험 지원
  - 망연동 End-to-End 패킷 전송시험
  - DDMI 분석 결과 제공 (예정)
- 프론트홀 분석/측정 장비 보유
  - VIAVI T-BERD/MTS-5800-100G
  - 5G 프론트홀 패킷 분석/성능 측정

5G MEC SW 개발 기술지원

- 5G MEC 활용 SW 기술개발 및 시험
  - Kubernetes 활용 마이크로서비스 관리 기술
  - 마이크로서비스 동작상태 분석
- 5G MEC 기반 AI 응용서비스 개발 지원
  - AI inference offloading framework

5G MEC 기반 AR/VR 기술지원

- 5G MEC AR/VR 응용서비스 시험 지원
  - PICO Neo2 HMD 보유
- 고성능 GPU 내장 MEC 서버
- Nvidia Ampere A40 GPU 내장 서버 보유
  - AR/VR 랜더링 서비스 활용

5G 오픈테스트랩은 5G 융합서비스 기술개발, 사업검증에 필요한 컨설팅을 제공하며 ETRI, TTA 등 국내 최고 시험검증 전문가를 통한 맞춤형 컨설팅 서비스를 제공하고 있습니다. 신규로 시험검증 결과에 대한 디버깅 및 트러블슈팅도 지원하고 있습니다.

- 맞춤형 시험검증 컨설팅 지원
- ETRI, TTA, 대구TP 등 국제표준 시험 전문가의 1:1 기술 컨설팅 제공

- 5G 융합서비스 기술개발 관련 컨설팅 지원
- **판교 거점 :** 5G 응용서비스에 대한 표준 적합성, 보안기술 등
- **대전 거점 :** 5G 관련 산·학·연 연구개발 결과물 등
- **광주 거점 :** 5G 드론 등신, AR/VR, WiFi6망 연계 Roaming 융합서비스 등
- **대구 거점 :** Private 5G 망 활용 서비스, 스마트시티 연계 서비스 등

- 5G 오픈테스트랩 연계기관과의 협력을 통한 컨설팅 지원
- 연계기관 : 로봇진흥원, 지능형자동차부품진흥원 등

- 시험검증 등 결과에 대한 디버깅 및 트러블슈팅
- 사업화 전략 수립 관련 컨설팅 지원

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V. 5G 테스트베드 구성 및 활용

❖ KOREN 기반 5G Testbeds
• 이용 절차

E-mail, 전화를 통해 연중 수시 신청 가능

5G 오픈테스트랩 이용절차

헬프데스크 (온/오프라인 문의) → 지원 상담 → 지원 신청 → 장비/시험 지원 컨설팅 지원

판교	대전	광주	대구
5G 테스트베드 전경	5G 테스트베드 전경	5G 테스트베드 전경	5G 테스트베드 전경

5G 오픈테스트랩(판교거점) 담당자
- 이찬주 수석 Tel. 031-780-9194 / e-mail : cjlee@tta.or.kr
- 이병진 책임 Tel. 031-780-9198 / e-mail : bjlee86@tta.or.kr

(13449) 경기도 성남시 수정구 대왕판교로 815(시흥동)
판교창조경제혁신 기업지원허브 2층 AI Network Lab

5G 오픈테스트랩(대전거점) 담당자
- 김정환 책임 Tel. 042-860-5868 / e-mail : ditto@etri.re.kr
- 강경순 책임 Tel. 042-860-6762 / e-mail : kskang@etri.re.kr

(34129) 대전광역시 유성구 가정로 218(가정동)
ETRI 융합기술연구생산센터 2층 ICT 융합테스트베드

5G 오픈테스트랩(경상거점) 담당자
- 박민우 선임 Tel. 053-602-1844 / e-mail : kknd11@ttp.org
- 차재민 선임 Tel. 053-602-1805 / e-mail : chajm@ttp.org

(42716) 대구광역시 달서구 성서공단로 46-17(대천동)
신기술산업지원센터 3동 2층

5G 오픈테스트랩(전라거점) 담당자
- 유 학 책임 Tel. 062-970-6530 / e-mail : harkyoo@etri.re.kr
- 윤광수 책임 Tel. 062-970-6612 / e-mail : yks0604@etri.re.kr

(61012) 광주광역시 북구 첨단과기로 176번길 11(오룡동)
ETRI 호남권연구센터 119호

5G 테스트베드센터 운영 지원 담당자
- 노상수 부장 Tel. 010-2646-0060 / e-mail : sangsoo.noh@kt.com
- 고정우 연구원 Tel. 010-2659-2013 / e-mail : kjw@eluon.com

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V. 5G 테스트베드 구성 및 활용

❖ **Capabilities of SDRs and their integration with RAN software**

SDR	TX/RX Channels	Frequency Range	Instantaneous Bandwidth (up to)	RAN Software	Target
bladeRF	1	[300 MHz, 3.8 GHz]	28 MHz	OAI, srsLTE	DAS node, small cell
bladeRF 2.0 micro	2	[47 MHz, 6 GHz]	56 MHz	OAI, srsLTE	DAS node, small cell
Iris	2	[50 MHz, 3.8 GHz]	56 MHz	OAI	DAS node, small cell, cell tower
LimeSDR	4 TX, 6 RX	[100 kHz, 3.8 GHz]	61.44 MHz	OAI, srsLTE	DAS node, small cell
USRP B205mini-i	1	[70 MHz, 6 GHz]	56 MHz	srsLTE	DAS node
USRP B210	2	[70 MHz, 6 GHz]	56 MHz	OAI, srsLTE	DAS node, small cell
USRP N310	4	[10 MHz, 6 GHz]	100 MHz	OAI	DAS node, small cell, cell tower, rooftop
USRP X310	up to 2 (daughterboards)	[DC, 6 GHz] (daughterboards)	160 MHz (daughterboards)	OAI, srsLTE	DAS node, small cell, cell tower

Source: Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead, Institute for the Wireless Internet of Things, Northeastern University, Boston, MA 02115, USA

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V. 5G 테스트베드 구성 및 활용

❖ **5G Testbeds** (국내 O-RAN 테스트베드 예정)

Testbed	Technology available	5G Open Source Software	Framework	Scenario
AERPAW	5G and CR for UASs	under development		City-scale outdoor
Arena	5G, CR, massive MIMO	RAN & Core	N/A	Large-scale office
Colosseum	5G, CR	RAN & Core	O-RAN RIC	Large-scale network emulator
CORNET	5G, CR	RAN & Core	N/A	Large-scale indoor
COSMOS	5G, mmWave, CR, optical switching	RAN & Core	O-RAN components	Indoor, city-scale outdoor
Drexel Grid	5G, CR	RAN & Core	N/A	Large-scale indoor
FIT testbeds	5G, CR, IoT, NFV	RAN & Core	OSM	Large-scale indoor
IRIS	5G, CR, Wi-Fi, WiMAX, cloud-RAN, NFV, S-band	RAN & Core	N/A	Indoor
NITOS	5G, CR, Wi-Fi, WiMAX	RAN & Core	N/A	Large-scale indoor and outdoor, office
POWDER-RENEW	5G, CR, massive MIMO, Network Orchestration	RAN & Core	O-RAN RIC	Indoor, city-scale outdoor
5TONIC	5G NFV, network orchestration	N/A	OSM	Data center

Source: Open, Programmable, and Virtualized 5G Networks:, State-of-the-Art and the Road Ahead, Institute for the Wireless Internet of Things, Northeastern University, Boston, MA 02115, USA

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V. 5G 테스트베드 구성 및 활용

❖ Open frameworks and projects.

	Framework	Main Focus	Status	License	Main Members	Community Support
	Mobile					
O-RAN	O-RAN [21]	Virtualized, intelligent RAN	available	Apache v2.0, O-RAN Software License v1.0	O-RAN Alliance w/ telecom operators	no
	COMAC [124]	Agile service delivery at the edge	available	Apache v2.0	ONF	mailing list
SD-RAN	SD-RAN [125]	CU/DU control and user planes	under development		ONF	N/A
	Aether [126]	5G/LTE, Edge-Cloud-as-a-Service (ECaaS)	under development		ONF	N/A
	Magma [127]	CN Orchestration	available	BSD	Facebook	mailing list / forum
	OpenRAN [128]	Programmable, disaggregated RAN w/ open interfaces	closed source		TIP	no
	Radio Edge Cloud [129]	O-RAN RIC automated configuration / integration testing blueprint	available	Apache v2.0	Akraino	no
	Aerial [130]	SDK for GPU-accelerated 5G vRAN	early access	proprietary	NVIDIA	N/A
	Slicing					
	5G-EmPOWER [131]	Centralized controlled for heterogeneous RAN	available	Apache v2.0	FBK (in the framework of multiple EU projects)	no
	FlexRAN [132]	Real-time controller for software-defined RAN	available	MIT License	Mosaic5G Consortium	mailing list
	Edge					
	CORD [133]	Data center for network edge	available	Apache v2.0	ONF, AT&T, Google, Telefonica	mailing list
	LL-MEC [134]	Low-latency MEC and network slicing	available	Apache v2.0	Mosaic5G Consortium	mailing list
	LightEdge [135]	MEC services	available	Apache v2.0	FBK (in the framework of multiple EU projects)	N/A

Source: Open, Programmable, and Virtualized 5G Networks:, State-of-the-Art and the Road Ahead, Institute for the Wireless Internet of Things, Northeastern University, Boston, MA 02115, USA

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V. 5G 테스트베드 구성 및 활용

❖ 5G 테스트베드

Testbed	Technology available	5G open source software	Framework	Scenario
AERPAW	5G and CR for UASs	Under development	Under development	City-scale outdoor
Arena	5G, CR, massive MIMO	RAN & Core	N/A	Large-scale office
Colosseum	5G, CR	RAN & Core	O-RAN RIC	Large-scale network emulator
CORNET	5G, CR	RAN & Core	N/A	Large-scale indoor
COSMOS	5G, mmWave, CR, optical switching	RAN & Core	O-RAN components	Indoor, city-scale outdoor
Drexel Grid	5G, CR	RAN & Core	N/A	Large-scale indoor
FIT testbeds	5G, CR, IoT, NFV	RAN & Core	OSM	Large-scale indoor
IRIS	5G, CR, Wi-Fi, WiMAX, cloud-RAN, NFV, S-band	RAN & Core	N/A	Indoor
NITOS	5G, CR, Wi-Fi, WiMAX	RAN & Core	N/A	Large-scale indoor and outdoor, office
POWDER-RENEW	5G, CR, massive MIMO, Network Orchestration	RAN & Core	O-RAN RIC	Indoor, city-scale outdoor
5TONIC	5G NFV, network orchestration	N/A	OSM	Data center

Source: Survey paper, Computer Networks 182 (2020) 107516, Open, Programmable, and Virtualized 5G Networks: State-of-the-Art and the Road Ahead☆ Leonardo Bonati *, Michele Polese, Salvatore D'Oro, Stefano Basagni, Tommaso Melodia, Institute for the Wireless Internet of Things, Northeastern University, Boston, MA 02115, USA

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❖ 5G Lab – 구성 (시연/실습)

- 5 Nodes in One-box Lab (시연)
- Operations for 2 Nodes (실습)

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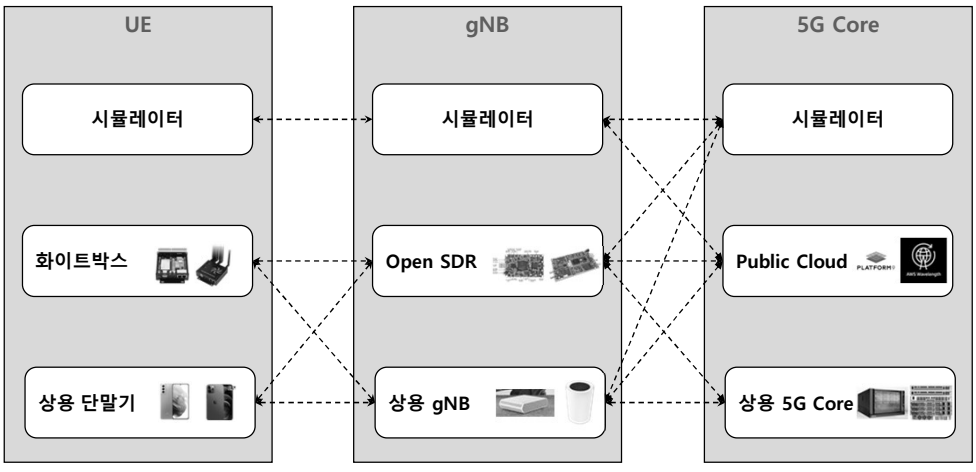
❖ 5G LAB – 구성 (시연/실습)

❖ 5G 시험 환경



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❖ 5G LAB – 구성 (시연/실습)

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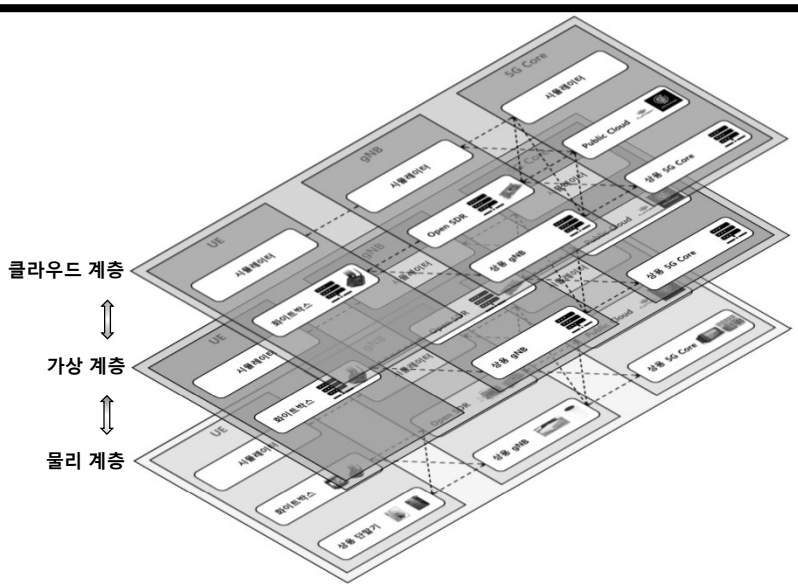
❖ 5G 시험 환경



JS Lab

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❖ 5G LAB – 구성 (시연/실습)

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❖ Core/UE/gNB 'One-box Lab' 구성

JS Lab

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❖ 5G LAB – 구성 (시연/실습)

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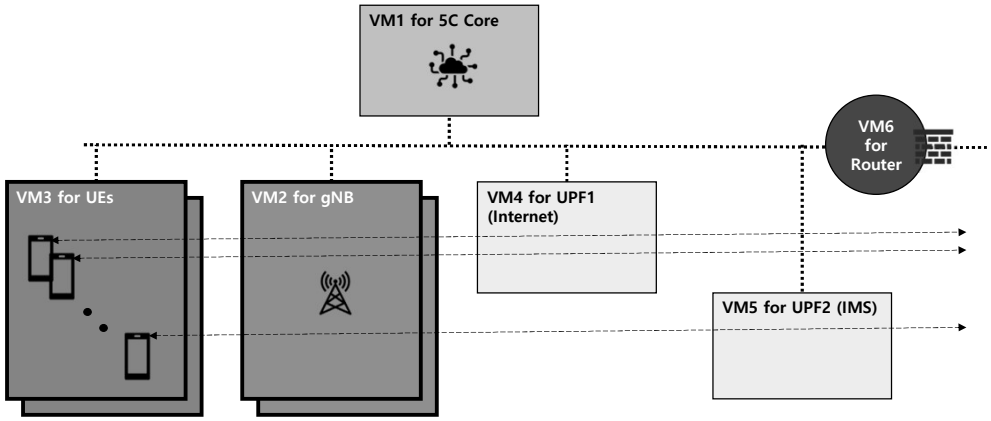
❖ 가상화 5 노드 사용 'One-box Lab' 구성



JS Lab

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❖ 5G LAB – 구성 (시연/실습)

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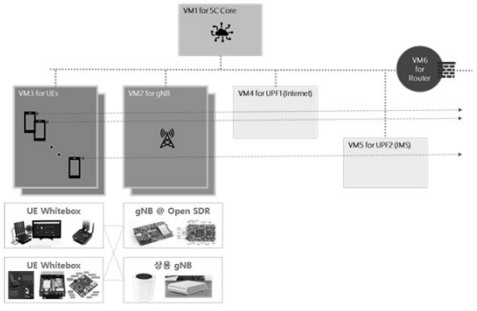
❖ 호환 하드웨어 (eNodeBs / gNodeBs tested)

- **Commercial 5G (호환)**
  - Airspan 5G OpenRange vCU + Airspan 5G OpenRange vDU + Airspan 5G OpenRANGE06 AirVelocity 2700 RU
  - LIONS RANathon O-CU and O-DU + RANathon RS8601 Indoor O-RU + RANathon XG8600 Fronthaul Gateway
  - NOKIA AEQE (SW: 5G20A)
  - NOKIA AEQD (SW: 5G20A)
  - NOKIA AEQP (SW: 5G21A)
  - Huawei BTS5900
- **4G/5G Software Stacks + SDRs (호환)**
  - Amarisoft + LimeSDR, USRP, Amarisoft PCI Express Card
  - srsLTE / srsENB + LimeSDR, USRP, BladeRF x40 (BladeRF Not stable)
  - Open Air Interface 5G (NR_SA_F1AP_5GRECORDS branch) + USRP B210
- **Misc Radio Hardware (호환)**
  - OpenAirInterface v1.0.3 4G RAN Simulator
  - OsmoBTS controlled ip.access NanoBTS (Used for CSFB with Osmocom)
  - UERANSIM 5G RAN Simulator



JS Lab

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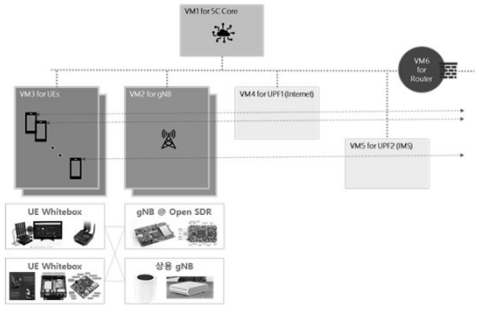
❖ 5G LAB – 구성 (시연/실습)

❖ 호환 하드웨어 (eNodeBs tested)

- **Commercial 4G**
  - Accelleran E1010 (LTE TDD B42)
  - AirHarmony 4000
  - AirHarmony 4200
  - AirHarmony 4400
  - Airspan AirSpeed 1030
  - Airspan AirHarmony 1000
  - Baicells Neutrino
  - Baicells Nova 243
  - Baicells Nova 246
  - Baicells Nova 249
  - Baicells Nova 436Q
  - Baicells Nova 227 (EBS & CBRS)
  - Baicells Nova 233



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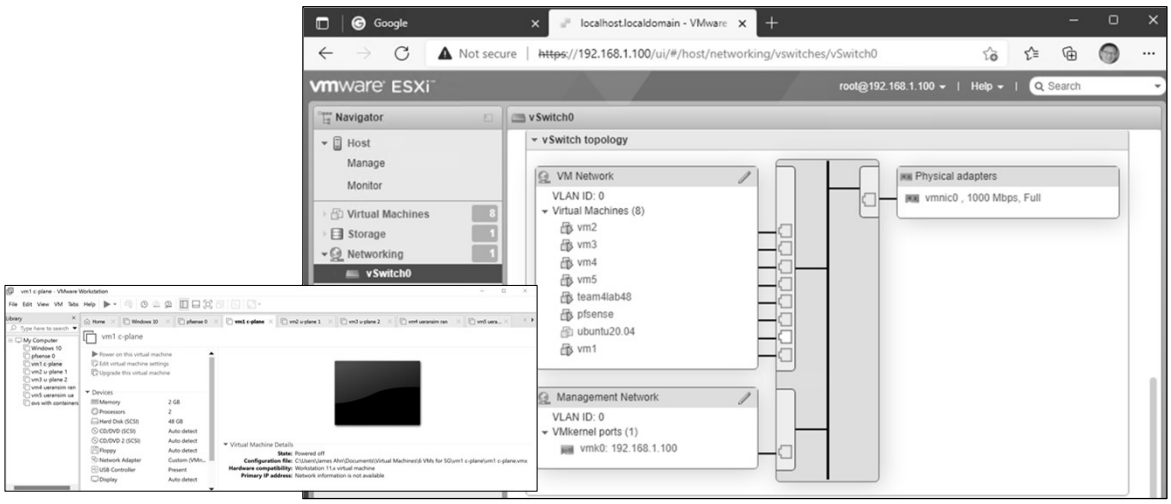
❖ 5G LAB – 구성 (시연/실습)

❖ 'One-box Lab' 가상화 구성



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❖ 5G LAB – 구성 (시연/실습)

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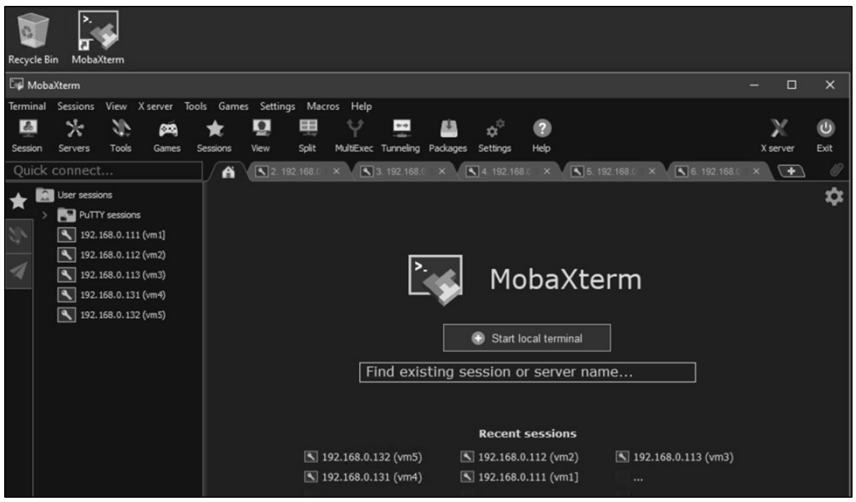
❖ 터미널 (MobaXterm)

- 5 VMs



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❖ 5G LAB – 구성 (시연/실습)

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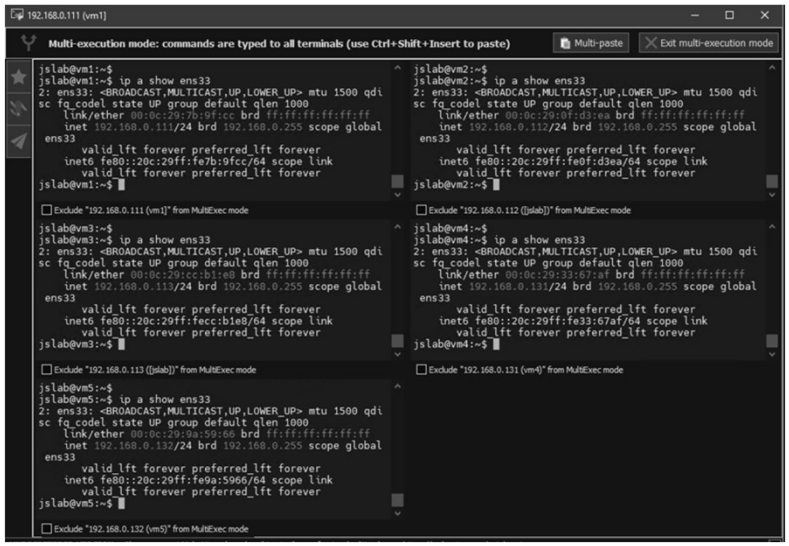
❖ 터미널 동시 접속

- 5 VMs @ Multi-execution mode



Source: https://youtu.be/iblvapanueU

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❖ 5G LAB – 구성 (시연/실습)

❖ Quickstart (Open5GS)

- sudo systemctl restart open5gs-amfd # AMF 재구동 @ vm1
- sudo systemctl restart open5gs-upfd # UPF 재구동 @ vm2/vm3
- sudo ./nr-gnb -c ~/UERANSIM/config/open5gs-gnb.yaml # @ vm4 /UERANSIM/build/
- sudo build/nr-ue -c config/open5gs-ue0.yaml # UE0 @ vm5 /UERANSIM/
- sudo build/nr-ue -c config/open5gs-ue1.yaml # UE1 @ vm5 /UERANSIM/
  - ping -I uesimtun0 google.com # Ping @ vm5 - UE1 (Fail)
  - sudo tcpdump -i ogstun # Data Capture @ vm2 - UPF1
  - sh nr-binder 10.45.0.2 curl google.com # UE0 @ vm5 - UERANSIM/build/
  - sh nr-binder 10.45.0.2 ping google.com # UE0 @ vm5 - UERANSIM/build/
  - sh nr-binder 10.45.0.3 ping google.com # UE1 @ vm5 - UERANSIM/build/

•Next, configure the TUNnel interface and NAPT. (sudo –i) @ User Plane 1 (vm2)	•Next, configure the TUNnel interface and NAPT. (sudo –i) @ User Plane 2 (vm3)
○ ip tuntap add name ogstun mode tun ○ ip addr add 10.45.0.1/16 dev ogstun ○ ip link set ogstun up	sudo ip tuntap add name ogstun mode tun sudo ip addr add 10.45.0.1/16 dev ogstun sudo ip link set ogstun up
○ iptables -t nat -A POSTROUTING -s 10.45.0.0/16 ! -o ogstun -j MASQUERADE	sudo iptables -t nat -A POSTROUTING -s 10.45.0.0/16 ! -o ogstun -j MASQUERADE
○ ip tuntap add name ogstun2 mode tun ○ ip addr add 10.46.0.1/16 dev ogstun2 ○ ip link set ogstun2 up	sudo ip tuntap add name ogstun3 mode tun sudo ip addr add 10.47.0.1/16 dev ogstun3 sudo ip link set ogstun3 up
○ iptables -t nat -A POSTROUTING -s 10.46.0.0/16 ! -o ogstun2 -j MASQUERADE	sudo iptables -t nat -A POSTROUTING -s 10.47.0.0/16 ! -o ogstun3 -j MASQUERADE

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❖ 5G LAB – 구성 (시연/실습)

❖ UE0/UE1 접속 (@vm5): sudo build/nr-ue -c config/open5gs-ue0.yaml
sudo build/nr-ue -c config/open5gs-ue1.yaml

```
jslab@vm5:~/UERANSIM$ sudo build/nr-ue -c config/open5gs-ue0.yaml
[sudo] password for jslab:
UERANSIM v3.2.5
[2022-03-16 14:37:04.432] [nas] [info] UE switches to state [MM-DEREGISTERED/PLMN-SEARCH]
[2022-03-16 14:37:04.433] [rrc] [debug] New signal detected for cell[1], total [1] cells in coverage
[2022-03-16 14:37:04.433] [nas] [info] Selected plmn[001/01]
[2022-03-16 14:37:04.433] [rrc] [info] Selected cell plmn[001/01] tac[1] category[SUITABLE]
[2022-03-16 14:37:04.433] [nas] [info] UE switches to state [MM-DEREGISTERED/PS]
[2022-03-16 14:37:04.433] [nas] [info] UE switches to state [MM-DEREGISTERED/NORMAL-SERVICE]
[2022-03-16 14:37:04.433] [nas] [debug] Initial registration required due to [MM-DEREG-NORMAL-SERVICE]
[2022-03-16 14:37:04.433] [nas] [debug] UAC access attempt is allowed for identity[0], category[MO_sig]
[2022-03-16 14:37:04.433] [nas] [debug] Sending Initial Registration
[2022-03-16 14:37:04.434] [nas] [info] UE switches to state [MM-REGISTER-INITIATED]
[2022-03-16 14:37:04.434] [rrc] [debug] Sending RRC Setup Request
[2022-03-16 14:37:04.435] [rrc] [info] RRC connection established
[2022-03-16 14:37:04.435] [rrc] [info] UE switches to state [RRC-CONNECTED]
[2022-03-16 14:37:04.435] [nas] [info] UE switches to state [CM-CONNECTED]
[2022-03-16 14:37:04.449] [nas] [debug] Authentication Request received
[2022-03-16 14:37:04.453] [nas] [debug] Security Mode Command received
[2022-03-16 14:37:04.453] [nas] [debug] Selected integrity[2] ciphering[0]
[2022-03-16 14:37:04.467] [nas] [debug] Registration accept received
[2022-03-16 14:37:04.467] [nas] [info] UE switches to state [MM-REGISTERED/NORMAL-SERVICE]
[2022-03-16 14:37:04.467] [nas] [debug] Sending Registration Complete
[2022-03-16 14:37:04.467] [nas] [info] Initial Registration is successful
[2022-03-16 14:37:04.467] [nas] [debug] Sending PDU Session Establishment Request
[2022-03-16 14:37:04.467] [nas] [debug] UAC access attempt is allowed for identity[0], category[MO_sig]
[2022-03-16 14:37:04.669] [nas] [debug] Configuration Update Command received
[2022-03-16 14:37:04.678] [nas] [debug] PDU Session Establishment Accept received
[2022-03-16 14:37:04.678] [nas] [info] PDU Session establishment is successful PSI[1]
[2022-03-16 14:37:04.687] [app] [info] Connection setup for PDU session[1] is successful, TUN interface[uesimtun0, 192.168.0.132] is up.
```


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❖ 5G LAB – 구성 (시연/실습)

❖ UPF Data Capture (@vm2): sudo tcpdump -i ogstun

```
root@vm2:~# sudo tcpdump -i ogstun
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on ogstun, link-type RAW (Raw IP), capture size 262144 bytes
14:41:44.361547 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 132629986:132630034, ack 4066425675, win 502, length 48
14:41:44.542340 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 48:96, ack 49, win 502, length 48
14:41:44.724352 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 96:144, ack 97, win 502, length 48
14:41:44.919515 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 144:192, ack 145, win 502, length 48
14:41:44.920772 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 192:256, ack 145, win 502, length 64
14:41:44.920952 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 256:304, ack 145, win 502, length 48
14:41:46.647669 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 304:352, ack 193, win 502, length 48
14:41:46.769911 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 352:400, ack 241, win 502, length 48
14:41:46.966890 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 400:448, ack 289, win 502, length 48
14:41:47.393137 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 448:496, ack 337, win 502, length 48
14:41:48.551609 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 496:560, ack 385, win 502, length 64
14:42:01.602864 IP 192.168.0.132.34956 > one.one.one.one.domain: 50162+ [1au] A? google.com. (39)
14:42:01.602940 IP 192.168.0.132.34066 > one.one.one.one.domain: 54664+ [1au] AAAA? google.com. (39)
14:42:01.607446 IP 192.168.0.132.52956 > nrt12s51-in-f14.1e100.net.http: Flags [S], seq 679006258, win 65280, options [mss 1360,sackOK,TS val 4125649178 ecr 0,nop,wscale 7], length 0
14:42:01.644860 IP 192.168.0.132.52956 > nrt12s51-in-f14.1e100.net.http: Flags [.], ack 102638069, win 510, options [nop,nop,TS val 4125649216 ecr 3913022093], length 0
14:42:01.644928 IP 192.168.0.132.52956 > nrt12s51-in-f14.1e100.net.http: Flags [P.], seq 0:74, ack 1, win 510, options [nop,nop,TS val 4125649216 ecr 3913022093], length 74: HTTP: GET / HTTP/1.1
14:42:01.772848 IP 192.168.0.132.52956 > nrt12s51-in-f14.1e100.net.http: Flags [.], ack 529, win 506, options [nop,nop,TS val 4125649344 ecr 3913022223], length 0
14:42:01.772943 IP 192.168.0.132.52956 > nrt12s51-in-f14.1e100.net.http: Flags [F.], seq 74, ack 529, win 506, options [nop,nop,TS val 4125649344 ecr 3913022223], length 0
14:42:01.773018 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 1504:1728, ack 1057, win 502, length 224
14:42:01.778251 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 1728:1776, ack 1057, win 502, length 48
14:42:01.805362 IP 192.168.0.132.52956 > nrt12s51-in-f14.1e100.net.http: Flags [.], ack 530, win 506, options [nop,nop,TS val 4125649376 ecr 3913022258], length 0
14:44:12.203842 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 1776:1840, ack 1121, win 502, length 64
14:44:16.907917 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 1840:1888, ack 1169, win 502, length 48
14:44:16.909567 IP 192.168.0.132.33839 > one.one.one.one.domain: 42867+ [1au] A? google.com. (39)
14:44:16.909658 IP 192.168.0.132.48735 > one.one.one.one.domain: 49261+ [1au] AAAA? google.com. (39)
14:44:16.914289 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 1, length 64
14:44:16.914382 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 1888:1968, ack 1169, win 502, length 80
14:44:17.930430 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 2, length 64
14:44:18.954279 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 3, length 64
14:44:19.978568 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 4, length 64
14:44:21.002379 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 5, length 64
14:44:22.026549 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 6, length 64
14:44:23.050760 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 7, length 64
14:44:24.074661 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 8, length 64
14:44:25.098864 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 9, length 64
14:44:26.122515 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 10, length 64
14:44:27.146279 IP 192.168.0.132 > nrt12s51-in-f14.1e100.net: ICMP echo request, id 4, seq 11, length 64
14:44:42.040709 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 1968:2016, ack 1217, win 502, length 48
14:44:42.040821 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 2016:2096, ack 1217, win 502, length 80
14:44:42.041033 IP 192.168.0.132.ssh > 192.168.0.45.1654: Flags [P.], seq 2096:2144, ack 1217, win 502, length 48
```


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❖ 5G LAB – 구성 (시연/실습)

❖ UE0/UE1 Operations (@vm5): sh nr-binder 10.45.0.2 curl google.com
sh nr-binder 10.45.0.2 ping 1.1.1.1
sh nr-binder 10.45.0.3 ping google.com

```
jslab@vm5:~/UERANSIM/build$ sh nr-binder 10.45.0.2 curl google.com
<HTML><HEAD><meta http-equiv="content-type" content="text/html;charset=utf-8">
<TITLE>301 Moved</TITLE></HEAD><BODY>
<H1>301 Moved</H1>
The document has moved
<A HREF="http://www.google.com/">here</A>.
</BODY></HTML>
jslab@vm5:~/UERANSIM/build$ ping -I uesimtun0 google.com
PING google.com (172.217.26.238) from 192.168.0.132 uesimtun0: 56(84) bytes of data.
^C
--- google.com ping statistics ---
25 packets transmitted, 0 received, 100% packet loss, time 24568ms

jslab@vm5:~/UERANSIM/build$ sh nr-binder 10.45.0.2 ping 1.1.1.1
PING 1.1.1.1 (1.1.1.1) 56(84) bytes of data.
64 bytes from 1.1.1.1: icmp_seq=1 ttl=56 time=9.90 ms
64 bytes from 1.1.1.1: icmp_seq=2 ttl=56 time=7.89 ms
64 bytes from 1.1.1.1: icmp_seq=3 ttl=56 time=5.73 ms
64 bytes from 1.1.1.1: icmp_seq=4 ttl=56 time=3.28 ms
64 bytes from 1.1.1.1: icmp_seq=5 ttl=56 time=2.74 ms
64 bytes from 1.1.1.1: icmp_seq=6 ttl=56 time=3.38 ms

jslab@vm5:~/UERANSIM/build$ sh nr-binder 10.45.0.3 ping google.com
PING google.com (172.217.175.78) 56(84) bytes of data.
64 bytes from nrt20s20-in-f14.1e100.net (172.217.175.78): icmp_seq=1 ttl=114 time=33.4 ms
64 bytes from nrt20s20-in-f14.1e100.net (172.217.175.78): icmp_seq=2 ttl=114 time=33.8 ms
64 bytes from nrt20s20-in-f14.1e100.net (172.217.175.78): icmp_seq=3 ttl=114 time=33.7 ms
64 bytes from nrt20s20-in-f14.1e100.net (172.217.175.78): icmp_seq=4 ttl=114 time=33.9 ms
64 bytes from nrt20s20-in-f14.1e100.net (172.217.175.78): icmp_seq=5 ttl=114 time=33.6 ms
```


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❖ 5G LAB – 구성 (시연/실습)

❖ 5G Local Test Lab for 2 VMs

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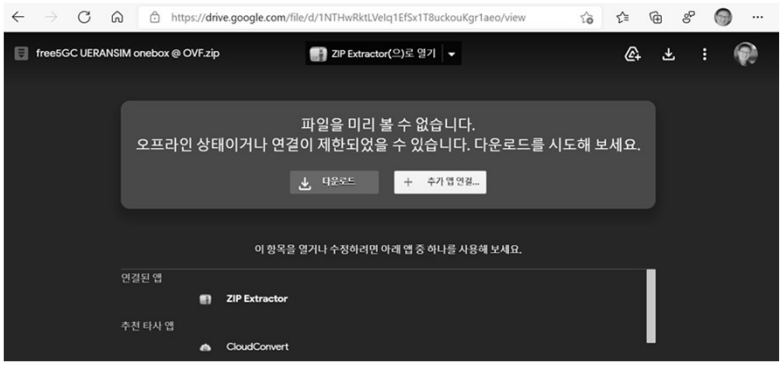
❖ 5G LAB – 구성 (시연/실습)

❖ 실습용 VM 이미지 .ovf 파일 download

• 교재 제작에 사용한 OVF 이미지 압축 파일 다운로드 URL:



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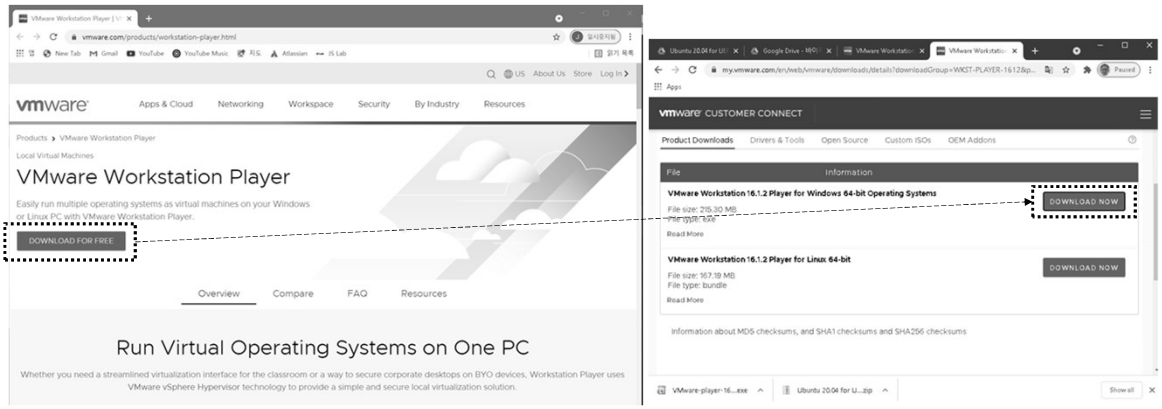
❖ 5G LAB – 구성 (시연/실습)

❖ **VMware Workstation Player 설치**

- **VMware Workstation Player 다운로드**
- **다운로드 URL: https://www.vmware.com/products/workstation-player.html**



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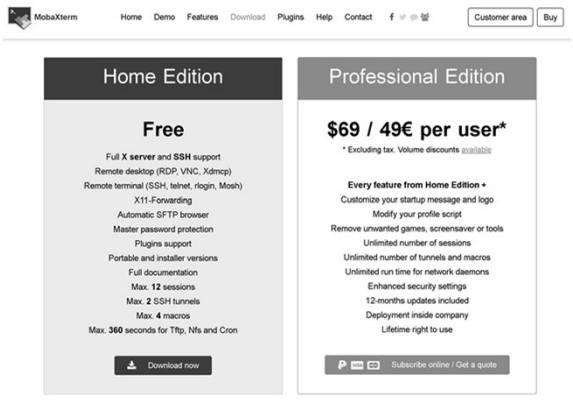
❖ 5G LAB – 구성 (시연/실습)

❖ **SSH 터미널 'MobaXterm' 설치 (선택)**

- **MobaXterm 다운로드**
- **다운로드 URL: https://mobaxterm.mobatek.net/download.html**



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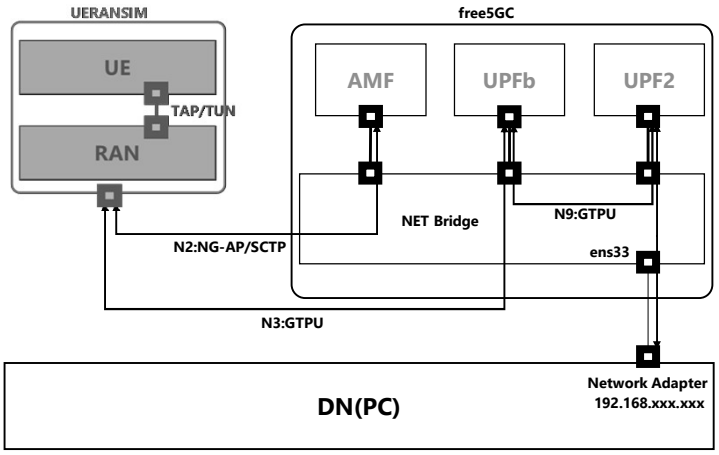
❖ 5G LAB – 구성 (시연/실습)

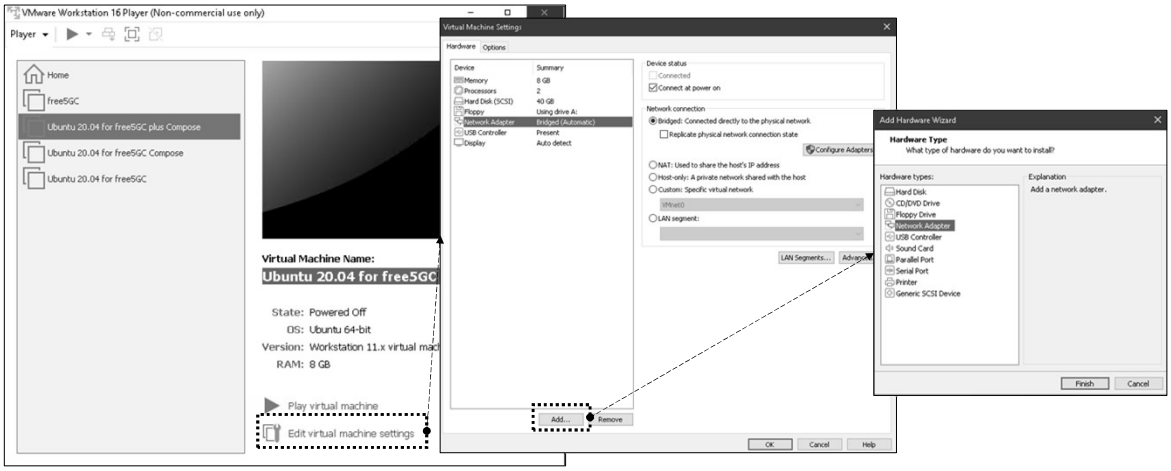
❖ 실습 구성



❖ 5G LAB – 구성 (시연/실습)

❖ VM 생성(Open) 후 네트워크 확인 (선택: 별도 VM 생성시)

- Make the Bridge/Host-only network interface (Bridge에 고정 IP 적용)



❖ 5G LAB – 구성 (시연/실습)

❖ **Setting Static IP Address (선택@콘솔)**

- cd /etc/netplan
- ls
- cat 00-installer-config.yaml
- sudo nano 00-installer-config.yaml

```
# This is the network config written by 'subiquity'
network:
  ethernets:
    ens33:
      dhcp4: true
    ens38:
      dhcp4: no
      addresses: [192.168.56.102/24]
  version: 2
```

```
jslab@free5gc:~$ cd /etc/netplan
jslab@free5gc:/etc/netplan$ ls
00-installer-config.yaml
jslab@free5gc:/etc/netplan$ cat 00-installer-config.yaml
# This is the network config written by 'subiquity'
network:
  ethernets:
    ens33:
      dhcp4: true
  version: 2
jslab@free5gc:/etc/netplan$
```

```
# This is the network config written by 'subiquity'
network:
  ethernets:
    ens33:
      dhcp4: true
    ens38:
      dhcp4: false
      addresses: [192.168.50.201/24]
      gateway4: 192.168.50.1
      nameservers:
        addresses: [1.1.1.1,8.8.8.8]
  version: 2
```


❖ 5G LAB – 구성 (시연/실습)

❖ **Setting Static IP Address (선택@콘솔)**

- sudo netplan try
- sudo netplan apply
- ip a
- route

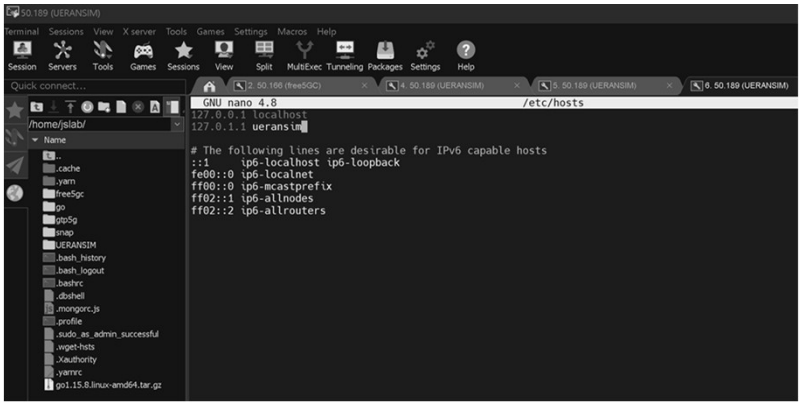
```
jslab@free5gc:/etc/netplan$ sudo netplan try
[sudo] password for jslab:
Warning: Stopping systemd-networkd.service, but it can still be activated by:
  systemd-networkd.socket
Do you want to keep these settings?

Press ENTER before the timeout to accept the new configuration

Changes will revert in 113 seconds
Configuration accepted.
jslab@free5gc:/etc/netplan$ sudo netplan apply
jslab@free5gc:/etc/netplan$ ip a
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN group default qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
2: ens33: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group default qlen 1000
    link/ether 00:0c:29:76:74:a9 brd ff:ff:ff:ff:ff:ff
    inet 192.168.128.136/24 brd 192.168.128.255 scope global dynamic ens33
       valid_lft 1794sec preferred_lft 1794sec
    inet6 fe80::20c:29ff:fe76:74a9/64 scope link
       valid_lft forever preferred_lft forever
3: ens38: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc fq_codel state UP group default qlen 1000
    link/ether 00:0c:29:76:74:b3 brd ff:ff:ff:ff:ff:ff
    inet 192.168.56.101/24 brd 192.168.56.255 scope global ens38
       valid_lft forever preferred_lft forever
    inet6 fe80::20c:29ff:fe76:74b3/64 scope link
       valid_lft forever preferred_lft forever
4: docker0: <NO-CARRIER,BROADCAST,MULTICAST,UP> mtu 1500 qdisc noqueue state DOWN group default
    link/ether 02:42:6b:17:53:59 brd ff:ff:ff:ff:ff:ff
    inet 172.17.0.1/16 brd 172.17.255.255 scope global docker0
       valid_lft forever preferred_lft forever
```

❖ 5G LAB – 구성 (시연/실습)

❖ **Change hostname (선택: 별도 VM 생성시)**

- sudo nano /etc/hostname # or sudo vi /etc/hostname
- sudo nano /etc/hosts
- sudo reboot

Host Name; ueransim



❖ 5G LAB – 구성 (시연/실습)

❖ **Setting Static IP Address (선택)**

- sudo netplan try
- sudo netplan apply
- ip a
- route

```
jslab@free5gc:/etc/netplan$ route

Command 'route' not found, but can be installed with:

sudo apt install net-tools

jslab@free5gc:/etc/netplan$ sudo apt install net-tools
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following NEW packages will be installed:
  net-tools
0 upgraded, 1 newly installed, 0 to remove and 0 not upgraded.
Need to get 196 kB of archives.
After this operation, 864 kB of additional disk space will be used.
Get:1 http://kr.archive.ubuntu.com/ubuntu focal/main amd64 net-tools amd64 1.60+git20180626.aebd88e-
1ubuntu1 [196 kB]
Fetched 196 kB in 2s (103 kB/s)
Selecting previously unselected package net-tools.
(Reading database ... 71475 files and directories currently installed.)
Preparing to unpack .../net-tools_1.60+git20180626.aebd88e-1ubuntu1_amd64.deb ...
Unpacking net-tools (1.60+git20180626.aebd88e-1ubuntu1) ...
Setting up net-tools (1.60+git20180626.aebd88e-1ubuntu1) ...
Processing triggers for man-db (2.9.1-1) ...

jslab@free5gc:/etc/netplan$ route
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
default         _gateway        0.0.0.0         UG    100    0        0 ens33
172.17.0.0      0.0.0.0         255.255.0.0     U     0      0        0 docker0
192.168.56.0    0.0.0.0         255.255.255.0   U     0      0        0 ens38
192.168.128.0   0.0.0.0         255.255.255.0   U     0      0        0 ens33
_gateway        0.0.0.0         255.255.255.255 UH    100    0        0 ens33
jslab@free5gc:/etc/netplan$
```

❖ 5G LAB – 구성 (시연/실습)

❖ 선택 (UERANSIM용 별도 VM 생성시): Setting free5gc and UERANSIM Parameters

- In free5gc VM, we need to edit three files:
  - ✓ ~/free5gc/config/amfcfg.yaml
  - ✓ ~/free5gc/config/smfcfg.yaml
  - ✓ ~/free5gc/NFs/upf/build/config/upfcfg.yaml

jslab@free5gc:~$ sudo nano ~/free5gc/config/amfcfg.yaml

```
...
  ngapIpList:  # the IP list of N2 interfaces on this AMF
  - 127.0.0.1
```

```
...
  ngapIpList:  # the IP list of N2 interfaces on this AMF
  - 192.168.50.200  # 127.0.0.1
```

jslab@free5gc:~$ sudo nano ~/free5gc/config/smfcfg.yaml

```
...
  interfaces: # Interface list for this UPF
  - interfaceType: N3 # the type of the interface (N3 or N9)
    endpoints: # the IP address of this N3/N9 interface on this UPF
      - 127.0.0.8
```

```
...
  interfaces: # Interface list for this UPF
  - interfaceType: N3 # the type of the interface (N3 or N9)
    endpoints: # the IP address of this N3/N9 interface on this UPF
      - 192.168.50.200  # 127.0.0.8
```

jslab@free5gc:~$ sudo nano ~/free5gc/NFs/upf/build/config/upfcfg.yaml

```
...
  gtpu:
  - addr: 127.0.0.8
```

```
...
  gtpu:
  - addr: 192.168.50.200  # 127.0.0.8
```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❖ 5G LAB – 구성 (시연/실습)

❖ 선택 (UERANSIM용 별도 VM 생성시): Setting UERANSIM:

- In the ueransim VM, there are two files related to free5gc:
  - ✓ /home/jslab/UERANSIM/config/free5gc-gnb.yaml
  - ✓ /home/jslab/UERANSIM/config/free5gc-ue.yaml

jslab@jslab-ueransim1:~$ sudo nano /home/jslab/UERANSIM/config/free5gc-gnb.yaml

```
...
  ngapIp: 127.0.0.1   # gNB's local IP address for N2 Interface (Usually same with local IP)
  gtpIp: 127.0.0.1    # gNB's local IP address for N3 Interface (Usually same with local IP)

  # List of AMF address information
  amfConfigs:
    - address: 127.0.0.1
```

```
...
  ngapIp: 192.168.50.201  # 127.0.0.1   # gNB's local IP address for N2 Interface (Usually same with local IP)
  gtpIp: 192.168.50.201  # 127.0.0.1    # gNB's local IP address for N3 Interface (Usually same with local IP)

  # List of AMF address information
  amfConfigs:
    - address: 192.168.50.200  # 127.0.0.1
```


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❖ 5G LAB – 구성 (시연/실습)

❖ **Setting UERANSIM:**

- In the ueransim VM, there are two files related to free5gc:
  - ✓ ~/UERANSIM/config/free5gc-gnb.yaml
  - ✓ ~/UERANSIM/config/free5gc-ue.yaml

```
jslab@jslab-ueransim1:~$ sudo nano ~/UERANSIM/config/free5gc-ue.yaml
```

```
# IMSI number of the UE. IMSI = [MCC|MNC|MSISDN] (In total 15 or 16 digits)
supi: 'imsi-208930000000003'
# Mobile Country Code value
mcc: '208'
# Mobile Network Code value (2 or 3 digits)
mnc: '93'

# Permanent subscription key
key: '8baf473f2f8fd09487cccbd7097c6862'
# Operator code (OP or OPC) of the UE
op: '8e27b6af0e692e750f32667a3b14605d'
# This value specifies the OP type and it can be either 'OP' or 'OPC'
opType: 'OP'
...

# Initial PDU sessions to be established
sessions:
  - type: 'IPv4'
    apn: 'internet'
    slice:
      sst: 0x01
      sd: 0x010203

# List of requested S-NSSAIs by this UE
slices:
  - sst: 0x01
    sd: 0x010203
```


❖ 5G LAB – 구성 (시연/실습)

❖ **Testing UERANSIM against free5gc:**

- SSH into free5gc. If you have rebooted free5gc, remember to do:
  - ✓ sudo sysctl -w net.ipv4.ip_forward=1
  - ✓ sudo iptables -t nat -A POSTROUTING -o ens33 -j MASQUERADE
  - ✓ sudo systemctl stop ufw
  - ✓ sudo iptables -I FORWARD 1 -j ACCEPT
  - ✓ cd ~/free5gc
  - ✓ ./run.sh

❖ 5G LAB – 구성 (시연/실습)

❖ **After reboot

- ./run.sh # free5GC
- go run server.go # Web Console
- sudo ./nr-gnb -c ../config/free5gc-gnb.yaml # gNB
- build/nr-gnb -c config/free5gc-gnb.yaml # gNB
- sudo build/nr-ue -c config/free5gc-ue.yaml # UE
- ping -I uesimtun0 google.com # ping

5G 코어 실행	jslab@free5gc:~/free5gc$ ./run.sh
웹콘솔실행	jslab@free5gc:~/free5gc/webconsole$ go run server.go
gNB실행	jslab@free5gc:~/UERANSIM/build$ sudo ./nr-gnb -c ../config/free5gc-gnb.yaml
gNB실행	jslab@free5gc:~/UERANSIM$ build/nr-gnb -c config/free5gc-gnb.yaml
UE실행	jslab@free5gc:~/UERANSIM$ sudo build/nr-ue -c config/free5gc-ue.yaml
Ping 실행	jslab@free5gc:~$ ping -I uesimtun0 google.com

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